face. But the barrier layer photocell would appear to have a much wider application than the author has covered in his paper. Circuit testing in opencast mines and quarries, quite obviously, can come within the scope of this device, and it would be interesting to know how the author regards daylight, with its ever changing actinic values, as an activator of the photocell for this purpose. It is possible that, in regard to the variable actinism of daylight, especially as known in the temperate zones, the author would recommend for surface testing the constancy of a hand torch which in some way excludes the variableness of the sun's rays under atmospheric filter.

Mr. D. Sutton said that the need for such an instrument provided food for thought. After reading the paper he had examined an ohmmeter which had been tested and approved as intrinsically safe and he wondered by what means a member of the mining fraternity could make it operate in unsafe manner. The ohmmeter examined was supplied with power by a small $1\frac{1}{2}$-V torch battery. Under short-circuit conditions, however, this was capable of supplying current, in excess of that required for firing, to a circuit containing three detonators. If, therefore, by a combination of unfortunate circumstances such conditions obtained in practice, trouble would ensue. Possibly some internal fault in the instrument could produce such a result, but his detailed examination had not convinced him that it could. Deliberate tampering was a very different matter and such malpractice could quickly lead to the most serious consequences.

The undesirability of having an electric battery in the instrument at all was a point well brought out by the introducer; anything done by way of removing an intrinsically dangerous power source must add appreciably to safety. The novel device described in the paper did not rely for its power supply upon such a battery but upon a selenium cell which was self-limiting and could never be dangerous. The point so aptly made by Mr. Dowie that that was not necessarily true of all selenium cells should be emphasized. With an unlimited source of light (as in daylight) the power output of which a cell was capable was proportional to its surface area, and while it was admittedly most unlikely that the output of the cell used by the author would be exceeded in a new instrument by the present safety factor of 600, careless assumptions should not be made.

Mr. J. Cowan,* who said he was very much concerned with the granting of certificates of intrinsic safety, commented that if as alleged miners opened the back of one of the present instruments and took out the cell in order to fire detonators, they were running a serious risk of causing danger, apart from not complying with the terms of the intrinsic safety certificates. As the previous speaker had made clear, the design of the new instrument was ingenious and could be safe in almost any circumstances. A paper in *Engineering*† dealt with an almost similar design by the Weapons Division of the Fairey Aviation Company. It might have little differences, but it

*H.M. Principal Electrical Inspector of Mines, Ministry of Power.
†Testing firing circuits. *Engineering, Lond.*, 8th November, 1957, 585.

worked on the Wheatstone bridge principle and the source of supply of current was from a selenium photo-layer cell. The light supply was probably obtained from daylight, as against a cap lamp in the pit. From the safety angle there was a great deal to be said for Mr. Moffat's instrument, but looking at the photograph and remembering some of the experiences of the past, the thought arose that it might be rather prone to damage, or the risk of damage, in the pit, in view of the way in which some gear was treated. Although the instrument described would not result in any danger if damaged one would nevertheless lose faith if it did not give regular and satisfactory service. It had been found over the years that however desirable a very sensitive indicator was, such as a 50 micro-amp ammeter, it could not generally stand up to mining practice. The pivots would become distorted probably after the first day and the whole instrument would be useless. Although some instruments had been made with a scale of 0–1 amp or even 0–100 milliamps at the very smallest, even such a well-built piece of apparatus could break down and the instrument itself not stand up to ordinary pit work. Some information on the experience with Mr. Moffat's instrument in service would be useful.

As had been said, detonators are made with a remarkable degree of accuracy; 300 milliamps is about the current necessary to fire them under normal conditions. In the recent agreement between the Ministry, the Coal Board and B.E.A.M.A. on the development of boundary conditions for remote control circuits, the maximum current was limited to 250 milliamps. Should anyone accidentally connect the leads of a detonator across such a circuit then the detonator would not fire. Working on that premise, if manufacturers could make a meter which would work with, say, a maximum of 100 or 150 milliamps, it would give much more scope in development and allow much greater robustness in design of a suitable testing instrument.

Performance analyses of screens, hydrocyclones, jigs and tables used in recovering heavy accessory minerals from an intensely decomposed granite on the Jos Plateau, Nigeria

F. A. WILLIAMS, B.Sc., MEMBER

Report of discussion at February, 1958, General Meeting (Chairman: Mr. G. Keith Allen, President). Paper published in December, 1957, pp. 89–108

Dr. G. A. Schnellmann, in introducing the paper, said it described part of a very long investigation which was one of the most remarkable assessments of an orebody ever to be undertaken. Certain others had impressed more by their scale—i.e. the Labrador iron ore or the Rhodesian Copperbelt—but for sheer intricacy of detail and painstaking research, this assessment of a type of orebody never previously mined stood in a class by itself.

Two errors in the paper might be pointed out. In Fig. 1 (p. 94) there should not be a line in the flowsheet indicating a return of material from the hand sorting to the 6-in gravel pump. In the same diagram, as on all the flowsheets (Figs. 2, 3, 4 and 6), the box referring to the clean-up jig should read 'Clean-up jig, 6-hutch'.

Members would no doubt recall Mr. Williams' earlier paper entitled 'Identification and valuation of decomposed columbite-bearing granites in the Jos area of the Nigerian Plateau', which embodied the results of a most complex piece of research in the short space of ten pages. It was that earlier paper which the speaker, as a geologist, had found of particular interest and of great value in undertaking a comparable job elsewhere on the Nigerian Plateau. The present paper, although a natural and very welcome supplement to the former, dealt essentially with matters that were more the concern of the mineral dresser. His only qualification for introducing it was that he had had the privilege of seeing the plant in operation and discussing some of the problems with the author on the spot.

