*(Paper No. 2912.)***"Mining and Treatment of Copper Ore at Tharsis, Spain."¹**

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IN the development of the Tharsis mines four periods of well-defined activity can be traced, the Prehistoric, the Phœnician, the Roman and the Modern.

During the first, the emergence from the stone period is indicated by the quantities of stone implements, made from the hard porphyry of the surrounding country, which have been from time to time found in the mines and caves of the district.

The second period occurred during the Phœnician occupation of Spain, which, according to Josephus, was 240 years before the building of Solomon's Temple, or about 1,200 years B.C. Gades (Cadiz) was then one of the most important ports, and only six hours' sail from Huelva; it may be assumed that the Phœnicians were at or near the Andalucian group of mines about this time. The period of their domination may be also ascertained, for the weakening effect of the inroads made by the Assyrian monarchs was so disastrous to their trade that their great power in their colonies was broken. The Carthaginians, taking advantage of their difficulties, are found to be making inroads into Spain, and depriving the Phœnicians of their authority, about 650 B.C. There is no distinct evidence of the mines having been worked about this time, although the fact of several heaps of a rough and spongy class of scoriæ being in close proximity to the lodes, and always near an abundant spring of water, has strengthened the belief that these heaps are the refuse of Phœnician smelting. The complete absence of Carthaginian mining enterprise in the province indicates that the Romans, in becoming masters of Spain, must have rediscovered the mines; and that between the Phœnician and the Roman domination, 200 years B.C., or a period of 400 years, no mining work was carried on in this district.

During the third, or Roman period, the population drawn together for the purpose of trade and mining numbered millions, and remains can now be seen of an industry that was undoubtedly

¹ The discussion upon this communication was taken in conjunction with the preceding and the following Papers.

colossal; roads, amphitheatres and aqueducts abound, as well as numberless articles of jewellery, copper pots and pans, coins, mining-lamps, and water-wheels. It is difficult to imagine how so great an amount of ore as that represented by the slag-heaps which cover the ground was extracted through the tortuous galleries at present existing. Many miles of railway and road have been ballasted with this slag, and still the volume is not perceptibly reduced. These slags are as fresh and clean in outline now as they were when run from the furnace 2,000 years ago. It is indeed strange that so vast an industry as was here established, of 500 years' duration, could so completely have ceased. For 1,000 years there was again an absence of work in the district, partially accounted for by the Moorish domination of 410 A.D.

The renewal of activity by the Spaniards marks the opening of the fourth or modern period, and may be traced to the desire for riches induced by the discovery of America. In the year 1866 the present company was formed with a capital of £300,000 to take over the mines and property from a French company; and, as the working of the lodes developed, it was found necessary from time to time to increase the capital, which now stands at £1,250,000. Since the commencement of operations by the present company 508 per cent. has been paid in dividends, and £1,884,885 written off the property, plant, &c.

The composition of Roman slag is compared with that of modern slag in the following Table. Phœnician slag differs from the Roman and modern slags in containing between 2 per cent. and 3 per cent. of copper.

—	Roman Slag.	Modern Slag.
	Per Cent.	Per Cent.
FeO	50·81	46·59
Fe	0·46	2·40
Fe ₂ O ₃	4·48	Trace
Al ₂ O ₃	6·85	6·80
CaO	2·23	0·90
Cu	0·12	0·47
Zn	None	0·58
PbO	1·00	None
S	None	1·60
KNaO	0·28	1·06
MgO	0·31	0·38
Silica	32·80	38·15
Moisture	0·16	None
Combined moisture . . .	0·89	None
	100·39	98·93

GEOLOGY OF THE DISTRICT.

The property of the Tharsis Company consists of the Calañás lode, from which the export ore is at present drawn, the six lodes in Tharsis, the main establishment, and the newly acquired Lagunazo mine about 5 miles distant. The Calañás mine, about 18 miles distant, is connected with the main establishment by railway, and a line, 29 miles in length, connects Tharsis with the port at Huelva.

