cost saving in five years. In fact, the available evidence suggested that the margin against the moving-bed plants in respect of reagent costs was about 2 cents per lb.

Moving-bed ion exchange had many advantages which it was difficult to quantify, but on the figures that were available it was also difficult to produce a clear-cut economic argument in its favour.

Dr. Arden had described some of those advantages. In particular, he had mentioned the question of under-bed blockage. To go a stage further and consider a hypothetical uranium plant which might be built to-day, using a two-bed instead of a three-bed system (which Dr. Arden had shown to be a practical possibility), there could be no question that the moving-bed would be the system to adopt.

The author stated in the paper that the moving-bed system made possible three-split elution. It was not clear whether that referred to elution with three columns in series or to the actual splitting of the eluate for separate treatment—e.g. nitrate recovery. It was somewhat surprising that Can-Met had not adopted that nitrate recovery step when, as the author stated, a saving of 1–2 cents per lb of uranium should result.

It was interesting to hear of the way in which the plant handled the royal barren and the high resin loading which had resulted. It might be suspected that the plant was tight for capacity and that that was the reason why the precipitation step was introduced. Dr. Arden had confirmed that to some extent, but as the mine found itself pressed for capacity again and had cut down on the amount of the royal barren precipitated, he wondered whether that move would not be found self-defeating with a return to the conditions which existed before owing to the lowered resin loadings.

It was certain that the value of the additional uranium which was recovered by precipitation of the royal barren was not very great, and it seemed difficult to justify the precipitation step, with its attendant increased capital requirement and operating cost, only on the basis of the additional uranium recovered.

The author had mentioned the excellent instrumentation provided with the plant and that applied to ion exchange plants in general, which had an enviable reputation for reliability. The moving-bed plant was less liable to misdirection of solution than the fixed-bed plant, but even so, with high-grade solution approaching something like $1 per gal and even pregnant liquor at, say, 5 cents, expenditure on elaborate control equipment was well justified. Some operators even found it worth while to put a monitor on barren solution just to warn the operator should the other control fail, but that was an extremely remote possibility.

Dr. Arden, in response to the President's invitation to reply to Mr. Cahalan, dealt first with the reference to the royal barren. In his recent letter, the author stated that the increase in loadings which had been obtained in recent working had been consistent and had accompanied the reduction in royal barren, which made it seem unlikely, therefore, that the reduction in royal barren would have the effect suggested by Mr. Cahalan.

Concerning the comparison of running costs, as well as of capital costs, of the two methods, they could be sure that all the facts in the paper by Ehrlich and others were correct. The trouble was that they were based on a wrong premise. The Blind River construction programme went ahead so quickly that the very big plants were constructed and operated with few laboratory tests, and no pilot-plant work. The Can-Met plant was the third unit to be built, and was identical with the first two sets at Consolidated Denison, the erection of which was not even finished when Can-Met was started. The fixed-bed plants, on the other hand, were the last of over 100 sets, installed over a period of five years in different parts of the world. The comparison, therefore, was really between one type of equipment taken to the limit of its ability and another one in its complete prototype stage.

As already stated, the three-column system was installed for no other reason than that all were agreed they had to play safe and make sure there were plenty of columns. It would have been possible to get by with two and the difference in capital cost would have gone a long way to balance the 2 cents difference on running costs.

It was difficult to see precisely why the fixed-bed plant should have lower running costs, because the chemical process was the same in both types of unit. The answer was probably that nitrate recovery was being practised on some of the fixed-bed plants and it was not being used at Can-Met. The chief reason was understood to be that to put in nitrate recovery would mean an unwelcome increase in capital costs.

His own opinion was that on overall balance a fixed-bed plant was undoubtedly better for a small installation. The two were difficult to balance out in a medium-sized installation, but on a really big mine the moving-bed plant as now designed was quite a long way ahead.

Serial Gravity Concentration: a New Tool in Mineral Processing

J. H. HARRIS, MEMBER, B.Sc., A.R.S.M.

Report of discussion at January, 1960, General Meeting (Chairman: Dr. J. H. Watson, President). Paper published in December, 1959, pp. 85–94

The President said that the Institution was fortunate in having the author himself present. On the last occasion when he submitted a paper he was engaged in Tanganyika.

'A new tool' in the title of the paper was somewhat surprising, because one's impression was that panning and such like had been known for a long time. It was interesting, also, that the author had described gravity concentration as an art; and indeed it must be a very skilled art if, as the paper recorded, cassiterite down to finer than 200 mesh was recovered in a pan.

Mr. J. H. Harris said that he was grateful to the Council for consenting to publish what must be regarded as a premature and incomplete paper, in view of the omission of more data to support the theory presented.

The collection of data to prove the point under the conditions prevailing for alluvial mining in Malaya and elsewhere was an extremely difficult matter. There, many millions of cubic yards were being shifted monthly in many thousands of cusecs, those vast dilute flows presenting a major problem of sampling. The smallest mine in Malaya treated 1 cu. yd/min carried in 3000 gal/min water. That would be multiplied by ten times for even a moderate size of dredge. One of his assistants had compiled the data accumulated in the past two years in the form of a paper for the International Mineral Processing Congress, so that in a month or two another paper would be available to amplify the processes described in the present paper and give some of the figures in support of their conclusions.

The other reason for what might be called premature publication was his sense of urgency about the whole problem of alluvial mining on a large scale. It was necessary to recover the finer grain-sizes of mineral, formerly lost; to reduce the nuisance in drainage systems caused by effluents of slime and other tailings; and to ensure the rehabilitation of mined land, the last being extremely important.

In Malaya the most spectacular deposits of tin were in the flat alluvial ground adjoining the central mountain range, and occupied much of the practicable living space. It was a problem present almost everywhere and if there was any mineral in the alluvial plains there was bound to be conflict, and current population pressures in the East were approaching a point that could be described as explosive. It was obviously incumbent on the mining industry to endeavour to mine in such a way that the land could be returned to use for agriculture, forestry and urban expansion, while, at the same time, it was incumbent upon the State not to blanket alluvial deposits by such expansion before the material had been won, thus automatically sterilizing a main source of revenue.

In the Florida phosphate deposits there was almost the same set of circumstances as in Malaya. Fertile orange plantations were removed in order to mine phosphate and there were intractable problems of rehabilitation. But old tailings could be rehabilitated: natural re-vegetation was evident in Malaya; progressive mining companies had planted trees, coconuts, rice, groundnuts and vegetables; and the Chinese miners turned old tailings into flourishing agricultural plots. There appeared to be no point in trying to rehabilitate the land, however, until all valuable mineral had been got out.

Old tailings, previously considered barren, had been shown recently to contain economically extractable values. Below them in many places there was residual virgin ground, either in pockets in the pinnacled limestone bedrock or at depths unreached by previous workings. It was necessary to devise a method for economic extraction of all possible mineral leaving residues unworkable at any conceivable future price of tin and to find a mining method which could extract alluvium to rock bottom in one pass before final filling and rehabilitation was atttempted. Bucket-line dredging now reached depths of 150 ft but the alluvium was deeper in places. A new type of opencast mining combined with hydraulic mining had been suggested and the first unit of a new type of excavator was now on trial for that purpose. Treatment methods had improved, as referred to in the paper and the possibility of re-laying tailings in usable form was in sight. One could foresee the Malayan mine of the future as an advancing mine at one end followed by an advancing plantation at the other.