The ultimate success of any mining operation depended on a correct and accurate assessment of the orebody. If it was under-valued there would very likely be no mining operation whatever. If, on the other hand, it was over-valued, the expected profit would not materialize. That was particularly true at the present time, when ores of ever-lower grade were being worked and the permissible margin of error in assessment was decreasing. The earlier paper described how the author and his colleagues had arrived at an assessment in which they had every reason to be confident. As the opening paragraphs of the present paper explained, the peculiar market conditions for columbite were such that it was necessary to go straight from assessment to full-scale production without the usual intermediate stage of a pilot plant. The first plant installed had failed to come up to expectations in the matter of recovery. The conclusion was quickly reached that the real trouble lay in the difficulty of recovering the smaller sizes of columbite and the paper showed how, by successive modifications of the plant, it had been possible to extend and improve recovery in the smaller sizes.

The author reported that the plant began operating in July, 1953, and that the treatment of decomposed granite, on which the paper was based, was discontinued in November, 1956. Presumably, although Mr. Williams had not said so, the reason for that was the company's completion of its contracts for the United States stockpile. Since then the plant had been used to recover cassiterite and columbite from alluvial material and this was taken to be the operation to which reference was made at the foot of p. 107. It was interesting to note that the plant had not been moved from its original site to the alluvial deposit, but that the alluvial material was being pumped rather more than 1300 ft from the alluvial paddock to the plant and the overall recovery was at present 95 per cent for columbite and slightly better for cassiterite.

The use of jigs in alluvial operations was not new and the author did not claim that it was. As far as could be seen, however, nowhere in the literature was there any comparable information on the performance of alluvial jigs in relation to grain size and specific gravity of the valuable minerals in the alluvium. Attention should be drawn to Table VI which, quite apart from being an admirable summary of the whole paper, could also be used to predict the recovery of such other heavy materials as rutile and monazite from beach sands.

Unlike a jig or table in, say, an ordinary lead recovery mill, the jigs in the operation described did not recover a salable product. The product which they yielded was a mixed concentrate of all the heavy minerals in the original feed and it had to be dressed up to produce salable products. Those who were familiar with Nigerian practice would be aware that that was done by dry concentrating processes, including pneumatic tables and magnetic and electrostatic separators. The operation was not made any simpler by the perversity of the minerals in possessing abnormal properties. Some of the cassiterite, for example, was magnetic and a clean separation between it and columbite was not as easy as one would be entitled to expect. Nevertheless, the object had been achieved, and in addition to the columbite and cassiterite, salable grades of xenotime had been produced and the 'tailings' had been sold for their thoria content. The author and his team were now engaged on the problems of the dry concentration stage, having retained 100 tons of the primary concentrate for that purpose. All would wish him success in the investigation and would look forward to another paper embodying the results.

Mr. F. B. Michell said that in both Nigeria and Malaya the problem of saving fine cassiterite, and sometimes columbite, was, perhaps, of greater magnitude than was usually supposed. The amount of fine cassiterite varied quite widely, but in some cases there was a major proportion finer than 100 mesh and some under 300 mesh, the latter being usually very difficult to recover. As the author had suggested in his previous paper, the lack of appreciation of the fineness of some of the valuable mineral was due to the methods used in the past to evaluate boreholes which were not capable of recovering the finer sizes, which were simply lost in the same way as with, say, a jig without proper handling. Consequently, estimations involving screening, elutriation, desliming and recovery on a superpanner such as the author had described, indicated the proportion of valuable mineral in the fine sizes. Such performance analyses could be most valuable in plant design.

In some alluvial operations the losses of the fine cassiterite were usually found in the size fractions below about 100 mesh and they were greatest between 150 and 200 mesh although occasionally they extended into the subsieve range. In one operation in which there was a great deal of clay, at times cassiterite particles as large as 72 mesh were found in the primary jig tailings due to carryover with the clay. Relatively that was slightly coarser than 72-mesh columbite (after making allowance for specific gravity differential) but it indicated how losses might occur when clay was present. In that particular instance usually about 6 per cent of the recoverable cassiterite in the tailing was in the $-72+100$ mesh, about 25 per cent was between 100 and 150 and all the remainder finer than 150 mesh. It had also been found that the tailing loss was greatly reduced by desliming in the same way as suggested in the paper, and was a very important stage.

In some cases it would appear that prior screening was also important, as it was desirable to eliminate coarse silica which might cause wear, while in some alluvials organic material was present which might choke the cyclone apex orifice. Another factor was that the removal of the coarser material would reduce the pulp density; and where water was short, as was sometimes the case in alluvial operations, it would make the correct density of cyclone feed easier to maintain. It would probably also render the 'cut' in the cyclone more accurate, because the presence of even small amounts of oversize material tended to make the overflow coarser irrespective of cyclone diameter. There was, therefore, everything to be gained by screening first, if possible at a finer size than that cited by the author. The D.S.M. screen appeared to be promising, and it would be of interest to know whether any work had been done in Nigeria with it.

With a cyclone the constant feed necessary for good operation was not always easy to obtain in alluvial treatment. Had the author experienced trouble with variation in feed? It would seem that in some cases, where conditions fluctuated, it might be necessary to control the feed in some way. It was possible that the Phoenix type of cyclone, which was reputed to tolerate feed surges, might be more suitable. One recently installed in Cornwall had shown that it did indeed tolerate certain fluctuations, and produced a 'ropey' discharge without an excessive loss of larger particles in the overflow.