To the south of the Sierra Morena, and forming part of that range, there is, extending from near Seville and running into Portugal, a zone of clay slate between 110 miles and 120 miles in length, which encloses the enormous deposits of cupreous iron pyrites at Rio Tinto, Tharsis, and San Domingos. The course is in a north-westerly direction; and parallel to the deposits of ore, dykes of quartz-porphry occur, there being in some parts a difficulty to distinguish the slate from the porphyry. These dykes and intrusions are, however, generally prominent, and the enclosing rock is believed to be of either Silurian or Devonian age. The lodes are about 800 feet above the level of the sea, and the colouring of the surrounding country and their immense iron capping form prominent features of the district. The masses of ore are of a more or less lenticular form, parallel to the enclosing slate, and of great length and width, being as much as 2,600 feet long, 65 feet to 500 feet wide, and in most cases of great depth. The upper portion, having absorbed the copper liberated by the oxidation of the outcrop, contains as much as 3 per cent. or 4 per cent. of copper, whilst at a depth of 300 feet to 400 feet, unoxidized specks of yellow ore are found, giving the mass only $\frac{1}{2}$ per cent. of copper. In this form, the ore, both from poverty in copper and compactness of structure, becomes useless for either export or local treatment. Owing to the rapid decomposition of the pyrites, the existing ironstone outcrop or capping marks very perfectly the underlying mass; and the enclosing slate, by the action of the acid salts, has become soft and of a yellow, red, and black colour. When the hydrated oxide of iron of the capping is associated with silver and other metals, these may be considered as an inset to the occurrence of cupriferous pyrites at greater depth. *Fig. 1*, p. 129, shows the form assumed, and the connection between the gossan and the lode. One of the lodes of the Tharsis group, however, merits special mention, as it is, at least in this district, unique, consisting of slate that has been impregnated by cupreous liquors. Such deposits are restricted to sites that have received the natural liquors produced by the oxidation of pyritic lodes at their outcrop,

and have originated in the action of these cupreous liquors upon slate containing disseminated sulphide of iron and zinc. The most characteristic indications are depositions of ferric oxide, either in blocks forming a conglomerate, or as films upon slate or other rocks.

The whole mass, of 2,300 feet length, with an average width of 197 feet, and depth of 98 feet, contains very little copper, its amount seldom exceeding $1\frac{1}{2}$ per cent., and corresponds exactly to the outer case of the pyritic lodes, where the ore, being in contact with the slate, has caused the latter by impregnations to become soft. Such deposits are very easily and economically worked, and permit of profitable extraction with a copper contents of a little

Fig. 1.

over $\frac{1}{2}$ per cent. The composition of the ores is as shown in the following Table.

	Cupriferous Iron Pyrites.		Cupriferous Schist.
	Export Ores.	Local Treatment Ores.	Local Treatment Ores.
	Per Cent.	Per Cent.	Per Cent.
Iron	43·10	42·80	0·10
Sulphur	49·50	48·30	0·15
Copper	2·50-3·00	1·50-2·00	1·00-1·25
Lead	0·30	1·30	..
Zinc	0·80	1·80	0·05
Arsenic	0·40	0·70	..
Water	0·50	0·80	3·15
Silica	0·60	0·70	93·60
Oxygen and various metals . . .	1·20	1·10	..
	99·40	99·50	98·30
Specific gravity	4·50	4·50	2·25

METHODS OF MINING.

Three methods of mining have been employed at Tharsis for the extraction of the ore. The pillar-and-stall system has been largely adopted, and by it somewhat over one-third of the entire mass can be extracted without the necessity of support or danger in working, the ore being very compact. Each floor has a height of 33 feet, and parallel galleries are driven through the entire length of the lode, 16 feet by 16 feet and 33 feet from centre to centre. A partition is left 16 feet thick, which is afterwards broken through in stalls of 16 feet width and 33 feet centres; the stall of one partition corresponding with, or facing, a pillar in the opposite partition. Great care has to be taken in the surveying of the various levels, as the safety of the lode depends upon the pillars falling vertically over or under each other on their superior or inferior floors: large faces of ore are exposed, affording freedom for the men in winning, and enabling the extraction to be continued with regularity. Each floor has a fall of not less than 1 in 150 towards the extraction shafts, which is found sufficient for both drainage and easy traction. The ore when broken down by the miners is loaded by a separate gang into small wagons, of 1 ton capacity, running in a 2-foot 6-inch gauge line, and made up into trains of three or four wagons for mule traction to the shafts. Each miner wins 2 tons per day, and a filler averages 20 tons per day of eight and a half hours, the consumption of dynamite No. 1 being about 0·175 lb. per ton. The miners and fillers are generally on contract and earn 3s. and 2s. 6d. per day respectively. By this system the ventilation is excellent, there are therefore no delays from dynamite fumes after blasting. The dryness of the ground has always facilitated underground working, as not more than 30 gallons per minute of liquor per day is given by these large lodes.

