TREATMENT OF BROKEN HILL ORES.

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Part I.—CONCENTRATION OF ORES.

Ores.

The immense lode of ore at Broken Hill is mined by ten large and several small companies. The upper or oxidised portion of the lode was marvellously rich in silver and argentiferous lead ores, besides ores and minerals of lesser economical value. The variety of minerals that has been found in the Broken Hill lode is, perhaps, unequalled at any other spot in the world. It is to be greatly regretted that no exhaustive and critical examination has been made of the various known and valuable collections of ores and minerals from this wonderful lode.

The unaltered ore consists of a mixture of galena, blende, quartz, rhodonite, garnet, and small quantities of calcite, pyrite, &c., in varying but omnipresent quantities. The ore generally contains lead and zinc in roughly equal amounts, with about as many ounces per ton of silver as there is per cent. of either lead or zinc. The average metal contents are gradually decreasing at greater depths. The galena is almost pure lead sulphide, except for the ever-present silver. The blende, on the other hand, is an impure zinc sulphide, with appreciable quantities of sulphides of iron and manganese. The percentage of rhodonite in the ore varies very considerably at different parts of the lode. The following is said to be a fair average percentage of rhodonite in the ores of the following mines:—

North Mine	3	per cent. rhodonite.
South Mine	7	,, ,,
Broken Hill Proprietary	15	,, ,,
British	25	,, ,,
Junction...	35	,, ,,
Junction North	45	,, ,,

In crushing, the rhodonite is left in large rounded grains, while quartz and the metal-bearing minerals splinter finer, and the latter, especially galena, have a great tendency to slime. These variations in the composition of the ore, which at first sight appear small, greatly affect the physical condition of the ore, and have resulted in considerable modifications of the treatment at different mines. For instance, compare that of the South Mine with that of the Junction North Mine, each, no doubt, being beter suited to its own ore than the other. (See figures 2 and 3.)

Above the unaltered sulphides was a zone of friable sulphide ore high in lead and silver values, but low in zinc. The zinc sulphide had been oxidised to sulphate, &c., and leached out, leaving the ore open and friable. The stopes in this zone were perceptibly hotter and fouler than those in the hard sulphides—no doubt due to the chemical action of oxidation still in progress.

Above the friable sulphides was the carbonate zone, containing oxidised lead ores with high silver contents, kaolin, and highly siliceous ores, containing at times exceedingly high silver values, and in places small patches of copper ore. Above this zone, where the lode outcropped, was the capping of iron manganese gossan, containing in places high values of silver chloride. Of the more important constituents it will be noticed that the zinc was the first to be oxidised and eliminated; later on, the copper; then lead; and last, the capping remains, composed of oxidised iron and manganese, and containing silver as chloride. The oxidised ores were smelted in blast furnaces, the iron manganese gosan being used as iron flux, and limestone brought from elsewhere.

A 50-head stamp battery and amalgamating plant was erected by the Broken Hill Proprietary Company for treating dry silver ores, but was not a success. A hyposulphite lixiviation plant, built by the same company for treating dry ores, was much more successful, and ran until the remaining dry ores were required for fluxing purposes at the Port Pirie smelters. The friable sulphide, after considerable preliminary trouble, was directly treated at the metallurgical works, but the crude unaltered sulphides could not be economically smelted for either lead or zinc. Large ore-dressing plants have been built, and complicated processes have been evolved for separating the ore into four products, viz.:—

1. Lead concentrates containing small quantities of zinc and gangue.
2. Zinc concentrates containing small quantities of lead and gangue. Both concentrates are shipped to various places to be smelted for their main constituent and silver.
3. The zincky (so-called) tails, of which there are upwards of 4,000,000 tons stacked. This is really an intermediate product containing high zinc values,

and now being treated by the various flotation processes for their large zinc and silver and small lead contents.

4. Worthless tails from one of the flotation or magnetic processes, being the valueless product of (3), or the continuous treatment of the crude ore.

