have just heard, a Gold Medal has been awarded to Dr. Orenstein, of Johannesburg. The splendid work done by the Institution of Mining and Metallurgy helps, not only to cement the friendship between countries by creating goodwill, but also promotes excellent relations by the establishment of a common high standard of professional and business integrity and efficiency.

Mr. President, on behalf of my fellow guests and myself, I want to thank you again very warmly indeed for your kindness and your hospitality, and I hope that the Institution of Mining and Metallurgy will continue to grow from strength to strength every year. Thank you.

Recovery of Semi-Heavy Minerals in Jigs

F. A. WILLIAMS,† B.Sc., MEMBER

Report of discussion at March, 1959, General Meeting (Chairman: Mr. J. B. Dennison, President). Paper published in February, 1959, pp. 161–175

The President regretted that Mr. Williams was not home from Nigeria in time to present the paper but said that Mr. Ackroyd from Warren Spring would introduce it on the author's behalf.

Mr. G. C. Ackroyd,* introducing the paper, said he thought it would be useful to refer briefly to the previous paper by the author, published by the Institution and discussed in February, 1958.† Both papers dealt with ores of a similar type, one a decomposed granite and the other an alluvial lead. In both cases the ore had been disintegrated by the monitor and it was economic to reject at the outset material coarser than ¼ to ½ in. In the sands the mineral was free and there was a minimum of chatty middlings which simplified subsequent handling. The term 'incoherent' was used in the paper and seemed to describe that type of ore adequately. Slimes were an appreciable part of both feeds, but as yet not much was known about their mineral content, for it had always to be borne in mind when considering the two papers that the work described was more particularly concerned with investigating the efficiency of unit processes to give the most earnestly needed data for guidance in altering the plant to meet commercial needs. In fact the author had made a plea for more fundamental research on jig performance which he felt could be done more appropriately in some mineral dressing research laboratory.

In the earlier paper the development of a plant for recovering columbite from intensely decomposed granite was described. The purpose of that plant was to produce a feed for subsequent dressing in a mill equipped with gravity equipment and with electro-magnetic and high-tension separators.

Four development stages were described in which the plant was modified to improve recovery of columbite from 30 to 78 per cent in the sand fractions. In stage one the feed was 35 tons dry feed per hour and there was no de-sliming before entry into the primary jigs; the recovery was only 30 per cent of columbite. When the feed was cut down to 18 tons

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†WILLIAMS, F. A. Performance analyses of screens, hydrocyclones, jigs and tables used in recovering heavy accessory minerals from an intensely decomposed granite on the Jos Plateau, Nigeria. *Trans. Instn Min. Metall., Lond.*, **67**, 1957–58, 89–108.

per hour the recovery went up to 60 per cent of columbite and there was a much better recovery of the finer material.

In the next stage de-sliming was carried out before the primary cyclones. The feed was 10·5 tons per hour of sand and the recovery went up to 69 per cent of columbite. It might be partly the result of the reduction in feed but the author felt that it was to the reduction in slimes in the jigs that the better recovery should be attributed.

In stage three it had been found that the circulating load could be a cause of loss and so tables were put after the clean-up jigs, increasing recovery to 74 per cent of columbite. Finally screens were placed after the secondary jigs to take out some of the oversize at this stage, thus reducing the recirculating load; the excellent recovery of 78 per cent of columbite was obtained. That was the background of the present paper.

Owing to changes in the market for columbite, treatment of decomposed granite was then discontinued, but the work, in conjunction with quantitative fragmental petrography, had demonstrated the value of that method in analysing plant performance. In particular the lessons learned were, first, the value of de-sliming the feed to the primary jigs and, secondly, that almost all the heavier minerals could be recovered in the primary jigs as a dirty concentrate.

Using the experience gained the plant was modified to work an alluvial lead containing cassiterite and columbite and the present paper analysed the performance of the primary jigs, not only for cassiterite and columbite recovery, but extended it down to semi-heavy minerals in the gravity range 3·5 to 4·5. The particular minerals selected for the examination were zircon, anatase and topaz. The work was carried out in Pan-American jigs, but it was believed that other jigs would give much the same results.

In the earlier work the feed had contained 50 per cent of slimes and the columbite content of the sands in that feed was about 0·6 per cent. When the slimes were removed the feed rate to each of the 4-cell primary jigs was about 10 tons per hour.

When working with the alluvial lead the slimes only amounted to about 25 to 30 per cent and the total content of heavy and semi-heavy minerals was less than 1 per cent. The feed rate to the jigs, after de-sliming, was the same as before, i.e. about 10 tons per hour.