The large amount of ore that was left in the lodes after working on the foregoing system led to the contemplation of other methods; and finally, after much thought and consideration, a bolder scheme was inaugurated—that of removing the overlying rock. The open casting of these lodes has been at work for many years, and some of the largest excavations in the world may now be seen in this province. The dip of the ore, not being more than 60°, assisted the open-cut system of working; whilst the more economical mining of the ores afterwards has permitted a very large amount of overlying rock to be removed profitably per ton of ore rendered available. Six hundred and fifty-four thousand cubic

yards have been removed from the surface of one lode within a year. The method employed, *Fig. 2*, is that of dividing the over-burden into floors, 33 feet in height, leaving a slope of 60° and a bank of 13 feet width; this gives an average batter of about 45° , allowance being made for the varying conditions of the hanging- or foot-walls. The hanging-wall permits of a batter of $3\frac{1}{2}$ in 10 being given as against $5\frac{1}{2}$ in 10 for the foot-wall. There is, however, no set rule, the slopes in all cases being governed by the strength or compactness of the enclosing rock; but this condition and the copper contents are conjointly the factors which fix the cube that can be allowed per ton of ore made available. From the large open cuttings, many banks being over 1,600 feet in length, a miner will blast and break down 250 cubic feet per day of eight

Fig. 2.

SECTION ACROSS A MAIN LODGE SHOWING ORE AND OVER-BURDEN REMOVED.

Scale, 240 feet to 1 Inch.

and a half hours at a wage of 2s. 6d., whilst a filler at 2s. $2\frac{1}{2}$ d. per day, assisted by a carrier to wagons at 1s. $3\frac{3}{4}$ d., will give 424 cubic feet during the same time. As in this case the work is generally by task rather than by contract, a closer supervision is required over the consumption of dynamite, the average amount used being 0.168 lb. No. 3 per cubic yard. An excavation that advances with the line of stratification will require one-half more dynamite than if advancing at right angles to it; it is therefore always advisable in open casting a lode of considerable length and ample width to drive a trench in advance, giving in this way a minimum of work with the stratification and a maximum at right angles to it. Whether the dip be great or slight, the work should always, where practicable, be commenced on the

hanging side, working towards the foot-wall, there being a considerable difference in the consumption of dynamite in favour of working with, as working against, the dip. After the removal of the over-burden the extraction of the mineral becomes much easier and consequently less costly. Each man will blast down 8 tons at a wage of about 2s. 8d. per day, as against 2 tons per man in close workings at a wage of 3s. per day, loading in both cases being about the same, whilst the consumption of dynamite No. 1 is about 0·099 lb. per ton in the open cutting, as against 0·175 lb. in underground workings. The advantage is, therefore, that the whole of the ore uncovered by the removal of its over-burden is rendered available for extraction, the lower cost of extraction more than paying for the removal of the superincumbent rock.

The third method of mining is more or less an adaptation of the long-wall system, and permits of the whole of the ore being

Fig. 3.

PLAN SHOWING METHOD OF EXTRACTION BY BUILDING AND FILLING.