Ore-breaking.

The general practice is as follows:—The crude ore from the mine is tipped on to grizzlies, the undersize going to the lower bin and the oversize into the breaker supply bin, from which it is fed to breakers of the gyrating type, the broken product rejoining the undersize that passed through the grizzly. In some mills the broken ore is passed through an intermediate swinging jaw breaker, usually of the Dodge type, before being sent to the rolls.

Rolls.

The almost universal practice is the use of slow-speed geared rolls of the Cornish type, 30-in. to 36in. diameter, and about 15 to 20 r.p.m. The oversize, after the product has been screened, is returned to the same rolls. The important exception to the general practice is the use of high-speed Gates rolls in the Broken Hill Proprietary Company's new mill. This mill has a nominal capacity of 6,000 tons per six days of 24 hours. Here progressive comminution has been more fully applied than elsewhere at Broken Hill. There are nine sets of these rolls, each 36in. diameter by 15in. wide. Crude ore, broken to 1in. to 2in. gauge, is, after screening, fed with a stream of water to three sets of rolls set ⅜in. to ½in. apart and making 30 r.p.m. After crushing and screening, the oversize from the shaking screen is conveyed on an endless horizontal belt to a bucket elevator, where it is elevated to bins which supply a second batch of three sets of rolls. These rolls are set ⅛in. to 3-16in. apart, and run at 45 r.p.m. The product is screened, and the oversize conveyed to an elevator and elevated to bins, which supply rolls Nos. 7 and 8, which are set at 1-16in. apart and running at 78 r.p.m. The oversize, after screening, is elevated to a bin, which supplies a No. 5 Krupp ball mill, in which finality is reached, as no ore can escape the ball mill before it is crushed to a sufficient fineness to pass the screens.*

It is interesting to note that the speed at which these rolls are driven has been reduced from time to time in order to obtain better efficiency. The rolls on 1½in. to 2in. ore were originaly run at about 45 r.p.m., and the others, on finer ore, at about 90 r.p.m. Four new mills have been built, and the

*G. D. Delprat, on "Ore Treatment at Broken Hill." Trans. Aust. Institute of M.E., vol. XII.

old ones remodelled since these high-speed rolls were installed, but in no case have similar rolls been installed. It is always the slow-speed geared type. It has been found that both classes of rolls do better work when crushing wet ore than dry ore. In the former case, the fine particles cling to the rolls, thus sanding the track and giving the rolls a more effective nip.

The ore is crushed to pass through 2 m.m. holes in punched plate screens. An interesting development in screening practise has taken place in recent years. Formerly a pair of cylindrical trommels, about 2ft. diameter by about 6ft. long, screened the product of each set of rolls. These small trommels were covered with either woven wire cloth or punched plate. The Broken Hill Proprietary Company introduced large conical trommels. Nearly all revolving trommels have now been replaced by shaking screens of various types. Shaking screens admit of more ready inspection and repairs, besides requiring less wash water. A very effective modification of the shaking screen is in use at the British Broken Hill Company's mill, and consists of a punched plate with corrugations of about 2in. radius at right angles to the direction of inclination and shake. The effect of the corrugations, in conjunction with the end shake, is to bring all particles in repeated contact with the screen, and giving the utmost facility of smalls passing through. The oversize discharged over the tail is visibly very free from fines.

In general, the oversize is returned for crushing to its own rolls, except in the Broken Hill Proprietary Company's new mill. The oversize is elevated to the rolls either by raff wheels or belt elevators, both means of elevation being largely used.

ANALYSES OF CRUDE ORE AND OVERSIZE FROM TROMMELS.