The improved treatment method he had introduced into Malaya involved cycloning to remove excess water and slime and then jigging the resulting long-range feed in two stages. 'Slime' denoted material less than 50 μ in size and mainly less than 10 μ. The method hinged on the discovery reported in Table I (p. 87), which indicated a high loss of a middle range of sizes although coarser and some finer sizes were completely recovered.

He had put his method before the Institution so that it could have publicity, and those interested in gravity concentration were invited to check it by whatever gravity process they might be using. He had the feeling that the curious loss in the middle size range persisted throughout other forms of gravity concentration. It might not be very apparent in streaming forms but in any kind where there was an applied up and down motion, or where an up and down motion was induced by the nature of the movement of the particles, that sort of effect could be detected. The observation might have had some bearing on the way that particles were distributed in sediments, and in the long run it might answer some of the problems of geologists.

There was a great difficulty in sampling the pulp flows and the alluvium mined in a country like Malaya, where flows were dilute and the values low. A rich ore in Malaya carried only ½ lb cassiterite per cu. yd, representing less than 0·05 per cent tin by chemical assay.

There was, therefore, the extreme difficulty of deciding how to assay the feed, the tailings and the middling products. The concentrate was satisfactory, but one never knew when starting what one had to deal with and what one was losing. In that respect, the problem had something in common with diamond mining; the material was of very low grade, chemically speaking, for which no assay method was available.

The author then described the methods normally used for evaluation, including panning by *dulang* of which a specimen was exhibited. Usual operations appeared to fail to reveal cassiterite finer than 200-mesh B.S. but his new analytical procedure, described in discussion on a recent paper,* gave a fuller picture. He then drew attention to the procedure reported in the paper for checking the concentrating power of a *dulang* and the explanation offered, by means of the diagram on page 88, for the

*Williams, F. A. Recovery of semi-heavy minerals in jigs. Discussion by J. H. Harris and I. R. M. Chaston. *Trans. Instn Min. Metall., Lond.*, **68,** 1958–59, 431–5.

partial loss of middle size-range. He included an observation on the reverse stratification noted in panning and jigging whereby coarse gangue worked to the top of the bed. A summary of the effects at work in a jig seemed to indicate that mechanical effects were more important than those due to hindered or free settling. No explanation, beyond the laws of chance, could be presented to account for the loss of only half the middle range of sizes; but the effect could be detected in the work of other investigators referred to on pages 87 and 90.

The proposed method for recovering the lost middle-size grains was to screen off oversize barren gangue from the tailing of the first jigging stage, thereby transferring the lost grains to a relatively coarse position in the remainder so that in a subsequent jigging stage they would react as coarse particles and thus be collected. The method had been tried in Malaya with substantial success but the results would be reported in a later paper.

The section of the paper dealing with the difference between parallel and serial concentration could be amplified. He assumed that, when a long-range feed was sized for feeding to a parallel system, each fraction would contain a middle range of sizes, part of which would be lost. Thus the total loss would be the arithmetic sum of the losses from each of the parallel sections. By the serial process it appeared that that loss could be reduced in geometric progression. In Malaya two serial stages were generally sufficient, a third being required when much ultra-fine tin was present.

Mr. J. E. Denyer said that although other investigators had determined the different recoveries in several size fractions of material treated in a jig and had perhaps noticed the strange fact that the greatest losses occurred in the middle size range, the author had thought it a matter of importance and had now thought out and explained why those losses occurred and how they might be prevented in an easy and inexpensive way.

No general figure could be given for the improvement in recovery which might be obtained by using serial gravity separation, though the author had given a figure of up to 50 per cent which would probably be obtained only in exceptional cases. He had, however, said when introducing the paper that 40 per cent was obtained in another case.

A calculation using the figures in Table I (p. 87) showed that if all the +200-mesh material were caught, which was not unreasonable, the amount of tin recovered would go up by 12 per cent. A 10 per cent increase in the amount recovered would be a most valuable improvement, particularly in the case of a low-grade or high-cost mine, where it might double the working profit. Even in the case of a mine where there was a working profit of 50 per cent, a 10 per cent increase in the product would increase the profit by one-third.

The speaker said he had formed the opinion that there was a tendency to look at a dredge from the wrong end and to regard it as a cheap excavator to produce gravel in large quantities, with some machinery on the back to catch any tin that the gravel might contain. He was now sure that there was a growing tendency to regard them as floating mineral dressing plants with a digging device in the front to provide the feed, due to a considerable extent to the enthusiastic work of the author and his colleagues.

In the past some dredge tailings had been retreated not just once, but twice, but the author had now given the assurance that in future tailings would be of no interest to anybody.

The author had now left Malaya and was to be engaged on research work in Britain. It was to be hoped that he would continue to pull rabbits out of the hat and to give more papers like the present one.

Mr. F. A. Williams said that the considerable losses of cassiterite which occurred both in accepted methods of alluvial bore valuation and in subsequent plant-scale recovery, especially from sluice boxes, had been experienced also in Nigeria and it had been possible to introduce some improvements, particularly jig plants instead of sluice boxes.

The new experimental data presented in Table I were extremely interesting. It should be worth while finding out whether that unexpected phenomenon was peculiar to the recovery of alluvial cassiterite in a dulang from alluvial wash or whether it ever occurred with other types of field sampling equipment such as the gold prospector's cradle and steel dish or the African calabash, or whether it occurred with sands of different long-range screen analyses and with other heavy minerals of different specific gravity and shape.

During his own investigations in Nigeria the phenomenon did not appear either with decomposed granite or with alluvium. What was needed now was to define the conditions in which it did occur. He wondered if the author could give more details, such as screen analyses of the sand.

The author had asked for critical comment in the light of individual experience. Most of his claims were unacceptable to the speaker for one or more of the following reasons: they were either historically inaccurate, fundamentally incorrect, at variance with published sampling data, or as yet unsupported by new published sampling data. The position might be altered when the promised data were made available.

With the aid of slides reproducing a flowsheet and several tables from his own paper,* the speaker made the following criticisms:

1. The system of screening jig tailing and retreating the undersize was *not* new. Moreover it was a useful system even if there was no increase in losses in the middle size range.

2. The published Nigerian results for recovery in jigs in relation to grain size showed in most cases a *progressive* decrease in recovery with decreasing grain size. Only in a few cases where the results were irregular was there rather doubtful support for the author's theory.

3. A jig was a classifier-concentrator and a table a counter-classifier-concentrator. If jig tails were screened the undersize would be the higher grade of the two products and perhaps worth retreatment. But if table tails

*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.

were screened then the screen oversize would be the higher grade of the two products and perhaps worth retreatment.

The speaker commented on the fact that the author had found very fine cassiterite in Malay alluvium. They had found the same thing in Nigeria, where he had solved the problem of always separating the fine cassiterite in bore valuation by a procedure involving three operations: (*a*) Slimes washed out of the bore samples were deslimed in a cyclone and the undersize added to the tailing from panning. (*b*) The −12-mesh fraction of the tailing from panning plus (*a*) above were then tabled several times in the laboratory, using Holman half-size tables with rubber decks and riffles. (*c*) Field and laboratory concentrates were then physically analysed to yield valuations and screen analyses of both cassiterite and columbite.