Scale, 340 feet to 1 inch.

removed by underground working. The lode is divided longitudinally at equal distances by diaphragms or walls, starting at the bottom level and working upwards, between each wall a space being left equal to their thickness, afterwards to be filled with loose rock or earth as the overhead extraction continues. This system, though expensive in working, has been adopted for the extraction of the ore from one of the lodes the form of which lent itself readily to the operation. The usual underground working would have given, as before stated, about one-third of the whole mass, the richness of the ore warranting a more expensive system of working though not the removal of its over-burden. This mass of ore, known as the Poca Pringue lode, contains about 3·75 per cent. of copper, its length being 679 feet, and having an average width of 52 feet, being evidently a spur from the adjoining lode, although separated therefrom, as it runs out at a depth of 112 feet. The lode is divided into floors 33 feet in height, and a gallery at each floor runs along one side of the mass, assisting ventilation and enabling the extraction to be carried on easily. Operations

begin at the lowest level or floor, the entire length being subdivided into spaces of 4 feet alternating with those of 8 feet in width, the 4-foot spaces being reserved for building in dry stone and the 8-foot spaces for filling. Galleries are driven across the lode at the bottom of 16-foot width, and the excavation continues upwards by overhead working. As the ore is removed the dry-stone walls are built along each side of the excavation, the centre portion being filled with waste. When the ore appertaining to this section is extracted there is left in its place a diaphragm from the bottom to the top of the mass composed of two dry-stone walls enclosing rough filling. Whilst this section is being worked, other

Figs. 4.

SECTION SHOWING METHOD OF EXTRACTION BY BUILDING AND FILLING.

Scale, 240 feet to 1 inch.

portions of the lode are being attacked in the same manner, the upper exterior galleries being used for the supply of stone, &c., for building and filling, whilst the lower galleries serve for the loading of the extracted ore. The stone for building and the waste for filling are obtained from the open cutting of the adjoining lode, being selected during removal and deposited near an automatic drop-shaft by which it is passed when required to the workings below. No difficulties are experienced from any movement or creep of the hanging-wall. The whole operation of mining, dry-stone packing and filling, with the present low market prices for copper, sulphur, &c., requires about 1.50 per cent. to 1.60 per cent. of copper per ton of ore obtained to cover the costs of working.

MACHINERY.

The shafts vary in size considerably, some being large enough for a double cage, and others for a single cage only; the output, however, for each shaft may be considered as between 900 tons and 1,000 tons per day, drawn from an average depth of 295 feet. The shafts are fitted with ordinary cages, safety-hooks and automatic gong indicator in the engine-room for the starting and delivery of the wagons. At the shaft mouths there are extensive platforms, along one side of which a series of tumblers is arranged by which the wagons are turned completely over by their own weight, righting themselves again when empty. To the tumblers are connected shoots at an angle of 36° in the form of riddles of $\frac{3}{4}$ -inch spaces, to allow the mineral for export to be cleansed of its smalls, which amount to about 17 per cent. of the whole weight. The smalls are sent to the local treatment ground for the extraction of their copper, and the reduction of the liquors before precipitation; other shoots are fitted with the Blake type of crushers or stone-breakers by which the ore is reduced to the required size for local treatment. These crushers have jaws 24 inches wide, and are capable of crushing 40 tons per hour at a cost of $2\frac{1}{4}$ d. per ton. The channelled and ribbed jaws of chilled iron are reversible and withstand the crushing of 1,700 tons each; they have therefore to be constantly replaced, and provision is made for their easy removal. An automatic balance-feeder is also attached to the end of the riddle where the ore drops into the crusher, to prevent the whole wagon-load rushing into the jaws and causing them to jam. By these arrangements very little labour is required to keep the crushers constantly fed; the ore after being crushed drops through a funnel into the wagons waiting for its reception beneath, and is ready for weighing before being drawn off in trains of twenty wagons to the local treatment ground.

Each shaft is fitted with a 12-inch bucket-pump for dealing with the drainage water, although the ground, as before stated, does not yield much water; the extent of the open cutting accumulates large quantities, which run in upon the lower floors suddenly, and sometimes requires heavy pumping for a few hours, especially during wet seasons or thunderstorms. As these liquors are very acid, and give great trouble by rapidly eating into the metal of the pumps, an alloy containing one part of antimony, two of lead, three of tin, and fifteen of copper for cylinder buckets, valves, etc., though difficult to cast, has been found to give the most excellent results, whilst for bolts, nuts, etc., one part of lead, two of tin, and

seventeen of copper, is preferable to withstand blows or strains, being more ductile.

