Department of Mines, Federation of Malaya. A recent paper* indicates the stage reached and the points on which we agree and differ with Mr. Williams's conclusions.

We, too, have been able to demonstrate that the recovery of cassiterite and other heavy minerals from alluvials could be improved by removal of slimes and excess water from the pulp fed to recovery plants; and subsequent jigging of the thickened, de-slimed pulp. For several years now we have been experimenting with hydrocyclones for this purpose and in the course of our work we have developed our own design of high-capacity low-pressure hydrocyclone which is now being used with considerable success in gravel-pump mines in Malaya. We are experimenting with these hydrocyclones on dredges where they have several attractive possibilities. In feeding the underflow of cyclones to jigs we have studied the operation of the jigs and agree that jigs can usefully recover cassiterite down to sizes finer than 300-mesh B.S., that they operate well on a long-range, slime-free feed, and that long strokes are required, as implied in Mr. Williams's paper; but we differ radically in our understanding of the nature of the jigging operation. The normal alluvials fed to primary jigs in Malaya consist of a long size range of mineral particles of which only a very small proportion is heavy-mineral. This material is fed into a bed consisting of a mixture of coarse hematite intermixed with particles derived from the alluvium. The bed is supported on a screen surface and is subjected to a pulsating motion by an intermittent flow of water from beneath the screen. As we see it, there are two ways in which heavy mineral can pass through the bed and the screen into the hutch of the jig. Coarse heavy-mineral above a certain size forces its way through the bed by virtue of its weight, particularly when the bed is in its fluid or expanded state. Fine heavy-mineral below a certain size slips through the interstices of the bed when the bed is closed and the flow of water is least.

For a given constant size range of feed it can be assumed that the interstices in the bed will also be fairly constant in size, so that the upper size of heavy particle which can slip through the holes in the bed is limited. Thus the coarser and finer particles can be concentrated as soon as the feed enters the bed; but there is a third class of heavy particle which is neither large nor heavy enough to force its way through the bed nor small enough to slip through the interstices in the bed, and on these particles the concentrating action in the jig acts very slowly. In addition to its concentrating action the jig must also ternsport material across the bed as fast as it is fed in, and this limits the residence time of the material in any cell. In passing to the next cell considerable re-mixing takes place and the operation starts again more or less from scratch. This view of the jigging action leads to the conclusion that there will be a middle size-range of heavy-mineral which will be mainly rejected from a jig operated under given conditions no matter how many times the jigging may be repeated.

*Harris, J. H. Innovations in treatment plant for gravel pump tin mines in Malaya. *Min. J., Lond.*, **252**, 1959, 23rd Jan., 93–5; 30th Jan., 116–8; and 6th Feb., 146–7.

The fine heavy-mineral takes longer to settle through the bed than the coarse heavy-mineral and so part of the fine will be carried from cell to cell, particularly if the flow across the cell is considerable. More of the fine heavy-mineral will be recovered from each successive cell in a series but the rate of recovery will drop off as the dilution is increased (and therefore the retention time decreased) by the addition of hutch water from the previous cell. It is also obvious that if there is a great deal of slime in the feed or in the hutch water the finest heavy particles will not be able to settle through the interstices in the bed but will be held in suspension and carried out with the final jig rejects.

The figures given by Mr. Williams in Table II (p. 169) of his paper demonstrate this loss of middle-range material. In his table the estimated percentage of cassiterite lost in the plus 325-mesh rises suddenly in the minus 120 plus 150-mesh size range and then decreases. Similarly the estimated percentage of columbite lost suddenly increases in the minus 100 plus 120-mesh size range and then decreases in the next finer size range.

The following table shows the results of samples taken from a two-cell Ruoss jig fed with a cyclone underflow containing a size-range ½-in to 300-mesh B.S., with a small amount of minus 300-mesh particles.