On page 92 of the paper the author had said that 'There are numerous examples in Malaya of installations of 4-cell jigs in which heavy mineral will be caught in the first two cells only, scarcely any being recovered in the last two, although free mineral can readily be detected in the tailing.' He had not produced sampling evidence in support of his statement and some of the tin found in the tailing might possibly have been shed from clay balls after sampling. That was something about which it was necessary to exercise due care when analysing samples in Nigeria. The author had gone on to say that 'Even when properly fed and operated the performance of such a jig must be hampered by the fact that the addition of hutch water dilutes the pulp progressively from cell to cell.' That was a hoary old statement which many people had been known to make and always, as in the author's case, without proof by sampling results.

The speaker had analysed all his own sampling results and had been unable to detect the alleged hampering effect. Even if it did exist, it could not generally be very pronounced. Undoubtedly, part of the added hutch water must rise through the ragging and dilute the bed of sand moving over the jig, but that did not necessarily hamper performance. By diluting the slime, it could conceivably even benefit performance. Shortly before his retirement from Nigeria, the speaker had introduced the procedure already outlined. A small Mono pump and cyclone were used to recover fine sand and heavy mineral from the slime washed out of the bore samples. That product and the −12-mesh fraction of the sand tailing after panning were mixed and sent to the laboratory, where it was concentrated on a James sand table fitted with a rubber deck and rubber riffles. The table tailing and middling were both retabled. The final table head was then cleaned up in a super-panner. Finally the field and laboratory concentrates were valued separately by micro mineral dressing and grain counting which yielded valuations and also screen analyses of both the cassiterite and columbite.

On page 86 the author stated: 'Cassiterite finer than 200-mesh is seldom, if ever, reported although recent work has shown it to exist.' The new method of alluvial bore valuation which the speaker had introduced in Nigeria could be used to ensure that in future the fine cassiterite would always be reported. Valuations of alluvial reserves should not now be accepted as satisfactory unless they had been checked by the new method.

The author's findings that a *dulang* lost tin in the middle range of grain sizes enhanced the need for that checking of alluvial tin reserves in Malaya.

In Table VI (p. 100) of his own paper which he had referred to previously, the speaker had shown that after screening and adequate desliming of the feed, a four-cell jig would make an excellent recovery of cassiterite considerably finer than 200 mesh. The author's system of additional screening and cycloning between the two pairs of cells, although more expensive, should give even better recoveries. It was logical that methods of alluvial bore valuation should now be brought into line with the best plant-scale recovery practice. Recovery plants for both gravel pumping and dredging in Malaya should now, when necessary, be modified to ensure that the recovery of cassiterite in the medium and fine size range was carried to the economic limit. Sluice boxes, of which there were plenty in Malaya, should be replaced by jig plants, as the author had instigated. There should be adequate desliming of the jig feeds by the use of hydrocyclones. Sieve bends, to which the author referred, could be considered for low cost screening, and tables could perform a limited but useful service in removing fine heavy mineral from jig closed circuits and sometimes from screen undersize too fine for jigging.

Mr. D. J. Ottley said that while the author and his colleagues were to be congratulated for the considerable improvement in recovery obtained in the tin treatment plant, one hesitated to share the author's enthusiasm, at the present stage, as to the application of the method to all forms of gravity concentration or to support his ambitious claims as to its potential beneficial effects on the recovery of numerous other heavy and semi-heavy minerals. Conditions were rarely as favourable for gravity separation as they were for cassiterite from a light gangue.

In the plant in question it was suggested that the improvements obtained by screening, thickening and desliming of the feed between jigging stages, over the earlier method of sluicing, followed by jigging of the 'palong' rougher concentrate, might be attributed to one of the three factors, which, however, might require some modification later when viewed in the light of the results promised by the author.

The first was the higher apparent density of the jig fluid, caused by the presence of the fine solids, which in effect gave a separating medium of a density greater than 1. That higher density fluid would increase the separation criterion from about 3·5 for sized feed and water, for cassiterite and quartz in conventional jigging, to about 4·1 for unsized feed using the conditions that the author had outlined.

Secondly, there was longer residence or retention time in the jig as a result of the thickening operation and, of course, a corresponding reduction in the total flow of pulp through the jig, compared with the more usual jigging practice. The cross currents, which, as the author mentioned, tended to sweep the material into the tailings and also reduce the effective vertical currents, would be lessened.

Thirdly, the longer stroke that was reportedly used in the first stage, coupled with the slightly denser and more viscous pulp, would favour the retention of the middle size values during the pulsion stroke and allow more time for the finer particles to reach the bed by consolidation trickling following the suction stroke which would compensate for the more viscous medium and more closely packed material.

The principal reason for the improvement was, perhaps, the better general control and operation of the jig-cyclone-screen circuit. The removal of the gangue between jigging stages would appear to be largely a practical expedient to enable the jig operating conditions to be adjusted to suit the recovery of the remaining values without interference from the coarse material and, at the same time, to remove the barren gangue from the circuit.

Had detailed results of those two treatment methods been reported, a more quantitative explanation of appreciation of the improvements would have been possible.

The paper, as had already been mentioned, contained a number of ambiguous and fallacious statements as well as a number of rather unconvincing generalizations based on supposition and unsubstantiated by acceptable facts, inadequate experimental data or confirmatory plant results. Since the paper was of a preliminary nature, many of those statements, by the author, should have been deferred preferably until there was sufficient evidence to support them. Some could not be allowed to pass without brief comment.

For example, on page 90, the author presumably meant that all operations of gravity separation were basically similar since they exploited the differences in specific gravity between the constituent minerals. Quite obviously, the mechanism of separation and the dynamic forces used were very different. By reason of the mechanism of separation and the different dynamic forces employed, the author was not justified in comparing jigging with *dulang* pans.

It would be helpful if the author would clarify the meaning of the last sentence on page 91. Surely the scope of the forces employed by nature for gravity concentration was limited and the application of other forces, such as the vertical pulsions and suctions in jigging, film sizing assisted by horizontal vibrations as in tabling, and centrifugal forces used in spirals and cyclones—to quote a few simple and obvious examples—could be used to advantage for many gravity treatments without changing the nature of the feed. All were separating methods which nature could not simulate.

Again, on page 91, to state without any supporting evidence or data, that conventional sizing and parallel gravity treatment, in Swedish plants, would result in the irrecoverable loss of some of the middle range size of values was not a fair or reasonable supposition.

Mr. C. H. Barwise said he wished to point out briefly that the author's opinions were not inexplicable by the normal ideas of jigging. It rather depended upon where one considered that the separation occurred in a jig—in the upper half of the jig bed, as the author implied when considering the coarse gangue in the Fig. 2 (p. 88), or at the bottom of the jig bed, in the ragging layer. The author had not specified ragging in his paper but had mentioned it in the discussion on the earlier paper by Mr. F. A. Williams, when he stated that hematite ragging was used.

The speaker suggested that, particularly with long-range jigging, the ragging layer and also the ragging effect caused by the concentrates passing through the ragging was the separation medium, that, in fact, long-range jigging could only be done where there was a wide range of values to give a wide range of ragging. If there was no middle range, surely the fine gangue would pass through the ragging.