Sieve.*	Crude Ore.	Raffs.
Caught on 8	55·8 per cent.	54·3 per cent.
,, 20	14·8 ,,	33·9 ,,
,, 40	9·0 ,,	7·3 ,,
,, 60	5·0 ,,	1·0 ,,
,, 80	3·8 ,,	0·7 ,,
,, 100	3.0 ,,	through 80 0·8 ,,
,, 120	2·3 ,,	
,, 150	1·9 ,,	
Through 150	4·1 ,,	

	Crude Ore.	Raffs.
Insoluble	41·0 per cent.	50·0 per cent.
FeO	5·8 ,,	4·7 ,,
CaO	2·8 ,,	6·3 ,,
Pb	18·9 ,,	14·5 ,,
Zn	14·6 ,,	13·3 ,,
Ag. ozs. per ton	13·0 ,,	11·0 ,,

*All sieves are quoted at openings per linear inch.

The sizing analyses show that the crude ore from the breakers contains a larger percentage of fines than the oversize from the trommels, and also that the former contains a larger percentage of metals and less siliceous matter than the latter.

Hydraulic Classifiers.—The undersize from the screens passes to hydraulic classifiers, the overflow passing to spitzkasten and the underflow to the jigs. These classifiers do not make a clean separation of fines and slimes, as a considerable portion of the latter passes to the jigs, as will be seen from the accompanying sieve analyses.

Jigs.—The jigs used are of two types—viz., Hancock jigs and May jigs. The Hancock jig is of movable sieve type, about 20ft. long and 2ft. 6in. wide, with four sieve product hutches and a tail hutch. These jigs do good work, but unless they are very carefully operated splashings containing ore grit get into the working parts, which are mostly underneath.

The May jig is of the fixed sieve type, and is built double —*i.e.*, has a set of plunger and sieve compartments on each side of the longitudinal centre line. There are four sieve product hutches and one tail hutch on each side, besides an overflow at the tail hutch for surplus water and slimes. The plungers are worked by rocking arms operated by cranks on a counter shaft. There are two rocker shafts with a pair of rocker arms to each shaft, a pair of plungers on one side working in unison with each other, and in alternation with the pair on the same shaft on the other side of the jig, and also alternating with the other pair on the same side of the jig, but attached to the other rocker shaft. The throw of the crank is adjustable, altering the stroke of its set of plungers. The stroke of each plunger may be also independently altered. The capacity of these jigs is great. They do good work, giving great satisfaction and little trouble, and are preferred to the Hancock, despite the great and justifiable reputation this latter jig has achieved in concentrating copper ores both in Australia and America. Both of these jigs were invented and perfected in South Australia. The bed sieve of the jigs is of woven brass wire held between two gridiron frames. The bedding on the sieve is granulated cast-iron or the punched discs of small diameter from iron plates. The May jigs on coarse feed are driven at a speed of about 180 pulsations per minute. Similar jigs on fine—*i.e.*, reground—feed, work at about 270 pulsations per minute.

Fine Grinding.—The regrinding of the middling product to free the intimately associated minerals presents an interesting development. At first, narrow high-speed rolls were used; then the Herberli mill was used for this purpose, and was almost exclusively so employed for a number of years. The Herberli mill is a grinder with vertical circular discs set slightly eccentric to each other, one disc revolving at high rate of speed and the other at a slow rate in the same or opposite—usually the latter—direction. The pulp is fed under slight hydraulic head through the hollow shaft on one disc. The pressure on the discs is regulated by a screw acting against a steel coil spring. The objections to these grinders was that they sometimes gave a poorly ground product and at the same time an undue amount of slime. This undesirable result was in part due to the grinding faces of the discs not being true to each other—*i.e.*, pressing tightly together at one side, producing slime, while the gap on the other side allowed material to pass through with little or no abrasion. This defect was partially remedied by a simple alteration—viz., instead of attaching the discs to their shaft the end of the solid shaft was squared, and the corresponding discs were cast with a hollow-square collar, so that the discs now fitted on loosely, and, on pressure being aplied by the regulation screw it fitted flat against the other disc. The effect of this simple alteration was marked. On the one hand it reduced the percentage of coarse, and on the other reduced that of slime. Wet crushing in Krupp ball mills was tried. The results were so satisfactory that the Herberli mills were rapidly discarded in their favour. The recrushing in the ball mills had the following advantages:—The product has to pass through a screen; it is, therefore, under perfect control as to maximum size of issuing pulp grains, and at the same time a lessened percentage of slime is produced, giving a higher percentage of lead and silver recovery.