With the alluvial wash the feed was taken from the paddock by gravel pumps to a ½-in Symons rod deck screen and the oversize rejected. The undersize went to primary cyclones, the underflow feeding the 4-cell primary jigs. De-sliming of the hutch product from the primary jigs was carried out before passing on to the secondary jigs. Then the hutch product was again deslimed in cyclones and passed to the clean-up jigs. The hutch product from the clean-up jigs could be treated in various ways according to the type of feed and the discretion of the operator, the object being to reduce the recirculating load.

An analysis of the performance of the primary jigs in order to determine the total heavy and semi-heavy mineral assemblage being recovered at that stage was important, for, given a sufficient demand and price for columbite, the subsequent stages of concentration in jigs and on tables and the withdrawal of concentrate could be modified for optimum recovery of columbite. Of course, optimum recovery of columbite would mean accepting the greater part of all the heavy and semi-heavy mineral content of the primary jig hutch products as concentrates for despatch to the mill.

The sampling procedure the author used had been adequately described in the paper, as also had the method for the analysis of the samples.

The percentage recovery of the three semi-heavy minerals, zircon, anatase and topaz in each hutch over a range of grain sizes showed that the recovery of the lightest semi-heavy mineral, topaz (sp. gr. 3·5), was over 90 per cent for the coarsest sizes and was still over 80 per cent at B.S. 100 mesh. That indicated that the recovery of still lighter minerals in jigs, e.g. sp. gr. 3·0 to 3·5, would be worth investigating. The recovery of the heavy minerals was also given in the paper. If those figures were compared with the recoveries of cassiterite and columbite given in the earlier paper they would be found to represent a poorer recovery, probably due to the more efficient de-sliming in the earlier work.

At the moment the average grade of concentrate sent to the mill was about 60 per cent of the total cassiterite and columbite. From the work described it was apparent that the most profitable grade of concentrate to withdraw from a jig plant would vary with the mineral content of different alluvial leads and the market price and demand for cassiterite, columbite, monazite and possibly also rutile, anatase and topaz. The semi-heavy minerals could be, to some extent, rejected cheaply by closed circuiting in the clean-up jig in the field plant, but only at the expense of losing some of the fine columbite.

Finally it was suggested that if a complex mineral concentrate could be recovered cheaply by the gravity concentration of comminuted ores, then it might be possible to apply to such concentrates methods of mineral separation or chemical separation which would be too expensive to apply to the original ore; and he considered that was quite an important thought.

He had received a letter from the author and would quote one paragraph from it. 'I am particularly keen to interest the ore dressing profession in the greater use of detailed screen and mineral analysis in ore dressing research. Such analysis could be tied in so successfully with the mineralogical study of ores. The fineness of grain size to which economic recovery in jigs could be extended by using four cells in series did not appear to be as widely appreciated as it should be.'

He had also said 'The unavoidable absence of a tailing sample from the primary jigs certainly invites criticism'. However, the speaker thought they should bear in mind that the facilities for sampling in such plant did not render the operation particularly easy, and they should be grateful to Mr. Williams and his organization for presenting them with such detailed and interesting information on jig operation.

Dr. R. A. Mackay said he would speak as one geologist on the work of another. The author some years ago, when the speaker knew his work well, was faced with the problem of recovering some of those minerals described with non-existent plant. The author's achievements showed what a thorough appreciation of the properties of minerals by a geologist could do. His laboratory facilities were by no means elaborate and when he came to put the plant together with the other members of the staff—the leading member being a mining engineer—it was literally from old units available from the workshops.

One point he would criticize was connected with the last paragraph (p. 175). The author was fully aware (it was inherent in everything he said) that the minerals with which he was dealing were virtually in the condition of total release, those of the present paper being alluvial minerals. In his earlier paper they came from a granite so rotted that it could be broken in the hand—the material was so weathered that all minerals were therefore almost always completely released; it was rare to find composite particles including columbite and another mineral. Taking that into account he thought that the results which the author gave in Table II (p. 169), and more so in Table I (p. 168), would hardly be likely to be achieved if there were not that disintegration and release. Using jigs for the fine material in the case of comminuted ores would, of course, not give 100 per cent release, and he thought mineral dressers would agree with him that recoveries even approaching the order in those two tables would not be likely to be achieved.

