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THE DESIGN, CONSTRUCTION AND TESTING OF A SIMPLE SHAKING TABLE FOR GOLD RECOVERY: LABORATORY TESTING AND FIELD TRIALS

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Field trials using the BGS shaking table in the Philippines

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THE DESIGN CONSTRUCTION AND TESTING OF A SIMPLE SHAKING TABLE FOR GOLD RECOVERY: LABORATORY TESTING AND FIELD TRIALS

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EXECUTIVE SUMMARY

One of the objectives of DFID / BGS Technology Development Research (TDR) project R6226 " Mitigation of mining-related mercury pollution hazards", was to provide improved methods for gold recovery for small scale miners to replace mercury amalgamation. Previous work carried out for this project indicated that the most appropriate method of recovering fine-grained gold is through the use of a shaking table type of gravity separator (Mitchell et al, 1997). Shaking tables are one of the most environmentally friendly methods of mineral processing as the only reagent used is water. Shaking tables are widely used in commercial mines but have found little use by small-scale miners due to their relatively high cost. The purpose of this phase of the project was to design, construct and test a cheap, simple shaking table that could be produced for use by small-scale miners in developing countries.

A set of test samples of gold ores and tailings from processing had been collected from small-scale mines on a previous visit to the Philippines. Laboratory characterisation of these samples established the gold content of the ores and tailings and grain size distribution of gold within the samples. The assays showed that ores varied from 12 to 96 grams/ton (for one very rich ore) and the tailings from 9 to 25 grams/ton, which is higher grade than ore material in many other areas. The grain size measurements showed that they contained dominantly fine-grained gold with one of the main samples studied having 60% <63µm. References in the literature suggest that shaking tables are only effective on grain sizes down to about 50µm.

A series of mineral separation and gold recovery tests were carried out in the laboratory using a commercially produced, laboratory scale Wilfley table (a type of shaking table). The high-grade ore from Acupan contained mainly fine-grained gold and a recovery of only 20% of the gold was achieved. In contrast the lower grade ore from Kias contained slightly coarser gold and a recovery of nearly 80% was achieved.

A simple, shaking table was designed and constructed of cheap materials that are available in developing countries and has a drive mechanism using bicycle gears and

chains and rubber bands made from car tyre inner tubes. A hand crank powers the drive mechanism of this prototype but it can readily be modified to be powered by a bicycle, motor cycle or a motor, either electric or diesel. Its design was particularly aimed at the recovery of fine-grained gold. Laboratory trials showed that for the separation of fine-grained gold, this simple table was as good as and probably slightly more effective than the commercial Wilfley table.

The laboratory trials had been carried out in almost perfect conditions; the samples were washed and deslimed prior to tests, the table was set up on large flat benches and a well controlled, even pressure water supply was available. It was important to ascertain whether similar good results could be obtained in the far from ideal setting of a small scale mine. The BGS shaking table was taken to the Philippines and field trials were carried out in collaboration with the Mines and Geosciences Bureau. The trials were held at Kias Creek and Acupan Benquet mine in the Baguio mining district, the area from which the test samples had been collected. Trials at Kias Creek were very successful; the table was easily set up and adjusted to a stable configuration and heavy mineral concentrates were readily recovered. Field examination with a hand lens showed that considerable amounts of fine-grained gold had been recovered from the tailings that had previously been processed by the miners' normal methods. Subsequent laboratory examination revealed that the effectiveness of the simple table was quite remarkable as most of the gold was only around 40μm in size and grains as small as 10μm had been recovered.

Trials at Acupan were problematical and it was far more difficult to set up the table in a stable configuration. This revealed shortcomings in the design of the prototype apparatus and gave valuable information for simple modifications that should make it more adaptable. Heavy concentrates were collected but with more difficulty than at Kias. Laboratory examination of the concentrates showed that despite the difficulties significant amounts of gold had been recovered from ores and tailings and again substantial amounts were very fine-grained around 30μm in size.