Grinding pans of the most modern types have since been very widely introduced, with most gratifying results, displacing or throwing out of commission many of the ball mills. Grinding pans instead of ball mills are being installed in the new mills recently completed or being erected. They have a lesser initial cost, are cheaper to operate, give less trouble, and, whilst grinding to a given maximum fineness, produces less slime than ball mills.

The capacity of the large grinding pans that have been installed is very great. The success of the highly improved grinding pans in reducing the galena-blende ores of Broken Hill parallels its success in fine grinding auriferous ore in Western Australia and elsewhere, and for tin ores in North Queensland. It has been found by experiment in North Queensland that the ball mill is inferior to the grinding pan for fine grinding tin, wolfram, and tin-wolfram. Very recently the Broken Hill Proprietary Company has been installing tube mills in place of ball mills for regrinding coarse tailings. The result is reported to be very satisfactory.

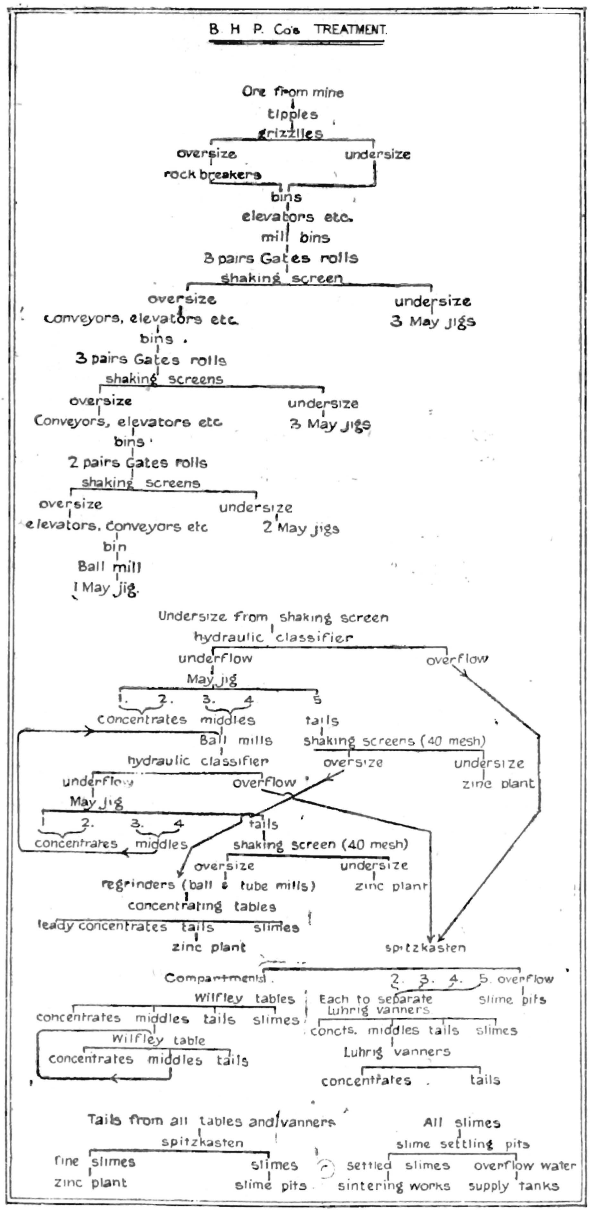

FIG. 1.

