tailings dump displayed a blue coloration suggestive of copper. This material was sampled separately from the remaining bulk of tailings, and was soon demonstrated to have 3 to 4 times the normal radioactivity of the bulk of tailings; samples of this material were subjected to flotation testing and could be made to yield about 1 to 1·5 per cent of its bulk as a concentrate (0·1 per cent *e* U_3O_8) and the refloat tailings were reduced to the level of the bulk of general tailings. It was only at a later stage that the presence of chalcopyrite in the pyrite was demonstrated as a result of mineragraphic examinations carried out in Melbourne, thus seeming to indicate an association of uraninite with chalcopyrite rather than pyrite. In view of the positive identification of chalcopyrite having been made after the conclusion of the test work no attempt was made to produce a chalcopyrite concentrate by differential flotation from the pyrite in the hope of revealing a difference in radioactivity of the products.

Acknowledgements.—The writer would like to record his appreciation of the opportunity of doing this work as a part of an investigation of nuclear resources in Brazil undertaken for the Government of that country by the International Atomic Energy Agency. This paper is published with the permission of both these bodies.

He also gratefully acknowledges co-operation in test work, assistance with chemical, spectrographic, radiographic, and mineragraphic determinations by Professor Elysiario Tavora, Drs. Luis de Oliveira Castro, Rubens Mesquita Ferriera, George Baker, and Mr. and Mrs. E. Gorsky. Assistance while visiting the Canavieiras mine was provided by Dr. Amando Santos de Oliveira and Commander C. J. M. Hamilton, who also made available maps compiled by Mr. G. F. Flaherty.

The ready co-operation of Mr. K. A. Fern, of Cyanamid of Great Britain, Ltd., in providing samples of available flotation reagents and flocculants promptly was a major factor in permitting completion of the test work.

REFERENCES

1. BRANNER, J. C. The geology and topography of the Serra de Jacobina. *Amer. J. Sci.*, **30**, 1910, 385–92.
2. WILLIAMS, H. E. Estudos geologicos na Chapada Diamantina, Estado da Baía. *Bol. Serv. geol. min. Brasil*, 1930, no. **44**, 16 p.
3. MELLO, J. L. de. Geologia e hidrologia do noroeste da Baía. *Bol. Serv. geol. min. Brasil*, 1938, no. 90, 105 p.
4. CAPPER ALVES DE SOUZA, H. Ouro na Serra de Jacobina (Estado da Baía). *Bol. Div. Fom. Prod. min., Rio de J.*, 1942, no. 51, 52 p.
5. WHITE, M. G. Uranium in the Serra de Jacobina, State of Bahia, Brazil. *U.N. Int. Conf. Peaceful Uses of Atomic Energy, Geneva, 1955*, 1956, **6**, 140–2.
6. BATEMAN, J. D. Uranium-bearing auriferous reefs at Jacobina, Brazil. *Econ. Geol.*, **53**, June-July 1958, 417–25.
7. HAYNES, D. D. Reconnaissance for uranium in the auriferous conglomerates and quartzites of the Serra de Jacobina, Bahia, Brazil (Report of Brazil-United States joint group evaluating the uranium resources of Brazil, Rio de Janeiro), 1960.
8. BAKER, G. Private communication, 1962.

DISCUSSIONS AND CONTRIBUTIONS

Investigation into Jig Performance

D. J. BATZER, B.Sc., A.R.S.M., ASSOCIATE MEMBER

Report of discussion at December, 1962, General Meeting (Chairman: Mr. J. B. Simpson, President). Paper published in November, 1962, pp. 61–8

Mr. Batzer, introducing his paper, said that the tests described formed part of a larger programme of investigation and in themselves covered only a limited aspect of the overall problem of jig operation. Nevertheless some definite results had been obtained and he hoped that their publication at that stage would stimulate constructive criticism and be of assistance to anyone who might be concerned with trying to improve jig performance.

Length of stroke, speed of stroke and jig bed current were chosen as the variables for investigation in that part of the programme; first, because they were of fundamental importance; secondly, because they were readily amenable to small-scale experiment, and, thirdly, because they were fairly easy to adjust in an existing full-scale plant. The overall conclusion from those tests was that, provided the intensity of stroke was sufficiently large, recovery of cassiterite by the jig was independent of the length or speed of stroke and jig bed current within wide limits. It was not considered at all likely that that result was due to chance. The probability that the numerous other variables and conditions were so chosen as to give just that result must be extremely small.

Table II (p. 68) showed that the level of recovery associated with a particular intensity of stroke would vary with differences in the size distribution of the jig feed and probably also with variation of other factors such as the feed rate. However, it was felt that the pattern of jig recovery in relation to intensity of stroke and jig bed current was not likely to be materially different from that found in the tests.

The means adopted of assessing the jig recovery—by gravity concentration of the tailings and spigot products, followed by weighing of the high-grade concentrate so produced—was thought more likely to give consistent comparative results than the alternative of direct sampling and assay of material which in some cases was of very low grade.

The reasons for using that method were partly the uncertainties of sampling and assaying low-grade tin-bearing material, but mainly because the tests were concerned with free cassiterite only and difficulties might have been encountered from tin in chemical and physical lock, which in low-grade tailings might constitute a substantial proportion of the total tin in the sample.

Since the paper was submitted the proposed tests on an increased scale, referred to in the last paragraph of the conclusion, had been put in hand, using a full-size 4-cell Ruoss jig in closed circuit with a 5-in rubber-lined pump. Those tests showed that the proportion of feed reporting at the jig spigot decreased as the feed rate was increased. At a feed rate of about 5 yd^3/h a total of approximately 11 per cent of the feed reported at the spigots, while at about 30 yd^3/h the proportion was between 3 and 4 per cent. Those figures were for an intensity of stroke of about 2·7 ft^3/ft^2/min at 130 strokes/min and an upward jig bed current of approximately $\frac{3}{4}$ gal/ft^2/min using material similar to that used in the laboratory Harz jig tests.

Had the extent of that dependence of spigot product discharge on feed rate been realized before the tests reported in the paper were begun, an automatic feeder would have been used instead of hand feeding.

The scatter of the points in Fig. 3 (p. 66) was probably due in part to the fact that the time taken to pass the specimen over the laboratory Harz jig, although usually about 6 min, varied from a minimum of $5\frac{1}{2}$ to a maximum of $6\frac{1}{2}$ min.

In the second paragraph of the conclusions on p. 68 it was stated that there were indications that the results with the laboratory jig might be applicable to plant-scale operations. The tests under discussion were carried out with material virtually free of −300-mesh slime and the results therefore were only comparable with the performances of jigs on dredges mining alluvium of low slime content. When figures for recovery and proportion of feed reporting at the spigots of the primary jigs on several such dredges were plotted on Figs. 1 and 2 (pp. 64 and 65), they were found to fit well with the pattern disclosed by the laboratory jig, although the proportion of the feed reporting at each spigot of the 4-cell jigs was less than for the 1-cell Harz jig.

The smaller spigot discharge per hutch on the dredge jigs might be explained as follows:

(1) The feed rate to the laboratory jig of about 0·4 $yd^3/h/ft^2$ of jig bed was equivalent on a full-size Ruoss jig with a bed area per hutch of 14 ft^2, to about $5\frac{1}{2}$ yd^3/h, whereas normally the dredge jigs in question carried a load of about 20 yd^3/h.

(2) The jig bed current on the dredge jigs was usually of the order of 2 gal/min/ft^2 of jig bed (rising) as against 0·5 to 0·8 gal/min/ft^2 (falling) in the laboratory jig tests.

(3) The depth of hematite ragging on the dredge jigs was about $3\frac{1}{2}$ in. as compared with $1\frac{1}{2}$ in. on the laboratory jig.

Those changes in operating conditions all had the effect of reducing the spigot discharge on the dredge jig as compared with the laboratory jig for the same intensity of stroke, although the effect of thickness of ragging on spigot discharge had not yet been investigated quantitatively.

Broadly speaking, the total spigot discharge from the full-scale Ruoss jig was evenly divided between the four spigots. The pattern of recovery in the four successive cells of the Ruoss jig was more complex and was the subject of current experiments with the full-scale test plant, and he hoped that the results of that work would be of sufficient interest and value to justify publication in due course.