The field trials demonstrated that the simple shaking table is an effective apparatus for the recovery of fine-grained gold. Its use is more difficult in adverse conditions where material to be processed is muddy, stability is a problem and water pressure is variable. The staff of MGB who took part in the trials and the small-scale miners were impressed by the table's simple construction and effective performance. The miners were very interested in such an apparatus as an alternative to cyanidation of their tailings if it were available at an appropriate price. The table has been donated to MGB for further trials, demonstrations, development and possible local manufacture. This is particularly in areas where mercury use is widespread and environmental benefits would be greatest.

It has been demonstrated that a simple shaking table is an environmentally friendly method of recovering fine-grained gold. It could have a significant role in the reduction of the use of mercury by small-scale miners by providing them with an alternative to mercury amalgamation for gold recovery.

1. INTRODUCTION

This report outlines the development and laboratory and field testing of a shaking table gravity separator. The aim of this work was to construct a simple device, using technology appropriate for less developed countries, for the recovery of fine-grained gold (<100 µm) from alluvial deposits or crushed bed rock ore. This device would be, to a large extent, an alternative to the environmentally damaging use of mercury for gold recovery. This work has been carried out as part of DFID / BGS Technology Development Research (TDR) project R6226 " Mitigation of mining-related mercury pollution hazards".

Previous work carried out for this project indicated that the most appropriate method of recovering fine-grained gold is through the use of a shaking table type gravity separator (Mitchell et al, 1997). Shaking tables are one of the commonest forms of gravity separators in use and are the most environmentally friendly as they only use water as a processing reagent. They consist of a flat 'deck' with parallel riffles that 'trap' gold and when the deck is vibrated longitudinally, with an 'end-knock', a heavy mineral concentrate is separated from the lighter components. The feed is introduced as a slurry, along with wash water, from the upslope side. The 'end-knock' encourages heavy minerals to migrate along the riffles to the end of the deck and light minerals are washed over the riffles to the downslope side of the deck. Shaking tables are effective in the processing of material in the size range 3 mm to around 50 µm and are capable of recovering up to 90 wt% of gold present in this size range but can also be used for finer material but with reduced efficiency.

In the absence of shaking tables, sluice boxes are the most commonly used means of recovering gold from alluvial gravels and crushed ores in less developed countries. Efficiently operated sluices can achieve gold recoveries of up to 80 wt%, whereas the makeshift sluices operated by small-scale miners recover less than 50 wt%. These low gold recoveries are in part related to the particle-size of the gold. Gold finer than 200 µm will invariably be lost to the tailings. Other factors leading to poor recoveries include inappropriate sluice box design & operation, high feed and wash water rates and long time intervals between riffle clean out to remove accumulated heavy minerals.

The recommendations of the previous report (Mitchell *et al.*, 1997) focus upon enhancing the recovery of gold coarser than 50 µm (gold finer than 50 µm is best recovered using chemical treatment methods). The recommendations were as follows:

i) Wet screening to remove material coarser than 500 µm (which should be passed over a sluice box to recover gold coarser than 500 µm).
ii) Material finer than 500 µm to be passed over a second sluice, to recover gold coarser than 200 µm.
iii) Tailings from stage ii) to be wet screened to remove material coarser than 200 µm (ideally free of gold) and then passed over a shaking table (to recover gold down to 50 µm).
NB The shaking table constructed as part of this work was designed to be used in stage iii) of this recommended gold recovery scheme.

A set of samples collected from the Philippines was first characterised and then used as test material for the shaking tables.

2. CHARACTERISATION OF GOLD-BEARING SAMPLES

2.1. Samples

Several samples, of gold-bearing material, were collected during a visit to the Philippines (Williams, 1997). These samples were used to evaluate the performance of the BGS-designed shaking table. Sample locality details are given in Table 1. A flowsheet detailing the characterisation and preparation for mineral processing is given in Figure 1.