There were a few other points on which further information would be welcome. On p. 90 the author stated that 50 per cent of the ore was said to be slime and on p. 92 he stated that 'slime was removed by careful elutriation'. There was, however, no mention of the actual 'cut' in the elutriation or indication of the columbite content and he wondered how much had been lost during that operation in the laboratory. The distribution given on p. 91 implied that 100 per cent was found in the deslimed sand, but some small percentage surely had been overflowed. If there was any really fine columbite present, was it recoverable?

The data given by the author would be even more valuable if he could supply the following further information: (*a*) the actual amount of slime discarded by the primary cyclones; (*b*) the amount of columbite in the overflow which was recoverable (say, on a superpanner) and whether anything other than a jig had been tested for recovering the finer material—e.g. if any work had been done on spirals or one of the launder methods of concentration; (*c*) the size of separation in the cyclone, the size of the cyclone and throughput, and whether or not it was more or less a standard design.

In dealing with table operation, it had been shown that tables did not recover columbite particularly well and that it tended to pass into the fifth product. While there was an appearance of substantial classification in the feed to the table, there was a much wider distribution of sizes in respect of the columbite and the pattern that appeared on the table might be considered roughly in accordance with what would be expected in relation to the mechanics of table concentration. More prior classification was probably indicated. There was also the possibility that cross-flow on the table at the feed end might be a contributory factor.

Mr. Philip Rabone said that the paper showed how an operating staff could set about improving the performance of a mineral concentrating plant by evaluating the performance of the individual machines. Though the paper was quite rightly not concerned with engineering detail, it would be helpful to know the types and sizes of the various items of equipment, including the cyclones.

The wording in some of the tables was not very explicit. In Table III (p. 95) the percentage of sand 'reporting in underflow' was given as 93·7 per cent, the remaining 6·3 per cent presumably being slime. He asked what was the slime in the line below, containing 18·2 per cent of sand, and the water in the last line containing apparently 10·8 per cent of sand.

Table VIII (p. 101) was equally perplexing. For instance, the 'percentage of undersize reporting with oversize' on 30 mesh was given as 50·7 per cent at the lower input and 72·0 per cent at the higher—on the face of it a very poor performance for equipment as efficient as the Symons V-screen. The author should state explicitly to what undersize and oversize he was referring both at the top and at the bottom of the table.

The paper explained how the performance of the individual machines was estimated and described with the help of flowsheets in Figs. 1 to 4 the logical steps that were taken after each estimation to improve the operation of the plant. That part of the paper merited nothing but praise.

A proposed flowsheet for future development was given in Fig. 6, and the speaker considered that it was capable of improvement and simplification. Tables VI (p. 100) and VII (p. 99) showed that the tailing from the secondary jigs contained fine mineral, and concentrating tables had to be added to clean it up. Those jigs recovered a large proportion of the very fine mineral, but it was evident from Tables IV and V (p. 97) that a considerable amount of it escaped in the clean-up jig tailing and again had to be recovered on tables. He suggested that a better method would be to take the fine mineral, say all below 150 mesh, right out of the main circuit by means of a classifier ahead of the secondary jigs and recover it in a separate circuit with all the available tables arranged as roughers and cleaners.

Mr. D. G. Armstrong described the paper as somewhat tantalizing because, as Mr. Rabone and Mr. Michell had suggested, the paper was possibly a little too concise. In particular, there were not enough figures for quantities, and it was rather involved. Although the paper was headed 'performance analyses' the size of the cyclones was disappointingly not mentioned and no throughput was given.

Table I (p. 91) showed that 35 per cent of the ore was larger than 52 mesh and contained only 7 per cent of the values; 50 per cent was slimes and 93 per cent of the values was in fine sand. Given this information, jigs were surely not what should be used.

Table II (p. 93) showed a very poor recovery of only 30 per cent when putting 124 cu. yd an hour through the jigs. If the throughput dropped to half—i.e. 62 cu. yd an hour—recovery rose to 60 per cent. In stage 2, cyclones were used before the primary jigs and if those cyclones were efficient they should remove most of the slime—i.e. 50 per cent of the ore. The feed to the jigs in stage 2 would be 77 cu. yd/hr minus 50 per cent (i.e. minus the slime), which was only 39 cu. yd/hr, and the recovery rose to 69 per cent. Was the increase in recovery due to the lower throughput through the primary jigs or to an absence of slimes? There was no indication of exactly what the cyclones were doing or how much slime they were taking off. There was a comment at the bottom of p. 96 about timed samples, but no figures were given.

Concerning the tables, the table feed was not properly classified. A considerable size range was indicated in Table IX (p. 103). Surely tables would give very much better results with a closely classified feed of such material.

A distribution peak in cut 4 was mentioned, but there was nothing unusual about that. Distribution was a function of weight and grade, and the weight split on the table was quite arbitrary. The author had simply taken various sections round the table, and there was no reason why there should not be a peak. Grade was the important thing and it showed a steady decline going round the table. An alteration to the position of the cuts where the samples were taken might well show a peak somewhere else.

It appeared that Humphreys spirals might do well on the ore provided that the feed was deslimed in cyclones. Spirals were not normally recommended for very fine values, but in the by-product plant of Climax Molybdenum spirals were used following cyclones. There they made two products—coarse sand and fine sand—for spiral treatment and the slime was removed with cyclones. The spirals recovered − 200-mesh wolframite, which had much the same specific gravity as columbite and cassiterite.

A plant was being put up in America for treating fine iron ore in spirals but only after two stages of desliming in cyclones. The speaker had some recent laboratory experience with another fine iron ore. It was treated in spirals and much better results were obtained after desliming in cyclones. Perhaps the jigs described in the paper would recover fine values provided that the feed was deslimed, but it was necessary to ensure that the increase in recovery was due to desliming and not simply to a lower throughput.