Mr. J. H. Harris said that, apart from the effects on performance of the variables described, great interest centred on the high recoveries achieved and on the observation that, within a range of values of feed from $\frac{1}{2}$ lb/yd^3 to 12 lb/yd^3 the recovery was independent of the feed value. Confirmation was thus given of the utility of jigs as efficient concentrators for raw alluvial feeds, unclassified except for the removal of coarse oversize plus $\frac{1}{2}$-in and containing a long size-range of cassiterite. While the use of jigs on dredges was now almost universal, a great number of land-based plants still used sluices as primary concentrators and such operators should be further encouraged to convert to the use of jigs, which gave a more compact and easily managed plant.

Where more slimes were present than was the case with the author's example or where, as in land-based plants, the ratio of water to solids was high, the raw feed could be effectively prepared for jigging in large low-pressure cyclones.

The ratio of concentration in the primary stage was admittedly low. From figures quoted by the author, with the feed at 1·5 lb/yd^3 and recovery at 98 per cent, the spigot concentrate would run about 15 lb/yd^3 (or approximately 0·5 per cent cassiterite) in about 10 per cent by weight of the feed (Example 1).

Example 1.

	Wt. %	*Value* *lb/yd³*	*Value* % *cassiterite*	*Distribution* %
Feed	100	1·5	0·05	100
Concentrate	10	14·7	0·49	98
Tailing	90	0·03	0·001	2

Those exceptionally low-grade concentrates could, however, be readily up-graded in cleaner and re-cleaner jigs. In the cleaner circuit the ratio of concentration might be 100 : 1, but the resultant tailing might then assay about the same as new primary feed and required treatment by means such as had previously been described,* instead of being discarded, as frequently occurred in practice (Example 2).

Example 2.

	Wt % (*approx.*)	*Value* % *cassiterite*	*Distribution* %
Rougher concentrate	100	0·5	100
Cleaner concentrate	1	†50	90
Tailing	99	0·05	10

†Balance other heavy minerals.

On the question of actual recovery achieved, the speaker was not certain that the method of assay used by the author gave the true picture. On p. 62 it was stated that, in tests of dulang washing, losses of free cassiterite in the range 14 to 200 mesh were less than 10 per cent. He would be glad to have details of those tests. Were the losses identical in all size

*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.

ranges? In previous work* it was shown that the losses could be higher in the fine and middle ranges of sizes than in the coarse and medium-fine sizes. If those losses occurred during jigging the lost grains transferred from the feed to the tailing. On panning the tailing, the same particles, having a tendency to be lost, again failed to report. Hence the pattern of distribution of sizes shown in Table I (p. 67) was as would be expected from the method used. Those sizes which could effectively be caught were reported and the losses did not appear, as they should appear, in the tailings.

He thought a chemical check was necessary to show up the true picture. At Williams, Harvey and Co., Ltd., a spectrographic method of analysis was now being used but standard chemical procedures could be modified to determine tin contents of the order quoted.

Mr. H. L. H. Harrison, commenting on the practical application of jigs, said it was in the 1920s that the first jigs were installed on tin dredges in Malaya by the Yukon Gold Co. near Ampang, quickly to be followed by two new Payne dredges, built for a company for which he was then assistant manager, equipped with Harz jigs. With no jig experience available to the company it was with much trial and error that operation and adjustment was satisfactorily achieved.

On a hard rock mine a regular and classified product could be fed to the jigs. Not so on dredges, where the product from the revolving screen varied hourly in quantity and sizing as a dredge traversed a face through clays, then into sandy clays, on to fine sands and into gravels perhaps, with possibly extreme variations in tin values. In consequence both the sand bed on the ragging and pulp to water ratios varied greatly. Feed water level would be affected by screen trouble at the pumps, while wear and tear on jig components would call for necessary readjustments.

Much could be done to improve efficiency by training dredge supervisers to undertake adjustments as and when necessary and to know when such adjustments were called for, but considerable advantages could accrue from the employment of a trained metallurgist to cover a group of mines, his salary being recouped many times over by the financial value of tin saved from escaping over the jig tails.

Malayan tin dredges have grown from 50 000 to around 500 000 yd^3 capacities, mechanical considerations prevailing, while tin values were not hard to come by. The future seemed to be more and more in lower-grade ground, and research into jig performance and pre-classification became so much more important and valuable.

The manner of jig sampling deserved mention. In 1928 ways were found to sample heads and tails and to express losses in terms of percentage of feed to jigs, whether the feed were rich or poor. When returning results in terms of content per cubic yard, what might appear a negligible loss could, in terms of a low-valued feed, be a relatively high percentage calling for readjustments.

Mr. F. A. Williams spoke briefly. His comments are contained in a written contribution on page 361.

Mr. D. G. Armstrong said he wanted to gain as much information as he could from the paper, because he was doing some research work on jigging as well.

The author said his laboratory jig was of the Harz type, but the speaker thought it was most important to find out exactly what kind of jig it was. The Harz jig had been described as having a reciprocating plunger *loosely* fitted, but it was stated on page 62 of the paper that the plunger was a *good* fit. At the top of that page it was stated that hutch make-up water was added above the plunger, so he would like to know how the water got past the plunger. There was no mention of valves, which were sometimes fitted to the plungers of Harz jigs and he would not have expected the presence of a valve in the plunger, except for the words, 'above the plunger'. That was an important point, because no one could comment constructively on the results given in the paper if it was not known what kind of stroke was producing them. Later in the paper results obtained with no make-up water were given, which suggested a tight-fitting plunger acting both ways, but that was not consistent with water added above the plunger. (He assumed that the terms 'hutch water' and 'make-up water' meant the same thing.)

Intensity of stroke was defined in the paper as 'cu. ft displaced in one direction per sq. ft of jig bed per min'. He wondered why that cumbersome expression was used and why the author considered displacement in one direction only. Which direction was meant, he asked, up or down? There were clearly two parts to each stroke and the intensity upward could be quite different from the downward stroke, and both could be important. Intensity upwards, using the author's symbols, was, surely, $l/12 \times S \times 2$. That, of course, was the intensity caused by the plunger independently of any flow of water which might add to it, or detract from it. It was simply 'mean linear velocity'. The use of the expression 'intensity' seemed to be unfortunate, because it smothered important details which had to be known to understand what was going on in the jig. What raised the mineral in the jig was velocity of water upwards. Likewise, it was velocity of water that controlled the fall of mineral back on to the screen. The way velocity changed throughout the complete stroke was of the greatest importance. Velocity and rate of change of velocity (which was, of course, acceleration) were fundamental data in the jigging process.

They were told in the paper that the plunger movement was simple harmonic, but the actual water movement in the jig chamber throughout the stroke was impossible to visualize. The jig bed current was said to be determined by 'difference between spigot flow and hutch water'. No mention was made of feed water, which the speaker said he had calculated as 7 gal/ft^2

*Harris, J. H. Serial gravity concentration: a new tool in mineral processing. *Trans. Instn Min. Metall., Lond.*, **69**, 1959–60 (*Bull. Instn Min. Metall., Lond.*, no. 637, Dec. 1959), 85–94.

per min. If his interpretation of the jig construction was correct, difference alone had very little meaning. They must know either the spigot flow or the hutch water flow. When the plunger moved downwards the hutch water played no part at all in the operation, but the spigot water reduced the displacement.

It could be seen in Fig. 3 (p. 66) that when make-up water was zero, jig bed current was $-2 \cdot 3$ gal. Could they assume that that was the amount flowing from the spigot throughout the tests?