That led to a possible explanation of why the middle range material was lost in some cases and not in others. The ragging acted as the bottleneck. If there was just the right amount of middle size values to fill the interstices and pass slowly through—they would pass more slowly than the coarser values—there would be the minimum loss of the middle size range. If, however, the proportion of middle size values was high, the bottleneck would stop some of those particles and the flow of material over the ragging would sweep them clear and into the tailings. That was a possible theoretical explanation and could logically be applied to the arguments between the advocates of wide sized jigging and those of close sized jigging. The close-sized jigging advocates had often said that when there was fine gangue in the feed it would pass through to the concentrate. That was certainly the case with certain size distributions of values in the feed.

Mr. F. D. L. Noakes complimented the author on demonstrating yet another philosophy of jigging practice, and mentioned some of the problems of assaying, sampling and interpreting results.

Mr. D. G. Armstrong commented that the author stated (p. 91): 'The method of "serial gravity concentration" has proved to be remarkably successful in treating the alluvial and eluvial tin-ores of Malaya. Virgin ground has yielded up to 50 per cent more tin than had previously been obtained'; and had gone on to say that 'De-sliming has been shown to be an essential stage and this has been accomplished with hydrocyclones'. How much of the 50 per cent extra was obtained through desliming with cyclones, and how much of it was due to the serial gravity concentration?

The President remarked that there was still plenty of life in the discussion, but in view of the late hour he must ask those who wished to make any further remarks to submit them in writing. He invited the author to reply briefly to the discussion.

Mr. Harris thanked all those who had contributed such condemnation of the paper because he was hampered by not being able to produce the figures which everybody wanted so badly. Even without the figures, however, he could answer some of the criticisms, although, because of the amount of detail involved, he would prefer to do most of it in writing.

Mr. Williams's main criticism was that he was not able to find the same results in his own sampling. That had already been commented upon in the discussion of Mr. Williams's own paper. Mr. Williams had not given the tailings assays and without them one did not know what the true recovery was; his tailing assays were inferred, whereas the author's were assayed.

Mr. Williams maintained that the assaying must be done on minerals and not by chemistry. By the former method, however, the assaying was by a gravity concentration with all the faults and failures that that could introduce—either the fault that was pointed out in the paper or any of the others which contributors to the discussion had inferred. He had described the method of chemical analysis employed when contributing to the discussion on Mr. Williams's paper. It showed how, by a special use of combined chemical and mineral analysis, a conclusion was reached which a mineral analysis alone would not give.

An explanation for the brevity of his statement that adequate methods of wet screening were now available, was that he was hampered by the patent situation. At the moment, unfortunately, it was extremely difficult to say anything about what had been done as regards fine wet screening in Malaya, apart from the fact that experimental extension of the curved screen principle had been achieved with economy. Mr. Williams quoted 200 hours use on a fine screen. The author had obtained 600 hours with a finer screen down to 150-mesh split. The cost of the screening was amply covered by the increase in recovery.

The loss of mineral by desliming during evaluation was found not to be very great. The majority of the tin lost was only 10 μ in size.

He would comment later in writing in detail on the contributions by Mr. Ottley and Mr. Barwise.

The answer to Mr. Armstrong's question on how much of the increased recovery was due to cyclones and how much to a change of method was as yet unknown, but a report would be available later.

WRITTEN CONTRIBUTIONS

Mr. J. C. Allan: Since the advent of flotation, gravity milling has been much neglected and it is refreshing to come across details of careful research work as described in this paper and the earlier ones by F. A. Williams. The failure to get high extraction of the intermediate range particles in both dulang washing and conventional rectangular jigs may be due to some similar defect in the concentrating cycle of both systems. The conditions described by Mr. Harris as being responsible for the lower recoveries of the intermediate-range particles may well arise from excessive compaction of the bed during the settlement phase, owing to undue suction. Furthermore, from a mechanical point of view, the dilation of the bed by means of strong upward currents of water can hardly be considered as efficient and must give rise to unequal and heavy disturbance of the bed.

For some years primary concentration at the Panasqueira mine in Portugal has been carried out in a circular jig. This mine produces wolfram and tin from underground vein mining, as distinct from alluvials and eluvials. The jig is similar to the Hardy Smith circular buddle jig described by Taggart,* with a modified head motion allowing for an improved accelerated downstroke and a retarded upstroke. It is an 8-ft diameter machine of the moving-tray type connected to the bottom cone by a flexible rubber sleeve.

Under normal operating conditions the jig handles up to 40 tons per hour of classifier rake product, the classifier being set to overflow at −60 mesh. The classifier rake product is fed to the machine as such, without the addition of further water, and hutch water at the rate of about 150 gal/min is fed to the cone beneath the moving tray from a steady head tank. The tank operates at a head of about 2 ft above the surface of the water and is set to provide just sufficient water to keep the bed alive. The feed moves towards the periphery by displacement and only with the lightest particles is there any visible transport effect due to the gentle flow of water across the surface. Owing to the shape of the jig the rate of cross travel decreases towards the perimeter, so that, contrary to what occurs in the conventional rectangular jig, the lower the grade of the material the longer is the treatment time.

At Panasqueira jigging has been successfully carried out up to a particle size of 12 mm with a stroke of $\frac{3}{8}$ in. at 190 strokes/min. As already noted, an 8-ft jig will treat 40 tons per hour under these conditions and requires about 3·5 h.p. to run. The object of primary jigging is to eliminate the maximum possible amount of low-grade tailings and make a primary concentrate with a concentration ratio of about 4:1. The ease with which the feed travels out to the periphery by displacement is a good indication of the fluidity of the bed and the short stroke and small volume of low-head water employed makes for freedom from any kind of violent action. A jig of the type described has a tailings discharge at the periphery of 25 ft in length so that when operating normally 30 tons of tailings will overflow the periphery, or 1·2 tons/h/ft of tailings weir. Mineralization consists of wolfram and cassiterite, and mixed sulphides, mainly arsenopyrite and pyrite, are present in the ratio of five parts of sulphides to one of valuable mineral.

Messrs. J. A. Bain† and K. Shaw: This very lucid and interesting paper has prompted a considerable amount of discussion among the technical staff of Amalgamated Tin Mines of Nigeria, Ltd., who are carrying out a similar research programme in mineral recovery by jig plants on the Jos Plateau. Many of the author's results are at variance with much of the data being obtained from this investigation, but the paper unfortunately does not contain sufficient practical results and actual figures for a proper comparison to be made. The figures set out in the paper would have been more valuable if a screen analysis of the cassiterite and gangue comprising

*Taggart, A. F. *Handbook of mineral dressing* (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1945), section 11, 42.

†Mineralogist, A.O. Nigeria, Ltd.

the samples washed up by the *dulang* had been included, also the number of washings that each sample was given and the method of analysis for cassiterite.

Samples from Banka drilling on the Plateau are concentrated by washing with a calabash or half gourd in a similar way to the *dulang*, but it is not considered efficient, especially for columbite, and steps are being taken to improve methods of bore evaluation. Recent work in this direction, however, showed that in a single washing the recovery of cassiterite by 'calabashing' decreased directly with decreasing grain size, and no anomaly has been noticed in the intermediate sizes. There was slight irregularity in the coarse +16-mesh sizes, where the recovery was actually less than in the finer 16–25-mesh grains, due to (*a*) the general scarcity of these very coarse grains and the consequent difficulty of seeing them, and/or (*b*) their large cross-sectional area.