2.2. Methods for determination of gold assay and mineralogy

The gold assay of the samples was determined by chemical analysis. Assay was conducted by Acme Analytical Laboratories Ltd (Vancouver, Canada) using a classical lead-collection fire assay method. Gold concentrations are determined by Inductively Coupled Plasma (ICP) analysis, with gold levels greater than 1 troy oz per short ton (equivalent to 34.3 grams per tonne) determined by gravimetric analysis. The gold content of products too small for chemical analysis (less than 8 grams in weight) was determined by visual estimation. The small concentrates were generally fine-grained and were carefully examined under a binocular microscope and the proportion of gold (volume %) was estimated by comparison with standard area % diagrams, such as are used during petrographic analyses. The figure quoted consists of an overall estimate of several fields of view of the microscope, as the gold abundance varies considerably within the sample due to the panning effect from swirling in the petri dish to spread the sample out. This method produces only a very approximate estimate of the gold content but to achieve the greatest consistency possible the examination of all samples were studied together by an experienced microscopist in a single session. The gold contents determined this way are probably within +/- 15 wt% of the true values. Photomicrographs of the gold concentrate produced are shown in the Figures for section 5 covering the field trials.

Bulk mineralogy was determined by X-ray diffraction (XRD) using a Phillips PW 1700 X-ray diffractometer operating at 45 kV and 40 mA. Sub-samples, of the 'as received' material, were ground and back loaded into an aluminium holder. The samples were scanned over an angular range of 2 to 50°2θ using Co-Kα radiation. The X-ray diffraction peaks were interpreted with reference to the JCPDS database to identify the peaks observed.

Table 1. Gold-bearing samples, Luzon & Mindanao, Philippines

Sample No.	**Sample weight**	**Description**
Acupan Benguet Gold Operation (BGO) concession, Baguio, Luzon		
BG 1	8 kg	Ball- & rod-milled feed to felt-bed sluice
BG 2	~200 g	Tailings (from the processing of BG 1 using a sluice box)
BG 3	-	No sample
BG 4	~100 g	Unmilled feed chips
Kias Creek, Baguio, Luzon		
BG 5	4.5 kg	Milled ore (operation similar to Acupan)
BG 6	1.6 kg	Tailings (from the processing of BG 5 using a sluice box)
BG 7	3.5 kg	Milled ore from panning / amalgamation operation
Gango, Cagayan de Oro, Mindanao		
Sample 1	6.5 kg	Hand-crushed rock, Edgar Quines Sr. tunnel
Sample 2	11 kg	Hand-crushed rock, Macanim tunnel

2.3. Gold assay & mineralogy

The gold assay and mineralogy of the 'as received' material is given in Table 2. The samples from the Acupan Benguet operation contain high gold contents, up to 97 grams per tonne (BG 1). The 'gangue' is dominated by quartz, with a minor amount of pyrite plus a trace of anglesite ($PbSO_4$) or dolomite. The samples from Kias Creek contain lower gold contents, up to 12 grams per tonne (BG 5). The 'gangue' is dominated by quartz, with a minor amount of pyrite plus trace amounts of albite, chlorite, ? dolomite & ? mica. The samples from Gango contain up to 13 grams per tonne gold (sample 1). The 'gangue' is dominated by quartz, with significant amounts of dolomite and pyrite, plus trace amounts of chlorite and mica.

Table 2. Gold assay & mineralogy of gold-bearing samples 'as received', Philippines

Sample	Sample description	Gold assay (g/t)	Mineralogy
Acupan Benguet Gold Operation (BGO) concession, Baguio, Luzon			
BG 1	Milled sluice feed	96.7	Quartz ****, pyrite **, anglesite *
BG 2	Tailings from BG 1	25.4	Quartz ****, pyrite *, anglesite *
BG 4	Unmilled feed chips	46.4	Quartz ****, pyrite *, ? dolomite *
Kias Creek, Baguio, Luzon			
BG 5	Milled sluice feed	12.1	Quartz ****, pyrite **, chlorite **, albite *, ? dolomite *
BG 6	Tailings from BG 5	9.8	Quartz ****, albite *, chlorite *, pyrite *, ? dolomite *
BG 7	Milled feed	3.0	Quartz ****, ? albite *, ? mica *
Gango, Cagayan de Oro, Mindanao			
Sample 1	Crushed ore	12.6	Quartz ****, dolomite **, pyrite *, chlorite *, muscovite *
Sample 2	Crushed ore	8.6	Quartz ****, dolomite ***, pyrite **, chlorite *

N.B. g/t = grams per tonne. **** = dominant (>50 wt%), *** = major (20-50 wt%), ** = minor (7-20 wt%) and * = trace (<7 wt%).