FINE JIGS.—After the middlings product of the coarse jigs has been reground it is elevated to hydraulic classifiers, the underflow passing to fine jigs and the overflow to the pointed boxes prior to treatment on tables and vanners. Three products are made—concentrates, middlings, and tailings. The middlings are reground, usually in ball mills with a fine sieve, or in grinding pans, and then returned to the hydraulic classifier of the same jig.

The following is an analysis of jig products:—

	Coarse Jigs.				Fine Jigs.	
	Feed.	Conct's.	Middl'gs	Tails.	Concentrates	Tails.
Insol., per cent. ...	38·0	12·0	42·0	64·0	31·0	49·0
FeO ,, ...	4·4	2·9	5·7	5·5	5·5	6·8
CaO ,, ...	5·1	9·9	6·7	1·4	2·2	trace
Pb ,, ...	26·6	67·3	12·4	4·8	30·8	5·8
Zn ,, ...	11·2	9·7	19·4	16·0	16·8	16·8
Ag. oz. per ton ...	13·1	30·1	9·6	6·5	28·5	8·3

SIZING ANALYSIS OF JIG PRODUCTS

Sieve.	Coarse Jig.				Fine Jig.	
	Feed.	Concnt's	Middles	Tails.	Concentrates	Tails.
Caught on ... 20	16·2 %	14·0 %	12·8 %	29·2 %	0·8 %	22·3 %
,, ,, ... 40	31·4 ,,	41·6 ,,	34·9 ,,	36·5 ,,	26·6 ,,	36·6 ,,
,, ,, ... 60	17·1 ,,	19·6 ,,	22·8 ,,	13·0 ,,	25·8 ,,	18·7 ,,
,, ,, ... 80	11·5 ,,	10·4 ,,	12·8 ,,	7·2 ,,	15·2 ,,	10·4 ,,
,, ,, ... 100	8·0 ,,	7·9 ,,	8·8 ,,	5·1 ,,	16·3 ,,	6·1 ,,
,, ,, ... 120	4·0 ,,	3·0 ,,	2·8 ,,	2·6 ,,	7·1 ,,	2·4 ,,
,, ,, ... 150	4·3 ,,	1·9 ,,	2·2 ,,	2·2 ,,	4·6 ,,	1·6 ,,
Through ... 150	7·5 ,,	2·2 ,,	2·9 ,,	4·2 ,,	3·6 ,,	1·9 ,,

Mr. V. F. Stanley Low* gives two interesting tables showing that, for coarse jigs, the tailings caught on 100 and coarser mesh sieves contained 2·2 per cent. to 3·2 per cent. lead, and that through 100 mesh contains 9·6 per cent. to 12·7 per cent lead, and for fine jigs 4·4 per cent. to 7·1 per cent. lead and 11·4 per cent. to 15·7 per cent. lead respectively. The above figures show that the hydraulic classifiers are far from effecting a clean separation of slimes. At the Broken Hill Proprietary Company's mills the tailings from both the coarse and fine jigs are passed over shaking screens, the oversize going to the dump and more recently to the grinding plant, and the undersize to the zinc plant (Delprat flotation process). This simple expedient greatly lessens the percentage of lead and zinc going to the dump.

Treatment of Fines and Slimes.

Considerable diversity of opinion exists as to the method of treatment of fines and slimes, ranging from attempts at close and careful classification to almost none, though in most cases there is a more or less serious attempt at classification.