It seems possible that the variation in recovery reported in the paper could be produced by washing the sample twice with the *dulang*, the first time concentrating on recovering the coarse cassiterite and the second time concentrating on the fines, with a consequent tendency to lose the intermediate sizes in both washings. It would be interesting to have Mr. Harris's views on this point. The 100 per cent recovery in the size range 150–200 mesh is remarkable. With the calabash the higher the grade of the ore the higher is the overall recovery. The figures in Table I for *dulang* washing appear to show the opposite effect.

No large-scale investigation of calabash recovery has been undertaken, however, and many detailed experiments would have to be carried out if Mr. Harris's contention was to be refuted for all cases of calabashing. Factors which influence calabash recovery of cassiterite include the size range of both cassiterite and gangue, the total amount of cassiterite present, the presence of other heavy minerals and other black minerals, the slime content, the number of times the sample is washed and a variable indeterminate personal factor. The recovery of columbite would appear to follow a similar pattern, after allowing for the difference in specific gravity and shape.

It is interesting to note that the author can support the results obtained with the *dulang* with similar results from other methods of gravity concentration. The writers have found no obvious anomaly in the recovery figures obtained from jigging on the Jos Plateau. Any departure from the normal curve of continually decreasing recovery figures for each successive grain size has usually been due to faulty sampling or some variation in plant operation. On the other hand, most of the results obtained so far have come from a pilot jig plant treating decomposed granite, and the feed undoubtedly had physical characteristics different from the alluvial ore mentioned in this paper.

Mr. Harris, in his contribution to the discussion on Mr. F. A. Williams's earlier paper* gave a table of results for the recovery of cassiterite by jigging which show the same trend as the results in the paper under

*Ref. 12 (p. 94) of the paper.

discussion. In this particular case it appears that the feed was deficient in very fine gangue, and the 200–300-mesh sand comprised only 2 per cent of the entire feed. The high recovery for the 100–200-mesh cassiterite may therefore have been due to the scarcity of 200–300-mesh gangue, some of which would normally have worked its way into the small pore spaces in the jig bed during the suction stroke and tended to obstruct the passage of the 100–200-mesh cassiterite. A cumulative percentage curve calculated from screen analyses of samples of decomposed granite shows a continuous slightly curving slope from 16 mesh to 300 mesh, representing a gradual decrease in the amount of fines in contrast to the sharp cut-off in the fines shown by the feed Mr. Harris used.

In this particular case it appears that he used a direct chemical analysis for estimation of cassiterite content to three places after the decimal point, with figures as low as 0·012 per cent. Even with a highly accurate method of colorimetric analysis the results cannot be closer than $\pm$ 0·002, and yet these figures are used to calculate screen analyses for cassiterite to one place after the decimal point. In our laboratories physical methods of analysis are preferred to chemical methods in all mineral dressing investigations as the latter are often not considered accurate enough and can be seriously misleading. Efficient means of concentration, e.g. the superpanner and Frantz isodynamic separator, are followed by calculation of mineral content in the final concentrate by grain counting under the microscope. This applies particularly to columbite where acid leaching is also employed.

A further factor in the recovery of fine cassiterite in jigs which is not mentioned by the author is the use of cyclones. Where the feed is being deslimed prior to jigging, a cyclone rejecting all -50-μ quartz sand will theoretically be rejecting -25-μ cassiterite. In the size range 25–50 μ the deslimed feed will contain cassiterite but no quartz (within the limits of the efficiency of the separation) and therefore aid the recovery of the very fine heavy mineral.

It is interesting to note, however, that Mr. Harris's conclusions concerning proposed flowsheets for jig plants parallel that of Associated Tin Mines of Nigeria, Ltd. It is eventually hoped to replace the present 10-in and 12-in cyclones by a much larger type working at a low pressure, and to experiment with inter-cell screening within the jigs themselves, especially for rejecting coarse barren gravel from the feed to the third cell of the primary jigs.

The further publication of more detailed results from the investigation into serial gravity concentration, as intimated by the author in his present paper, will be eagerly awaited.

Mr. J. A. Bartnik: From investigations into gravity concentration at the Bisichi Tin Co. (Nigeria), Ltd., similar conclusions were arrived at and we have been able to show* that columbite and cassiterite recovery is better

*WILLIAMS, F. A. Recovery of semi-heavy minerals in jigs. Discussion in Nigeria. *Trans. Instn Min. Metall., Lond.*, **68**, 1958–59, 436 448. (*Bull. Instn Min. Metall., Lond.*, 631, June 1959).

when the jigs are arranged in series than when arranged in parallel.

Our approach to the problem was different, however; it had to be more practical as we had to design a gravity plant capable of dressing 150 cu./yd/h of intensely decomposed granite containing both columbite and cassiterite. Our investigation has shown that the screening efficiency of the sieve bend which the author recommends was only 40 per cent. Even when we used a 4-mm sieve bend for screening material having −20-mesh valuable minerals we had considerable losses (about 12 per cent) of columbite in the oversize, and we came to the conclusion that for screening valuable minerals a sieve bend is not good enough as a screening tool. When we tried to use 4-mesh wet vibrating screens they were screening efficiently only for one hour after cleaning and after 8 hours the screening efficiency dropped to 20 per cent. To attempt to clean the screens every hour while screening about 100 cu./yd/h feed would certainly not be a practicable proposition.

From the operation of pilot plant we had gained enough experience to prove that wet screening of large quantities of a product is troublesome and inefficient, causing considerable losses of valuable minerals. This method should be avoided where possible.

It was decided to carry out an investigation with various types of jigs and their settings with the object of finding the most advantageous jig arrangement for dressing our particular type of ore products for maximum recovery of columbite and cassiterite. The best recovery of columbite and cassiterite in the first jig hutch was achieved with 1½-in stroke (120 rev/min) and in the second hutch with about 1-in stroke, but no alteration in water pressure or stroke did much to improve the recoveries of heavy minerals in the third or fourth jig hutch where recovery was very poor (5 per cent, giving overall recovery 80 per cent). It was found that most of the heavy minerals were washed by the water current into the tailings. It proved the inefficiency of the jigs arranged in parallel.

A different approach was obviously necessary. Screening and jigging proved troublesome, with heavy losses of valuable minerals during screening, while hydroclassification and tabling would require a lot of machinery with consequent maintenance. After further investigation it was decided that the best gravity method for dressing of our type of ores after removing slimes by cyclone classifiers, would be in jigs set with hutch 1 at 1½-in stroke (120 rev/min) and hutch 2 at 1-in stroke. The second jig hutch overflow product (tailings) should be then thickened by cyclone to 40 per cent solids and fed into the third jig hutch with the stroke drastically reduced to ¼ in. at 200 rev/min and so arranged that there is no drop between hutches 3 and 4 in order not to disturb the stratified layers of minerals. With such a jig setting the recovery of the heavy minerals in the range of middle and fine sizes lost in jig hutches 1 and 2 was greater than 70 per cent, giving a total columbite and cassiterite recovery of nearly 95 per cent (ratio of concentration 40:1). If necessary the concentrate from jig hutches 3 and 4 can be upgraded on shaking tables.