3. PARTICLE-SIZE DISTRIBUTION OF GOLD-BEARING SAMPLES

3.1. Methods for determination of particle-size distribution

The particle-size distribution of the samples was determined by wet screening. Sub-samples were separated into five size fractions by wet screening using sieves with the following apertures: 1mm, 500 μm, 250 μm, 125 μm and 63 μm. The material retained on the sieves was dried and weighed. The size of the particles less than 63μm was determined by Micromeritics X-ray Sedigraph.

The particle-size distribution of the gold present in BG1 and BG5 was determined. The gold present in each of the size fractions was removed by concentration of the heavy minerals using a Superpanner (a laboratory panner form of gravity separator). The proportion of gold in the heavy mineral concentrates of each size fraction was determined by chemical assay.

3.2. Particle-size distribution (& gold particle-size distribution)

The particle-size distribution is expressed as size class weight percentages (Table 3) and as cumulative frequency size distribution curves (Figs. 2 to 4). The majority of particles present in the samples are finer than 500 μm. The samples have relatively 'normal' (i.e. gaussian) particle-size distributions, with up to 96% of particles between 500 and 10 μm in diameter. The mean particle size (d_{50} from cumulative frequency plots) ranges from 95 to 107 μm.

Table 3. Particle-size distribution of gold-bearing samples 'as received', Philippines

Size fraction	BG 1 wt %	BG 2 wt %	BG 5 wt %	BG 6 wt %	BG 7 wt %
Sample Description	Milled sluice feed	Tailings from BG1	Milled sluice feed	Tailings from BG5	Milled feed
+2 mm	0.00	0.00	0.00	0.00	1.85
-2+1 mm	0.00	0.00	0.00	0.05	0.05
-1 mm+500 μm	0.19	0.00	0.27	0.80	0.43
-500+250 μm	3.28	1.95	14.17	25.50	13.29
-250+125 μm	38.98	36.06	43.13	51.70	34.35
-125+63 μm	34.38	42.54	30.83	17.23	20.77
-63+10 μm	11.12	14.98	4.75	1.46	11.99
-10+2 μm	3.94	1.36	5.68	0.47	5.56
-2 μm	8.11	3.11	1.16	2.79	11.70
Total	100.00	100.00	100.00	100.00	100.00
Mean size (d_{50})	100 μm	95 μm	104 μm	107 μm	103 μm

NB Mean size(d_{50}) determined from cumulative frequency plots (Figures 2 - 4).

The particle-size distribution of the gold is expressed as size class weight percentages and as cumulative frequency size distribution curves (Fig. 5). Sample BG 1 contains a higher proportion of fine gold, with approximately 80% finer than 125 μm (compared to 70% in BG 5). A feature of importance to this study is that around 60% of the gold is less than 63μm, the size range where shaking tables are known to be towards the lower limit of their effective range and where separation starts to become inefficient.

Table 4. Particle-size distribution of gold in 'as received' samples BG 1 & BG 5, Philippines

Size fraction	BG 1 wt %	BG 5 wt %
Sample description	Milled sluice feed	Milled sluice feed
-1 mm +500 μm	0.00	0.00
-500 +250 μm	0.98	3.62
-250 +125 μm	19.21	26.06
-125 +63 μm	17.89	12.78
-63 μm	61.92	57.54
Total	100.00	100.00