Product mesh B.S.	Feed		Tailings		Concentrate	
	% Sn	Distn. Sn %	% Sn	Distn. Sn %	% Sn	Distn. Sn %
− 10 + 22	0·016	8·2	0·010	6·6	0·02	4·2
− 22 + 52	0·056	39·9	0·025	23·2	0·04	37·2
− 52 + 100	0·052	29·7	0·042	49·9	0·10	21·4
− 100 + 200	0·052	13·1	0·20	9·4	0·26	31·2
− 200 + 300	0·087	4·0	0·035	2·6	0·42	3·9
− 300	0·017	5·1	0·012	8·3	0·05	2·1
Totals	0·041	100·0	0·021	100·0	0·56	100·0

A note on the sampling process might be of some interest. The jigs were sampled at 15-min intervals over a period of 6 hours and the samples collected in 44-gal drums. The final samples, each containing about 100 lb of solids, were hand-screened to remove the plus 5-mesh material (including clay-balls, which sometimes retain cassiterite) which was dried and weighed. The minus 5-mesh material was then hand-screened wet on 300-mesh to remove water and fine slime and the oversize dried and weighed. The plus 10-mesh material was screened off and weighed and the undersize sampled to give a convenient amount for machine-screening, which included a 300-mesh screen. The slime from the wet-screening was filtered and dried and a proportionate sample added to the minus 300-mesh product from dry-screening. Each size-fraction was sampled and assayed chemically for tin content. This system avoids the troubles inherent in sampling material of wide size-range, with the necessary crushing and grinding of large quantities of material to obtain a representative sample and enables a direct size-distribution of the tin to be determined. As an assay check, a head sample is taken from the combined minus 5- or 10-mesh material. The tin values in the coarser sizes may represent locked tin and thus it requires a knowledge of the individual mine to determine the significance of assayed tin values in the coarser sizes. The mine from which the tabulated data are derived does not produce a significant amount of cassiterite coarser than 10-mesh, so those values are omitted.

Nearly 50 per cent of the tin lost in the tailings is in the minus 52- plus 100-mesh range and from the assay of this fraction in feed and tailings it can be seen that recovery in this size-range is low. To confirm that the cassiterite in this size-range was free, a sample was separated in *sym*-tetra-bromo-ethane at a specific gravity of 2·9. The float fraction assayed 0·007 per cent Sn and contained 16 per cent of the tin present and the sink fraction assayed 0·310 per cent Sn and contained 84 per cent of the tin present. A further sample of this size-fraction of the tailings was tabled and the table-concentrate treated in a magnetic separator; the non-magnetic portion of the concentrate assayed 2·45 per cent Sn and contained 61 per cent of the tin present. All the cassiterite in this concentrate proved under microscopic examination to be free.

In our opinion this loss of valuable material can best be prevented by jigging in stages, altering the nature of the feed between stages. We find, with Mr. Williams, that coarse heavy-mineral is recovered in the first cell or two but further jigging will not improve the recovery of the intermediate-range heavy-mineral unless the feed conditions are altered. If the coarsest gangue is left in the feed, jigging conditions in the third, fourth, or any subsequent compartments must necessarily be adjusted to transport it. Consequently, equivalent proportions of intermediate-size heavy-mineral will likewise be transported while the increased dilution due to added hutch-water will decrease the residence-time in the cell and increase the rate of flow, thus reducing the possibility of catching the finer sizes of heavy-mineral. We believe it best to screen out the coarse gangue (which will by then be more or less free of tin) after the first two cells and then re-jig the undersize. This alters the size-relationship of what was previously intermediate-size material to the rest of the feed. In this second stage the intermediate-size mineral now bears the same relation to the new size-range of gangue as the coarser mineral did to the original size-range of gangue in the first stage and is as readily recoverable. A thickening stage can be included which, by increasing the residence time in the second stage of jigging, increases the recovery of the fine heavy-mineral.

Jigging on dredges is subject to adverse conditions additional to those encountered in land-based plants. The fore-and-aft trim of the dredge varies according to the position of the bucket ladder and this causes variation in the feed to individual jigs which the best distribution systems so far installed do not entirely correct. There is also a tendency for the distribution to favour the side to which the revolving screen is turning. When the dredge is digging clayey ground the sand content of the feed to the jigs is reduced and in any case some of the ground is not broken up in the screen and passes through to the tailing; the jigs then tend to be overloaded with slimes and water. When the digging is in gravel and sand the material passes the screen more readily; the jigs then tend to be overloaded with sand and, unless the digging-rate or the jig-settings are properly controlled, the feed-launders will sand up and the jigs will go dead.

We consider that our use of hydrocyclones and multi-stage concentration developed for land-based plants can be applied to dredges. The main advantages when using hydrocyclones will be (*a*) the possibility of de-sliming before treatment and the removal of the slime from the dredge area without fouling the paddock (and thus the make-up water for the jigs), and (*b*) the improved operation possible by feeding the jigs with a regular amount of thickened de-slimed feed, irrespective of the attitude of the dredge or the nature of the ground.