The plant with the jigs arranged as described above proved very successful in dressing the cassiterite and columbite from the alluvial and primary deposits in Nigeria.

Mr. F. B. Michell: Mr. Harris has introduced a new aspect of gravity concentration based on careful study of jigging results. When a jig is used for treating a long-range feed, losses in the middle size range do indeed appear and the procedure suggested, namely, of removing a proportion of the larger gangue particles before further concentration, is an effective way of improving recovery.

It seems possible, however, that the rejection of the so-called middle size concentrate may be due to a combination of the resistance of the upper part of the jig bed and the ragging whether the latter be natural or artificial. It is possible to visualize a condition where the upper layers might be dilated sufficiently to allow the passage of such particles through the interstices only to be prevented from passing through the ragging owing to the difference in the degree of dilation and the possible close-packed arrangement prevailing. In such a situation a 'build-up' would probably occur which might find an outlet in the tailing discharge. I think that sampling a jig bed at various depths might be undertaken with advantage; it would provide additional information on the undoubted complexity of the concentrating action.

Referring to Fig. 2 (p. 88) and considering the relation between the size of the group B particles and the size of gangue which should be removed in order that the group B minerals may be recovered, it will be seen that the size ratio is fairly considerable, ranging from 100:1 to 5:1, with possibly an average value of about 20:1. If a closely classified feed were being treated, a great deal of the heavy mineral would have a size ratio outside this range and I think it would be wrong to suppose that the same magnitude of loss would occur in the middle range of mineral sizes with a classified feed. With a screen-sized feed, losses of such middle range material would surely only occur when the ratio of the limiting sizes was large—the ratio being related to the sp. gr. differential. Consequently, although I agree that such losses are possible with a long-range feed, I fail to see that a middle range of concentrate should be lost when the material has been split into a 'great number of short ranges'. I agree, however, that desliming is essential for good jig operation, since not only is the apparent viscosity of the interstitial fluid increased but the combined effect of the cross-flow and the rising current through the bed can easily prevent small particles from coming to rest.

In the case of table concentration, the effect of both viscosity, due to colloidal and near colloidal slime and the cross current, is probably greater.

Normally, as Taggart* states, 'the principal losses from film concentrators with relatively smooth surfaces occur in the finest and coarsest sizes. The very fine grains are lost in suspension in the water; the coarse because they roll.'

The loss of the finest sizes is related to the amount of flow across the

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*TAGGART, A. F. *Elements of ore dressing* (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1951), 212.

deck, usually near the feed end and a consideration of the expression*

$$Z = \tfrac{3}{2} \frac{\Delta'}{\Delta - \Delta'} \frac{\tan \alpha}{r^2} \theta^3$$

where Z = the distance travelled before the particle touches the deck,
Δ = sp. gr. of the solid,
Δ' = sp. gr. of the liquid,
α = the angle of slope,
r = particle radius, and
θ = the film thickness

shows that a 20-μ particle will not settle until it has travelled about 100 in. from the point of entry on a deck with a 5° slope and carrying a 2-mm water film. This may be an extreme case and no account is taken of the effect of riffles, but it serves to show how small particles can be lost.

If such cross-flow is excessive there may also be a tendency for some small particles to be carried into the middling along with much larger particles which are transported into the same product owing to the combination of the 'reversed classification' effect and lengthwise travel due to the conveying action of the deck.

With a riffled surface it is true that a bed is formed which dilates and contracts and some middle-size particles might be expected to resist penetration, but conditions are somewhat different, since the bottom layer of finer particles of high sp. gr. moves forward along the line of riffles at a faster rate than the coarser material near the surface. At the same time this coarser material is swept over the riffle top. If some smaller particles of high sp. gr. are also swept over, they come under the influence of the flowing film when the larger grains of lower sp. gr. will travel farther than the smaller ones of high sp. gr., so that conditions in the 'jig' bed are changed.

I therefore suggest that, whereas the findings of the author are no doubt true in jigging a long-range feed, the extension of the principle to shorter range feeds needs more experimental work and, in the case of flowing film concentration, the value of 'serial concentration' is open to question. Indeed as far as the concentration of extremely small particles is concerned, I suggest that rather than abandon feed preparation by classification, more effective classification should be provided, together with thorough removal of colloidal material.† On the other hand, when a table is used with a wide cleaning zone, to produce a clean concentrate, the middling will carry large free particles of mineral of high sp. gr. along with finer material and screening can often be used with good effect, since it removes the large particles of high sp. gr. leaving the inevitable mixture of finer waste and concentrate in the undersize which can then be treated readily. I introduced this practice some years ago in certain tin sheds in Malaya.

*Gaudin, A. M. *Principles of mineral dressing* (New York, London: McGraw-Hill Book Co., Inc., 1939), 305.

†Michell, F. B. A study of the gravity concentration of fine cassiterite. *Trans. Cornish Inst. Min. Engrs,* **12,** new series, 1956–57, 55–74.

Unfortunately commercial wet screening of relatively fine sizes is far from satisfactory and I cannot agree with the statement that 'adequate methods are now available for economical wet-screening at all sizes' (p. 93). Much wet screening has a low efficiency with material as coarse as 30 mesh and I can visualize conditions which would require much finer screening.

With most ores the greatest problem is that of the unliberated mineral in the middling products and often 90 per cent of the tailing loss (apart from losses int he −10-μ range) is simply due to failure to liberate. In view of the magnitude of this factor, I think the statements (p. 91) that 'locked grains tend to accumulate in the oversize from the screen after each stage of the "serial" process' and 'if this material is still ore it can be ground and returned to the circuit at an appropriate point' need qualification, since it would be necessary to grind the whole of such oversize whether it was barren or not unless it were subjected to suitable concentration stages in order to eliminate the uneconomic material before grinding.

Dr. I. Schlogl: A basic difference between the arts and the sciences is that the former are postulated and/or demonstrated; the latter, however, can and must be proved by evidence. The paper brings an adaptation of an established mineral dressing process to a particular ore. In a detailed investigation for which full data are to be published the author succeeded in improving the recovery of alluvial tin ore. During these investigations he discovered that in jigging long-range feed, losses of heavy mineral occurred in the 'middle range'. This led to the development of 'serial gravity concentration' and to the theory concerning losses in that 'middle range'.

This is a well-known phenomenon, however, and it is to avoid just this that jigging feed is usually prepared by screening, in contrast to table feed which, due to reverse classification on the table, has to be prepared hydraulically. This phenomenon can be proved readily on a laboratory scale—provided that the feed range is long enough to cover larger light and smaller heavy particles of the same settling rates. For this reason, short-range feed is normally used for jigging, the range being carefully chosen to avoid equal settling rates of value and gangue.

On this consideration it is somewhat surprising that the author postulates from his findings with a long feed range that a 'middle range' would still be lost with a short feed range designed precisely to avoid this loss.

Whether the ore is best screened initially into short size ranges and then jigged, or whether the long range of material as obtained is jigged in series, i.e. the screening stages along the line instead of parallel, would seem to depend on the nature of the ore, its natural size distribution, and that of the heavy mineral contained. It also would depend on the daily tonnage to be treated and thus on the required capacity of the initial stage which, with the long feed range, would have to be considerably larger.

The author is to be congratulated on his success in adopting a process to an ore. When all his experimental data are available it will be interesting to see what saving in jig capacity may be possible by employing serial gravity concentration against the conventional and satisfactory practice of jigging selected short-range feed.

