IA and IIA, could of course be generalized for the purpose of estimating the recovery of composite grains in the specific gravity range 7·0 to 3·5. This contention is illustrated by Table VII now submitted showing the percentage composition and specific gravity of some composite grains, one set of data for cassiterite and quartz and the other for gold and quartz. This table suggests that greater use should be made of jigs in both the crushing and grinding circuits of many mills to recover rich middlings products for separate treatment. *Modern jigs could eliminate strakes from most of those gold mills in which they still survive and reduce overgrinding in tin mills.* This contention receives support from Mr. Rabone's contribution to the discussion.

TABLE VII.—*Composition and Specific Gravity of Some Composite Grains*

Proportions by volume		Specific Gravity
Cassiterite	Quartz	
%	%	
100	—	7·0
90	10	6·6
80	20	6·1
70	30	5·7
60	40	5·1
50	50	4·8
40	60	4·4
30	70	4·0
20	80	3·5
Gold*	Quartz	
%	%	
30	70	7·3
25	75	6·5
20	80	5·7
15	85	4·9
10	90	4·2
9	91	4·0
8	92	3·9
7	93	3·7
6	94	3·6
5	95	3·4

As stated in the paper research work on the subsequent mineral dressing of the jig concentrates was outside its scope. However, brief mention was made of the fact that the electrical conductivity and magnetic permeability of some minerals could be changed by heat (p. 171). In his contribution to the discussion Mr. Andrews enlarged on the heat treatment of ilmenite to change its magnetic permeability, and an additional contribution on this subject was submitted by Mr. R. N. Hammon. A paper dealing,

*Native gold, sp. gr. range 15·6–19·3 (Dana)—assume sp. gr. 18·0.

inter alia, with changes in the electrical conductivity of orangite and zircon induced by moderate heat, will be published in the *Transactions*.

I was surprised that Mr. P. Rabone should have said that he had never seen the Harz jig used successfully on unclassified feed. Actually Harz jigs were the only type used on tin dredges in Malaya for about fifteen years and were very successful. The classifiers installed on some of the earlier dredges were soon discarded as they were found to be unnecessary. In those days I had made similar performance analyses of Harz jigs on dredges, and the recovery efficiencies do not differ materially from those obtained in recent years with diaphragm jigs. Mr. F. B. Michell's appreciative remarks about Harz jigs are interesting in this connexion. The big advantage of diaphragm jigs over the Harz type is that the former occupy much less space for a given throughput. Choice between the different makes of simple diaphragm jigs can be based only on those engineering details which determine capital cost, maintenance cost, running time and ease of adjustment. The mineral saving efficiencies of Yuba, Pan-American and Bendelari jigs must be substantially the same, but for purely engineering reasons the Yuba jig has become the most popular type in Nigeria.

Mr. Rabone refers to the Denver type of diaphragm jig which is provided with a special valve admitting a pulse of water to modify the suction stroke. This type has been tried out by two companies on the Jos Plateau with very disappointing results. In fact, better results were obtained when this valve was removed and the jig converted to a simple diaphragm type. The Denver type of jig also occupies too much space for the rate of throughput.

Dr. Wrobel asked about the effect of shape on recovery. It has a very pronounced effect as Mr. F. B. Michell has stressed. If Dr. Wrobel will compare the percentage recoveries of columbite and xenotime in Table VI (p. 100) of the previous paper, also those for columbite and zircon in Tables I and II (pp. 168 and 169) of the present paper, and Tables IA and IIA (in the current discussion), he will note that the recovery of columbite differs very little from that of xenotime or zircon. But the columbite has a specific gravity of 5·5 while that of both the xenotime and the zircon is only 4·5. The recovery of columbite is well below interpolated figures based on the results for cassiterite and either xenotime or zircon. The relatively poor recovery of columbite is due to its unfavourable shape which is platy and acicular while the xenotime, zircon and cassiterite are all three substantially equant. It would be possible, but rather laborious, to make a statistical analysis of the shapes of any of those minerals and correlate it with results obtained in recovery tests in jigs.

In regard to Dr. Wrobel's other questions, the thickness of sand above the ragging varied between about 1 and 3 in. The ragging was changed about once a week. The figures given for rates of feed refer to solids only. The total water rate to each rake of jigs was not measured.

Mr. D. G. Armstrong used the figure 2400 lb to a cubic yard. That was the figure used originally for the decomposed granite. The figure for this alluvial wash, which was heavily iron stained and partly cemented by iron oxides, would be at least 3000 lb dry weight to a cubic yard. At that factor the figures given in the paper balance.