The workshops are well fitted with modern machinery, and all the smiths, mechanics, fitters, boiler-makers and carpenters are Spaniards. All locomotive and wagon repairs are carried out at the mines.

TREATMENT OF THE ORE.

The old and simple method of extracting the copper was by calcination, the sulphide of copper during the process being turned to cupric sulphate, and the ore to a spongy condition by the consumption of its sulphur; the copper was then very readily washed out with fresh water. A large area of ground was occupied by the ore both in active calcination and that which had been calcined, being first conveyed to the site, either crushed by the crushers at the pit's mouth to the requisite size, or hand-broken when tipped on the ground. Long triangular heaps were built, having a series of rough dry-stone flues and chimneys, with brushwood in mounds placed at intervals of 13 feet; these heaps were built parallel to one another, and mostly 98 feet long by 16 feet wide and 8 feet high, containing about 330 tons. The exterior was carefully covered with the finely riddled smalls or burnt ore that had been previously washed; this enabled the combustion to be controlled, and great care and experience were necessary to ensure a perfect calcination. These heaps were generally burning five, six to eight months, or, as was found by experience, a month for each metre-width of the heap; about 12 per cent. of weight was lost by calcination, and 84 per cent. of the copper made soluble; this permitted the ore to be washed down to 0·20 per cent. of copper, with five consecutive washings. When cold, the heaps were broken open, loaded into wagons, and the material conveyed to the dissolution tanks, into which it was tipped. Here it was saturated with water, the resultant liquor being drawn off when clear; by this process six or seven waters were generally found sufficient to extract the copper, each successive saturation being given greater time; the resultant liquors were passed to a settling-dam, and drawn off as required by the precipitating plant. When the copper in the ore was reduced to about 0·20 per cent. the tanks were cleaned and the washed ore deposited on a site conveniently near, where the residual copper was extracted by further washings; by this process $2\frac{1}{2}$ tons to 3 tons of iron were consumed to produce 1 ton of fine copper, whilst the quality of

the precipitate was very poor, often not reaching 60 per cent. of copper.

It was found, however, that by passing the liquors from the lixiviation of the calcined ore over the crude smalls as a filter, a marked change took place, the ferric sulphate being very readily turned to ferrous sulphate, as the copper was taken up from the smalls. This gave an almost ideal liquor for precipitation purposes, and by the development of this process under constant care the consumption of iron in the precipitation of the copper from these liquors was reduced to 1.25 per unit of copper produced, and the quality of the precipitate raised to 80 per cent. Here, then, was a great advance upon the old system; the cost of handling the ore was reduced at once by one-half, and later, this was brought down to a minimum of expense by the burnt heaps being washed *in situ*. The new heaps of crude ore being built upon those that were already washed, there was ultimately only the cost of traction from the pit's mouth to the calcination ground, the making into heaps, calcination and lixiviation, by either washing the burnt ore in dissolution tanks or *in situ*; 35.32 cubic feet of water was used per ton of ore.

The nuisance caused by the calcination of upwards of 200,000 tons of cupriferous pyrites per annum can be readily imagined. Vast clouds of sulphurous-acid gas extended for miles over the country, withering up everything that they touched in their flight; many attempts were therefore made to abolish or at least modify this nuisance, but without result. Many chemical treatments were tried, and were, apart from their partial success, prohibitive in consequence of their expense; the necessary economical treatment of such low-grade ores was a drawback against any complicated treatment. It was, however, ultimately found that an induced natural oxidation of the ores that were specially crushed and tipped in large deposits would, though taking slightly longer to obtain the copper than by direct calcination, give an equally good result, more economically, and at once abolish the noxious fumes. This process has now been working four years, and consists in first crushing the ores to a fineness that 45 per cent. would pass a 1-inch sieve with only 10 per cent. larger than 2 inches; tipping in heaps as large in area as possible, 33 feet in depth, the whole ground occupied by the deposit being laid out in a network of dry-stone drains for ventilation and drainage. Occasional small shafts were built up in the heap for purposes of testing the temperature, a record being carefully kept of these readings for reference, as the success of the operation