Mr. F. A. Williams: Table I (p. 87) shows figures for recovery of cassiterite in relation to grain size achieved in tests with the *dulang* using synthetic samples made up of barren tailing and added heavy minerals. For comparison I now submit figures showing the overall recovery of cassiterite in relation to grain size achieved after the normal two operations of desliming and calabashing actual alluvial bore samples in Nigeria. These figures (Table A) are the averages of a number of tests. I have already outlined the method used to obtain such figures and it will be seen that except for minor irregularities the overall recovery diminishes progressively with decreasing grain size.

TABLE A

B.S. sieve no.	Recovery of cassiterite from alluvial bore samples in Nigeria	
	Field recovery in relation to grain size	
	From overburden	From wash
	%	%
+25 . .	46·2	95·2
25/ 52 . .	39·2	90·8
52/ 72 . .	46·3	85·1
72/150 . .	15·9	63·2
150/240 . .	0·8	19·8
240/325 c . .	0·4	1·9
−325 c . .	0·3	5·9
Total recovery	10·3	82·0

c = commercial.

Separate sets of figures are not at present available for the recovery achieved in the two distinct operations of desliming the samples and concentrating the deslimed sands in a calabash, but they could easily be obtained.

Screen analyses of the total free cassiterite in the ground are likely to show considerable variations from place to place. However, Table B for a line of bores across an alluvial lead in Nigeria may be deemed worth publishing for comparison with figures which may be available now or later in Malaya. The cassiterite in the overburden amounted to 21 per cent of the total.

The writer would be keenly interested in any figures which the author or others could produce relating to Malayan ores for comparison with Table B. Such figures are important when the merits of a particular method of gravity concentration are being discussed. The amount of extremely fine cassiterite present will determine whether screening, cycloning and jigging will suffice in plant-scale recovery or whether there is economic justification

TABLE B

B.S. sieve no.	Total recovery in field and laboratory	
	Screen analysis of cassiterite	
	From overburden	From wash
	%	%
+ 25 . .	4·0	18·3
25/ 52 . .	10·8	43·1
52/ 72 . .	3·9	18·3
72/150 . .	11·9	14·4
150/240 . .	49·7	3·8
240/325 c . .	11·6	1·3
−325 c . .	8·1	0·8
Total . . .	100·0	100·0

c = commercial.

for an extension of serial gravity concentration to include tables, spirals or buddles, a possibility already visualized for some applications by the author. I have already produced published figures relating to a jig plant in Nigeria which showed that, after screening and adequate desliming of the feed, the recovery of cassiterite in a jig of four cells in series was over 99 per cent down to 240 mesh and still over 90 per cent at 300 mesh.

There would appear to be an economic need in Malaya for a comprehensive study of the geology and fragmentary petrography of the alluvial deposits in support of the research work on the recovery of cassiterite being carried out by the Research Division of the Department of Mines.

Mr. I. R. M. Chaston: This paper sheds new light on jigging practice but I am afraid that I cannot agree with all the author's conclusions. The important features brought out in the paper are that a properly run jig can make a good recovery of coarse and fine heavy mineral simultaneously, that there will be a loss in the middle size range of heavy mineral in jigging operations and that there is little point in using jigs with more than two cells. Other workers finding the loss of middle size range material have concluded that the jig ceases to be an efficient concentrator below a coarse size. Taggart* gives 2 mm as the minimum size of heavy mineral worth concentrating in such machines. The work of the Research Division of the Malayan Department of Mines has revealed that good recoveries can be made in jigs down to 300 mesh and below. As the author states, the work of Richards† which supports this view has been largely overlooked.

The main point on which the author and I differ is over the best method

*TAGGART, A. F. *Handbook of mineral dressing* (New York: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1945).

†Ref. 4 (p. 94) of the paper.

of recovering the middle size range of heavy mineral lost in the primary jigging. He assumes that after removing the coarse gangue from the tailing of the primary jig and feeding the thickened finer fraction to a second stage of jig, the middle size range of heavy mineral, 'group B' particles, will be as easily recovered in the second jig as the coarse size range of heavy mineral, 'group A' particles, were recovered in the primary jig. In my view this cannot be so. To be collected in the concentrate, super- and par-interstitial particles of heavy mineral must sink through the bed of the jig by forcing their way past the other mineral present, i.e. under hindered settling conditions. None of the subsidiary concentrating actions taking place in the jig is as important as this one for these super-interstitial particle sizes. Sub-interstitial particles settle through the gaps in the bed virtually under free-settling conditions and under the action of the changing flow currents in the bed. Coarse heavy mineral settles quickly even under hindered settling conditions while the middle size range particles of heavy mineral settle very slowly under these conditions. In practical jig operation, the material is only in the jig for a limited period of time, which results in a loss of this slow-settling material. Since this middle size range of heavy mineral is recovered under hindered settling conditions in both stages of serial gravity concentration as advocated by the author, the rate of recovery of these particles will not be substantially increased in the second stage.

Richards's figures for the rates of settlement of mineral particles are very revealing. The hindered settling rate for galena falls rapidly in the size range of heavy mineral particles which we have found by our tests to be lost in jigging with long-range feeds. At 25-mesh B.S. the hindered settling rate for galena is given as about 52 mm/sec, while at 72-mesh B.S. the rate is only about 10 mm/sec. The rates of free settlement are, of course, much higher. The free settling rate for 100-mesh B.S. galena is about 60 mm/sec, while at 200-mesh the rate is still 28 mm/sec. This shows that if the time of residence of material in a jig, operating with a size of interstitial spacing equivalent to about, say, 85 mesh, is such that most of the 25-mesh particles of heavy mineral are collected, then most of the 100-mesh particles of heavy mineral will also be collected and there will be a loss of a middle size range of heavy mineral particles between 30 and 85 mesh. This is because the fine particles will collect under free settlement at about the same rate as the 25-mesh particles collect under the hindered settling conditions while some of the middle size range particles will be lost because they do not have time to settle through the bed before being swept out. Removal of the coarse gangue from the tailings from this jig will not make it easier to collect the middle size range of heavy mineral unless the amount of coarse material removed is such that the residence time of the material in the second jig is greatly increased. Even then, the grade of concentrate from the second jig will be very low, since the time taken to make a given recovery and the grade of the concentrate recovered vary inversely in jigging. In addition, as the author points out, the removal of the coarse gangue will result in a reduction in the interstitial spacing in the bed and will therefore hinder the recovery of any of the finer heavy mineral which has been lost from the first jig.

Speedy and efficient recovery of the middle size range of heavy mineral particles by jigging can only be achieved if these particles settle rapidly through the jig bed. Under free settling conditions such particles would penetrate the jig bed very rapidly and so, for efficient recovery in a second stage of jigging, the bed of the jig must be opened out to increase the interstitial spacing. That this effect can be achieved under controlled conditions can be seen from Richards's figures.* Those quoted by the author were for the case when 'much suction' was used for jigging. When they are compared with the figures for the same material with 'little suction' the difference is striking.