We have developed hydrocyclones which, although restricted to moderate size, handle large quantities at low feed-pressures while splitting effectively at 300-mesh B.S. even though the feed contains particles up to 1 in. in size. Installed on the deck of a dredge, amidships underneath the screen case and, if necessary, lying on their side, such hydrocyclones can be operated by gravity from the distribution box. A considerable tonnage of slimes and surplus water can thus be split off, relieving the concentration plant of much of its load, while the slimes could be led out of the paddock through floating pipe lines and delivered to the settlement area, thus keeping the paddock clean. The gravel sand underflow of the cyclones can then be elevated to the jigs for treatment. Experiments on these lines are in progress.

Alternatively the screen undersize can be pumped to cyclones which discharge their underflow direct to jigs. An installation of this type was put into one of the Malayan dredges a little over two years ago but included an older type of high-pressure hydrocyclone. It is clear that the pumping costs entailed would be considerably reduced if low-pressure cyclones were used. The flexibility of this system would offer considerable advantages.

Mr. R. N. Hammon*: Following the experimental work referred to by Mr. Andrews, The Bisichi Tin Co. (Nigeria), Ltd., installed a furnace, designed by Messrs. Huntington, Heberlein for plant-scale operation.

This is a 6-in diameter, six-hearth oil-fired Herreshoff-type furnace. Feed rate is about 1300 lb/hour and this is held for about one hour in the temperature range 550°–700° C. Exact conditions of temperature and retention time to give optimum results have not been determined but operation as above has been very satisfactory. Following heat treatment, over 70 per cent of the bulk can be discarded by passing over a magnetic separator without prior screening and at a very much higher feed rate than was formerly used on these machines. The remaining columbite-

*General Manager of The Bisichi Tin Co. (Nigeria), Ltd.

enriched material is brought to shipping grade after screening by magnetic and air-float separation.

Mr. J. A. Bartnik: I should like to have Mr. Williams's replies on the following points:

(1) What is the ratio of concentration for the recoveries in Tables I and II?

(2) How often was the jig screen cleaned?

(3) What is the effect on the cyclone and the jig operation of the variation in the rate of feed (p. 163) and the slime content of the feed?

With such variety of feed (p. 163) reaching the field plant it is impossible to estimate the value of minerals in the tailing from the value of minerals in the jig hutches, and instead sampling of the tailings should be carried out.

The writer agrees that the field plant should produce low-grade concentrates (20 per cent) which will give simplification and mobility in the plant, while the recoveries of valuable minerals under better-controlled conditions at the mill (dressing plant) will be improved.

Application of jigs and cyclones for dressing the semi-heavy minerals is well described, but no account is taken of the friability.

A few words on the heat-treatment of ilmenite/columbite middlings might be of interest as the process was first developed at The Bisichi Tin Co. (Nigeria), Ltd., and is now operated there on plant scale.

The lower magnetic permeability of some ilmenites or columbites can be raised to normal by heat-treatment, such as 1 hour at 600° C, ½ hour at 700° C, or 3 minutes at 900° C, the increase in permeability being due probably to strain release.

Overheating causes dark-brown scale formation on ilmenite with a decrease in magnetic permeability, and should therefore be avoided.

DISCUSSION IN NIGERIA

Report of discussion at General Meeting of the Nigerian Section of the Institution held on 18th March, 1959, at Bukuru (Mr. T. W. Bennetts in the Chair)

Mr. Williams stated that the research work on the problems presented by the recovery of semi-heavy minerals in jigs had continued since his paper was written, and in introducing it he proposed to present new data to bring the record of the investigation up to date.

He wished first to comment on the unavoidable absence of a tailing sample for the primary jigs. Sooner or later the industry would have to face up to the need to provide adequate sampling facilities when building jig plants. Progress in the design engineering of jig plants was likely to