In talking about the use of cyclones on dredges Mr. Michell mentioned that the underflow from the secondary cyclones did not jig very well. In the plant as described in the previous paper this difficulty was overcome by mixing the underflow of the secondary cyclones with the hutch products of the primary jigs and feeding this mixture via a cyclone to the secondary jigs where a worthwhile recovery of very fine cassiterite was made cheaply (see Fig. 2, p. 96, and Table VI, p. 100, of the previous paper). Recovery of fine cassiterite could be most cheaply improved by using six instead of four cells in series. Mr. Michell's scheme for inserting a screen midway in the four-cell operation would cost more to run if there was insufficient head for a gravity feed from the first pair through the screen to the second pair and an additional pump had to be installed. It is therefore open to doubt whether the additional recovery compared with six cells in series would be profitable.

I do not altogether agree with Mr. Michell that it is not feasible to employ tables on a dredge. There is normally some unused deck space aft sufficient for several tables. They could be inserted in the closed circuit of the cleaner jigs as was done later in the shore-based plant described in the paper (see improved flowsheet Fig. 1A (p. 437)). In that position in the flowsheet the performance of tables is not critical. It suffices that they withdraw an appreciable amount of fine cassiterite from the closed circuit to reduce the amount passing to the jig tailing in repeated passages through the jig. At the same time the circulating load of semi-heavy minerals can be reduced by withdrawing a table middling. I would also commend this idea to Mr. J. H. Harris and Mr. I. R. M. Chaston.

It is interesting that results of their research on the removal of slimes and excess water from the pulp fed to jigs agree with Nigerian experience that this practice improves recovery in the jigs. Their successful use of *low pressure* cyclones ahead of jigs in gravel-pump mining in Malaya parallels that of Bisichi Tin Co. (Nigeria), Ltd., in Nigeria. The type of flowsheet used by Bisichi has been published.* The high-pressure cyclones ahead of the primary jigs shown in the flowsheet (Fig. 1, p. 165) in the paper under discussion are a legacy of the past. They wear rapidly and are costly to maintain by welding. Consideration is therefore being given to carrying out some experiments with low-pressure cyclones.

The success of the combination of cyclones and jigs in recovering fine heavy mineral has created a need for better methods of alluvial bore valuation. Mr. Harris and Mr. Chaston found that jigs treating cyclone underflow recovered fine cassiterite not recovered in normal bore samplings.† Our experience in Nigeria has been the same, with the additional problem that alluvial bores had hitherto not been individually valued for columbite. Just before I retired from Nigeria I introduced cycloning and tabling into alluvial bore valuation procedure there. A 3-in cyclone and a small Mono pump were mounted on a Land Rover and the pump driven from the rear power take-off. The bore samples were first deslimed and the washed sands panned as hitherto. The slimes were then pumped through the cyclone. The underflow was diluted with the water used for panning and pumped through the cyclone a second time. The final cyclone underflow was mixed with the sand tailing from panning and sent to the laboratory. Here it was concentrated three times on a Holman half-size sand-table and the final heading cleaned up on a super-panner. Field and laboratory concentrates were valued separately. The latter yielded a considerable addition to the field recovery, particularly in the case of columbite. Screen analyses of cassiterite and columbite recovered by field panning and in the laboratory were also recorded. These are needed for calculating the values recoverable in jig plants of varying design, incorporating two, four or even six cells in series, both with and without some tables. The laboratory procedure could, if required, be modified to include valuations in terms of other heavy and semi-heavy minerals present, e.g. monazite and anatase, but this would slow up the rate of throughput of samples considerably. Under Malayan conditions, where most frequently the bore sites would be inaccessible to even a Land Rover, a small portable petrol-driven pump should prove suitable for feeding the cyclone.

*Trans. vol. 67, pp. 563–564.
†See reference p. 432.

I must take Mr. Harris and Mr. Chaston to task for valuing their samples by direct chemical assaying. When, as in that case, the valuable mineral is heavy and free, it should always be separated in the form of a crude gravity concentrate which should then preferably be physically assayed by micro mineral dressing and grain counting. *This procedure often reveals the unexpected which is the quintessence of good research planning.* For our research work on cyclones, jigs and tables we could have used direct chemical assaying to value the samples in terms of the two known economic minerals cassiterite and columbite. But we would then have remained unaware of the presence of a number of economically interesting minerals including orangite, xenotime, monazite and anatase. Ore dressers, and particularly those engaged in research, should always remain acutely aware of the fact that, in most cases, they are dealing directly with minerals and only indirectly with the elements contained in those minerals. In the interests of speed and cheapness chemical assaying is often necessary for valuing mill control samples but it should be avoided whenever possible in ore testing and in ore dressing research and the samples should be valued by concentration, micro mineral dressing and grain counting. The author and his team, who were all geologists, applied to ore dressing research methods of fragmental petrography originally developed for the analysis of incoherent intensely decomposed igneous rocks and ores.