consists in maintaining a regular heat through the deposit. Ores containing so much sulphur oxidize very readily, and the heat generated in the deposit is also influenced by the percentage of copper contained in the ore. By a very careful system of intermittent washing with fresh water, oxidation is encouraged, and, three months after washing operations begin, considerable heat is noticeable in the heap; in six months, the full heat that can be permitted is attained, and from that time forward a check has to be kept on the general temperature. As the copper is washed out, there is a tendency for the heat to subside. As far as experience has indicated, the temperature should not be higher than 120° F., whilst below 70° the rapid extraction of copper is retarded. From ores containing between 1 per cent. to 1.50 per cent. of copper, 45 per cent. of the total can be washed out during the first year, 20 per cent. the second year, and 10 per cent. in the third year. This leaves a small residue, obtainable if desired by light washings. After three years' washings the original tonnage laid down for treatment is reduced by 23 per cent. in consequence of its loss in copper, sulphur, iron, etc. Ores richer in copper will yield a better result, the poorer class slightly worse in consequence of their origin in the lower floors where it is unoxidized and more compact in structure. The top of the heap has a gradient of not less than 1 in 300, which is formed in tipping, and the whole surface is divided into equal areas by shallow drains made with the finer ore, along which the water is conveyed to such parts as are under treatment. The water filters rapidly through the heap, taking up the sulphate of copper produced by oxidation; the whole of the water used in washing, less 19 per cent. absorbed and evaporated, is caught by a main drain which conveys it to a valley filled with what are locally called smalls, given by the screening of the export ore. There being over 750,000 tons in this valley, the area is large and forms a convenient filter for the reductions of the ferric sulphate in the liquors received from the upper heap. Besides the advantages gained in the suppression of the smoke, the ore, after it has been under treatment three years, becomes a valuable asset, its sulphur contents giving it a decided commercial value. The whole process requires considerable care and attention, and is kept under working control both night and day by a number of trained assistants. The liquors obtained by the treatment contain per gallon on an average 210.3 grains of copper, 1225.3 grains of iron as FeO , 171.0 grains as Fe_2O_3 , 1296.9 grains of sulphuric acid, 11.22 grains of arsenic, etc.; whilst after passing the filter the amounts are

273·4 grains, 1421·6 grains, 36·5 grains, 1366·9 grains, and 11·22 grains respectively. This liquor is passed on direct to the precipitating plant.

The cupriferous schist extracted from what is known as the Esperanza lode is tipped in a valley below, and in close proximity to the lode. The output amounts to a little over 300,000 tons per annum, and, as a similar extraction has been made for several years, there is now an immense deposit in the lower valley. The material is tipped as it is received from the lode and undergoes no preparation such as the mineral before washing. The most rapid and efficient method of obtaining the copper is to first give a saturation with an acidulated liquor such as is pumped from the mine, or a spent liquor from the precipitating department; and, after two or three months' rest, the heap is in condition for leaching with fresh water. The schist washes freely and there is but little difficulty in reducing its copper contents to 0·10 per cent. The liquors given by the leaching are not strong in ferric sulphate, and therefore a contact of short duration with small crude ore is sufficient to bring them into excellent precipitating condition; these liquors, though seldom rising above 140 grains of copper per gallon, produce, when passed over iron, a very fine class of precipitate, free of arsenic and assaying 87 per cent. of copper.

The quantity of water requisite for the efficient washing of the crude mineral is 440 gallons per ton of ore for the first year, 220 gallons per ton the second year, and 110 gallons for the third year. If the tonnage of ore laid down for treatment each year be more or less constant, it follows that during the third year the largest consumption of water takes place, as not less than 250,000 tons of ore are annually placed under treatment, besides 300,000 tons of cupriferous schist; very large storage reservoirs are required to enable the work to be carried on without intermission during the dry season, which may be considered to fall between the months of June and October. Provision has therefore been made in Tharsis alone for the storage of upwards of 572,000,000 gallons of water brought to the reservoirs by many miles of catch drains. The burning of the cupreous ores for so many years has cleared the country for some distance of vegetation, the ground is therefore in a condition to give a considerable proportion of the rain that falls; many tests have been made and the average over thirteen months was found to be 54 per cent. of the total rainfall.