It was interesting to see that cyclones would recover fine heavy mineral in the spigot product. He had himself been trying to show mathematically that a cyclone would recover fine heavy minerals more easily than a hydraulic classifier. In fact, the classification spread in a cyclone was greater than in a hydraulic classifier; the relative difference in size between light and heavy particles was greater in the cyclone because of the centrifugal force. It would be interesting to prove this mathematically and, when time permitted, to follow it up by experiments in the laboratory to illustrate it.

WRITTEN CONTRIBUTION

Mr. J. A. Bartnik: As I am working on a similar problem I wish to ask a few questions and make a few suggestions.

Was a comparison ever made between the results from bore-holes of decomposed granite and the actual content of minerals in it? Valuation of alluvial deposits by bore-holes within ± 30 per cent is considered extremely accurate. To take correct hand samples of the various products in these conditions is difficult and it would be helpful to know at which periods and intervals the samples were taken and if there was close agreement between these results.

Were the results of physical assays chemically checked periodically and was there no difficulty in estimating physically fine minerals of ilmenite-columbite, monazite-xenotime, especially in the subsieve sizes?

I found also in my experience of dressing columbite from alluvial ores by jigs that there is a great improvement in recovery when slimes are removed previously by hydrocyclones, but did any alteration in the water pressure, stroke and rev/min of the primary jigs improve the 30 per cent recovery?

It was disappointing to find no complete metallurgical balance of the circuit, as each consequent test on this experimental jig plant is not represented by subsequent capacity. It is, therefore, difficult to estimate the true losses in the plant as it varies considerably with capacities.

Table X shows a typical distribution of minerals on a Holman table when the table is overloaded. To produce over 90 per cent of recovery of columbite by a Holman table the following rates of feed on the table are recommended:

Majority of columbite + 100 mesh (B.S.)	2000 lb/hr.
Majority of columbite − 100 mesh + 170 mesh (B.S.) .	1500 lb/hr.
Majority of columbite − 170 mesh (B.S.)	1000 lb/hr.

Looking at Fig. 6 (p. 106) I would consider the coarse mineral from primary jigs (hutch 1 and 2 only) should be treated by jigs to make a final concentrate, while the concentrate from the rest of the primary jig hutches should be treated by the tables, thus improving the recovery of fine minerals, simplifying the flowsheet and lowering first costs of the relatively small-capacity plant. There should be no need for hydroclassifiers to treat the table feed as the hutch products from Pan American jigs are already classified.

Mr. Sutton's remark concerning 'an unlimited source of light (as in daylight)', it may be of interest to note that in Central Africa, on a midsummer day and at an altitude of 4000 ft with no cloud, the midday reading of a fully exposed photocell was 7 mA through a 1·5-ohm resistance. The illumination sources used during investigation were at least seven times as strong as anything which will be naturally encountered.

Mr. J. Cowan raises the aspect of reliability and suggests the use of an instrument working on 100–150 mA as a means of obtaining reliable operation. It should be noted that instruments at present in use as battery-operated detonator-testing ohmmeters employ moving-coil instruments having full-scale deflections of 10–20 mA. These instruments are normally cheap and have very poor damping, thin glass facings and the pointers have a large arc of movement. The movement chosen for the photocell ohmmeter was one which had proved its reliability in a field type of geiger counter. This type of counter had been used for two years underground without any trouble from the meters. The prototype was passed to the Mine Study Department at Nkana for underground tests and, after a fortnight's use, was returned to us in good condition, but with its bright shiny new appearance gone for ever. The comparative immunity to shock damage is attributed to: (*a*) the use of good quality instrument having high inherent damping; (*b*) the extremely heavy damping imposed by the bridge upon the movement. This damping resistance is never more than 100 ohms and is effectively a short circuit on the moving coil (sensitive and delicate galvanometers normally survive long journeys when transported with their movements short-circuited); (*c*) the restriction of the movement of the pointer to $\pm$ 15°; (*d*) the use of heavy perspex facing.

Performance Analyses of Screens, Hydrocyclones, Jigs and Tables used in Recovering Heavy Accessory Minerals from an Intensely Decomposed Granite on the Jos Plateau, Nigeria

F. A. WILLIAMS, B.Sc., MEMBER

Report of discussion at General Meeting of the Nigerian Section of the Institution held on 21st March, 1958, at the Plateau United Services Association Hall, Bukuru (Mr. H. Roberts in the Chair). Paper published in December, 1957, pp. 89–108

Mr. F. A. Williams, in presenting his paper for discussion, first drew attention to two of its limitations. The plant was designed and operated as a commercial production installation, not as a pilot plant. Thus the investigation was not as comprehensive as would have been possible with a pilot plant designed and operated to produce information rather than profit. The paper dealt with the sampling results and their interpretation but did not describe the engineering details of the plant.

Against that background he called attention to the value of the data from two points of view. The information could provide guidance in designing still better jig plants for treating decomposed columbite-bearing granite. It could also be used for guidance in designing jig plants to replace sluice boxes in alluvial mining with monitor and gravel pump.