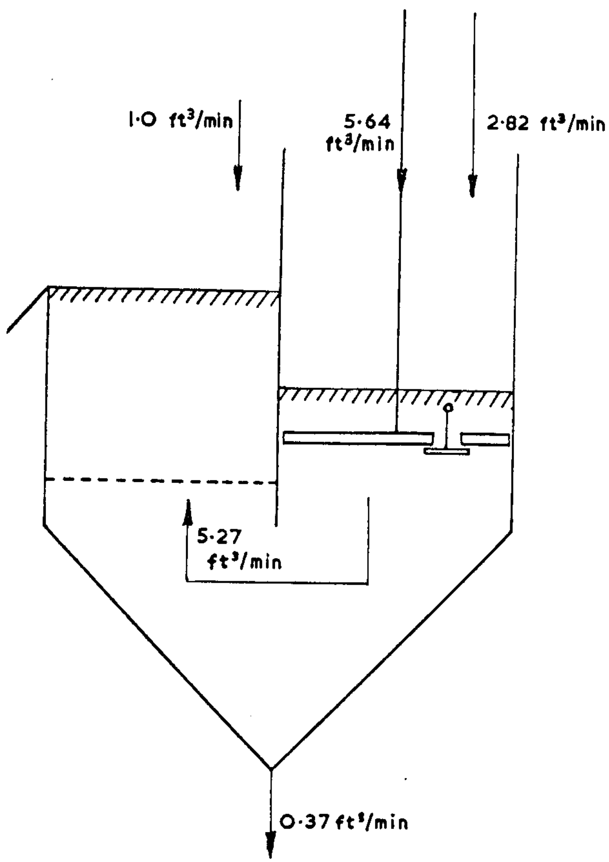

Fig. A.

The speaker said he had tried to work out the stroke characteristics, or wave form (Fig. A).

If they took a stroke length of 0·24 in. at 138 strokes/min with intensity 2·8 as in Fig. 3, it would be found that the plunger displacement, when moving downwards, was $4 \cdot 85$ ft^3/min, or $5 \cdot 64$ ft^3/ft^2/min, or simply 5·64 ft/min. It must be remembered that that was not uniform velocity

because there was a continuous change throughout the half sine wave. If the plunger moved up without creating suction, the volume which it displaced must be replaced by make-up water during the full cycle—not a half cycle—and the make-up water would be $5 \cdot 64/2 = 2 \cdot 82$ ft^3/min. If that volume were not replaced, either the plunger would suck back from the screen chamber, or water would gravitate back underneath the plunger. He had estimated spigot water at $2 \cdot 3$ gal/ft^2/min, as was indicated by Fig. 3. That was $0 \cdot 37$ ft^3. Net upward displacement on the upstroke would be, therefore, $5 \cdot 64 - 0 \cdot 37 = 5 \cdot 27$ ft^3/ft^2/min, or a mean rising velocity of 5·27 ft/min. Net jig bed current was $2 \cdot 82 - 0 \cdot 37 = 2 \cdot 45$ ft^3/ft^2/min $= 15 \cdot 3$ gal/ft^2/min, which unfortunately was much higher than any current mentioned by the author. Clearly something was wrong. Net downward velocity in that case could be slightly greater than 0·37 ft/min because there could be a slight levelling up shortly before the plunger reversed.

He was a little surprised at the relatively large amount of jig concentrate, and he noticed in Table I (p. 67) that it was appreciably finer than the tailing. He asked if there were any other heavy minerals beside cassiterite in the feed.

Considering the effect of stroke length, or displacement, and frequency, or speed, on the amount of concentrate, Mr. Armstrong had formed the following conclusions as a result of his own work on jigging. He preferred the word 'frequency' to 'speed' because speed implied velocity.

If the displacement/time diagram was a sine wave, the velocity/time diagram was also a sine wave, but displaced by one quarter cycle along the time axis. If frequency was increased while displacement remained constant, the middle part of the curve became steeper. If displacement was increased while frequency remained constant, the middle part of the curve again became steeper and also longer. The steeper and longer that part of the velocity/time diagram, the larger would be the amount of concentrate drawn into the hutch. That confirmed Fig. 1.

He was not very happy about the test procedure using only 1 ft^3 of feed in a jig nearly 1 ft square. They were not told the bed depth, but if it was 3 in., the 1 ft^3 looked much too small.

The amount of cassiterite in the feed was only small and therefore the practice of running an indefinite amount of feed through the jig to bed it down before running a test seemed to be asking for trouble, and he was amazed the author had obtained consistent results with that technique. He said that with admiration rather than with criticism, because the paper was obviously the result of a considerable amount of skill and patience.

Mr. I. R. M. Chaston said that he would like to talk a little about the author's conclusions and interpret them in his own fashion. He himself had suggested before in discussion* that one of the main factors controlling jig

*Harris, J. H. Serial gravity concentration. Discussion by I. R. M. Chaston. *Trans. Instn Min. Metall., Lond.*, **69**, 1959–60 (*Bull. Instn Min. Metall., Lond.*, no. 640, March 1960), 313–8.

concentration was the extent to which the jig bed was dilated during the jigging cycle. That dilation controlled the size of the interstices in the jig bed and determined whether a given size of heavy mineral was collected under free settling conditions or under the slower hindered settling conditions. It followed that for given feed and jigging conditions there should be an optimum state of bed dilation which would recover the maximum amount of the heavy mineral present with the minimum of gangue.

He interpreted the results given in Figs. 1 and 2 as showing that there were various combinations of speed and stroke which resulted in that optimum dilation state and that once it had been reached, further dilation by increased stroke or speed would only result in an increase in the amount of gangue collected in the spigot product. With the given feed, jig and jigging conditions it was apparent from the results that the necessary dilation had been more effectively achieved with a long slow stroke than with a short fast stroke.

Mr. Armstrong had commented at length on the question of the bed current. In considering that point it should be realized that 1 gal/ft²/min was a velocity of only 0·8 mm/s. A rising current of that order, or even of ten times that, would only affect a very small proportion of the relatively slime-free feed used in the tests. As had already been suggested, there was in practice often a much higher proportion of fines in the jig feed than in the feed used in the tests described. In those circumstances, an appreciable portion of the feed could be affected by the low velocity currents and the size and direction of the currents would make a great difference to the jig operation. For example, if the jig were operated under an overall suction, the slime would be dragged down into the bed and increase the viscosity of the fluid medium in which concentration was taking place, thus hampering the recovery.

The speaker noted that the author had not found any loss of middle-size range cassiterite, but had commented on the presence of so-called 'floating' cassiterite and had taken steps to guard against that material affecting his results by priming the bed before each test. It would have been extremely interesting if the author had recovered some of that 'floating' cassiterite and determined its size range. In an earlier discussion* it had been predicted that the size range of heavy mineral which was just too big to collect under free settlement through the interstices of the jig bed would settle very slowly through the jig bed, and he thought that that would account for so-called 'floating' material and suggested that, although it was not surprising that that material had not been lost under the carefully controlled test conditions, under the continuous and often surging conditions of full-scale jig operation a proportion of such slow-settling cassiterite would be swept out with the jig tailing and would give rise to the middle-size range losses which had been referred to.

He was impressed by the dulang washing procedure, but thought that it must have taken a considerable time to carry out each determination. To

*See footnote on page 357.

treat a cubic ft of material, 200 cm³ at a time, required 140 separate washes. To appreciate the difficulties facing the assayer one had only to consider the treatment of one of the tailing samples in the reported tests. A cubic-ft sample of ground containing 1½ lb cassiterite to the cubic yd would itself contain only 25 g of cassiterite. A treatment of the sample giving 98 per cent recovery would result in a tailing containing 0·5 g of cassiterite. That tailing, say 0·93 ft³, would require 130 separate washes, each of which would yield on average less than 0·004 g of cassiterite or about two 25-mesh particles. Obviously the possibility of error was high.

Without wishing to reopen the earlier discussions on the limitations of physical assaying, he felt that the author could usefully have made one or two checks on his assay procedure, using perhaps the excellent colorimetric method for determining tin described by Stanton and McDonald.†

The speaker said he did not agree with the interpretation of the results of the final test comparing the operation of the jig on screened and unscreened feeds. The earlier test results had shown that, with correct jig settings, recoveries of 99 per cent could be achieved with the unscreened feed, whereas in the final test the recovery was only 91 per cent on that feed. That seemed to suggest that the jig settings for that test had not produced the optimum dilation condition necessary for good recovery. The improvement in recovery achieved by screening the feed at 10 mesh might therefore solely have been due to the jig settings giving better dilation with the finer feed. Even so, it was noticeable that the recovery and ratio of concentration on the screened feed were both lower than in the earlier more successful tests using unscreened feed. Screening off the coarse material in the feed to a jig could, by reducing the size of the bed interstices, result in having to recover a greater proportion of the heavy mineral present under the slower hindered settling conditions.* To obtain a given recovery would then entail jigging for a longer period which would offset any gain in jig capacity due to the reduced amount of feed and would in addition result in the collection of more gangue with the spigot product.