The evaporation is very great and is found to represent, in the case of the largest reservoir, 96,800,000 gallons per year. During the months of July and August very great heat is ex-

perienced, the thermometer occasionally rising to 110° F. in the shade, with 85° for several weeks as a minimum; the healthiest portion of the year, however, corresponds to these hot dry months, and the most unhealthy towards the end of September or the beginning of the first autumn rains.

A Table is given in the Appendix of the rainfall for the last fifteen years and the evaporation for the last seven years.

SAMPLING.

In treating such large quantities of poor ores and schists accurate sampling and analysis form an essential part of the operation. The tendency has always been to err on the higher rather than the lower side; and, under various methods of sampling, designed either with the object or not of counteracting the human error, the same constant tendency is noticeable. It may be safely assumed that no large heap of cupriferous ores has ever given more copper than was originally returned by sampling and analysis; in fact, the whole history of the working of these immense heaps has proved that their copper contents were less than was at first estimated. As the utmost care and vigilance is required, a system has been instituted which is equivalent to mechanical sampling; each wagon at the pit-mouth, as well as on the tipping ground, yields its quota, a method which ensures never less than two returns, and in many cases a third sample is independently taken. The undoubted possibility of error, coupled with the absorption of the ground, etc., makes it impossible to expect that the whole of the copper in the ore laid down for treatment is ultimately obtained.

PRECIPITATION OF THE COPPER.

The general disposition of the ground and its natural fall from around the lodes has been taken advantage of in the arrangement for the supply of fresh water, etc.; the valleys running from the fresh-water reservoir being utilized in the upper portion for the tips of crude ore, below which there are the filter-beds and a series of collecting dams, and, finally, in continuation, the precipitating plant. The most approved method of precipitating the copper from its liquor is by passing it over pig-iron laid in a double layer in canals constructed especially for its reception. These canals, of creosoted timber, are 2 feet 9 inches wide with a depth of 9 inches laid in quadruple, triple or double series; if the fall of the ground

permits, about half the total length is laid with a fall of not less than 1 in 200, a quarter of the length following with 1 in 100, and the final quarter with 1 in 50. This arrangement permits of a gradually increasing agitation of the liquors as they advance and become poorer in copper, thereby improving and enriching the precipitate produced. One metre length of canal of the above dimension holds 573 lbs. of iron, and is capable of producing one ton of fine copper per annum. There is, therefore, considerable length of these canals employed at the mines, the total reaching 9,624 lineal yards, the pigs of iron used are 2 feet 6 inches long, weigh 33 lbs, and contain on an average 94 per cent. of iron. The liquors on entering the service contain per gallon on an average 227·8 grains of copper, 1480·5 grains of iron as FeO , 33·65 grains Fe_2O_3 , 1380·9 grains of sulphuric acid, and 11·22 grains of arsenic; hundreds of thousands of gallons are passed per day, and, by the affinity which copper has for iron, a rapid galvanic action is set up, the free acid attacking the iron, giving sulphate of iron, and the copper taking the place of the iron in a metallic state. The liquor, when rendered of its copper, passes out of the service with 0·841 grain of copper per gallon, 1811·4 grains of FeO , 1331·9 grains of sulphuric acid, and 5·748 grains of arsenic; the copper is therefore almost all precipitated, the iron increased, and the ferric sulphate turned to ferrous sulphate, at the expense of the metallic iron. A small portion of the free acid is used in the precipitation of the copper and about half the arsenic is precipitated. Each day a certain length of the canals is cleaned, the pig-iron is lifted out, the metallic copper scraped off, and the iron replaced; a "cleaner" can despatch on an average thirty-four lineal yards of canal per day. The precipitate is loaded into wagons, taken to a yard where it is washed with fresh water, being drawn by large hoes against a running stream, the heavier grains and scales reaching the top of the washing canal, the finer grains passing on with the water to a depositing canal where they settle according to gravity, the lighter portion being deposited in a series of tanks adjoining the canal. In this manner an economical classification is made automatically. The next operation consists of throwing the scales into heaps and drying, after which they are ready to be sacked for export; the larger grain precipitate is pressed into cylinders of 22 lbs. weight, and, when dry, also sacked, whilst the poorer class deposited in the tanks is made up into heaps and burnt. By this arrangement the large portion of the arsenic, which is extremely injurious to the quality of the copper, is concentrated in the calcined precipitate. The foregoing

