The Copper Queen Mine, Arizona.

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THE Copper Queen mine was opened in 1880 by Messrs. Martin, Ballard & Reilly, and the first copper-furnace was blown-in on August 20th of that year. Prior to that summer nothing but prospect-work had been done on the Copper Queen and on a number of adjacent claims. In fact, it was a small deposit, not of copper-ore, but of cerussite, which still remains undeveloped, on the western slope of the Queen hill, which

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first tempted miners to the spot. To reduce this lead-ore, a primitive furnace was erected near a spring, now dry. The development, just then, of this and other copper-deposits in the southern Territories was due to the simultaneous arrival of the Southern Pacific and the Atchison, Topeka and Santa Fé railroads, though it was stimulated by the business revival of 1880, with the consequent rise in the value of copper.

The geology of the Dragoon and Mule Pass mountains, in which the Copper Queen mine is situated, has not been systematically studied. On the flanks of a granite core lie beds of limestone supposed to be Carboniferous, but possibly of earlier origin. Those to the west carry, either enclosed or as contact-deposits, the silver-bearing minerals which in the early '80's made Tombstone one of the most famous mining-districts of the West. The limestones on the eastern slope of the Mule Pass mountains carry the ores of the Copper Queen mine. The limestone masses appear to be broken and filled by extensive bodies of intrusive feldspathic rocks, which seem to have exerted a decisive influence on the genesis of the ore, though their relation to the ore-masses, whether these lie on the contact or are completely and deeply imbedded in the limestones, is a matter upon which theorists will differ. The feldspathic rocks to the east of the copper-bearing mass of limestones of the Copper Queen group are deeply colored superficially by oxides of iron, and, as recent explorations made by other companies than the Copper Queen show, carry iron- and copper-pyrites disseminated in particles and in bunches, but whether in profitable quantities or not has not yet been determined. The colored band of these adjacent rocks (which are supposed to be rhyolites, though their decayed character renders any determination of their original mineralogical composition doubtful) is broadest in contact with the Copper Queen and the Atlanta claims, where the largest bodies of copper-ore have been discovered in the limestones, and tapers towards the south, where the ore-bodies as yet found in the limestones are smaller and deeper. The contact of the limestones and rhyolites appears to represent the line of a great fault, which is also indicated by a marked depression in the surface.

Beneath this depression lie ferruginous clays, locally called "ledge-matter," enclosing masses of ore, both oxidized and un-

oxidized; but the rocks at this level are altered by decay to such a degree that it is difficult, if not impossible, to define the line between altered limestone and altered rhyolite. Where, however, the deep workings of the Copper Queen have penetrated the feldspathic rocks, the ground has proved to be barren. Nevertheless, since the wealth of other mining districts in Arizona resides almost exclusively in the so-called porphyries, exploration in the same class of rocks in the Warren district is a legitimate enterprise.

The successful development of the Copper Queen mine, however, has been confined to the limestone belt lying between what appear to be two prominent faults—the one already referred to, and another to the west of the Queen hill.

The outcrop of copper which was first attacked, and which was, in fact, the only extensive surface-indication, was on the northern exposure of a limestone hill. In this place stripping revealed a solid body of oxidized copper-, iron- and manganese-ore over 60 by 60 feet in area, and so rich in copper that the furnace, fed from the surface-ores alone, yielded for a few months 23 per cent. of metal. Fig. 1 shows a section through the open-cut made on this body, and Fig. 2 an outside view thereof. This large outcrop was enclosed in an almost circular unaltered limestone frame. Associated with the ore was an abundance of calcite; but the percentage of silica was so small that quartz had to be added to the furnace-charge. This body, retaining its general dimensions and well-defined limestone walls, dipped at an angle of about 30 degrees southeasterly into the hill. Between the 100- and 200-foot levels the ore changed into a clay, with well-marked bedding, too lean in copper-carbonate to be profitably worked; but below this zone of clay the copper, as carbonates and oxides, increased to 12 per cent., and was associated in a measure with limonite, imbedded in ferruginous clay. This ore-body extended to a depth of 400 feet on the incline from the surface, and there terminated abruptly in hard limestone.

The enrichment of surface copper-ores and their rapid impoverishment at a shallow depth is not an uncommon occurrence in the "arid region" of the United States. It probably takes place through the oxidation and precipitation, in this hot, dry climate, from the copper-solutions which rise to the

surface during the decay of the ore. A lower layer of ore is thus necessarily depleted, in proportion as the surface-layer is enriched. The insensible flow, through the apparently dry rocks of the region, of moisture charged with soluble salts is often evinced by the thick efflorescence of copper-alum which rapidly covers the walls of drifts run through or near feldspathic or argillaceous rocks, even when the copper-contents of these rocks are so low as to be barely appreciable. During the dry season a waste-heap of such refuse will be completely covered with a green coating.

On the other hand, in the wet eastern climate, as in Tennessee, the surface-ore, where it has not been denuded by glacial action, consists of insoluble ferric oxide deprived by lixiviation of the copper which, in Arizona, under favorable atmospheric conditions, would be fixed as oxides. The rapidity with which a soluble copper sulphate when exposed to the air is converted into insoluble basic sulphate, and this into more permanent compounds, is illustrated in many copper-regions of the Southwest, where copper-solutions ooze from almost barren decaying feldspathic rocks, and, on reaching the surface and filtering through the gravels, form copper-bearing conglomerates.

The first ore-body, above mentioned, was not exhausted until 1884, when it had yielded about 80,000 tons of ore and 20,000,000 pounds of copper. The earliest months of that year were the gloomiest which the district had known up to that (or, fortunately, up to the present) time. Simultaneously with the commencement of active operations on the Queen, a large group of claims on the southern slope of the Queen hill had been explored by the Neptune Co., and a furnace-plant had been erected by it on the San Pedro river, some miles distant. The reason for building the reduction-plant so far from the mine was the scarcity of water in Bisbee, which at that period was so serious that the Copper Queen occasionally had to damp its single furnace for lack of a sufficiency of water to cool the jacket. The Neptune Co., after expending its capital and bonded debt, suspended operations in 1882. Another corporation, the Atlanta Mining Co., owning claims adjacent to the Queen, had been searching in vain more than three years for an ore-body by following, to no profit, surface-indications. Other minor operations of a like kind had been equally unsuc-

cessful. At that date the Queen Co., having reached the bottom of its ore-body and the 400-foot level of the incline, could count only some three months' ore in sight; and the Atlanta had decided to abandon the enterprise after one more effort should have been made to discover ore. The foot of the Queen incline, which coincided with the bottom of the original Queen ore-body, had nearly reached the side-line of the claim, and therefore a drift easterly along the side-line in hard limestone was the exploratory work undertaken by the Queen—a long drift having been previously run to the west without encountering any ore.

Meanwhile the Atlanta Co. was sinking a shaft in barren limestone a little to the south of the point towards which the Queen drift was directed. Thus, final pieces of exploratory work were under way, prior to the abandonment of their property by both companies, when, almost at the same time, each of them struck a new ore-body which appeared to be dipping northwest, or in a direction the reverse of that of the body originally discovered. The two companies then wisely decided to consolidate on equitable terms, rather than waste their funds in obtaining a legal interpretation of an even more complicated problem than that involved in the Richmond-Eureka " apex " case. Since then the claims of the Neptune Co., the Holbrook and Cave Co., the Silver Bear Co. and a number of private owners have been acquired. Many of them have proved to be barren, but not a few contribute their quota of ore to the total of the consolidated company's product, which is drawn at present from what would be some twenty different unprofitable mines, if each were under separate management.