As Mr. Armstrong had suggested, the bed depth was an essential factor in jigging and should be added to Mr. F. A. Williams's list of variables. The force, or stroke intensity, required to produce the necessary optimum bed dilation would depend to a large extent on the total bed depth and not just on the depth of ragging.

Mr. Batzer replied to a number of points raised in discussion and undertook to send in a full written reply for publication later.

The President thanked him for his very useful paper and those who had taken part in the discussion for their contributions. The author was warmly applauded.

*See footnote on page 357.

†STANTON, R. E., and McDONALD, Alison J. Field determination of tin in geochemical soil and stream sediment surveys. *Trans. Instn Min. Metall., Lond.*, **71**, 1961–62 (*Bull. Instn Min. Metall., Lond.*, no. 659, October 1961), 27–9.

WRITTEN CONTRIBUTIONS

Mr. P. M. Sheahan*: Mr. Batzer's tests support the Research Division's contentions that a long stroke should be used, at the speed necessary to ensure a live bed. His Fig. 2 illustrates the wisdom of not attempting too high a ratio of concentration.

At first sight it is surprising that recoveries were so consistently good, regardless of the jig settings. This is due, I think, first, to the relatively low feed rate of 0·4 yd^3/h, across a jig width of 1 ft, as compared with the flow of 5·0 yd^3/h across an equivalent 1-ft width of a full-sized jig. Even on an area basis an equivalent 42-in by 42-in cell would be handling just less than 5 yd^3/h at the feed rate used in this investigation. Secondly, the large amount of feed dilution water greatly assists the operation of the jig at these low feed rates, even though similar dilutions are disastrous at higher feed rates.

Although I think that one day there is a possibility of controlling stroke speed automatically in response to variations in feed rate, I do not like the concept of stroke intensity as a primary basis for investigational work. The Malayan Department of Mines has recently acquired a powerful stroboscope for use with transparent-sided jigs, and uses a small modified Knapp and Bates jig and a 2-cell 24-in Yuba jig with glass side-windows. According to the jig settings and type of feed, three different phenomena can be observed. At very low speeds, a pulse of water lifts the entire bed, then rises up through the bed as a layer of dilution, into which overlying sand is seen to fall by free settling. At higher speeds, the entire bed expands, and by setting the stroboscope to run at a slightly different frequency to the jig the apparent motion can be slowed down so that the bed has the appearance of 'breathing'. It was also possible to detect rarefactions and compressions in the bed. The waves were particularly well defined in the lighter material at high jig speeds.

In the larger jig, at the speed so far used, there was insufficient bed depth to develop a train of waves, although the passage of the wave front could be observed, and so far I am encouraged to hope that a consistent theory can be evolved and various measurements made to provide numerical data for the design and operation of jigs.

To secure wave motion in a medium it is necessary that when particles of the medium are displaced there should be produced a restoring force proportional to some positive function of the displacement. In the case of a jig bed there is a positive increase in resistance to displacement as the particles in front of a water pulse proceed to pack together. If there is pulsion and no suction, equilibrium is restored by settlement under gravity at various rates inversely dependent on crowding, to an extent dictated by the settling velocities and the onset of the next pulsion wave. When a suction pulse is superimposed on the falling particles it would appear that resistance to displacement would be somewhat less due to the natural tendency to settle. To achieve equal condensation of particles in a wave front during suction, would, it seems, require a stronger suction pulse than the equivalent upward pulsion stroke. With suction less than pulsion by a small amount, the bed would tend to remain fairly open through most of the cycle. With the glass-sided jig, when these conditions obtain, it can be seen that apparently ideal jigging conditions are operating.

*Chief Research Officer, Department of Mines, Research Division, Malaya.

Mr. F. A. Williams: The author has produced valuable basic data from batch tests alone carried out with only a small single-cell Harz-type jig. As he pointed out, the investigation described deals with only some of the many variables which influence the performance of jigs on tin dredges. I have selected and classified eleven variables in List 1 which I think are particularly important. The author's paper deals with five of them, although not exhaustively. This is a good beginning, and no doubt all these variables will be adequately dealt with during the extended programme of research he has mentioned.

Both the value and the limitations of the paper can be assessed if the research needed on the effects of each of these major variables is considered.

LIST 1.—*Classified list of principal variables determining the performance of jigs as used for concentrating alluvial wash on tin dredges*

Feed	*Size range of feed	*Ragging*	Density
	*Grade of feed		Size range
	Slime content		Depth
	Size range of cassiterite	*Operation*	*Length of stroke
	Rate of feed		*Speed of stroke
			*Hutch water control

*Dealt with in the paper.

Size range of feed.—Table II (p. 68) presents jig performance data for a natural size range of tin-bearing wash screened at ½ in. and at 10 mesh. There are other types of jig feeds on dredges which are of interest in regard to their size range in relation to jig performance: (1) the combined primary jig hutch products fed to the secondary or clean-up jig, and (2) the underflow from the secondary cyclones when these are used for re-cycloning the primary cyclone overflows. Although this secondary cyclone underflow is rather fine it has been successfully concentrated in jigs.

Grade of feed.—The series of tests carried out with feeds varying from ½ lb/yd^3 to 12 lb/yd^3 could with advantage be extended to still higher grades. The feeds to clean-up jigs are often of higher grade than 12 lb/yd^3 particularly when, as is usually the case, some of the hutch products are returned in closed circuit.

Slime content.—The author mentioned the adverse effect of slime on recovery, but this variable was not covered by the investigation. Although it is recognized in general in both Malaya and Nigeria that reduction of the slime content of the feed improves recoveries, particularly in the fine size range, there is need for quantitative research data tying in actual percentages of slime with percentage recovery for different sizes of cassiterite.

Size range of cassiterite.—The paper deals only with total recoveries of cassiterite. Data on recovery in relation to particle size are particularly important. This would entail spending considerably more time on the analysis of the samples, but this information is vital for guidance in changing the flowsheet of treatment plants on dredges.

Rate of feed.—The tendency during recent years has been to provide more jig screen area for a given yardage throughput, but the effect of rate of feed on percentage recovery has not yet been studied quantitatively.

Ragging.—In Nigeria I studied the effects of different sizes and densities of ragging in a 6-cell clean-up jig with a screening length of 20 ft.† The results illustrated the versatility of control over concentration ratios which can be achieved through varying the size range and density of the ragging. It should be worth while carrying out a similar investigation as part of the research programme described and extending it to the primary jigging. The almost universal use of hematite ragging in Malaya should not be accepted without question.

Operation.—The author's paper is mainly concerned with the three major variables, length of stroke, speed of stroke and hutch-water control. The results are analysed with reference to the *area* of the screen. The continuance of the investigation with a plant-scale jig will provide an opportunity of studying performance in relation to length as well as area of screen.

The much larger programme of research planned by Anglo-Oriental (Malaya), Ltd., includes not only the batch tests but also the concurrent sampling of jig spigot products and discards on several dredges and the provision of a full-size jig installed for closed-circuit tests, still only part of

LIST 2.—*Classified list of the principal parameters determining the scope for a comprehensive programme of research on the performance of jigs for the tin mining industry of the world*

Types of tests	*Batch treatment
	*Closed circuit
	*Continuous flow
Coverage	*Alluvial cassiterite
	Associated alluvial minerals
	Comminuted lode tin ores
Levels of investigation	*Company
	National
	International

the much more comprehensive programme of research on the performance of jigs needed by the tin-mining industry as a whole. In List 2 I have classified and presented the nine principal parameters of such a programme, with five of which the Anglo-Oriental (Malaya) programme is concerned.