It was fortunate that the first shore-based jig plant to be operated and systematically investigated on the Jos Plateau should have been used in the first instance for treating decomposed columbite-bearing granite, as that greatly simplified the sampling problems. There was no significant variation in values with depth and very little laterally within the area of the paddock. Furthermore, the system of excavation by DW 21 scraper loaders, dumping at the plant and finally bulldozing into the sump ensured a good mixing of the ore. Lastly, the pulp density and rate of water flow from the gravel pump could be kept more nearly constant than was usual in alluvial gravel pump mining. Therefore, samples of the various discharges taken for very short periods at different times were sufficiently in agreement for the results to be significant. That was important because, as had been said, the plant was built for commercial production, not as a pilot plant; there was no provision for automatic sampling. Fortunately, for reasons given, that handicap was not serious during the initial stages of developing the plant, but the higher the recovery, of course, the more difficult it became to improve it still further, which meant that performance analyses had to be made in more detail. Automatic sampling would be desirable for the future, even when investigating recoveries from decomposed granite.

The sampling in a jig plant in use for concentrating material pumped from a paddock on an alluvial lead would be much more difficult for several reasons. Head values ranged from a trace of extremely fine heavy mineral in the overburden to coarse rich values in the wash. Solids throughout varied from a minimum when undercutting the face to a maximum after a good fall; it also varied with the gradient of races to the sump. To obtain significant results from sampling an alluvial plant automatic sampling of the large volumes of jig tails and hydrocyclone overflows would be particularly desirable but it was not difficult to take regular samples of hutch products and even hydrocyclone underflows by hand. However, the accumulative representative samples would tend to be large. It was difficult to value such large samples expeditiously, but special equipment was being obtained to tackle the problem, including a two-deck wet screen, small Mono pumps and hydrocyclones, a wet sample splitter, a laboratory shaking table and a vacuum filter. Superpanners would still be used for checking the performance of that larger-scale sample valuation equipment, which would be used for the check valuation of alluvial bores also.

The Company had in the meantime used the performance analyses of unit processes for treating decomposed granite, as recorded in the paper, for guidance in the design engineering of jig plants for treating alluvium. Variables which had to be taken into account were whether or not some of the overburden was to be stripped; the amount, size and shape of the stone in the material to be pumped to the plant; its percentage of slime; the relative amounts of cassiterite and columbite and perhaps some other valuable mineral such as monazite; and finally screen analyses of those minerals. Methods of alluvial bore valuation in current use needed revision to provide those data in advance of plant design.

Mr. Williams thought it might be useful if he compared the performances of the various unit processes for working decomposed granite and alluvium. The all-in cost of alluvial-type methods of mining and gravity concentration, even when applied to decomposed granite, was only a few shillings per ton. That imposed severe limitations on the selection and elaboration of unit processes for inclusion in flowsheets intended to improve recoveries.

The fixed grizzly was only a temporary improvisation but it was reasonably satisfactory with the decomposed granite as that ore contained very little stone. The circulating load of stone and lumps of decomposed granite could be kept within bounds by hand sorting and trucking away the washed stone. Difficulties arose when they came to treat the wash from an alluvial lead containing a lot of flat ironstone. The wash had been excavated mechanically and transported to the plant by the Euclid fleet. The amount of grizzly oversize was too great for the hand-sorting and trucking system; the remainder had to be returned to the sump. Every few hours the plant had to be stopped while the accumulated stone was removed from the sump by hand labour. Stones up to ½ in. thick and up to 5 in. wide passed through the grizzly and caused excessive wear in the primary hydrocyclones, frequently blocking them. They also displaced the primary jig bedding. The difficulties were overcome by installing the ½-in Rod-deck Screen and three 3-mesh Symons V Screens, but then another difficulty arose—the gallonage exceeded the limit of the V Screen, which was about 600 gal/min. That difficulty was surmounted by converting the rod-deck undersize bin into a surge bin, the V screens then being fed through 7-in pipes fitted with rubber pinch valves to restrict the feed to less than 600 gal/min to each. The overflow of the surge bin joined the screen underflow. To avoid coarse tin reporting in the V-screen undersize it was advisable to have three sets of mesh available, say ¼-in, ⅜-in and ½-in, which could be fitted as required. For decomposed granite which contains no coarse columbite and only a little coarse cassiterite the ¼-in mesh could probably be used. With a finer feed the primary jigs could probably be adjusted in speed and stroke to make a higher recovery.

The next unit process to be considered was desliming with hydrocyclones. With decomposed granite, which contained only 50 per cent sand, the capacity of the four 12-in primary hydrocyclones was about sufficient for an average throughput of about 80 cu. yd/hr, which did not vary much. With alluvium ranging up to 80 per cent sand and throughput averaging about the same but varying up to about 110 cu. yd/hr, the four 12-in primary cyclones were obviously overloaded. Coarse cassiterite appeared in the overflows and not infrequently the hydrocyclones sanded up completely. It was intended to replace them by eight 10-in hydrocyclones. As a temporary measure the overflow of the primary hydrocyclones was piped direct to the old secondary hydrocyclones to take care of any poor functioning of the first separation, which illustrated how plant design must be varied to suit the type of material being treated. Provided the feed was adequately screened and the total capacity of the hydrocyclones was adequate, the performance of the primary hydrocyclones should approximate to that of the secondary hydrocyclones given in Table III of the paper (p. 95). The excellent recovery of heavy mineral would be noted, but as the underflow would still contain up to about 20 per cent of the original slime the economics of diluting and recycloning were worth considering for decomposed granite containing extremely fine mineral which tended to be carried over the jigs in suspension if the slime content of the water was appreciable.