The first ore-body extracted extended from the surface to the original 400-foot level of the old incline, which corresponds to the 200-foot level of the new Czar shaft. The second ore-body, discovered about 600 feet east of the first, was covered at the surface by 200 feet of limestone, and abruptly terminated at a depth of 300 feet from its apex. A narrow seam of ore was known to extend into the limestone to the south of the original ore-body, but it was not followed until years after its discovery. Then it was found to be the connecting-link between the ore-body from which it sprung and another, still larger, in the southwest of the Atlanta claim. This ore-body extended in

depth from above the 100-foot to below the 300-foot Czar leve
and on the sill-floor of the latter level the stope was 200 fee
by 150 feet—by far the largest opening made in any ore-body
As it was of such magnificent size, we thought ourselves saf
in running a long drift for 1500 feet, through limestones, from
the Czar shaft, to strike it on the 400-foot level. (See Fig. 1
giving cross-section No. 25.) On reaching the position which
the ore should have occupied, none was found, nor has the
extension of the ore-body in any direction been discovered by
diamond drill-holes bored radially for thousands of feet. A
drill-hole pointed upwards entered the ore at 30 feet below the
300-foot level, where the ore abruptly terminated.

Disappointments of a like character have beset operations in
other sections of the mine. A large ore-body in the southern
section of the mine was traced downward to a point 40 feet
below the 400-foot level. A search in all directions on the
level below has failed to find it. Where ore-bodies are so ec-
centric in their size and the direction of their curves, it is often
well-nigh impossible to trace their extension, or be sure of their
extinction, until they are being actually extracted. In search-
ing for ore in these limestones, it is extremely difficult to inter-
pret the signs which point to its presence, or to distinguish
accidental occurrences from actual laws of deposition. The
presence of ore in more than one place on the 500-foot level,
and elsewhere in the southern portion of the mine, was indi-
cated as probable by the presence of ore on the 400-foot level
and the intermediate level below; but in no single instance
has the ore been found on the 500-foot level where expected.
In fact, nearly a mile of drifts was run on that level before
any copper was encountered.

Certain general conclusions have been provisionally reached.
There seem to be two series of limestone-beds, both of Carbon-
iferous age: the upper bedding, recognized as the white; and
the lower, as the blue—though this distinction of color is not
always well marked. They dip conformably to the south, but
at varying angles. At some places they lie almost flat, at
others they attain an angle of over 30 degrees. The large
masses of copper, whether oxidized or unaltered, have as yet
been discovered exclusively in the upper series, and only at the
base of that series. Its total thickness is probably about 1100

feet, but only in the lower 300 feet has ore been found in profit-able quantity. Where the series is thickest, under the apex of the Queen hill, no ore-masses are known to exist. Large quan-tities of ore lie, as already described, under the valley where exists the obscure dividing-line between the limestones and rhyolite, and where the former are probably shallow; but the largest isolated ore-body yet extracted was separated by many hundreds of feet of barren limestone, and what is locally called "ledge-matter," from this contact.
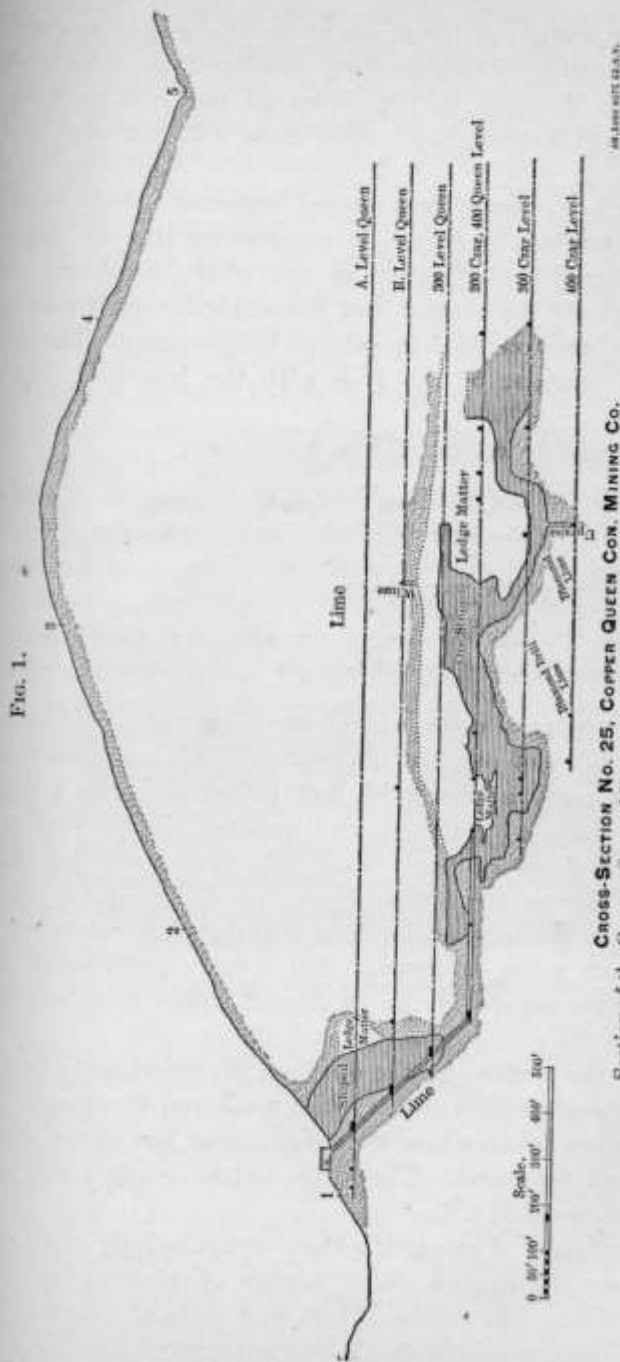
As we work to the southward, the ore-bodies attain greater depth from the datum-line of the collar of the Czar shaft. No ore has been discovered below the 400-foot level in the north-erly section of the mine, whereas in the section to the south, reached by the Holbrook shaft, ore-bodies have been found at 500 feet below that point, and still further south the ore attains a greater depth. But the ore-bodies hitherto encountered here are small in comparison with those explored and extracted in the northern sections.

The conclusion that the profitable ore is confined to the up-per series of limestones is based on the experience that large, compact ore-bodies have not been found to extend below a certain horizon. Nevertheless, the limestones of the supposed lower series, as far as they have been explored, are more thor-oughly impregnated with iron-sulphides, associated with minute quantities of copper-sulphide, than the upper limestones. But so little work has been done below the upper chain of ore-bodies that no conclusive opinion can be formed as to the metalliferous value of the underlying limestones. There is slight probability of oxidized ore being encountered, but the general dissemina-tion of pyrite and chalcopyrite in fine grains through the rock leads to the hope that areas of ground may be entered where the latter mineral may be abundant enough to render the lime-stone a "concentrating-ore."