Although alluvials are the principal proved tin reserves of the world, cassiterite the principal product, and dredges the main producers, the

*Within the scope of research programme by Anglo-Oriental (Malaya), Ltd.

†WILLIAMS, F. A. The role of jigs in modern ore dressing. *J. S. Afr. Inst. Min. Metall.*, **61**, May 1961, 443–67.

industry is also concerned with opencast methods of mining alluvials, with the recovery of other minerals associated with the cassiterite, and with the gravity concentration of comminuted lode tin ores.

Types of tests.—The paper deals only with batch tests, concurrent sampling on several dredges being mentioned but no details given. In due course, perhaps, a paper on the investigation with the plant-size jig in closed circuit may be given. Each of the three types of tests has its advantages and disadvantages, but in a comprehensive programme of research all three should be used. Batch tests are most convenient for laboratory-scale work, but the author draws attention to the amount of sand and cassiterite of mesh finer than the jig screen which remains in the ragging more or less indefinitely, which reduces the reliability of such results.

Closed-circuit operation, whatever the scale, provided stable operation can be achieved, is much easier to sample reliably than plant-scale commercial-production operation. However, the almost complete elimination of slime would result in recoveries appreciably higher than on a dredge, so that the results may, to some extent, be unrealistic. On some dredges there may be space available for a research jig of reduced width but up to full overall length. It could be fed with cuts from the feeds to the primary and clean-up jigs to which cuts from the secondary cyclone overflows could be added, although, to obtain reliable results, sampling might have to be continued over three shifts.

Coverage.—The programme described in the paper has so far been confined to free cassiterite of sp. gr. 7·0, but appreciable economic interest also attaches to two other saleable minerals—monazite, sp. gr. 5·1, and ilmenite, sp. gr. 4·7. Furthermore the whole assemblage of heavy and semi-heavy minerals down to at least topaz, sp. gr. 3·5, and sometimes also laterite nodules of still lower specific gravity, has a 'nuisance value' in the tinshed. I hope that it will be found possible during the research programme to value a representative number of samples for several minerals in this specific gravity range over the full size range. Perhaps a selection of samples could be passed to the Research Division of the Mines Department or to the Geological Survey. The latter has good facilities for carrying out such combined size and mineral analyses. The results of an investigation on a commercial production plant in Nigeria* have since proved to have many and varied applications, one being the prediction of the recovery of locked grains of varying composition in this specific gravity range from comminuted lode tin ores. Variables could not be altered for research purposes in this commercial production plant, but they can and presumably will be altered in the Anglo-Oriental research test plant, and comparable sets of results for some of the associated minerals could be produced under a selection of conditions.

It is particularly difficult to analyse jig performance when the feed is

*WILLIAMS, F. A. Recovery of semi-heavy minerals in jigs. *Trans. Instn Min. Metall., Lond.*, **68**, 1958–59 (*Bull. Instn Min. Metall., Lond.*, no. 627, February 1959), 161–75.

comminuted lode tin ore because the particles form a continuous range of specific gravity from 100 per cent gangue to 100 per cent cassiterite—hence the special value of data on recovery in relation to specific gravity and particle size more easily obtained with alluvial material and an assemblage of free minerals covering a wide range of specific gravity.

Levels of investigation.—A research programme by a tin-dredging company must necessarily be limited to problems which will arise in tin dredging, but research at national level in Malaya might justifiably be extended to include some work on comminuted lode tin ores. At international level the tin-mining industry is well organized and gives substantial collective support for research directed to expanding consumption of metal, but so far there has been no corresponding support for research on the recovery of the original cassiterite. Both the alluvial and lode sections of the industry are having to work progressively lower-grade ores to which better methods of recovery should be applied, so that there is a growing need for basic research on jig performance and the treatment of jig concentrates. In List 3 I have presented a selection of research projects for which there is need. A separate research laboratory would not necessarily be required. Any or all of these research projects could probably be undertaken by the D.S.I.R. Warren Spring Laboratory if the work were sponsored.

LIST 3.—*A selection of research projects on gravity concentration suitable for collective financing by the major tin producers of the world*

1. Development of radioactivated alloys covering adequate ranges of specific gravity and particle size and the development of techniques for their use in research work on the performance of jigs and shaking tables
2. Basic research on the performance of jigs and shaking tables by means of radioactivated alloys
3. Improvement in the existing range of equipment and techniques for the laboratory-scale density-fractionation of samples of comminuted lode tin ores and gravity concentration products
4. Application of flotation to non-sulphide gravity concentrates of cassiterite and associated minerals too fine for efficient processing by high tension and magnetic separation

Radioactivated alloys for research

The use of radioactivated alloys for research on mineral recovery in jigs was initiated by the Diamond Research Laboratory near Johannesburg and has been described by Adamson* and by Weavind and McLachlan.† The original sponsors of this laboratory were De Beers Consolidated Mines, Ltd., Consolidated Diamond Mines of South-West Africa, Ltd., Société Minière du Beceka, Société Forestière et Minière du Congo, and Companhia de Diamantes de Angola. The international support for this laboratory is thus comparable with that from the tin-mining industry for the Tin

*ADAMSON, R. J. Some account of diamond winning practices in Southern Africa. (Presidential Address.) *J. S. Afr. Inst. Min. Metall.*, **60**, August 1959, 23–50.

†WEAVIND, R. G., and MCLACHLAN, D. F. C. Modification of a diaphragm jig to treat large tonnages of diamond bearing kimberlite. *J. S. Afr. Inst. Min. Metall.*, **61**, January 1961, 325–32.

Research Institute. But whereas the activities of the Tin Research Institute are confined to developing *uses* for tin, those of the Diamond Research Laboratory range from problems arising in the valuation of alluvial diamond-bearing deposits, through all stages of plant-scale recovery, including the use of jigs, to the marketing and utilization of industrial diamonds. The use of radioactivated alloys for research work on mineral recovery in jigs and in other types of gravity concentrators is only one of several very useful technologies which this laboratory has developed and passed on to the mines. The laboratory staff also visit mine properties to carry out research work on commercial production plants.

Basic research on jigs with radioactivated alloys

I have witnessed the investigation of plant-scale jig performance with radioactivated diamonds in South Africa and am of the opinion that the use of radioactivated alloys presents interesting possibilities for broadening the scope of both the laboratory-scale type of investigation dealt with in Mr. Batzer's paper and the extended programme by Anglo-Oriental (Malaya), Ltd., with full-size jig operated in closed circuit. With comminuted lode ores radioactivated alloys are even more promising for basic research. The performance of jigs tested with such alloys in the specific gravity range 2·65 to 7·0 and in a size range down to as fine as practicable should be a valuable contribution to general research work on the gravity concentration of comminuted material. At present such investigations on comminuted ores are usually assessed rather unsatisfactorily by means of chemical assays, a procedure which does not distinguish between locked and free cassiterite. After the method had been developed by co-operative effort and used for basic research it might also be used to advantage for research applied to specific ores by individual mining companies.

Density-fractionation of samples

Research on jig performance with alluvial material containing free cassiterite is comparatively simple over the full size range especially if a superpanner is available. But if the feed is a comminuted lode tin ore jig performance cannot be directly investigated in detail without making size-density-assay analyses of samples. Considerable quantities of each sized fraction have to be separated in heavy liquids at the lower end of the specific gravity range in order to have sufficient for assay at the upper end of this range. Cold heavy liquids, such as bromoform and methylene iodide, are used at the lower end of the density range, hot solutions such as lead sulphamate solution and Clerici solution in the intermediate range, and fused salts such as lead chloride at the upper end. For these purposes existing centrifuges will not take samples of sufficient size and none is available which can be suitably heated. There is a very definite need for the design and commercial production of suitable centrifuges.

An alternative approach which might repay research is centrifuging in suspensions of fine heavy particles in heavy liquids. Some unpublished investigations have given very promising results.