The next unit process to be considered included the primary jigs which had not yet been systematically sampled. With efficient screening and desliming of the feed, recovery of heavy minerals in relation to grain size should approach the performance of the secondary jigs given in Table VI (p. 100). Each rake of primary jigs consisted of four hutches in series, each hutch 40 in. by 40 in. Table VI suggested that it might be worth while to use six in series for decomposed granite, as shown as an optimal feature in the proposed flowsheet, Fig. 6 (p. 106), the last two to be returned in closed circuit. For alluvium, which, as far as had been found, contained much less extremely fine heavy mineral, at least four hutches in series would be desirable, to take care of temporary overloading or malfunctioning. With the plant concentrating alluvial wash it was intended to take representative samples over several days to see what the average recovery was in each hutch. If the last two could safely be returned in closed circuit there would be the advantage of less sand to treat in the rest of the plant. When working decomposed granite ⅛-in by ½-in slotted screens were used in the primary jigs, but with alluvium it was found necessary to use 3/16-in by ½-in units to avoid an excessive build-up of coarse cassiterite.

Whether or not to use two or three stages of jigging in sequence was debatable. When designing the original plant for treating decomposed granite Mr. Punnett cautiously allowed for three stages of concentration in jigs, i.e. primary, secondary and clean-up. That caution was repaid as, later, it proved profitable to screen the secondary jig tails and table the screen undersize, but such tabling did not pay with alluvial wash. For an alluvial plant, therefore, it should be practicable to use only two stages of jig concentration, particularly if six hutches in series were used for the second stage, some being close-circuited. With a small jig plant handling a small yardage the quantity of hutch product from the primary jigs might even be small enough for concentration on a table, as at Bisichi.

The secondary jigs were mainly of interest in that their performance was investigated in detail. As mentioned already, it should be possible to bring the performance of primary jigs to nearly the same standard if the feed were first screened and well deslimed. Xenotime had a specific gravity of only 4·5 yet recovery was still over 90 per cent at 170 mesh. Jigs should, therefore, make a good recovery of monazite, which had a specific gravity of 5·1—i.e. less than columbite. There was probably a lot more monazite in alluvial deposits on the Plateau than was indicated by the recoveries made in sluice boxes.

The next unit process to consider was the clean-up jig. Table IV of the paper showed how close-circuiting to produce an almost sand-free high-grade concentrate from the first two hutches forced fine columbite into the tails, although the combination of clean-up jig and tables was excellent. It ensured the recovery of both coarse and fine heavy minerals as high-grade concentrates containing very little sand. The building up of an excessive circulating load of heavy mineral of intermediate grainsize was prevented by bleeding off the product of the fourth hutch periodically, as shown by the flowsheets in the paper. When treating decomposed granite which contained only 50 per cent sand the two Holman tables could easily handle the clean-up jig tails, but with alluvium containing up to 80 per cent sand the amount of clean-up jig tails was often in excess of the table capacity. The fine heavy mineral circulating, which, of course, was less than when treating decomposed granite, was then bled out by tabling the lower hutch products. The jig tails were either returned to the secondary jig feed as a precaution against any appreciable loss or discharged direct to waste.

Another interesting unit process involved screening the secondary jig tails with a Symons V-screen fitted with 25 B.S. mesh. It was characteristic of all screens that some undersize was retained in the oversize discharge, especially grains only slightly smaller than the screen aperture; that was clearly shown in Table VIII (p. 101). Even the use of centrifugal force instead of gravity as in the V-screen could not eliminate that feature of plant-scale screening. The 25 B.S. mesh lasted about five weeks, which was satisfactory. However, the analysis of the secondary jig tails given in Table VII (p. 99) showed that screening at 52 B.S. mesh would be preferable in order to lighten the load on the tables. They had tried a 44 B.S. mesh but it wore through in a few hours. One with thicker wires might have lasted longer but the smaller percentage of open area would have reduced the screen capacity and necessitated using two or more screens; the cost might not be acceptable.

Finally, it was necessary to consider the performance of the four Holman tables used to concentrate the screen undersize from the secondary jig tails when working decomposed granite. They had kept the number of tables to a minimum because of their high capital cost when complete with a corrugated iron building to protect them from the sun and their high operating cost per ton of throughput as compared with jigs. Although fed at over 2000 lb/hr the recovery of cassiterite on the tables was excellent; nearly 100 per cent of it was recovered in the top strip cut. However, recovery of columbite at that rate of feed was disappointing, as shown by Table X (p. 104), although still payable. When treating alluvium there was not enough fine mineral present in the secondary jig tails to warrant using the tables.

It was rather surprising, he thought, that the Nigerian alluvial mining industry did not change over from sluice boxes to jigs in gravel-pump mining many years ago, especially in the 1930s when columbite began to become an important by-product mineral. The Australian mining company for which the speaker went to Malaya in 1927 already had a jig plant in use for alluvial mining with gravel pump and monitor. He thought that the failure of Nigeria to modernize its mineral saving practice earlier was probably due to there being too much mineral too easily won. It was not until they had demonstrated what could be achieved with jigs in recovering fine columbite and cassiterite from decomposed granite that the Nigerian industry became interested.

Mr. J. A. Bartnik, after reading the remarks he had already contributed in writing to the discussion in London,* added a few words about tabling. Table X (p. 104) showed that with the products tabled there was a better recovery of fine columbite than of coarse columbite. Tabling was a counter classification process and separated minerals into fine heavy flat particles and coarse light round particles, with the fine heavy particles farthest upstream; then came fine light and coarse heavy, followed by light coarse particles on the lower parts of the table. The water film velocity on the deck of a table was at a minimum near the deck and at a maximum near the top of the film, so that it was a function of the distance from the deck of the table.

The crosswise movement of a particle on a table was proportional to the square of the particle diameter and the forward movement of the particle on the table was proportional to the particle diameter raised to a power between 1 and 2. That was why separation by table of fine heavy particles from light coarse particles was a cleaner process than separating coarse heavy particles from coarse light particles.