The Copper Queen mine has become famous for its beautiful specimens of carbonates, both malachite and azurite. The malachite is never found in such large and compact masses as to make it commercially valuable for decorative purposes; be-sides, occurring generally in thin botryoidal masses, it is usually streaked with manganese, which detracts from its purity. Its most striking mode of occurrence is in geodes, which are lined

with velvety crystals of the same mineral. These hollow spheres, the walls of which are composed of concentric layers, are rare, but, when found, are usually in nests imbedded in soft, wet, ferruginous or manganiferous clays, such as constitute the gangue, or "ledge-matter," of nearly all the ore; and they occur at no great distance from a limestone wall or partition. The slabs of azurite, also, usually occur near limestone, but preferably in the manganiferous, clayey gangue. The oxidized copper-ores, however, which are mined in economic quantities, consist usually of cuprite and carbonate, disseminated through limonite; or of carbonates, chiefly of the green variety, in streaks or crystals scattered through ferruginous or manganiferous clay; or of minute particles of metallic copper, with more or less cuprite crystals, disseminated through yellow clay. These yellow clays are generally more distinctly bedded than the masses of red and black clays which carry the highly oxidized copper-compounds. Masses of any considerable size of native copper are found almost exclusively, not at the surface, where the oxidizing agencies have been most active, but in the deepest layers of the large ore-bodies, where apparently some reducing-agent has been more actively at work than elsewhere, and where the ore is furthest removed from atmospheric interference.   On the sill-floor of the 300-foot level (at the bottom of the great southwest ore-body already referred to), native copper was abundant in masses, some of them of several hundred pounds in weight.   The surface of the native copper lumps and masses is always more or less perfectly crystallized, as of course is the case in those mines where all the secondary copper-ores were deposited slowly from the dissolved constituents of the original sulphides.

While selected specimens of the oxidized ores carry a very high percentage of copper, the percentage in the ore as actually mined is much lower, inasmuch as the particles of ore proper are, as explained, associated with clays or limonite; and these cupriferous clays or limonites are themselves embedded in vastly larger masses of clayey ledge-matter, absolutely barren of copper. The approach to the so-called ledge-matter, when drifting through limestone, is generally indicated by a softening of the rock and a gradual replacement of the lime by silicates of alumina. A series of analyses taken from a drift in

Fig. 1.

CROSS-SECTION No. 25. COPPER QUEEN CON. MINING CO.

Section of the Copper Queen Mine through the Open-Cut and the Southwest Stope.

the eastern section of the mine, as an ore-body is approached, indicate the gradual change from unaltered limestone to clays, involving a decrease in lime from 24 per cent. to 0.33 per cent. and an increase in alumina from 2.20 per cent. to 16.9 per cent.

The further passage from altered limestone to ledge-matter is often less marked by change in composition than by change in color. Figs. 3 and 4, taken in one of the southwest drifts, show distinctly the contact and the sudden transition in color from pale limestone to deep-colored ledge-matter. The assays show the increase of the iron with the increased depth of color.

The altered limestone of Fig. 4 contains:

CaO.	MgO.	SiO$_2$.	Al$_2$O$_3$.	F$_2$O$_3$.	CO$_2$
50.0	......	8.04	3.04	1.6	38

The subjacent ledge-matter:

CaO.	MgO.	SiO$_2$.	Al$_2$O$_3$.	F$_2$O$_3$.	CO$_2$
1.62	5.98	53.9	14.0	14.4	6.85

The ferruginous clays, when entered, are regarded as hopeful indications of ore, but exploratory drifts are often made in them for many hundreds of feet before reaching a trace of copper. Suddenly, without any premonition, the clay carries copper; and as suddenly the drift runs again into barren ground. Large areas have been stoped from these sporadic masses, and the locality has been abandoned as exhausted, only to discover years afterwards that a mere partition of barren ledge-matter separated the exhausted stopes from still larger reserves.

As at the surface in the open-cut, so occasionally in depth, the ledge-matter is in contact with unaltered limestone.

Fig. 5 was taken where the ledge-matter has parted abruptly from hard limestone. The ledge-matter is often very much contorted, as in Fig. 6.

The difficulty of extracting these comparatively small masses of soft ore from such large masses of plastic clay is very considerable. The whole hill is in a state of ceaseless movement. The comparatively shallow capping of limestone is fissured to the surface in all directions, and the lateral strains on

the partitions of limestones which separate the masses of ledge-matter, when large stopes are made in them, cause these partitions to yield. The slag-dump in the valley east of the hill (Fig. 7) rests on detritus, beneath which is ledge-matter, and is a source of considerable annoyance in the mine, as its pressure is continuously squeezing up the ledge-matter in the eastern stopes of the mine. And so soft is the ledge-matter which is under this valley, that cone-shaped caves extend to the surface from the stopes through 80 to 100 feet of barren clay,—but fortunately the movement of ground is slow, and ample warn-

Fig. 2.

Open-Cut of the Copper Queen Mine.

ing is given. The tendency of the clays, under this pressure, is to rise, and therefore it is impossible to maintain a perfectly level track in the permanent ways. At the same time the walls of the drifts are either forced out of line by lateral pressure from one side or the other, or the drifts are contracted by the irresistible pressure, from all sides, of the swelling ground. Hence it is impossible to use underground the most economical modes of traction. The stopes can be held up only by timbering in square sets, and the face of the stopes can never be safely broken down ahead of the timbering. The yield of this class of ore is about 7 per cent., after rough selection in the

FIG. 3.

Contact of Altered Limestone and Ledge-Matter.

FIG. 4.

Contact of Altered Limestone and Ledge-Matter.

FIG. 5.

Parting of Ledge-Matter from Unaltered Limestone.

FIG. 6.

Contorted Clays in the Baxter Tunnel.

FIG. 7.

Slag-Dump East of Copper Queen Hill.
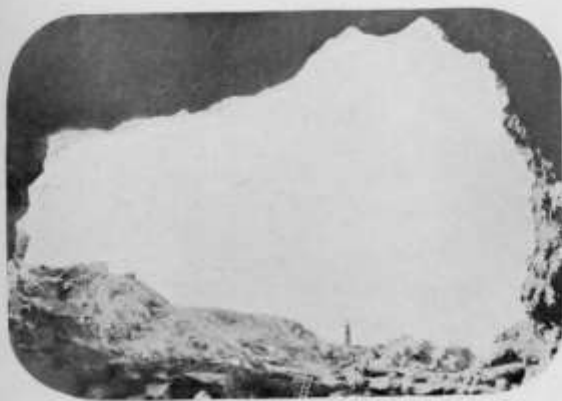
FIG. 8.

Limestone Boulder, Found Imbedded in Ore.

Fig. 9.

Fissure on the 200-foot Czar Level.

Fig. 10.

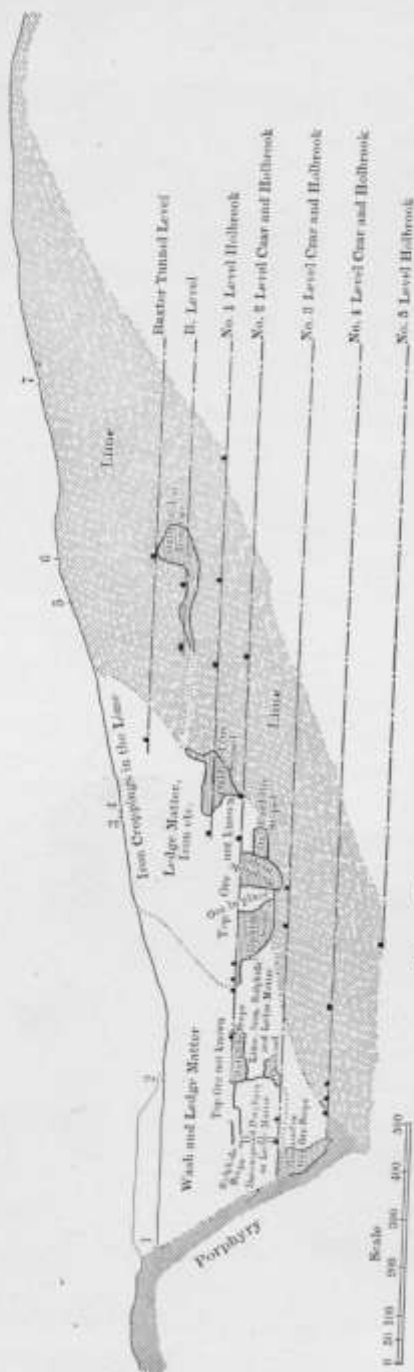Open Cut from the Interior of Mine.