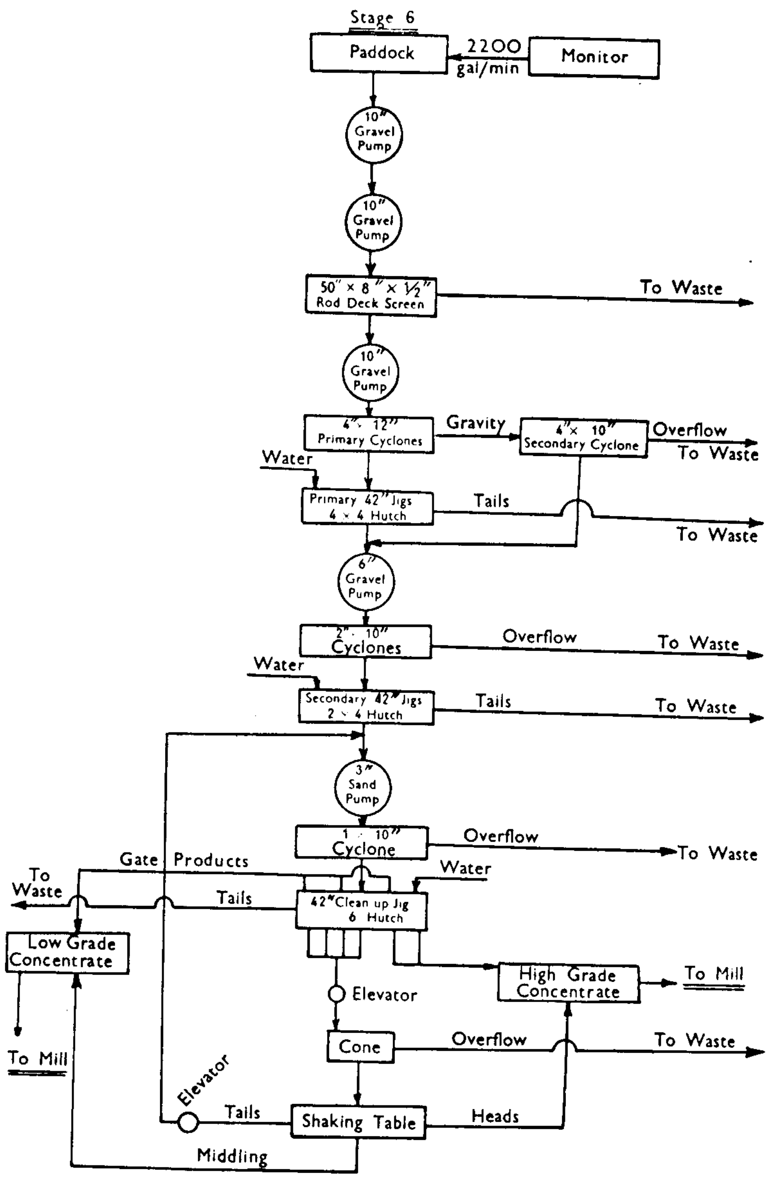

Fig. 1A.—Improved flowsheet of the alluvial jig plant, Rayfield, Nigeria.

TABLE IV.—*Recovery of Heavy Minerals in Clean-up Jig: Plant A*

B.S. Sieve No.	Distribution: Percentages reporting in hutch products — Hutch number 1	2	3	4	5	6	Total	Percentage lost
	Cassiterite sp. gr. 7·0							
	%	%	%	%	%	%	%	%
16	60·2	21·7	17·6	0·5	—	—	100·0	—
16/25	60·5	29·3	9·8	0·4	—	—	100·0	—
25/52	33·1	61·7	4·8	0·4	—	—	100·0	—
52/72	6·3	86·1	6·2	1·2	0·1	0·1	100·0	—
72/100	10·8	71·9	15·2	1·9	0·1	0·1	100·0	—
100/120	13·6	69·0	13·5	3·5	0·2	0·2	100·0	—
120/150	19·4	66·5	8·7	4·0	0·7	0·7	100·0	—
150/170	22·8	54·8	13·8	5·1	2·4	1·1	100·0	—
170/240	25·5	25·6	24·5	15·6	5·4	3·4	100·0	—
240/300	27·6	11·4	23·2	13·8	12·6	4·8	93·4	6·6
300/325	18·8	Tr	15·6	6·2	7·0	8·9	56·5	43·5
− 325	6·7	Tr	13·0	4·8	14·3	2·5	41·3	58·7
	Columbite sp. gr. 5·5							
	%	%	%	%	%	%	%	%
16	10·7	7·7	57·6	24·0	—	—	100·0	—
16/25	4·2	53·9	35·1	5·4	1·3	—	99·9	0·1
25/52	0·7	66·3	27·8	3·6	1·3	0·2	99·9	0·1
52/72	0·3	50·7	36·3	9·9	2·2	0·5	99·9	0·1
72/100	2·9	43·1	36·0	13·4	3·3	1·2	99·9	0·1
100/120	6·3	44·9	26·7	15·7	4·2	2·0	99·8	0·2
120/150	10·1	41·3	22·6	16·5	6·0	2·8	99·3	0·7
150/170	15·6	26·1	23·8	18·8	9·2	5·6	99·1	0·9
170/240	21·1	13·8	21·7	16·6	17·1	8·1	98·4	1·6
240/300	16·7	6·8	26·4	12·2	22·8	7·5	92·4	7·6
300/325	24·6	—	24·6	8·4	20·7	16·2	93·3	6·7
− 325	13·2	—	21·9	5·4	43·9	3·3	87·7	12·3