classification produces in relative proportion 72 per cent. of scales, 12 per cent. of cylinder, and 16 per cent. of calcined; the scale precipitate containing 92·5 per cent. of copper, the cylinders 78·5 per cent., and the calcined 48·3 per cent., the average contents being 81 per cent. of copper, with 2·80 per cent. of arsenical ferric oxide, the residue of 16·20 per cent. being graphite from the pig-iron, silica, etc.

The amount of iron consumed in the precipitation of the copper is about 1·25 time that of the copper produced; this is considered a very favourable result, although, according to theory, 56 parts of iron should precipitate 63·5 parts of copper, or in the ratio of about 8 to 9. This result, is, however, never attained in practice, owing to the ferric salts which are always present, as also the free oxygen which is relatively in large proportion in weak solutions such as are used, and tends to oxidize the iron; the arsenic also requires for its precipitation about 1·5 per unit, whilst the pig-iron itself generally contains not less than 6 per cent. of impurities. The whole of the liquors before entering the cementing plant are measured and analysed, a record being kept of the total amount of copper produced according to the liquors received. This serves two objects; first, the production of the month is known before it is possible to ascertain it by the actual copper produced, as generally three weeks elapse before the precipitate is dry and ready for export; and secondly, should there be more than one source from which the copper is derived, by the aid of the measurements and analysis it can be credited with its due amount. The company produces annually between 10,000 tons and 11,000 tons of fine copper.

RAILWAY AND PIER.

The main establishment at Tharsis and the port of embarkation are connected by a railway of 4-foot gauge, having ordinary web and flanged rails of 60 lbs. per yard spiked to the sleepers. Six to eight trains run daily according to the requirements of the shipping, each train carrying 100 tons of mineral, whilst an up and down passenger service is also worked in combination with the mineral trains. Each locomotive weighs 25 tons, and the entire journey of 29 miles occupies two hours. The cost of working the service is $\frac{1}{2}d.$ per ton of ore per mile, the line being kept in efficient working state by the employment on the maintenance of one man per mile of road.

The pier is an iron structure, 2,624 feet in length, having at its head ample berth for three vessels; it is provided with turn-tables

and steam cranes, the whole being equipped for the loading of 2,500 tons per day if necessary. Near to the pier is a storage-ground capable of holding 30,000 tons of ore, by the assistance of which the loading of the vessels is carried on continuously, there being no necessity to wait for down trains. During any reduction of shipping the excess received from the mines is tipped into the deposit, thus enabling either a large or small tonnage to be supplied to the pier-head for shipment, and a regular train service to be maintained; should also any serious breakdown occur there is always between 20,000 tons and 30,000 tons of ore to draw upon during repairs; contingencies are therefore amply provided against.

LABOUR.

The number of persons employed at the mines, on the railways, pier-head, etc., is, including men, women and boys, about 3,500. The average working day is eight-and-a-half hours, and overtime is of exceptional occurrence. The following are the wages paid for the different classes of labour:—

	s.	d.
Underground miners	3	0
„ fillers	2	6
Opencast miners	2	6
„ fillers	2	2½
Masons	3	0
Carpenters	3	0
Ore washers	2	0
Canal cleaners	2	9½
Mechanics	4	0
Engine drivers	4	0
Blacksmiths and fitters	3	6
Labourers	2	0
Mule drivers	2	6
Boys	1	2½

TREATMENT OF ORE IN ENGLAND.

The exported ore is shipped to Cardiff, Newcastle-on-Tyne, Glasgow and other ports, where it is treated by the alkali makers for the production of sulphuric acid; it is then returned to the works of the Tharsis Company at these ports, where its copper, silver and gold are extracted, the residue being sold as iron ore. The calcined ore, as received from the chemical manufacturers, is first tested for sulphur, which should, for facilitating the operation, exceed that of the copper contents by about ½ per cent.; when less an addition is made of unburnt pyrites. On obtaining