FIG. 11.

Stalactites in a Cave in the Copper Queen Mine.

FIG. 12.

Altered Limestone, Showing Marks of the Pick.

FIG. 13.
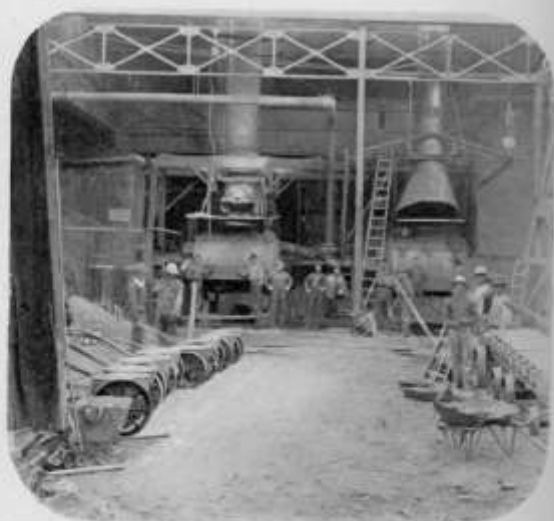

CROSS-SECTION No. 23, COPPER QUEEN CON. MINING CO.
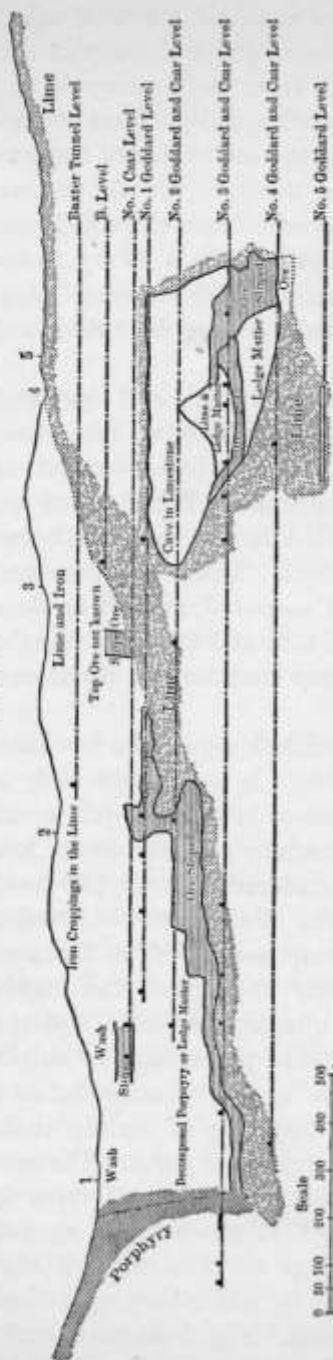
FIG. 15.

Tilting-Furnace Well.

FIG. 16.

In the Bessemer-Pit.

Fig. 14.

CROSS-SECTION No. 24, COPPER QUEEN CON. MINING CO.

stopes, where about one-half the total material broken is rejected. To supplement the deficiency in filling up the stopes, barren ledge-matter from exploratory drifts is used. Though the timbering of worked-out portions of the stopes is thus enforced, so violent is the movement of the ground that, when an old stope is drifted through, the old timbers are found upset and dislocated or crushed into chips. The size of timbers usually employed in square sets is 10 by 10 inches and 12 by 12 inches, and the most available source of supply is Puget sound. About 30 feet, board measure, is buried in the mine to the ton of ore extracted.

A notable quantity of oxidized ore is also obtained from narrow irregular deposits between limestone walls, or from still more undefined bodies, which cement together limestone boulders, large and small. Fig. 8 shows a limestone boulder, which was imbedded in ore, and has been left in the stope, supported by timbers. These boulders are generally superficially gnarled and corroded, as well as decayed to a depth of several inches, and they and the ore entangled among them are never situated at any considerable distance from the solid confining limestones.

The depth to which decay of ore has extended from the surface is very variable. A very large body of sulphide-ore was struck on the 200-foot level, and yet in other sections of the mines the ore is partially oxidized to the lowest depth at which ore has been encountered, namely, 570 feet below the collar of the Holbrook shaft. Yet below the 300-foot level, completely oxidized ores became scarce. The furnace-mixture, for years before the company abandoned the making of bars direct, yielded a certain quantity of matte, and the copper bars were debased by a notable percentage of sulphur. The depth to which atmospheric agency reaches is, of course, determined largely by the permeability of certain rocks to the insensible flow of water through their pores. The compact carboniferous limestones, however, in which the Copper Queen mine occurs, permit the passage of atmospheric agencies to considerable depth, rather through the fissures and joints (expanding occasionally into caves), by which they are reticulated than through the pores of the rock. Fig. 9 shows one of these open fissures. An interesting phenomenon in the West, where the climate is

so extremely dry, is the great depth to which roots will strike down through rock-fissures in search of moisture.

The sulphurets in these limestones occur in layers of various thickness and solidity. When solid and thin, they are generally partially oxidized, and are rich. Two very large compact masses have been encountered, and in part explored. The largest apexes on the 200-foot level and has been traced to the 400-foot level, and a string of stopes nearly 500 feet in length has been opened upon it; but the profitable ore bears only a small proportion to the whole mass. Roughly speaking, the mass is enveloped in a shell of oxysulphide, and streaks of similar black copper-ore of good grade intersect it; but the core consists of compact bisulphide of iron, very lean in copper. The same condition holds good of most of the large iron-pyrites masses the world over, where oxidation is occurring; and, therefore, while estimates of quantity can generally be easily made, certainty as to value is more difficult to reach.

The genesis of these ore-bodies, the progress of their decay, and the contemporaneous changes wrought in the surrounding rocks, are interesting subjects of study and speculation. During the early stages of the mine's development, the opinion was prevalent, based exclusively on the clean-cut outline of the great outcrop and the well-defined cavity of limestone in which the first ore-body was enclosed (see Fig. 10, a view taken from within the mine, but through the open-cut), that the original unaltered ores, prior to their alteration, had filled caves previously formed in the limestone, and that this filling had been effected partly through infiltration and partly through mechanical action. The barren clays below the 100-foot level were distinctly stratified; and at still greater depths in these and other sections of the mine large, round, siliceous pebbles, isolated or in layers, are found. Further developments have shaken this hypothesis, though there is abundant evidence that, through cracks and fissures in the limestone, surface-detritus has been carried to considerable depth, and that mechanical as well as atmospheric agencies have played their part in creating and distributing the ore-bodies in their present secondary altered condition. Large caves exist in the hill. It is therefore conceivable that into pre-existing caves copper-solutions might have

entered concurrently with mechanically transported clays and gravels, thus forming the alumino-ferruginous copper-ores which constitute the great mass of the oxidized bodies. But the almost total absence of lime in these oxidized ore-bodies is, in itself, a strong argument against the supposition; for had the copper been carried into them through infiltration from limestones, and with lime, the ores would have possessed the composition of the cupriferous stalactites, such as are shown in Fig. 11, which line the caves, and therefore would have contained a large proportion of lime as calcite. But this is not true, either of the ledge-matter or of the ores.