TABLE I.—*Number of Pulsations Required to Recover Galena in a Jig*

Diameter of quartz, mm	Diameter of galena, mm	Pulsations needed for separation	
		Much suction	Little suction
1·735	1·735	257	95
1·735	1·090	302	384
1·735	0·665	748	153
1·735	0·495	337	210
1·735	0·241	190	153
1·735	0·107	86	354

Richards suggests that the size of the interstices in the jig bed can be derived from these figures. His argument would appear to be that the number of pulsations required for recovery will increase as the galena becomes finer and settles through the bed more slowly under hindered settlement. When the galena becomes finer than the interstices of the bed it will slip through easily and the number of pulsations required before recovery is complete will be much less. When much suction is employed the 0·665-mm grains of galena find great difficulty in penetrating the bed, while the 0·495-mm grains of galena slip through readily. The size of interstices in this bed is therefore presumed to lie between these figures. When the suction is reduced as in the second column, the 0·665-mm grains of galena slip easily through the bed and the peak lies with the 1·090-mm grains. This clearly indicates that the interstices of the bed have been enlarged by altering the suction stroke. Suppose a mixed range of galena had been treated in the jig used for these tests and much suction employed for the first 300 pulsations. All the galena would have been recovered except in the middle size range. If the suction had now been reduced, all the remaining galena could have been recovered in the next 200 pulsations, while if the suction had not been reduced it would have taken another 450 pulsations before the middle size range of galena was recovered.

*RICHARDS, R. H., and LOCKE, C. E. *Textbook of ore dressing* (New York, London: McGraw-Hill Publishing Co. Inc., 1940), 201.

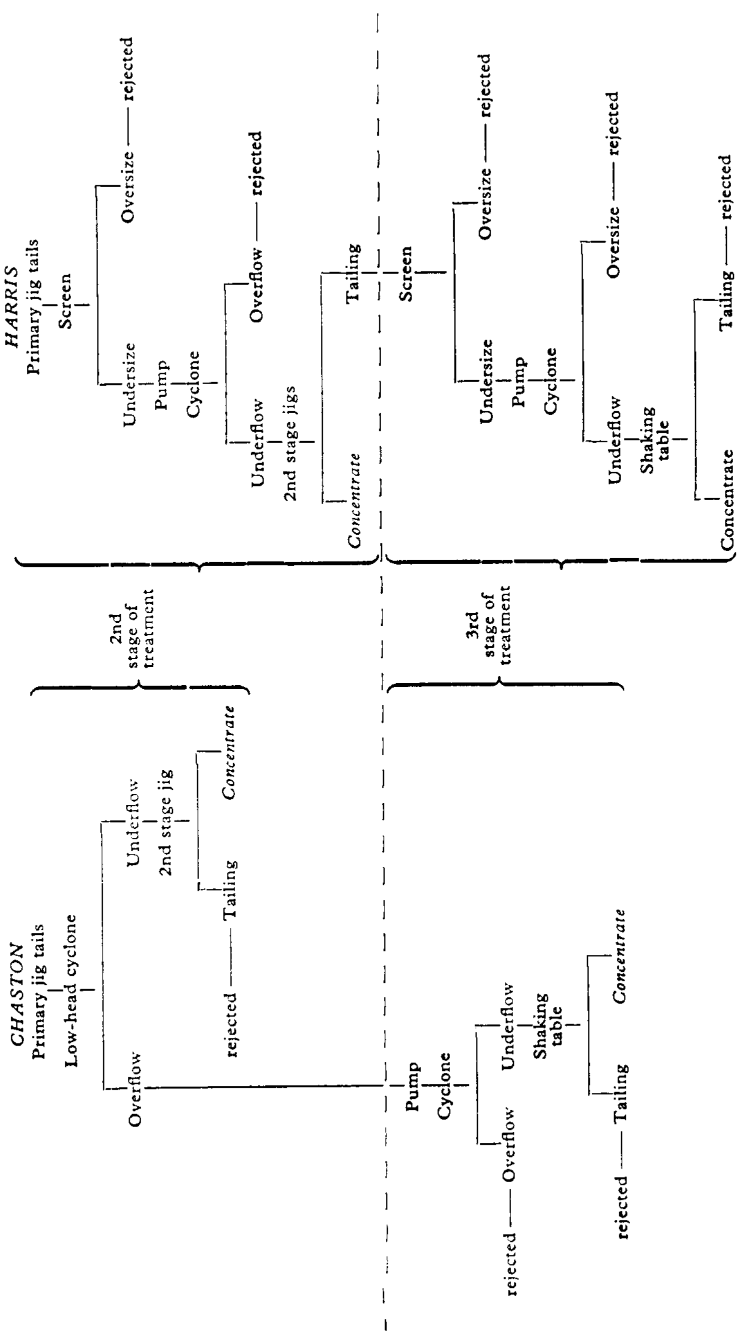

Fig. 1.—Comparison of Second and Third Stages of Treatment as Recommended by Chaston and by Harris.

Before taking these results further it must be remembered that they are obtained with a *uniform size of coarse gangue.* In practice, when jigging a long-range feed material, the interstices of the bed are partly filled, as the author points out, by fine grains of silt and sand and it seems very unlikely that alteration of the suction will actually cause such a dramatic change in the interstitial spacing as it did in Richards's experiments. If, however, the fine material is removed before the second stage of jigging, the interstitial spacing can almost certainly be increased by correct control of the suction. Having increased the interstitial spacing, the middle size range of heavy mineral lost from the first jig would be very rapidly recovered under the free settling conditions which would then exist. Indeed, the rate of recovery would be so great that it would probably be possible to use a smaller size of jig for the second stage since the residence time required for recovery would be reduced. Because of the high rate of recovery, the grade of the concentrate would also be high.

Removal of the fine material from the tailing from the first jig could be by screening or classification. A screen would be required to screen at a size just below the interstitial spacing of the first jig. The oversize *including all the coarse gangue* could then be re-jigged. Better results would be obtained by classification in a low-head cyclone or hydraulic classifier since it would then be possible to remove some of the middle size range of light gangue together with the fines, while leaving the middle size range of heavy mineral particles to be treated in the second jig with the coarse material. An advantage of this method of treatment is that the feed to the second jig, whether it is screen oversize or cyclone or classifier underflow, is automatically thickened without the second stage of thickening required by the author. The disadvantage of the system is that the extremely fine particles of heavy mineral lost from the first jig do not get a second chance of being recovered in the second stage of jigging. If these losses are significant, the fine undersize from screening or the overflow from the cyclone or classifier could well be thickened in another cyclone and the thickened pulp would form an ideal fine feed for a shaking table. This method of treatment is compared in Fig. 1 with that suggested by the author.

The saving in pumps which accrues from the use of the suggested system is very plain. It may be argued that the two-stage system as suggested by the author may recover more of the very fine heavy mineral than my two-stage system but this must be balanced against the inevitable loss of the middle range of heavy mineral, which has been shown to be inevitable using Harris's system, and also the probable lower grade of concentrate. It is also interesting to compare the equipment and operating differences between the two systems. The author uses a screen which will handle very coarse material and a pump and cyclone to handle coarse material where I suggest a low-head cyclone to handle the coarse material, a pump and cyclone handling only fine material, and a shaking table. The rest of the equipment is the same, apart from the possibility that my system may only require a small second-stage jig. In other words there is only a small difference between the amount of equipment required for the two systems, but the rate of wear on the pumps and cyclones in my suggested system, handling only fine material, would be much less.