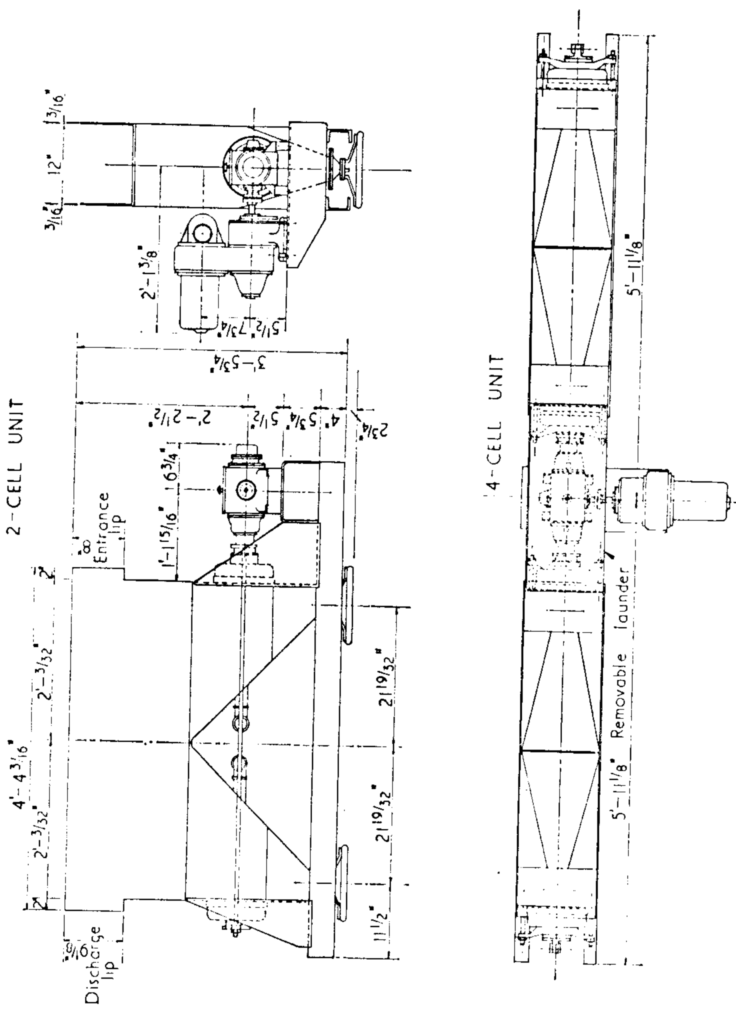

Fig. B.—12-in research jig.

Flotation of jig concentrates

The use of cyclones ahead of jigs has extended the recovery of cassiterite and associated heavy minerals down to 300 mesh and finer. This has created new problems in the tinsheds where previously there was no appreciable amount of mineral finer than about 150 mesh. In Nigeria it has been found that with sizes finer than about 150 mesh the effectiveness of the dry processing of the gravity concentrates by pneumatic concentration, high-tension separation and magnetic separation falls off rapidly. Wet tabling is not a very satisfactory substitute.

The possibility that flotation might help to solve this group of problems or even provide a complete answer would appear to be worth investigation. There is a wide field of choice because reagent costs which would be definitely too high with ores could be economic with such concentrates.

Jigs for research

According to Taggart,* 'Capacity of a given jig under given operating conditions is proportional to sieve area, with width the predominant dimension and length contributing rather to recovery.' Mr. Batzer had to carry out his laboratory-scale tests with only a single-cell jig and could therefore relate the results only to the area of the screen. For a comprehensive investigation, even at laboratory scale, a jig with at least two cells in series is necessary. Recovery can then be investigated in relation to the total length of screen as well as just its area. For instance the effect of progressive dilution of the bed by rising hutch water is a function of length which calls for investigation.

Recently I have been concerned with testing a small jig, designed specially for research work. It is a 2-cell unit 12 in. wide, and 4 ft long, as shown in Fig. B. When fitted with the double-ended version of the small drive box 4 cells in series can be operated giving an overall jigging length of 8 ft. Two such double units in series would have a screen area as long as that of the longest jigs normally used on dredges, but would occupy much less width and height. One or more of the 2-cell units could be used for research purposes in three different ways: (1) batch tests in a laboratory, (2) incorporation in a closed-circuit research plant of quite moderate size compared with the one using a full-scale jig mentioned in the paper, and (3) installation on a dredge for tests with cuts from normal primary and secondary jig feeds with and without additions of slime from the secondary cyclone overflow.

I should like to ask the author for some practical details of how his tests were carried out, e.g. the method used to measure the rate of inflow of the hutch water. A photograph of his laboratory jig complete with ancillary equipment employed would be useful.

My photograph, Fig. C, shows the research jig which I have been testing, as fitted with some additional equipment. At the intake end is a constant-rate feed box. The material is carried forward by a fixed-speed drum with an internal drive and passes beneath an adjustable gate. The jig was found

*Taggart, A. F. *Handbook of mineral dressing* (New York: John Wiley and Sons 1945), section 11, 54.

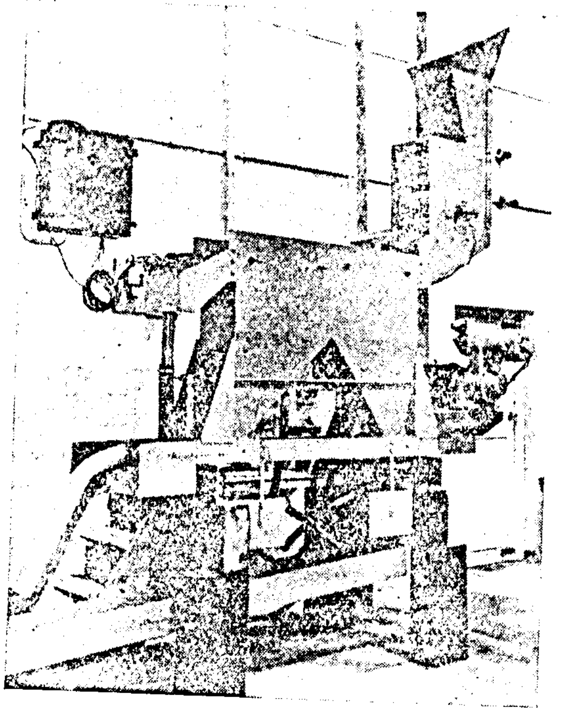

Fig. C.

to work satisfactorily with both dry and wet feeds screened to pass ¼-in mesh. The solids contents of the hutch and tails discharges are retained in the boxes shown. These boxes could be made bigger to reduce turbulence. The surplus water can either be discharged to waste by launder as shown or, with longer hoses, can be run into tanks for measurement of volume and the slimes content and a check on any fine heavy mineral which might be carried over.

Mineral accounting

There are three facets to the activities of any tin-dredging company—engineering, monetary accounting, and mineral accounting. All are essential for the profitable working of the alluvial deposits, especially low-grade ground. Until quite recently mineral accounting was confined to the valuation of the ground by methods which, according to Chaston* of the Mines Department, failed by a considerable margin to record all the cassiterite present, particularly in the fine size range. During the last few years, however, the dredging companies have shown an increasing interest in mineral accounting and have spent considerable amounts of money on developing and applying more accurate methods of valuing the ground, on determining what the actual losses are from the dredges, and on the plant-scale testing of cyclones used to improve jig performance.

*Author's reference 4 on p. 68.

Dr. D. J. Brown*: An alternative method of presenting his results shows up important factors not immediately obvious in Mr. Batzer's treatment.

Fig. 2 shows the relationship between the recovery of cassiterite and the proportion of feed in the spigot product. Since the former varies little in the tests reported, attention has been concentrated upon the way in which the proportion of the feed in the spigot product changes as experimental conditions change. The starting-point for the calculation is the assumption that the most important factor influencing the separation is the differential acceleration of the particles at the beginning of fall, on the downward part of the jig stroke. This assumption is not new, differential acceleration being recognized as important many years ago, in company with hindered-settling classification and consolidation trickling.

The plunger movement is a simple harmonic one with stroke length L and frequency S. For simple harmonic motion about the mid-point of the stroke, the amplitude $R = L/2$ and the period $T = 1/S$. The maximum velocity (midway through the upward or downward motion) $V = \pi LS$, and the maximum acceleration (at the beginning and end of the upward or downward motion), $A = (2\pi^2) LS^2$. One might expect, therefore, a correlation between per cent in spigot product and an acceleration term, LS^2. From Fig. 1 of the paper, the values of S were taken as 50, 75, 110, 140, 155, 182, and 257 strokes/min. Values of L were also obtained from Fig. 1, since displacement = $144L$. A calculation was then made of LS^2; a plot of per cent in spigot product against LS^2 is shown in my diagram, Fig. D.