In framing a reasonable theory to account for the formation of the oxidized ore-bodies, we may start with the assumption that the copper they contain existed originally as a sulphuretted compound. Another assumption, which cannot be made with so much certainty, but which, I think, may be fairly allowed, is that the composition and distribution of the unaltered masses of sulphurets, which are contiguous to the altered ores, are identical with the composition and distribution of the now oxidized ore-bodies before decay had set in.

As I have already remarked, limestones contain more or less disseminated iron- and copper-pyrites, but these particles, protected from atmospheric action by the envelope of rock, are unaltered even at shallow depths. Not so, however, the large mass, for instance, of compact pyrites which extends from the 200-foot level to the 400-foot level. It exhibits every stage of decay, and the enclosing limestones are widely and completely altered. A section through this portion of the mine would exhibit the limestones becoming gradually softer and exchanging their lime for clay, while yet retaining the structure and color of the original rock. Fig. 12, from a photograph taken in this section of the mine, shows distinctly the structure of the limestone; but the hard rock is so altered that it can be removed by pick, the pick-marks showing distinctly in the picture. This altered limestone contains CaO, 7.1; MgO, 8.36; SiO_2, 27.1; Al_2O_3, 15.5; CO_2, 17 per cent. Immediately on it lies ledge-matter, the composition of which is CaO, trace; MgO, trace; SiO_2, 27.4; Al_2O_3, 15.1; F_2O_3, 33.9; CO_2, 10.6. The light, clayey, aluminous rock thus suddenly changes to a ferruginous clay, generally barren of copper. This envelope gives

place to a black sulphuretted ore of very diverse composition. At places it runs very high in copper, as indicated by the erubescite streak under the pick. At other places, though the same in appearance, it consists merely of an oxysulphide of iron. On the whole, however, this second shell contains the most profitable of the sulphuretted ores. It is not of uniform thickness, any more than of uniform composition, but thick enough to permit large stopes to be opened upon it. The kernel of the mass is very much leaner in copper than the shell, and consists of compact iron-pyrites averaging about 45 per cent. sulphur.

On the same horizon as this particular body of both partially altered and wholly unaltered pyrites, we have large quantities of ledge-matter, in which occur, as already described, great masses of cupriferous limonite, while, elsewhere in the same ledge-matter, we have areas of cupriferous clays. These differ from the barren ledge-matter in little else than the percentage of copper. The limestones, as ledge-matter is approached, have undergone substantially the same alteration as in the vicinity of the black oxysulphide.

Though, as a rule, the clays of the ledge-matter are ferruginous, they enclose, here and there, masses consisting of pure white clay, so free from iron as to be suitable for the plastic material of converter-linings. Such white clays may have been originally partitions of pure limestone between masses of sulphuretted ore, or blocks of limestone intercalated in the ore, which we assume the ledge-matter to have originally been.

If, therefore, we assume that the ledge-matter represents or replaces ore as originally deposited, in what condition was that ore, and through what process of alteration has it come to assume its present composition and appearance? It has been suggested that the ledge-matter is an altered feldspathic rock in place; that this intrusive rock carries the ore; and that the ledge-matter and the ore, as found to-day, are merely instances of alteration. It is difficult to conceive how irregular, isolated masses of intrusive rock could be injected into the limestone so as to fill the spaces occupied by the ledge-matter; but a more cogent reason for questioning the correctness of the theory is the fact that outside of, and below, the area of altera-

tion we find no such bodies of copper-bearing " porphyry " (to use the popular term) as the theory calls for; whereas we do find large bodies of unaltered copper-bearing iron-pyrites in contiguity with the altered bodies.

Fig. 13 is a cross-section through altered and unaltered ore-bodies.

One or more granite veins traverse the limestones of the Queen hill, and even cut through, without appearing to affect, the ore-bodies; but these veins are barren. They have not been traced from the surface, but they correspond approximately in position and direction with heavy quartzite croppings, which break through the limestones near the crest of the hill. If the surface quartzites and the deeper granites belong to the same system, this instance would confirm the evidence presented elsewhere, that feldspathic rocks, under such potent influences of decay as exist in the Southwest, lose all their basic ingredients at, or near, the surface, and are altered into very acid felsites, or even quartzites. We have used the decayed feldspathic rocks on the 400-foot level as plastic lining for the converters.

With regard to the ledge-matter and the oxidized ore, my own opinion is that they are the product of replacement and local concentration; that where there is ledge-matter to-day, there was, originally, more or less compact iron-pyrites carrying a small percentage of copper; and that, during the process of alteration, not only did ferruginous solutions of alumina replace the pyrites, but the copper, by a process of segregation akin to crystallization, was concentrated and collected into areas of limited size, thus constituting the comparatively small bodies of oxidized ores which are disseminated irregularly through the very large masses of ledge-matter. The acid-products of decay thus liberated must have been enormous. As the outline of the masses of ledge-matter has never been traced, it is impossible to determine their actual size, and thus arrive at an accurate estimate of their quantity; but, approximately, there has been exposed on all the levels above the 400-foot level not less than ten million tons of ledge-matter. If this was, before alteration, a sulphide-ore of the average composition of the existing unaltered masses, there must have been set free at least four million tons of sulphur. That the ore be-

fore alteration was as compact, and therefore carried as high a percentage of sulphur, as the existing unaltered ore, may be doubted. It is possible that one reason why the sulphide-ores of to-day on the upper levels are only partially decayed is that they were composed of more compact pyrites than the ores which have been completely altered and are imbedded in ledge-matter. In any case, assuming that the ledge-matter and ore represent sulphuretted compounds now altered, there must have been oxidixed and rendered soluble more than a million tons of sulphur, which would be sufficient to produce widespread alterations in the adjacent limestones and hasten decay in the ore-masses themselves; to reach by diffusion the adjacent feldspathic rocks; to alter them; and to carry back some of their basic constituents and silica, to replace the dissolved elements of the limestones and ores.*

As I have already pointed out, the limestones themselves which enclose the ledge-matter are extensively altered. As the result of such alteration, there must have been produced correspondingly large quantities of sulphate of lime. Through the percolation of water this has been completely dissolved and removed. In dryer mines, such as those at Globe, small quantities of gypsum are found; and in such extremely dry regions as that in which the Boleo mines of Lower California are situated, gypsum accompanies the oxidized copper-ores in such quantities as to convert the furnace-product very largely into matte. At Bisbee, however, where the ledge-matter is everywhere wet, where fissures and caves afford channels for the flow of water, and where, during the wet season, our pumps have to handle from one to two million gallons of water a day, even such sparingly soluble products of decay as gypsum have been dissolved and have disappeared.

It is more difficult to account for the enormous quantities of alumina which must have been derived from extraneous sources to form the clays. They must have been derived and conveyed by diffusion from the adjacent feldspathic rocks. As I have already remarked, when we drift from the limestones into the feldspathic rocks, assumed to be rhyolite, to the east, it is impos-

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* There are, within the limestone area, calcareous shales, which are probably the products of alteration, as they differ less in composition than in structure from the clays.

sible to distinguish the difference between altered limestone and altered rhyolite. But in the distinctly feldspathic rocks we find that widespread decay, though less destructive, has occurred. As this rhyolite carries more or less iron- and copper-pyrites, it may be argued that the enclosed pyrites is the effective agent in assisting decay. But except at the surface, where the rhyolite is colored, the pyrites is undecomposed. Below the surface the rhyolite is white and softened to considerable depth. It is therefore quite conceivable that, by means of the insensible interchange of solutions from the decaying bodies of pyrites through the adjacent feldspathic rocks, alumina and a certain amount of silica should be dissolved, and that they, in their turn, should displace the carbonate of lime and replace some of the iron in the altered pyrites.