Mr. T. Andrews said that the author mentioned that magnetic separation of ilmenite from columbite usually carried out on a belt-type magnetic separator was slow and that a magnetic middling product, difficult to separate, tended to accumulate. He suggested that the low output of the magnetic separator equipment was due to the middling fraction referred to and that heat treatment to increase the magnetic permeability of ilmenite would be beneficial. The speaker, having had some recent experience in that field of mineral treatment, would support that view. He had had the opportunity of following up the work carried out by S. B. Hudson to which the author had made passing reference. Hudson's investigation was made on an ilmenite-columbite magnetic middling in all probability similar to the fraction referred to by the author, for it had been sent to the Mining Department of Melbourne for research tests by the Bisichi Tin Co. (Nigeria), Ltd. The results obtained by Hudson were sufficiently interesting to justify larger-scale pilot tests and those were carried out by the speaker's company on behalf of Bisichi.

The work at Melbourne had indicated that at a temperature not exceeding 650° C the magnetic permeability differential between ilmenite and columbite was substantially widened and accordingly that figure was accepted as a maximum for the pilot-scale tests. Six furnace tests were made, three at 650° C and three at 600° C, with varying detention periods of 1, $1\frac{1}{2}$, and 2 hours. The subsequent magnetic separation of the respective furnace products clearly showed that the furnace-treated material was more easily separated and that the permeability differential between the ilmenite and columbite had been widened. The investigation indicated that heat treatment for one hour at 600° C was sufficient and the speaker

believed that the following table which presented a comparison between the raw and the heat-treated material, would be of interest.

Percentage Weight of Magnetic Separated Fractions

	1st magnet assembly	*2nd magnet assembly*	*3rd magnet assembly*	*Non-magnetic assembly*
Raw material . .	20·48	66·75	9·84	2·93
Heat-treated material .	73·87	10·48	12·11	3·54

The magnetic separation tests were made with a commercial size separator having three magnetic assemblies and seven attracting poles. After optimum settings had been established the series of magnetic separation tests were made under identical conditions and there could be no doubt that heat treatment effected a considerable and beneficial change. The tests also showed a marked change in the distribution of the columbite, for whereas in the raw material only 20·48 per cent—the fraction picked up by the first magnet assembly—was columbite-free the comparable fraction after heat treatment was 73·87 per cent.

Since heat treatment did materially affect the permeability characteristics of the mineral composites referred to in the paper, it would be of interest to know if the author considered heat treatment of the whole of the magnetic fraction from the Exolon roughers would render subsequent selective separation more rapid.

Mr. P. Rabone pointed out that the author had shown in his previous paper on the plant at Rayfield that jigs could be used to concentrate heavy minerals very effectively from a deslimed but otherwise unclassified feed over a wide size range, roughly from 0·2 in. to 300 mesh. In the paper under discussion he had successfully extended the operation to semi-heavy minerals and clearly brought out the advantages of jigs for the type of ore that was being mined. As had already been mentioned, the accuracy of his figures might be questioned but they were not likely to be far out, and, in any event, it was not reasonable to expect results of extreme accuracy from a producing plant which had to pay its way and could not spend a lot of money on experimental refinements.

The speaker did not altogether agree with the author's statement that Harz, Yuba, Ruoss, Pan-American, and Bendelari jigs achieved practically the same type of pulsation in the jig bed. It might be true of the last four, in which the stroke was produced by a rubber diaphragm. The Harz jig, however, had a rigid piston, which gave much sharper upward and, in particular, downward strokes than did the rubber diaphragms of the other types. He had never seen the Harz jig used successfully on unclassified feed. That was exemplified in the Denver 'mineral jig', which had a rigid piston but was also provided with a special valve admitting a pulse of water to modify the suction stroke, which, it was claimed, enabled it to treat unclassified feed successfully.

The great advantage of the type of plant developed at Rayfield was explained at the end of the paper, where the author pointed out that a 4-cell 42-in jig occupied about the same floor space as a single concentrating table, but would handle up to 20 times the tonnage. He suggested that the type of operation described in his paper would be equally applicable to the concentration of ores that needed rod- and ball-milling to release the valuable minerals. A previous speaker had doubted whether the plant would work as well with such ores. Probably it would not, because a large quantity of middling products containing unreleased mineral would accumulate in the circuit and would require special treatment. The great advantage of the jigging plant, however, would remain, because, for every jig in operation, the space and complexity of 20 tables would still be saved. Recoveries might not be so high, as less mineral would be released in the jigging size range, but every jig installed would save space, capital costs, and running expenses, and would simplify the plant.