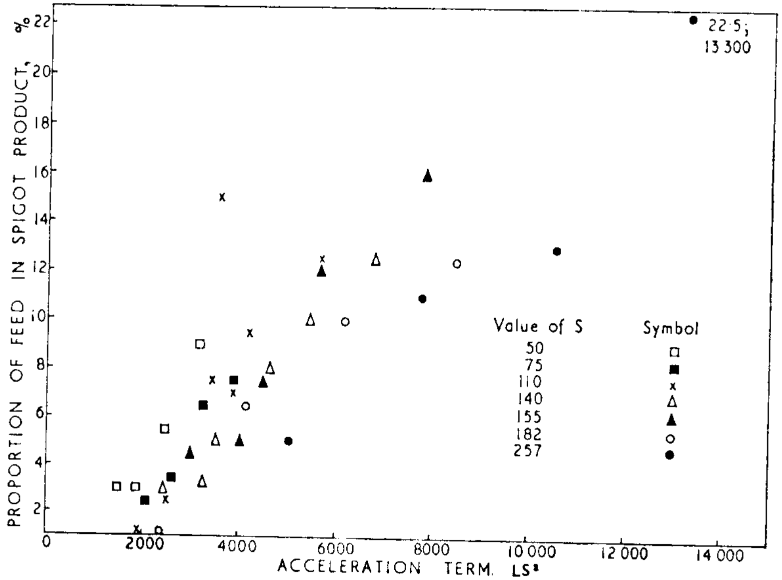

Fig. D.—Variation of proportion of feed in spigot product with magnitude of acceleration term.

*National Coal Board Scientific Department, London.

A statistical analysis of the results shows that if one of the results is ignored (spigot product = 15·0 per cent, $LS^2 = 3614$), then within experimental error the lines through the different sets of results have a common slope of $2{\cdot}5\times10^{-3}$ (if the odd point is included, the value of the slope becomes $2{\cdot}7\times10^{-3}$). Further, the intercept on the LS^2 axis depends upon S, as illustrated by the figures below.

Intercept	*Value of S*	*Intercept*	*Value of S*
400	50	1700	155
1100	75	2500	182
700	110	4400	257
1800	140		

Allowing that there is some scatter, there is still evidence for a linear relation

$$\text{Intercept} = 14S$$

Each set of data is described by an equation

$$\text{per cent in spigot product} = 2{\cdot}5 \times 10^{-3}\,(LS^2 - 14S),$$

where L is variable and S constant.

A conclusion to be drawn from this equation is that even though the net jig bed current is a falling one (0·5–0·8 gal/ft²/min) there is evidence for a continued upward flow of water after the end of the upward stroke of the jig and a consequent reduction of the downward acceleration of the mineral particles.

Turning now to the results shown in Fig. 3 of the paper, it is possible to deduce the value of L, since intensity (I) = $SL/12$.

The values of I, S and LS^2 are:

I	S	LS^2
3·2	155	5950
2·8	138	4640
2·1	138	3480

For a net bed current of 0·5–0·8 gal/ft²/min downward, for each set of data,

$$\text{per cent spigot product} = 2{\cdot}5 \times 10^{-3}\,(LS^2 - 14S).$$

As the upward current becomes more pronounced, the figure to be subtracted from the acceleration term will become greater than $14S$. Taking the point in Fig. 3 corresponding to (per cent in spigot product = 6, jig bed current = +5 gal/ft²/min, $S = 155$), then the coefficient of S is 23 rather than 14.

Although I have not had time to do a full analysis of the results, it would appear that the value of the coefficient of S increases in proportion to the upward bed current.

To sum up, it has been shown that the sets of experimental results may be described by relationships of the form:

$$\text{per cent in spigot product} = 2{\cdot}5 \times 10^{-3}\,(LS^2 - KS),$$

where K depends upon the value of bed current. This is taken to show that for this type of jig at least, the dominant factor in determining spigot yield is the downward acceleration of the particles in the bed.

Mr. R. C. M. van der Spuy: I feel that the author has overlooked a very important variable in jig operation, that is, depth of bed, or height of tailing board above the screen. In their paper,* Lill and Smith determined the optimum bed thickness for a given stroke and speed by observing the rate at which the heavy particles penetrated beds of different thicknesses. Tests were carried out in a transparent compartment 4 in. square and the authors state: 'With a bed thickness of 4·5 cm . . . the particles moved very slowly through the top layers of the bed, but on reaching a point approximately 3·2 cm above the jigging screen a sharp increase in downward velocity occurred. In tests with a bed 3·1 cm deep no tendency for particles to stick in the top layers was observed, but with a bed of 3·8 cm deep both types of behaviour were noted. It was concluded that the loosening wave . . . only reached a point between 3·1 cm and 3·8 cm above the screen.'

From this it may be assumed that for different materials and varying pulse velocities and amplitudes, there are different optimum depths of bed. My own experience has shown that bed depth is as important a variable as stroke length and speed. References show that practice as to depth of bed varies from 9 in. to as little as 2¼ in.

When recovering cassiterite from crushed ore by jigging I have always set the amplitude of the pulse to approximately three times the maximum particle size and then calculated the mean pulsion velocity (and thus the speed) from H. S. Munroe's formula†

$$V = 26{\cdot}32\,\sqrt{D(S-1)}$$

where V = mean pulsion velocity in mm per second, D = diameter of largest particle in mm, S = sp.gr. of gangue particles.

The depth of the bed was then altered by raising or lowering the screen until maximum recovery was obtained. Using this method of setting a jig, one can almost say that speed and length of stroke can be calculated and are therefore not really variables. The two main variables for setting the jig are then the volume of hutch water and the height of the tailings board.

DISCUSSION AT A MEETING OF THE MALAYAN SECTION

Report of discussion at a General Meeting of the Malayan Section of the Institution of Mining and Metallurgy, held at Ipoh on 30th May, 1962

Mr. G. C. R. MacDonald and Mr. L. S. Lim, in a joint contribution, said it was generally agreed that the size distribution of cassiterite in a jig-feed was one of the more important factors governing jig recovery. The author had stated in his paper that he found recovery better in the coarse and medium mesh fractions than in fractions below 100 mesh B.S.S. While

*Author's reference 1, p. 68.

†Richards, R. H., and Locke, C. E. *Textbook of ore dressing* (London: McGraw-Hill, 3rd ed., 1940), 196.

agreeing in general with that observation, they thought it would have been of great interest if figures of specific recovery achieved in each size range had been available.

From jig sampling carried out on dredges of Malayan Tin Dredging, Ltd., it was found that with a long-range feed good recoveries could be achieved down to 150 mesh B.S.S., but there was a sharp decline after that.

The figures given in Table A might be of interest. The relatively better recovery achieved by the Ruoss jig in the finer size range was probably due to the lower rate of feed, while the fact that the converted Harz jig had a substantially larger bed area would most likely have contributed to its higher recovery (test B). When the feed was deslimed (test A) the same recovery pattern was apparent, although there would seem to be an improvement in the recovery of the coarser size-ranges.

TABLE A

Mesh B.S.S.	*A* *Recovery* %	*B* *Recovery* %	*C* *Recovery* %
+60	94·9	97·0	100·0
−60+100	99·1	96·2	88·2
−100+150	93·5	92·2	95·3
−150+200	52·7	48·9	60·0
−200	12·3	24·7	61·0
Composite	91·8	95·0	90·9

A—Pan American jig, 4 cells (42 in. by 42 in.)
Stroke, 1½ in. Stroke/min, 120
Deslimed feed (11 yd³/h)

B—Converted Harz jig, 4 cells (72 in. by 48 in.)
Stroke, ¾ in. Stroke/min, 120
Normal feed (10 yd³/h)

C—Ruoss jig, 4 cells (42 in. by 48 in.)
Stroke, ½ in. Stroke/min, 131
Normal feed (8 yd³/h)

In his tests with varying grades of feed, the author did not find any significant changes in recoveries. However, results from a series of six tests run at Malayan Tin Dredging, with a narrower range of values, were as follows:

SnO_2	*Recovery* %	*SnO_2*	*Recovery* %
0·03	82·6	0·12	94·4
0·09	87·2	0·14	96·3
0·10	90·0	0·16	96·9

It should be pointed out that chemical assays were used for evaluation in all the test work just mentioned.