At the Copper Basin in Yavapai county, Arizona, a copper-solution oozes from feldspathic rocks which carry only a trace of copper. On exposure to the air, there separates in the bottom of the streams an insoluble magma, the solid constituents of which are:

	Per Cent.
Silica,	7.17
Fe_2O_3 and Al_2O_3,	16.21
CuO,	64.40
SO_3,	12.22
	100.00

In time this sludge is converted into a mixed carbonate of copper and alumina, which binds together the gravels into conglomerates, of which some twenty thousand tons constitute horizontal beds of copper-ore. The alumina and silica are in this case dissolved from the granite, through which percolate the soluble products of the decay of copper- and iron-pyrites.

A feature of the Bisbee mine is the large caves, which have had some influence on the occurrence of the oxidized ore-bodies. The walls, roofs and floors of these caves are always covered with stalactitic accretions, which are often tinted green, blue and red by the copper- and iron-solutions which are mixed with a solution of carbonate of lime. What, however, gives these caverns practical interest is that they have invariably covered oxidized ore-bodies. Fig. 14 gives a cross-section through one of the large caves. Three such caves of considerable

extent have been encountered, and in every instance this combination has occurred. It may be accidental; but so satisfied are we to the contrary that, when a cave is now met with, drifts are run beneath it to strike the ore-body. It is a fair assumption that the cave, if not originally formed by the contraction of an ore-body, was increased by the shrinkage of the latter during its oxidation, and that, therefore, a genetic relation really exists between the cave and the underlying ore.

Moreover, some real, and not accidental, relation can be traced between the surface-contour of the country and the underlying ore-bodies.* Where the ore-bodies have come to the surface, and have been decayed into ledge-matter, erosion has been extensive, as in the case of the depression east of the Copper Queen hill, through which the Arizona and Southeastern R. R. enters the town, and in which the slag-dump shown in Fig. 7 is being made. This depression, as already observed, marks the line of contact between the limestones and the rhyolite. The fissure between the Copper Queen hill and the Copper King hill to the west uncovers the deposit of cerussite which first attracted attention to the district; and this gulch may occupy the position of ore-bodies which, there is reason to think, have been completely removed by denudation. South of the Copper Queen hill there is a broad depression, which corresponds roughly to the ore-bearing ground in depth. It would be drawing an unwarrantable conclusion to predict the position of an ore-body from the surface-contour of any country; but where the rocks are known to be ore-bearing, it is often as fair an assumption that surface elevations and depressions represent ore-bodies in depth as that the colors of soils and rocks are indicative signs.

The metallurgical practice has necessarily undergone radical modifications with the change in the character of the ore; and

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* The tremendous erosive action of water is illustrated by Fig. 2. The picture was taken when a flood, caused by a heavy shower which fell on the mountains to the rear of the town, was rushing down the main street, as well as filling the bed of the stream (always dry, except during flood). Formerly these floods were very rare; but since the timber has been cut off the range, and its scanty grass has been torn up by the roots, there is nothing to impede the rush of water, carrying with it sand, gravel and rocks.

Within a few minutes after a black cloud floats up the gulch over the town these destructive torrents tear down the valley, washing all before them.

the plant also has grown, both in size and in the dimension of its separate parts, with the expansion of the mine. The water-jacketed furnace which was introduced when the mine was opened by Mr. Lewis Williams, who was probably the first metallurgist to apply it to copper-smelting, has remained the type of furnace used; but the 36-inch round shell has, by successive changes, developed into furnaces of 120 inches by 42 inches. There is no other reason for confining them to this size than that the capacity of such a furnace is approximately that of the converters, which are coupled with the furnaces. Originally the furnace-plant, consisting of two 36-inch jackets, was built directly below the open-cut, and the ore was crushed under a separate roof, thus involving unnecessary handling; but in 1886–1887 the smelting-works were removed to their present site, though they were still planned for the treatment exclusively of oxidized ores. Already, however, the percentage of sulphur in the oxidized ores was increasing to a degree which injured the quality of the black-copper bars, and involved the retreatment of part of the product as matte. Simultaneously, large bodies of compact sulphurets were being discovered, the utilization of which involved a change of treatment. By that time the pneumatic method of concentrating matte had acquired such undisputed acceptance in Butte that the company decided to adopt it; but, instead of building the vertical converter, which had heretofore been exclusively used in this country, the horizontal barrel-type was copied, with modifications, from those in use at the metallurgical works in Leghorn, Italy, at Aiguilles, France, and at Vivians' works in Swansea, Wales.

At first the converters were fed from a remelting furnace; but this wasteful operation was soon abandoned, and each of the three converters was placed opposite its companion smelting-furnace, and the molten matte was poured from tilting-wells directly into the converters. Fig. 15 shows a tilting-well, from which matte is being poured into one of the converters, situated on a lower level, as shown in Fig. 16. This plan secured notable economy over the cost of remelting, with its attendant handling of the cooled matte, but was found to involve occasional delay—at one time of the furnaces, at another of the converters—so that neither furnaces nor converters could be

pushed to their maximum capacity. An electric crane is therefore being introduced to transport the matte from any one of the furnace-wells to any one of the converters. The smelting-plant of the mine will hereafter consist of four water-jacketed cupolas, 42 inches by 120 inches, of oval shape, and with taper from the feed-door to the tuyeres. Each furnace is provided with two tilting-wells, arranged in tandem. From the second well the slag will flow into 2-ton ladles, which are moved by the electric crane to the 4-ton slag-cars, drawn by a steam locomotive. The matte will be poured from whichever of the tilting-wells of each furnace is quite full, and conveyed to a converter; and the same crane will return the converter-slag to the well nearest to the furnace, thus allowing the slag ample time and space to settle while travelling to the discharge of the second well. The converters are 8 feet long and 5 feet 6 inches in diameter. The average daily capacity of each furnace is about 160 tons of ore, exclusive of extra charge of foul slag, and each converter can blow daily 30 to 40 tons of 45 per cent. matte to metallic copper, averaging a trifle over 99 per cent. The blast is derived either from a horizontal duplex Riedler engine or a vertical Scranton engine. The pressure usually maintained is from 7 to 8 pounds. While the matte can be blown at much lower pressure, a lower blast retards the operation.

In *Mineral Resources of the United States* for 1883–1884, I described the construction and operation of the old 36-inch jackets then treating the oxidized ores of the mine.

At present a charge of the large 42- by 120-inch furnace is composed of naturally oxidized ores mixed with sulphuretted ores in such proportion as to yield a matte of about 45 per cent. The following samples of ore-charge and slag were taken during a day's run of the same furnace.

Each ore-charge consisted of:

	Pounds.
Oxidized ores from various parts of the mine, carrying more or less sulphur,	1,500
Low-grade clay-ore,	1,000
Raw sulphide-ore,	1,000
Roasted sulphide-ore,	100
Total,	3,600

One charge of briquettes, made from fine ore-screenings, flue-dust and coke-dust, in a Chisholm & Boyd press, is fed for every 10 charges of ore. The coarse screenings from the converter are added as extras. The larger proportion of silica and alumina in the slag than the composition of the ore-charge would warrant, comes from these screenings, and from the ash of the coke.