Mr. R. N. Hammon† said he found it interesting to follow the progressive steps towards the final flowsheet. With the tables giving mineral recoveries at various sizes and stages the paper could become a textbook for operators on the minesfield as the results should be widely applicable, though the treatment problem which had been solved was rather different from that confronting most other operators. The Harwell plant was treating ore from a very large and rich deposit and a fairly complicated and extensive installation was justified.

Where low-grade alluvial deposits were being mined a simple and readily transportable plant was necessary if long-distance pumping was to be avoided.

The Bisichi Company had developed a flowsheet (Fig. A overleaf) to meet that requirement, giving satisfactory results in three units which had been in operation for some months.

*p. 357.

†General Manager, Bisichi Tin Co. (Nigeria), Ltd.

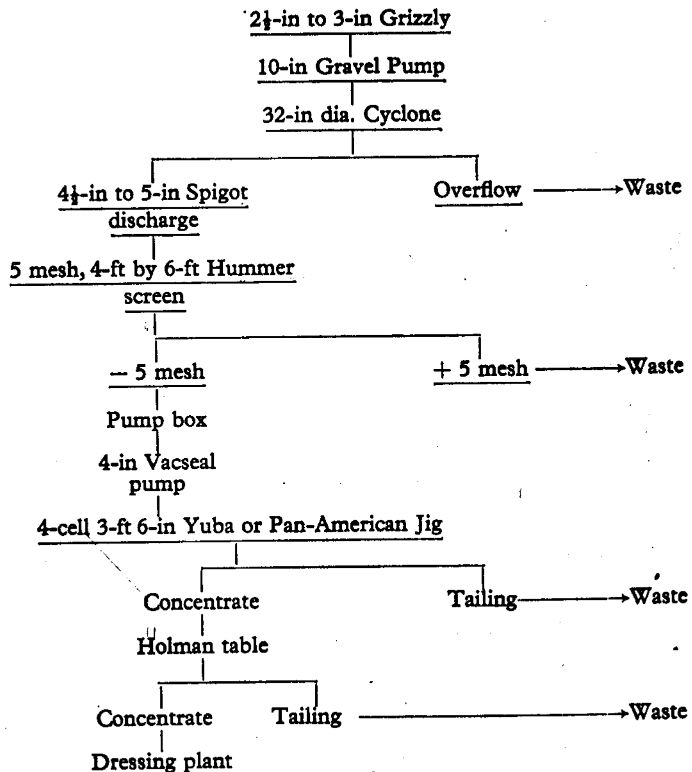

Fig. A.

Mr. L. O'N. Thomson commented on two features—recirculation and tabling. With the principle in mind that a build-up of recirculating heavy minerals tended to force valuable fines over both jigs and tables, the author had arranged for elimination of fine heavy minerals from the circuit progressively. In each of the flowsheets it was bled periodically from the fourth hutch of the clean-up jig, while in Stage 3 the clean-up jig tails, and in Stage 4 the secondary jig tails, were scalped by tables. As the efficiency of the tables was not high, the proposed Stage 5 provided for complete discard of the secondary jig tails after retabling the table middlings, but the clean-up jig tails were still to be recirculated after a mild scalping.

It was conceded that the economic limit of tailings and middlings retreatment often enforced recirculation as an alternative, and also that the low-grade clean-up jig tails were not a formidable recirculating load, but their discard by improvement in tabling or by other means was worth considering in conjunction with a general revision of the tabling circuits.

The data in Table X (p. 104) provided a valuable basis of discussion. It was known that the tables were overloaded, and also that classification

would have improved recovery. Those conditions called for excess of both turbulence and wash water.

Table IX (p. 103) showed the feed to be of the fine-heavy/coarse-light variety, but the size range was far too wide and the predominance of ultra-fines tended to render it voidless. A sedimentation analysis would probably illustrate its unsuitability for tabling. A concentrating table must be able to effect stratification and rough desliming before the heavy mineral was dispersed, and such a feed gave it little opportunity to do so.

Table X revealed what might be expected: Cut 1 was predominantly fines, but the concentrate was dirty, while concentration in Cuts 2 and 3 was poor; belated counter-classification appeared in Cuts 3, 4 and 5, in which the predominance of heavy mineral was fine, medium and coarse respectively, with the result that the distribution peak over the whole size range (28·1 per cent of the columbite and 30·5 per cent of the zircon) congregated at the 'middling corner' (Cut 4); the remaining 12·1 per cent of the columbite and 11·4 per cent of the zircon, mainly coarse, reached Cut 5 and only 0·9 per cent and 1·8 per cent respectively passed that zone. The table was obviously capable of better performance under more favourable conditions.

Vortex-type classifiers fitted in the table-feed launder would be relatively inexpensive. They would not only improve recovery on the existing tables but also allow the use of different deck types for the various classifications. In the sand range, say + 170 mesh, experiments could be tried with dummy decks using variations such as those recommended by F. B. Michell, which included sloping-sided riffles to reduce agitation, and wider spacing and the addition of pooling riffles for the finer fractions.

From Table IX it appeared that the final overflow at about –170 mesh would be a suitable feed, of about the right quantity, for a slime table. The remainder, spread over the other three tables, would still cause overloading on at least one of them, but the pooling of all tables into one circuit for the combined secondary and clean-up jig tails, possibly with the addition of one more table, might permit a balance of distribution with middlings re-tabled and most, if not all, of the tails discarded.