Dr. S. A. Wrobel thought the gist of the paper was to be found at the end of p. 166 where the author stated that it was essentially a preliminary exploration of a potentially wide field of investigation which appeared to warrant more intensive and extensive research. Carefully read, it was clear that Mr. Williams, a geologist in his own right, was also a very clever and certainly a most persuasive field-metallurgist. He quite clearly stated that he could not take either representative samples of feed-heads to the jig nor the tailings from the jig, while he would have preferred to obtain the samples of the hutch concentrate-products by an automatic sampling device. Despite those difficulties and shortcomings he presented his results in the form of tables giving detailed distributions, while his arguments, together with conclusions, were put forward quite convincingly and in a logical manner. One felt, however, that the degree of accuracy of the quoted figures must be questioned.

With reference to p. 162 it was agreed that the separation in jigs was based primarily on specific gravity difference. It would be of interest to learn if the author had evaluated the differences, if any, particularly in the shape of the minerals in question. In that connexion it was taken for granted that the minerals mentioned were 100 per cent released.

With regard to the data on the jig-cell on p. 163, it would be of interest to know the effective height of the cell above the ragging. Mention was also made of the progressive changes in the ragging. He wondered if it was necessary, and how often, to renew that bedding. As to the last paragraph on the same page he asked if the rate of feed in cubic yards per hour denoted solids alone or solids plus water, and, if the figures referred to solids alone, what was the total water rate of feed to each bank of jigs. He agreed with a previous speaker that not all types of jigs would give the same result or be suitable for the concentration of medium-fine solids.

Mr. D. G. Armstrong said that he had no reason to doubt the accuracy of the author's work but he had to take up the point made by Dr. Wrobel; Mr. Williams said (p. 163) that 'under these conditions it was not possible to obtain a reliably representative head sample' and then (p. 164) 'it was not possible to obtain and value a similarly representative sample of the primary jig tailing', so how did he arrive at recoveries? An explanation was needed. The speaker thought that the most important thing in the paper, and in the previous one, was that good recoveries of fine heavy and semi-heavy minerals could be obtained from jigs if the feed was deslimed in cyclones. The author himself said (p. 162) that 'a high percentage recovery in jigs from an unsized feed is dependent on a low slime content of the feed and that slime can be effectively removed with hydrocyclones without appreciable loss of heavy mineral'. Unfortunately there were practically no data about the cyclones in the papers and there was no clear evidence to prove that there had not been considerable losses of heavy minerals in the cyclones. Geological methods for assessing results were not as suitable for slimes as for sands and he would like to see some proof of the smallness of the loss in the cyclone overflow.

On p. 163, the average rate of feed to the plant was given as 40 cu. yd/hour, i.e. 10 cu. yd/hour for each jig; that was plant feed, not jig feed. In the previous paper they had 2400 lb to a cu. yd and 10 cu. yd was equivalent to 10·7 tons. The jig feed was said to be 10 tons of sand per hour. The difference of 0·7 tons/hour was slime, which could be removed by cyclones. As they were told that the feed contained $\frac{2}{3}$ to $\frac{3}{4}$ sand, the figures did not tally. He would like to know how much slime was being removed by the cyclones.

He thought that a very important part of the information on jigging concerned the ragging. It was all very well to say that the ragging was hematite but they found that in fact it changed progressively as other minerals accumulated. He asked if the author had to change the ragging at intervals and replace it with fresh hematite or did the composition become stabilized and what was the composition of the ragging then?

Mr. F. B. Michell said quite apart from querying the build-up of ragging in the jigs which had been raised by other speakers, he would like to deal with one or two other points. First, however, he thought the author had done a great deal of useful work in spite of the fact that it appeared to have suffered some criticism. Nevertheless it was essentially a mineralogical examination and was really monumental. There was scope for more as little attention had been paid to the recovery of moderately high specific gravity minerals associated with alluvial cassiterite until quite recently because, of course, those minerals formerly had very little value. Now some of the minerals, monazite in particular, were quite valuable, and people had started to look at the recovery of other by-product minerals. Quite apart from that aspect the results submitted by the author indicated the recovery which might be expected of other minerals of similar gravity and probably the same shape. The latter, he thought, needed stressing—shape was a major determining factor and all one could say was that if the specific gravity was the same and the shape was the same one should get the same result. It should be pointed out that the recoveries reported by the author were those obtainable when making what was essentially a rougher concentrate. It was quite a different matter to say that similar results would be obtainable when producing a high-grade concentrate. As many of them knew-one could jig a barite ore and make a good recovery with little gangue remaining in the concentrate, but any attempt to remove the last traces of gangue was a different matter. For such a duty the jig did not do quite as good work but for rougher duty it was very efficient.