Analysis of Ore-Charge.

		Per cent.
Copper,	.	9.1
Silica,	.	17.1
Lime,	.	Trace
Sulphur,	.	16.44
Iron,	.	29.7
Aluminum,	.	5.4
Zinc,	.	Trace
Lead,	.	Trace
Manganese,	.	0.58
Moisture in the ore,	.	9.2
		Oz. per ton.
Silver,	.	0.9
Gold,	.	Trace

Analysis of Resulting Slag.

		Per cent.
Copper,	.	0.6
Silica,	.	33.8
Lime,	.	1.11
Sulphur,	.	1.1
Iron,	.	37.7
Aluminum,	.	13.15
Zinc,	.	Nil.
Lead,	.	Nil.
Manganese,	.	1.95
Silver,	.	Trace
Gold,	.	Nil.

The copper-content of the wet ore, as fed into the furnace, was therefore 8.27 per cent. This, of course, represents not the average run of the mine, but selected ore; as rough-sorting is done underground. No flux is ever added to the furnace-charge, as by a judicious selection of acid and basic ores a fusible mixture can always be obtained. The coke-consumption is 12.5 per cent. of burden of furnace. The coke used is a very impure product of the Trinidad, Colo., ovens, carrying over 20 per cent. of ash; but the furnace-charge is sufficiently basic to permit its economical use.

The operation of one of the converters when fed from a single furnace, involving, as already stated, a considerable waste of time, can be followed by tracing the steps of the life of a single lining, as in the following table; and the behavior of the principal ingredients of the matte is indicated by the analysis and the products of the blow.

Samples of Products of Bessemer Converter No. 3, at Bisbee, During the Life of One Lining.

NEW LINING: FIRST CHARGE.

First tap of matte from well No. 3. Blast turned on at 12.13 P.M.; blast turned off at 12.28 P.M. Time of first blast, 15 minutes.

Pour finished at 12.33 P.M.

Sample No. 1.—First tap of matte into converter; ladle at beginning, middle and end of tap.

Sample No. 2.*—First pour of slag, $4\frac{1}{2}$ pots; dip-sample, two rods to each pot.

Sample No. 3.—Ladle-sample of white metal from converter.

Second blow began at 12.52 P.M.; second blow ended at 1.20 P.M. Time of blow, 28 minutes.

Third blow began at 1.30 P.M.; third blow ended at 1.58 P.M. Time of blow, 28 minutes.

Bullion all poured at 2.06 P.M.

Length of blast on charge: first blow, 15 minutes; second blow, 28 minutes; third blow, 28 minutes. Total, 1 hour 11 minutes.

Sample No. 4.—Second tap of matte into converter from well No. 3.

Sample No. 5.—Six pots, poured slag. *Sample No.* 6.—Two pots, skimmed slag.

Sample No. 7.—White metal from converter.

Sample No. 8.—Metallic copper; ladle-sample taken near beginning and end of pour. Copper made from this charge, $9\frac{1}{2}$ bars.

SECOND CHARGE OF CONVERTER.

First tap of matte from No. 3 well into converter.

First blow began at 2.20 P.M.; first blow ended at 2.48 P.M. Time of blow, 28 minutes.

Sample No. 9.—First tap of matte taken as for sample No. 1.

Sample No. 10.—First pour of slag, 10 pots.

Sample No. 11.—White metal in converter, end of first blow.

Sample No. 12.—Second tap of matte from well No. 3 into converter.

Second blow began at 3.12 P.M.; second blow ended at 3.37 P.M. Time of blow, 25 minutes.

Sample No. 13.—Second pouring of slag, 9 pots.

Sample No. 14.—Two pots skimmings.

Sample No. 15.—White metal, end of second blow.

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* Sample No. 2 probably too high, as dip of rods from last pot was too deep.

Third blow began at 3.50 P.M.; third blow ended at 4.32 P.M. Time of blow, 42 minutes.

Length of blast on charge: first blow, 28 minutes; second blow, 25 minutes; third blow, 42 minutes. Total, 1 hour 35 minutes.

NOTE.—Converter-lining patched with one wheelbarrow-load of lining after this run.

THIRD CHARGE OF CONVERTER.

First blow began at 5.10 P.M.; first blow ended at 5.41 P.M. Time of blow, 31 minutes.

Second blow began at 6.10 P.M.; second blow ended at 6.35 P.M. Time of blow, 25 minutes.

Third blow began at 6.45 P.M.; third blow ended at 7.26 P.M. Time of blow, 41 minutes.

Length of blast on charge: first blow, 31 minutes; second blow, 25 minutes; third blow, 41 minutes. Total, 1 hour 37 minutes.

NOTE.—Converter-lining reinforced with one wheelbarrow-load of lining after the run.

FOURTH AND LAST CHARGE OF CONVERTER.

NOTE.—Had to wait nearly an hour for matte, as No. 3 furnace had been run down.

First blow began at 8.43 P.M.; first blow ended at 9.09 P.M. Time of blow, 26 minutes.

Second blow began at 9.19 P.M.; second blow ended at 9.56 P.M. Time of blow, 37 minutes.

Total time of blast: first blow, 26 minutes; second blow, 37 minutes. Total, 63 minutes.

Product, 52 bars; weight, 15,070 pounds.

Sample No. 16.—Taken like sample No. 8; 14½ bars of metallic copper.

Sample No. 17.—First tap of matte from settler No. 3, taken like sample No. 1.

Sample No. 18.—First pour of slag, 10 pots.

Sample No. 19.—White metal, after first blow.

Sample No. 20.—Second charge of matte from No. 3 well into converter.

Sample No. 21.—Nine pots slag, second pour.

Sample No. 22.—Two pots skimmings.

Sample No. 23.—White metal, after second blow.

Sample No. 24.—Metallic copper, 14½ bars, taken like No. 8.

Sample No. 25.—Matte (only tap) poured from No. 3 well.

Sample No. 26.—Nine pots slag poured.

Sample No. 27.—One pot of skimmings.

Sample No. 28.—White metal in converter after first blow.

Sample No. 29.—Metallic copper, 12 bars.

Sample No. 30.—"Granulated slag," 2 pots grab as raked out.

Sample No. 31.

Sample No. 32.

Note.—In blowing up the charges to white metal, there were always some fumes coming from the converter. But the fumes were very much heavier than usual in the last charge. In fact there were very dense fumes, probably lead, through almost all of the time of the first blow on the fourth charge.

Assays of Above Samples.

First Charge.

	Matte. No. 1.	Slag. No. 2.	White Metal. No. 3.	Matte. No. 4.	Slag. No. 5.	Slag Skim-mings. No. 6.	White Metal. No. 7.	Copper. No. 8.
	Per cent	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica................	....	36.78	....	....	34.64	36.62	....	....
Copper.............	55.48	3.09	78.79	55.40	4.36	6.84	79.22	98.64
Iron................	21.09	45.82	0.86	21.06	48.47	43.01	0.47	0.159
Nickel	0.34	0.28	0.07	0.26	0.56	0.38	0.15	0.04
Zinc	0.16	....	0.04	0.09	....	....	0.06	0.027
Lead	0.612	....	0.12	1.04	....	....	0.13	0.084
Antimony.........	0.021	....	0.010	0.031	....	....	0.014	0.009
Arsenic	0.051	....	0.014	0.032	....	....	0.015	0.012
Selenium and Tellurium.....	0.05	....	0.015	0.029	....	....	0.043	0.043
Sulphur...........	21.39	0.26	19.78	21.93	....	....	19.45	0.244
Silver*.............	(9.42)	(0.20)	(9.12)	(6.82)	....	....	(10.22)	(12.24)
Gold*..............	(0.12)	....	(0.20)	(0.10)	....	....	(0.22)	(0.24)
Insol. resid.......	0.34	....	....	....	....	....	....	0.196

Second Charge.