From purely theoretical reasoning about jigging action Mr. Harris and Mr. Chaston conclude that there will be a middle-size range of heavy minerals which will be mainly rejected from a jig operated under given conditions no matter how many times the jigging may be repeated. Their conclusion would appear to be disproved by the sampling results which

I have submitted in Tables IA and IIA. Incidentally these later tables were based on timed samples of the tailings as well as the hutch products. They refer to another plant where the tailings discharge had been made accessible for sampling. From Tables IA and IIA, and Tables IV and V for the clean-up jig of the plant described in the paper, the following conclusions can be drawn:

(1) For minerals with a specific gravity higher than that of the ragging the percentage recovery will be highest for the coarsest sizes and will diminish progressively with decreasing size.

(2) For minerals with a specific gravity lower than that of the ragging the percentage recovery will be highest for some intermediate size and will decrease for sizes both coarser and finer than this.

I support Mr. Harris and Mr. Chaston in their advocacy of short primary jigs followed by screens. The function of the primary jigs is then only to prepare the feed for screening so that the usual amount of undersize discharged with the oversize from a screen does not then contain any appreciable amount of cassiterite. The screen undersize and the jig hutch products could be combined, pumped through a hydrocyclone and the undersize fed to jigs. That these secondary jigs would give a better recovery, particularly in the finer sizes, is indicated by comparing the results for secondary jigs given in my previous paper with those for primary jigs contained in the paper under discussion, supported by results for primary jigs in another plant (Tables IA, IIA). Incidentally, performance analyses of a Symons V-screen at 25 B.S. mesh given in Table VIII of the previous paper (p. 101) is of interest in this connexion. The 25 B.S. mesh wire screen lasted for 200 hours running time, which is considered to be satisfactory.

Mr. J. A. Bartnik asked a number of questions to some of which answers can be supplied. The ratio of concentration was not determined because of the absence of a tailing sample. Had the tailing discharges of all the jigs been accessible for taking timed samples of the total outflows they would of course have been sampled. The jig screens were usually thoroughly cleaned about once a week but scraped when necessary during the week. Variations in the rate, composition and grade of feed may have caused some losses in the primary cyclone overflow but, as already stated, these small high-pressure cyclones are a legacy of the past. Subject to the results of experimentation yet to be carried out, they may perhaps be replaced by larger lower-pressure cyclones if and when the plant is reconstructed. Extreme variation in the value of the feed is one of the reasons why I advocate the use of six cells in series. The loss of, say, 10 per cent from an alluvial wash containing only about 1 lb of cassiterite per cubic yard is not serious but it represents an appreciable amount when, as may occur when races are being blown in, the value of the feed is over 100 lb of cassiterite per ton of sand.

Some Further Factors Affecting Percussive Drilling Performance and their Influence on the Size Distribution of the Cuttings

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Author's reply to discussion on paper published in November, 1958, pp. 37–51*

Dr. E. W. Inett: Discussing the first of Mr. Fish's points, I would agree with him that the size of debris *might* not necessarily reflect operational efficiency in percussive drilling. He has inferred (and quite rightly so) that many other factors must be considered. However, in no circumstances would I even consider attempting to ascertain the relative drilling efficiencies of two very different drilling methods by an assessment of debris size. Furthermore, even within the scope of the same drilling system, a debris analysis cannot be regarded as a guide to overall efficiency. For instance, it has been shown that increased penetration rates can be obtained by either of two methods with percussive drilling. Fig. 2 (p. 41) illustrates that increased thrusts increase the rate, while Fig. 4 (p. 42) illustrates that higher operating air pressures also increase it. Figs. 3 and 5 (pp. 41, 43) respectively show that in the first instance a reduction in the size content results, while in the second instance, a larger product results. However, when all operating factors (air pressure, thrust, rod length and size of hole drilled) are substantially constant and the only variable is the mode or degree of flushing, the efficiency of any system will probably be reflected in the size of the cuttings.

Mr. Fish's second point regarding the quantity of flushing water is quite important. I have no excuse to offer, other than that of lack of time, for not fully investigating the influence of a varying quantity of water flush on debris size. In our earlier paper† Dr. W. R. Cheetham and I reported the results of an investigation of the effect of water flush on penetration rate. Fig. 18 (p. 71 of that paper) showed the effect of quantity of water on the penetration rate. This relationship determined the basis of the quantity of water flow for the tests now under discussion. Sufficient water was applied to ensure maximum efficiency.

I thank Mr. Teale for his very thoughtful contribution. I would suggest that the reasons for the inaccuracies of the conclusions drawn by Ertl and Burgh are the lack of adequate control they had over the operational variables and a failure to appreciate the full effect of these variables on penetration rate.

Mr. Baldwin Davies asks about the test constants. The constants were the same as reported in the first paper, i.e. for a constant thrust, the air pressure was 87 lb/sq. in and for the constant air pressures, the thrusts were 108 lb. I have dealt above with the question of water pressure. While

*pp. 151–158 and 279–281.
†*Trans. Instn Min. Metall., Lond.*, **63**, 1953–54, 45–74.