The practice of making too rich a concentration in the sluice box as mentioned by the author had undoubtedly been responsible for quite heavy losses of the accessory minerals in the past as well as a not inconsiderable loss of tin. The production of monazite and ilmenite was now a regular feature in a number of Malayan plants. It had been found that the production of a lower-grade concentrate had contributed appreciable revenue from by-products and, at the same time, the making of a lower-grade concentrate had improved recovery on the dredges. That had been made possible by mechanization of the shore treatment plant which replaced the old hand dressing methods. The author had made that point at the bottom of p. 170, where he said if a lower-grade concentrate was made a better recovery could be obtained but the treatment would be more expensive. The speaker did not think the treatment was necessarily always more expensive. It depended on the degree of mechanization in the plant and the transport costs of the concentrate from the field, or the dredge, to the final treatment plant, but there was no doubt that better all-round recovery could be made by producing a lower-grade concentrate in the field.

In Malaya de-sliming jig feed had been found to be one of the most important operations as well as the provision of reasonably clean water to the hutches, which might amount to 80–100 gal/min per hutch, while when dealing with a material carrying a high proportion of clay, he considered it imperative to de-slime the feed, using cyclones. In such cases two-stage cyclone operation was essential for good results, and pilot-plant tests had indicated that the underflow of the secondary cyclones did not jig very well. It was rather fine and the speaker thought a spiral would do very much better work. In some cases indeed it was extremely fine and beyond the range of a jig. It would seem desirable to insert a screen mid-way in a 4-cell jig operation so that some oversize was rejected after the first two compartments, the undersize from the screen being de-slimed again in a cyclone and then scavenged in a further 2-cell jig—in other words, splitting the 4-cell operation into two 2-cell operations. The first operation could then be adjusted quite separately in respect of the feed, not so readily done in a normal 4-cell jig.

On the dredge the problem of engineering an idealized flowsheet was far from easy, but he thought it true to say that a considerable amount of material formerly lost was now being recovered by greater attention to de-sliming, by better distribution, by treating fine material after de-sliming or by scavenging the primary jig tailing. While it was not feasible to employ tables on a dredge in the same way that the author had done, there was no difficulty in installing and operating cyclones or indeed rake classifiers, and both thickening cones and spirals could be mounted in such a way that alteration of the trim of the dredge had no appreciable effect on their operation and was, in fact, negligible. He agreed with the author that insufficient attention appeared to have been given in many alluvial fields to the question of de-sliming, which he felt was a very important pre-requisite for good jigging. Much depended on the ground which, if very slimy, caused the jig to fill with water.

Mr. Rabone had mentioned that the diaphragm jigs were better than the old Harz pattern. They certainly possessed excellent control of cell water but provided the jig was in good mechanical condition the Harz-type could probably do nearly as good work. He thought it was largely a question of wear on the diaphragm and control of the cell water.

Another speaker had mentioned losses in the cyclone overflow. Tests which he had seen on 2-stage operation indicated that the overflow from the second stage did not contain any appreciable mineral which was recoverable, but the underflow of the secondary cyclones mentioned previously was extremely fine, and there would be rather heavy losses if jigged alone.

The Secretary then read part of a contribution from Mr. J. H. Harris and Mr. I. R. M. Chaston of the Department of Mines, Malaya. (This is published in full below.)

Mr. Ackroyd said he had anticipated that there might be questions on the lack of head and tail samples. However, the fact that 'it was not possible to obtain a reliably representative head sample' did not necessarily mean that no head samples had been taken. He hoped the author would explain that point.

Commenting on Dr. Wrobel's observations on the feed to the plant he referred to the first paragraph on p. 164 which gave figures of weight of feed to the 4-cell primary jigs after de-sliming by the primary cyclone. They represented a dry weight of sand of approximately 10 tons/hour. That seemed to be the really relevant figure.

The President said he was sure the author would feel rewarded by the interest so obviously shown in his paper, and he thanked Mr. Ackroyd and contributors to the discussion.

WRITTEN CONTRIBUTIONS

Mr. J. H. Harris and Mr. I. R. M. Chaston: The paper is of considerable interest and value to us as the work reported is parallel to that which we have undertaken for the past two years in the Research Division,