	Cassiterite sp. gr. 7·0		Hematite sp. gr. 4·4
Ragging . .	− 1/4″ + 1/8″	− 1/2″ + 1/4″	− 1/2″ + 3/8″
Speed . .	180 strokes/min		
Stroke . .	1/8″		

TABLE V.—*Recovery of Semi-heavy Minerals in Clean-up Jig: Plant A*

B.S. Sieve No.	Distribution: Percentages reporting in hutch products — Hutch number 1	2	3	4	5	6	Total	Percentage lost
	Zircon sp. gr. 4·5							
	%	%	%	%	%	%	%	%
16	—	0·1	6·1	51·1	13·5	1·5	72·3	27·7
16/25	—	0·2	30·1	47·5	14·4	1·6	93·8	6·2
25/52	—	2·0	40·6	19·4	25·8	5·2	93·0	7·0
52/72	0·1	4·0	37·1	12·6	27·9	12·4	94·1	5·9
72/100	0·5	4·5	35·8	13·9	26·7	13·4	94·8	5·2
100/120	1·2	6·0	32·2	16·6	20·7	12·6	89·3	10·7
120/150	1·8	6·4	23·4	14·6	20·6	13·0	79·8	20·2
150/170	4·5	5·5	24·8	12·8	16·4	11·1	75·1	24·9
170/240	7·1	4·3	20·0	9·1	21·1	8·8	70·4	29·6
240/300	8·3	1·7	14·3	5·0	16·0	4·7	50·0	50·0
300/325	5·8	0·8	7·0	2·7	8·7	5·2	30·2	69·8
− 325	3·8	2·3	7·4	2·4	24·2	1·7	41·8	58·2
	Topaz sp. gr. 3·5							
	%	%	%	%	%	%	%	%
16	—	—	0·1	0·1	0·7	—	0·9	99·1
16/25	—	—	1·5	2·1	7·4	0·3	11·3	88·7
25/52	—	0·1	10·8	0·6	14·1	2·0	27·6	72·4
52/72	—	0·1	13·4	1·3	19·6	7·3	41·7	58·3
72/100	0·1	0·1	14·8	2·4	22·7	10·4	50·5	49·5
100/120	0·2	0·1	10·2	2·2	17·3	6·5	36·5	63·5
120/150	0·2	0·1	8·8	1·9	11·9	4·5	27·4	72·6
150/170	0·8	0·1	12·6	2·9	16·1	4·8	37·3	62·7
170/240	1·3	0·1	5·4	2·4	9·6	3·7	22·5	77·5
240/300	1·5	—	5·4	0·8	2·7	1·5	11·9	88·1
300/325	4·2	—	5·4	1·2	—	3·8	14·6	85·4
− 325								

	Cassiterite sp. gr. 7·0		Hematite sp. gr. 4·4
Ragging . .	− 1/4″ + 1/8″	− 1/2″ + 1/4″	− 1/2″ + 3/8″
Speed . .	180 strokes/min		
Stroke . .	1/8″		

become stultified unless accurate performance analyses of the various unit processes could be made. In the meantime the best use had to be made of approximate performance analyses such as those given in Tables I and II (pp. 168 and 169) of the paper.