*Concentration of Silver-lead Ores. Trans. Aust. I.M.E., Vol. XI, Generally the treatment is as follows:—The fines and slimes from various sources—*e.g.*, hydraulic classifiers, overflow from jigs, or fine screens (as at the Junction North)—are passed to spitzkasten or pointed boxes with a regularly increasing cross-section towards the overflow end. The coarser material from the earlier spigots is treated on Wilfley, Card, or Krupp tables, the latter spigots on belt vanners of the Luhrig or Warren types. The end spigot may be treated on vanners or sent direct to the slime settling pits. Companies which have not their own plants to treat the slimes make a more serious attempt to save the utmost amount of values on the tables and vanners. The heads from the various concentrating tables or vanners are concentrates to be sent to market or to the company's smelter. The middlings are generally classified and treated on separate concentrators, giving concentrates and tails. It is generally accepted that retreating middlings on the same table without reclassification is defective practice. The coarse tails go to dump. The slime, which runs straight down the table, is in many cases kept as a separate table product, sent to a thickening box, and thence treated or sent direct to the slime pits. It was early recognised that a high percentage of lead in the tails from tables of the Wilfley type was due to values contained in the slime product, which ran straight down the table. This has led to making a coarse and slime tail-product, the former carrying little value and going directly to the dump, and the latter being thickened or retreated, or saved as slime and transformed into a product that can be smelted in blast furnaces. Tables of the Wilfley type are recognised in Australia not only as good concentrators, but also as excellent slime separators. Slime products are being obtained for further treatment in the manner mentioned not only in the concentration of lead but also of gold and tin ores.

The notable example of the non-classification of fines and slimes is the Broken Hill South Mine. Here the middling product of jigs is reground in pans of the improved Wheeler type. The whole product is directly treated on Wilfley tables, which give concentrates to market, middlings back to pans, tails to dump, and slimes which are thickened in boxes and treated on vanners which give concentrates to market and tails to dump. It is found that the most of the lead is recovered when the ore is ground to pass 100 to 150 mesh. It must not be overlooked that undoubtedly good results, claimed to be the best at Broken Hill, are obtained at this plant. The new 6,000-ton mill is built directly for this system of treatment. At the Broken Hill Proprietary Company's plant four products are obtained from the Wilfley and similar type tables and from the vanners—viz., concentrates, middlings, coarse tailings, and slimes. The middlings of the Wilfleys are retreated on other

Wilfleys, giving concentrates, tails, and middlings, the latter being retreated on the same table; the vanner middlings are run into spitzkasten, and thence on to the vanners, giving concentrates and tailings. The coarse tailings from the Wilfleys and vanners are run out into a spitzkasten to remove the small amount of slime left in them, and then sent to the zinc plant for further treatment by the flotation process. The slimes are settled, dried, heap roasted, and sent to Port Pirie to be smelted. The slimes of most of the other companies are, for the time being, a waste product.

The following are analyses of Wilfley and vanner products:—

Mesh.	Wilfleys.				Vanners.				Settled Slimes.
	Feed.	Cons.	Middles	Tails.	Feed.	Cons.	Middles	Tails.	
	P. cent	P. cent	P. cent	P. cent	P. cent	P. cent	P. cent	P. cent	P. cent
Caught on 20 ..	0·3	0·0	0·0	0·4	0·0	0·0	0·0	0·0	nil.
,, 40 ..	1·8	0·8	2·7	2·0	0·3	0·0	0·1	0·3	0·2*
,, 60 ..	3·2	1·2	3·8	3·6	0·5	0·2	0·3	2·5	0·3*
,, 80 ..	18·0	1·8	7·6	10·7	1·2	0·8	0·3	5·7	0·3
,, 100 ..	15·0	2·8	17·0	18·1	2·9	1·2	1·2	13·5	0·5
,, 120 ..	11·5	4·6	11·8	16·4	3·5	1·2	1·5	14·6	0·6
,, 150 ..	16·5	13·0	20·0	16·2	2·6	3·3	6·8	18·3	1·3
Through 150 ..	43·7	75·8	37·1	32·6	89·0	93·3	89·8	45·2	96·2

*Contains wood pulp.