In the plant under discussion, zircon, xenotime, etc., were also commercial products, separated, mainly electrostatically, at the dry-dressing plant. Many other operators exported only the cassiterite, columbite and occasionally monazite, and from their point of view the behaviour of the zircon on the table was of great interest. Possibly because the tabularity of the columbite compensated for the moderate difference in specific gravity between it and the equidimensional zircon, the zircon slavishly followed the columbite to the extent that the percentages of total mineral recovered as far as Cut 4 are 87·8 for columbite and 88·6 for zircon. Though zircon in other parts of the minesfield varied considerably in character, ranging even to acicular, it was obvious that in tabling columbite (*a*) the lighter-coloured zircon was a useful indicator for control purposes, and (*b*) it was necessary to accept a columbite-zircon concentrate and to resort to either electrostatic or magnetic methods for final separation.

Mr. F. A. Williams, in a brief reply, acknowledged the speakers' contributions and the value of the discussion. He agreed that with a suitably classified feed at not too high a rate of throughput, tables should make a better recovery of very fine columbite than jigs. However, the relatively high capital cost and operating cost of classification and tabling had to be taken into account, and the system described in the paper made the best possible use of jigs, was relatively cheap and was particularly suitable for dealing with a large tonnage throughput.

AUTHOR'S REPLY TO LONDON DISCUSSION*

Mr. F. A. Williams: I wish to thank Dr. G. A. Schnellmann for introducing the paper, and the several contributors to the discussion.

Mr. D. G. Armstrong queried our decision to use jigs in spite of the fineness of the columbite shown by Table I (p. 91). In the proposed flow-sheet, Fig. 6 (p. 106), by far the greater part of the recovery would be made at low cost by screens, hydrocyclones, and jigs, in sequence. The high recovery made by hydrocyclones and jigs is at once apparent from Tables III and VI (pp. 95 and 99). The range of grain sizes of heavy minerals which can be effectively recovered in jigs needs to be more widely known. The margin for additional recovery by tabling is relatively small and the cost considerably higher. A 4-hutch jig requires only 3 h.p. but has a capacity of up to 20 tons per hour, can be operated in the open and requires a minimum of attention. Direct-driven tables require a 1·5-h.p. motor, have a capacity of only 0·5 to 1·0 tons per hour, need to be roofed over and their operation has to be more closely watched. So considerable restraint had to be exercised in adding tables to the flowsheet to improve recovery, let alone classifiers ahead of them.

As mentioned in the paper, the plant had to be improvised from equipment and material available on the property. It was perhaps fortunate that we had a supply of jigs but only two spare tables and no classifiers. It limited us to designing a plant which would have a large throughput and low operating cost.

I agree with Mr. Michell that better classification ahead of the tables should improve recovery. I also agree with Mr. Bartnik that lower rates of feed should likewise improve recovery. But with the economic limit of recovery well in mind we decided to try tabling the second jig tails with only the type and degree of classification resulting from the jigging and screening and at rates of feed of about a ton an hour. This proved satisfactory for the recovery of cassiterite, which was nearly 100 per cent in the top cut alone. But the recovery of columbite proved to be only 40 per cent in that cut or 50 per cent in the acceptable cuts 1 and 2 combined. In the proposed flowsheet Fig. 6 we have allowed for retabling the table middlings. The addition of classifiers and yet more tables might overstep the economic limit of recovery, particularly when the extra amount of water in circulation is taken into account. This type of plant is very flexible. It can be kept fairly simple or it can be elaborated by adding more tables with or without additional classifiers according to the grade of the ore and the realization value of the products. It is soundly based on the reasonable recovery and low operating cost of the sequence—screens, hydrocyclones, jigs.

*pp. 351–357.

Mr. Rabone wanted to know the types and sizes of the various items of equipment. The Holman tables used were their full-size sand tables. The screen area of each jig hutch is 40 in. by 40 in. The dimensions of the primary and secondary hydrocyclones which were designed and fabricated on the mine are

	Primary	Secondary
Diameter	12 in.	10 in.
Length of barrel	4 ft 7½ in.	4 ft 1½ in.
Angle	10°	10°
Inlet diameter	4 in.	3 in.
Spigot diameter	3 in.	2½ in.
Vortex finder length	12¾ in.	12¾ in.
diameter	5½ in.	4½ in.

I quite agree with Mr. Armstrong that the peak in cut 4 is the product of the grade and quantity of the discharge over that length. What I wanted to emphasize is the large amount of columbite reporting so low down the table. The big deterioration in table performance from nearly 100 per cent in cut 1 for cassiterite (sp. gr. 7·0) to the figures revealed for columbite (sp. gr. 5·5) was disappointing. This result turned our ideas for the future away from large-capacity classifiers and a multiplicity of tables back to trying to extend low-cost recovery in jigs more effectively to finer grain sizes by more efficient pre-screening and desliming, by using more hutches in series, and by closed circuiting.

In response to two requests for more information on the performance of the hydrocyclones, I now submit Table IIIA for the battery of four 10-in secondary hydrocyclones. This records in full the data used to calculate the simplified presentation of performance given in Table III of the paper (p. 95).

Mr. Michell asked for information about the performance of the 12-in primary hydrocyclones. These were not sampled. Their efficiency at stage 2–4 of plant development with improvised and poor pre-screening was not of permanent interest. Heavy minerals reporting in the primary hydrocyclone overflow were very effectively recovered in the secondary hydrocyclones as shown by Table III. It is hoped that, with the proposed flowsheet Fig. 6 (p. 106) in which the feed would be screened at ½ in. before cycloning, the recovery efficiency of an adequate number of primary hydrocyclones will prove to be about the same as recorded for the