As mentioned in the paper the flowsheet (Fig. 1, p. 165) was not regarded as final. It had since been simplified and improved to the form now presented as Fig. 1A. That flowsheet had a number of advantages resulting in better recovery and lower operating costs:

(1) It was no longer necessary to use the 6-in gravel pump and the four tables which it fed;

(2) Only one table was now used, and it was sited to the best advantage, receiving a relatively small quantity of hutch products. There it effectively prevented the build-up of fine cassiterite and columbite in closed circuit, which was formerly one of the main causes of tailing losses from the clean-up jig;

(3) The efficiency of the clean-up jig was still further improved by withdrawing gate products and a table middling to prevent the excessive build-up of semi-heavy minerals in closed circuit;

(4) The clean-up jig tails were now so low-grade that they no longer needed to be tabled but could be discharged direct to waste.

The present flowsheet was thus both cheaper to operate and more effective in recovery than the provisional flowsheet shown in the paper.

Particular interest attached to what happened to the mixture of heavy and semi-heavy minerals in the clean-up jig. Representative timed samples had since been taken of all six hutch products and the tailing of that clean-up jig at half-hourly intervals over four shifts. Screen and mineral analyses of those samples were made in the laboratory. A performance analysis based on those samples was now presented as Tables IV and V. The different types of ragging used in the several cells would be noted. From the viewpoint of mineral recovery importance attached to both the specific gravity of the ragging and to the size of the open spaces between the particles. The rather fine cassiterite ragging in the first cells let cassiterite through readily but tended to exclude columbite; it was still more effective in excluding the semi-heavy minerals zircon and topaz. The rather coarser cassiterite ragging in the second cells let columbite through readily but was still fairly effective in excluding zircon and topaz. It would be noted that the hematite of sp. gr. 4·4 tended to exclude the coarse semi-heavy minerals of about the same or lesser specific gravity. That began to show up with zircon of sp. gr. 4·5 and was very pronounced with topaz, 3·5. If those semi-heavy minerals happened to be valuable then a lighter ragging would be necessary for effective recovery of the coarse sizes.

The hutch product withdrawn represented 84 per cent of the cassiterite and columbite and the table heading 13 per cent, while the low-grade concentrates represented only 3 per cent. The cassiterite and columbite together amounted to 84 per cent in the hutch product and 54 per cent

TABLE IA.—*Recovery of Semi-heavy Minerals in the Primary Jigs of Plant B*

B.S. Sieve No.	Distribution					
	Percentages reporting in hutch products					Percentage lost
	Hutch number				Total	
	1	2	3	4		
	Zircon sp. gr. 4·5					
	%	%	%	%	%	%
10	84·6	3·7	11·7	—	100·0	—
10/12	83·8	7·1	2·4	6·7	100·0	—
12/16	69·0	27·7	2·0	1·3	100·0	—
16/25	62·8	30·2	5·6	1·4	100·0	—
25/52	65·4	16·3	14·3	1·3	97·3	2·7
52/72	65·9	21·0	6·6	2·3	95·9	4·1
72/100	39·7	28·5	10·1	12·0	90·3	9·7
100/120	30·1	22·1	15·1	21·0	88·3	11·7
120/150	22·8	20·0	12·5	21·6	76·9	23·1
150/170	16·7	17·2	12·5	27·3	73·7	26·3
170/240	4·4	8·1	7·2	15·2	34·9	65·1
	Topaz sp. gr. 3·5					
	%	%	%	%	%	%
5	1·6	1·6	0·9	0·8	4·9	95·1
5/6	14·0	13·6	3·5	6·9	38·0	62·0
6/8	33·9	31·8	14·6	6·3	86·6	13·4
8/10	41·4	36·8	10·8	5·2	94·2	5·8
10/12	36·4	41·7	12·1	4·8	95·0	5·0
12/16	32·5	41·8	12·2	10·3	96·8	3·2
16/25	45·4	32·2	9·0	9·7	96·3	3·7
25/52	55·7	23·9	6·1	7·4	93·1	6·9
52/72	48·8	18·3	8·2	8·8	84·1	15·9
72/100	24·1	21·8	9·5	16·8	72·2	27·8
100/120	18·3	15·5	9·3	16·4	59·5	40·5
120/150	11·1	13·6	7·5	12·4	44·6	55·4
150/170	6·0	9·3	6·2	13·2	34·7	65·3
170/240	3·1	4·6	4·0	6·0	17·7	82·3

Ragging — ¾″ + ½″ hematite sp. gr. 4·4
Speed 125 strokes/min
Stroke 1½″

in the table heading. The dressing of those high-grade concentrates in the mill presented no special difficulty. There remained only the problem of dealing with the low-grade gate product and table middling sent to the mill. Cassiterite and columbite together amounted to only about 4 per cent