	Matte. No. 9.	Slag. No. 10.	White Metal. No. 11.	Matte. No. 12.	Slag Poured. No. 13.	Slag Skim-mings. No. 14.	White Metal. No. 15.	Copper. No. 16.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	Per cent.
Silica................	....	35.30	....	....	33.46	39.62	....	....
Copper.............	54.04	4.08	79.10	50.50	4.47	4.31	78.44	98.90
Iron	21.35	47.05	0.595	24.95	49.60	42.44	0.86	0.184
Nickel	0.24	0.39	0.072	0.22	0.96	0.49	0.15	0.033
Zinc	0.145	....	0.031	0.08	....	....	0.063	0.004
Lead................	1.21	....	0.192	2.12	....	....	0.37	0.103
Antimony	0.02	....	0.006	0.033	....	....	0.013	0.014
Arsenic............	0.04	....	0.015	0.035	....	....	0.016	0.016
Selenium and Tellurium.....	0.04	....	0.022	0.035	....	....	0.042	0.045
Sulphur............	21.67	....	19.46	21.61	....	....	19.59	0.463
Silver*.............	(6.08)	(0.18)	(10.64)	(6.08)	....	....	(9.28)	(11.13)
Gold*..............	(0.16)	....	(0.18)	(0.12)	....	....	(0.20)	(0.25)
Insol. resid.......	0.51	....	....	....	....	....	....	....

* The figures for silver and gold, in parenthesis, represent ounces per ton. As 9.02 ounces is much more silver than any of our low-grade melts contain, this sample is undoubtedly incorrect; and therefore the silver and gold in the second sample (next table) should be taken for purposes of comparison.

THIRD CHARGE.

	Matte. No. 17.	Slag. No. 18.	White Metal. No. 19.	Matte. No. 20.	Slag Poured. No. 21.	Slag Skimmings. No. 22.	White Metal. No. 23.	Copper. No. 24.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica.............	....	34.35	....	....	32.60	37.84	....	....
Copper............	53.46	2.87	78.98	55.30	4.12	4.94	78.92	98.02
Iron	21.95	48.40	1.10	19.99	54.33	43.10	0.86	0.161
Nickel............	0.24	0.76	0.07	0.29	0.99	2.02	0.12	0.042
Zinc	0.18	0.39	0.03	0.09	....	....	0.06	0.016
Lead..............	1.89	1.51	0.10	1.37	....	....	0.26	0.11
Antimony	0.03	....	0.005	0.03	....	....	0.014	0.02
Arsenic...........	0.05	....	0.014	0.04	....	....	0.015	0.016
Selenium and Tellurium.....	0.04	....	0.018	0.03	....	....	0.026	0.048
Sulphur..........	21.72	....	19.32	22.49	....	....	19.47	0.51
Silver*............	(6.76)	(0.11)	(9.80)	(6.40)	....	....	(8.88)	(11.86)
Gold*..............	(0.14)	....	(0.20)	(0.12)	....	....	(0.18)	(0.24)

FOURTH CHARGE.

	Matte. No. 25.	Slag Poured. No. 26.	Slag Skimmings. No. 27.	White Metal. No. 28.	Copper. No. 29.		Granul. Slag Rakings. No. 30.	Hood. No. 31.	Lining. No. 32.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
Silica	....	82.57	85.16	....	....	Silica............	43.14	1.14	85.64
Copper............	57.86	3.18	4.22	77.58	*29.05	Copper..........	9.27	75.72	0.28
Iron..............	17.68	50.84	50.43	0.98	0.164	Iron.............	27.195	3.31	2.22
Nickel ....{	0.12	0.19	1.34	0.13	0.024	Nickel...........	0.912	0.26	....
	0.33					Aluminum....	....	0.22	3.71
Zinc................	0.21	0.42	....	0.05	0.016	Zinc.............	0.04	0.168	....
Lead...............	1.85	2.25	....	0.48	0.08	Lead.............	2.84	1.51	....
Antimony........	0.03	....	....	0.15	0.018	Antimony.....	....	0.025	....
Arsenic...........	0.04	....	....	0.17	0.016	Arsenic	....	0.033	....
Selenium and Tellurium.....	0.04	....	....	0.02	0.044	Selenium and Tellurium...	....	0.053	....
Sulphur..........	21.34	....	....	20.11	0.07	Sulphur.........	....	12.40	....
Silver*............	(5.86)	(0.16)	....	(7.86)	(12.78)	Silver*..........	(0.52)	(7.50)	....
Gold*.............	(0.12)	....	....	(0.18)	(0.27)	Gold*............	....	(0.10)	....
Insol. resid........	0.39	....	....	....	....				

* The figures for silver and gold, in parenthesis, represent ounces per ton.

In summary: 9 h. 43 min. were consumed in making 15,070 pounds of copper, in four charges, or 2 h. 25 min. per charge. To this, 20 min. must be added for the time allowed for changing converter-shells.

The first charge was blown up to copper in 1 h. 11 min.; the second, in 1 h. 35 min.; the third, in 1 h. 37 min.; and the fourth, in 63 min. Total, 5 h. 26 min.

The skimming and second matte-filling actually occupied 34 min. for the first charge; 37 min. for the second; 39 min. for the third; and the skimming of the fourth charge occupied 16 min. Total, 2 h. 6 min.

The difference of 2 h. 11 min., or 33 min. per charge, between the total of 9 h. 43 min. and the 7 h. 32 min. taken in blowing, skimming and matte-filling, was therefore spent in pouring copper, patching and charging,—an excessive allowance, due in part, as previously explained, to the system, otherwise so economical, of linking a furnace to one converter.

The converter-lining used in Bisbee is composed of quartzite and clay from the mine, the latter carrying a small percentage of copper. No ore sufficiently siliceous, and, at the same time, sufficiently plastic, has been found at Bisbee to serve as lining; but at Morenci an ore with an average composition of 54 per cent. SiO_2 and 20 per cent. Al_2O_3 is used to line the body of the converter. A more siliceous mixture is preferred for the zone of the tuyeres. The small quantity of gold and silver, which the above analyses reveal, comes from every section of the mine—a certain stope containing more on one day than on another day. For a time a selection was made, one converter and one furnace being run on the more highly argentiferous ore, and bars of slightly higher tenor in gold and silver were made from them; but the difference between these and the average was too small to encourage us in continuing the practice. No roasting is actually needed; but two cylinder calcining-furnaces are kept running on very heavily sulphuretted ores, extracted chiefly during exploration. The furnaces are automatic and self-roasting. Each handles 8 tons of coarsely crushed ore a day, reducing the average sulphur contents from 45 to 8 per cent.

The power-plant of the works, like that of all plants built up

by instalments, is very defective.   No steps are being taken to improve it, because the company contemplates building, in the near future, a large gas-producer and gas-engine plant, the experience of both the Arizona Copper Co. and the Detroit Copper Mining Co. having been overwhelmingly and unreservedly favorable to that mode of generating power, at least under the local conditions here existing.