There was a considerable amount of controversy over the recovery of cassiterite in the medium size ranges. The author gave screen analyses of the cassiterite from both the tailings and spigot products from a number of tests which indicated a somewhat better recovery in the coarse and medium

range than in the fractions below 100 mesh B.S.S. That general pattern of recovery was supported in the three examples of recovery in specific size ranges shown in Table A. However, if the screen analysis of the concentrate from tailings as given by the author was considered on its own face value, and without comparison to the screen analysis of the spigot, it would appear that the jig was rejecting the medium-range cassiterite in preference to the finer sizes, and it was probably mainly on those grounds that the suggestion of decreased recovery in the medium size range was founded. A test carried out on a Harz Bendalari jig operating under normal dredging conditions, with the results given in Table B, would serve as an example.

TABLE B

Mesh, B.S.S.	*Feed, wt.* %	*Spigot product* *Recovery* %	*Spigot product* *Wt.* %	*Tailings* *Loss* %	*Tailings* *Wt.* %
+60	20·9	96·96	21·35	3·04	12·7
−60 +100	65·2	96·22	66·00	3·78	49·0
−100 +150	12·4	92·20	12·04	7·80	19·2
−150 +200	0·8	48·94	0·42	51·06	8·2
−200	0·7	24·70	0·19	75·30	10·9
	100·0		100·0		100·0

Although recovery in the medium ranges, i.e. −60 to +150 mesh, was well over 90 per cent, nevertheless 68·2 per cent of the free tin accounted for in the tailings was in that medium range. It was, of course, due to the fact that nearly 80 per cent of the total cassiterite in the feed lay in that range and that even small percentage losses in those ranges would constitute substantial overall losses, in many cases much greater than those which occurred in the finer ranges where recovery was acknowledged to be poor.

It was therefore the opinion of the contributors that, while under normal conditions a jig would not reject the medium-size ranges in preference to the finer ranges, in cases where the bulk of the cassiterite lay in the medium ranges any efforts to improve recoveries in those ranges would certainly not be wasted.

Mr. Yan Sip Leow wished to know if the fluidity of the jig bed was affected by particle size of feed.

Mr. K. D. Shaw asked how the proportion of feed reporting at the spigot in the tests compared with figures from dredges.

Mr. E. B. Davies queried the desirability of screening out the +10-mesh fraction in practice on dredges, as it was considered that, while that would reduce the amount of material that had to be handled by the primary jigs, the finer shorter-range feed would probably reduce the optimum feed rate of the jigs in at least the same proportion as the material screened out, not to mention the practical difficulty of screening large flow rates at very high efficiency.

Mr. Y. L. Wong said that he was inclined to think that the results derived from volume measurements, as practised by Mr. Batzer, would be less accurate than when the actual dry weights of the jig products were considered. As it was, he was sure that it would be rather difficult to maintain a reasonably constant pulp density for both the spigot products and the tailing products, and hence there might be a tendency of discrepancy in pulp density between the two jig products. Perhaps a high standard of accuracy was not so important in that case, but he wondered if the patterns of the graphs would be affected if weights were taken instead of volumes.

Mr. Batzer, in his reply, said that no trouble was experienced with bed fluidity in the tests on the small jig as all $+\frac{1}{2}$-in material was screened out and the feed rate and pulp density kept at comparatively low levels.

Referring to jig recovery at varying grades of feed, Mr. Batzer pointed out that during the tests a constant size distribution of the cassiterite was maintained, and gave a constant recovery, whereas in natural alluvium lower values were usually associated with finer cassiterite, and in consequence, a lower recovery by the jig.

The rate of the feed to the test jig was controlled by trying to avoid overloading, without the load being excessively light. Even so, there were some indications of overloading during tests at the lowest intensities of stroke, while the same load was handled with ease at higher intensities.

With regard to the proportion of feed reporting at the spigot in the tests compared with dredge figures, numerically the proportion in the tests and on dredges using Ruoss jigs was about the same for a given intensity and speed of stroke. That must be coincidental since the jigs on dredges had four hutches as against the one of the test jig. In the full-size Ruoss jig the proportion of feed reporting at the spigot per hutch averaged about a quarter the proportion reporting in the test jig hutch. The reasons were thought to be the larger upward jig bed current in the Ruoss jigs, the thicker ragging, and the fact that the ragging contained more rounded grains and more worn grains between $\frac{1}{8}$ in. and $\frac{1}{4}$ in. in diameter, giving a more compact bed.

The results of dredge sampling nevertheless appeared to follow the pattern indicated by Fig. 1.

Concerning accuracy of results based on volume measurements, that procedure was adopted for convenience. The results required were relative and it was therefore more important to maintain a standard procedure than to attain a theoretically high standard of accuracy. The difference in density between the tailings and spigot products was not large.

The timing of the tests was so arranged that each test lasted from the moment the material started to be fed on to the jig to the time the last of the material left the feed box. As the results required were comparative in nature, the most important thing was to have a set procedure. It would have been better to have used a larger specimen, which would reduce the relative importance of the starting and stopping periods. The jig was run until no more tailings were being discharged.

Elemental Constitution of the Black Star Orebodies, Mount Isa, Queensland, and its Interpretation

R. L. STANTON, M.Sc., Ph.D., F.G.S.

Report of discussion at December, 1962, General Meeting (Chairman: Mr. J. B. Simpson, President). Paper published in November, 1962, pp. 69–124

Professor K. C. Dunham said that he was sorry that Dr. Stanton, who was at the University of New England, Armidale, New South Wales, was unable to be present to introduce his paper, but in his absence he was glad to have the opportunity of doing so.

As there appeared to have been no previous discussion of the geology of Mount Isa at the Institution, he proposed to devote a short time to a description of the salient geological features of that remarkable property and district which he had had the opportunity of visiting through the generosity of Mount Isa Mines, Ltd., and New Consolidated Gold Fields (Australasia) Pty., Ltd. [Professor Dunham showed colour slides of the Mount Isa region to illustrate his remarks.]

The late Pre-Cambrian rocks in which the orebodies occurred were dolomitic, carbonaceous shales or slaty phyllites, forming part of a series of only very lightly metamorphosed rocks which also included a thick series of altered volcanics and pyroclastics (the Eastern Creek Series), quartzites and dolomites.

The rocks struck N–S and dipped steeply to the west. They had been affected by isoclinal folding on axes which, according to S. R. Carter* were steeper than the dip of the beds; that was accompanied by some drag folding. Steep faults mainly in axial directions affected the strata and there was also evidence of low-angle faulting in the district. About 10 miles west of Mount Isa, a long strip of intrusive granite separated the Younger Pre-Cambrian rocks from an older Archaen series. Granite also outcropped west of the district but according to Carter that pre-dated the host-rocks of the orebodies.

The lead-zinc orebodies, which were the first to be developed, lay with apparent conformity within the Urquhart shales, a formation which could be traced for about 50 miles along the strike, and which not only characteristically contained clay minerals, dolomite and bituminous matter, but was also well supplied with micro-specular pyrite. That was first described by H. F. Grondijs and C. Schouten† who were opposed to Schneiderhöhn's suggestion that the myriads of tiny spheres in black shales were the pyritized relics of sulphur bacteria, but in the light of more recent studies

*Carter, S. R. Mount Isa geology, paragenesis and ore reserves. *18th Int. geol. Congr., Lond.*, 1948 (*Symposium on lead and zinc*). (London: The Congress, 1950), part 7, 195–205.

†Grondijs, H. F., and Schouten, C. A study of the Mount Isa ores. *Econ. Geol.*, **32**, June–July 1937, 407–50.