—	Wilfley Tables.				Vanners.				Settled Slimes.
	Feed.	Cons.	Middles	Tails.	Feed.	Cons.	Middles	Tails.	
Insoluble, per cent.	40·0	28·0	36·0	46·0	35·0	13·0	34·0	48·0	31·0
FeO ,,	4·4	2·9	8·1	7·0	8·1	4·4	8·1	6·8	8·1
CaO ,,	3·2	2·1	1·8	4·5	2·2	2·4	3·8	2·9	3·4
Pb ,,	21.4	48·2	19·8	4·9	15·8	57·1	5·1	4·4	20·0
Zn ,,	16·8	6·2	19·0	16·8	17·6	9·2	20·8	17·3	16·8
Ag. oz. per ton.	13·8	28·9	15·4	8·9	16·9	29·6	15·7	9·5	18·7

Zinc Concentrates.

The economical recovery of the blende as a marketable zinc concentrate has been the greatest problem which has confronted the technical men of Broken Hill during recent years. Much money, time, and ceaseless patience have been bestowed upon the solution of this problem. As previously mentioned, Broken Hill ores always contain varying quantities of garnet and rhodonite, in addition to galena and blende, also other minerals of less importance. The high specific gravity of galena enables a large percentage of that mineral to be readily recoverable by the skilful use of jigs, concentrating tables, and vanners, but no such use can be made of these appliances to make a separation of blende from the garnet and rhodonite into a marketable concentrate. The Broken Hill garnet has a specific gravity about 4·2, the blende about 4·0, and the rhodonite about 3·6. The garnet can frequently be seen on Wilfley tables and vanners, making a distinct reddish band slightly in advance of but blending into the body of blende, while the rhodonite hopelessly overlaps and mingles with the blende, the quartz often forming a distinct whitish band in the rear.

As it was hopeless to seek a solution by wet concentration, it was sought in a different quarter—viz., by magnetic concentration, and later by flotation processes.

MAGNETIC SEPARATION.—The Australian Metal Company erected a magnetic concentrating plant known as the Zinc Works, at which concentrates were made at intermittent periods.

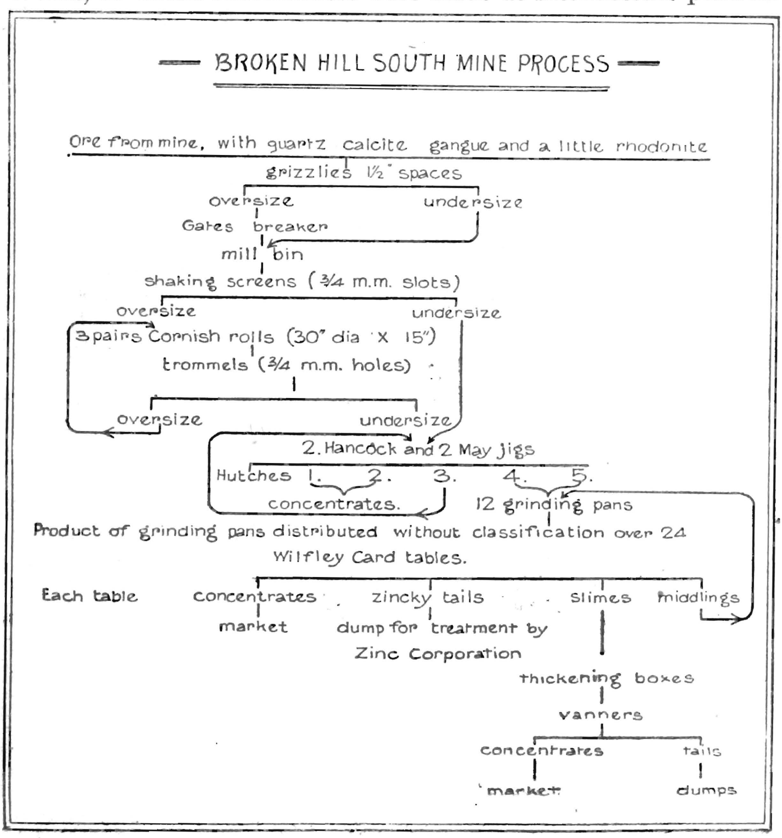

FIG. 2.