4. MINERAL PROCESSING TRIALS

4.1. BGS-designed shaking table

The BGS-designed shaking table adopted technology appropriate for less developed countries, as outlined in the introduction. Therefore, the design was restricted to that of a traditional riffled-deck using widely available materials and a manual drive mechanism (Figure 1; Plates 1a & 1b; in operation Plates 2a & 2b). The frame, and supporting base, of the separator were constructed out of hard wood, with a Formica deck surface (slightly roughened with wet and dry abrasive paper). The drive mechanism consists of bicycle gear wheels and chains, with an appropriate gearing ratio to step up the manual drive input. The drive is powered via a hand-operated crank. The manual drive input is stepped up via a two-stage gearing process, producing an overall-gearing ratio of approximately 5 to 1. This rotational motion is translated into reciprocal motion by the use of an eccentric cam, which is in turn attached, via a universal ball joint, to the shaking table deck. When the handle is turned at 1 revolution/second, a comfortable speed, this produces a longitudinal motion of about 300 strokes/minute, which is appropriate for the separation of fine particles. The eccentric cam causes stretching of a strong rubber band (made from old car tyre inner tube), which releases suddenly to produce the 'end-knock' effect. Appropriate 'wedging' of the deck sub-base controls the slope of the deck. Wash water is supplied via perforated plastic piping. The tailings and concentrate collectors consist of plastic drainpipe, partitioned to allow correct collection of products.

The prototype table was produced with a hand cranked drive mechanism but this could readily be modified to be powered by a bicycle, or an electric motor after appropriate alterations to the gearing mechanism.

4.2. Preparation of samples

The samples were prepared for mineral processing trials by a combination of wet screening and desliming (i.e. removal of material finer than 10 μm). The mineral processing was sub-divided into large- and small-scale laboratory trials.

The large-scale trials were carried out on samples BG1 and BG5 (see flowsheet in Figure 7). The samples were wet screened using a 63 μm aperture sieve to remove all sand-grade and coarser material. Material finer than 63 μm was deslimed using a Mozley 1" hydrocyclone attached to a Mozley hydrocyclone test rig. After desliming, the finer silt-grade and coarser sand grade-material was recombined to provide a 'clean' feed for the processing trials.

The small-scale trials were carried out on samples BG2 and BG6 (see flowsheet in Figure 8). Smaller scale mineral processing was carried out on these samples as there was insufficient sample mass for the larger scale processing trials. The samples were treated as for the large-scale samples, apart from desliming. This was carried out by sedimentation, i.e. the samples were dispersed in water and allowed to settle. After a fixed time interval (46 minutes in a 25 cm deep column) all particles coarser than 10 μm have settled out of suspension. Removal of the remaining suspension therefore removes most of the particles finer than 10 μm.

4.3. Large-scale mineral processing trials

4.3.1. Methods

Large-scale processing trials were mainly carried out to determine the effectiveness for gold recovery of the BGS-designed and constructed shaking table. The trials were carried out in two parts; the first using a commercially produced Wilfley laboratory shaking table and the second using the BGS-designed shaking table. The Wilfley shaking table is commonly used for the concentration of heavy minerals from the laboratory up to the industrial scale. It has a traditional shaking table design with a riffled deck (as described in the introduction). A Superpanner (described in section 4.4.1.) was used to further concentrate the gold contained in the shaking table concentrates; this was akin to the use of a gold pan.

In order to enable a direct comparison of the results (and gauge the efficiency of the BGS-designed shaking table with the Wilfley table) the trials were identical (as outlined in the flowsheet, figure 7). The trials involved five steps :

i) First shaking table pass (P1)

- Gravity separation using shaking table at 10° slope to remove most of the less-dense minerals (mainly quartz) and produce a gold pre-concentrate.

ii) First Superpanner 'clean-up' pass (SP1)

- Gravity separation of pre-concentrate from i) to remove any remaining less-dense minerals and produce a gold concentrate.

iii) Second shaking table pass (P2)

- Gravity separation of combined middling & tailings from i) at 5° slope to remove any gold entrained with the less-dense minerals

iv) Third shaking table pass (P3)

- Gravity separation of combined concentrate & middling from iii) at 10° slope to remove remaining less-dense minerals & produce a gold pre-concentrate

v) Second Superpanner 'clean-up' pass (SP2)

- Gravity separation of pre-concentrate from iv) to remove the last trace of less dense minerals and produce a gold concentrate.

4.3.2. Results

The results of the large-scale trials using the Wilfley table are summarised in Table 5 and are given in full in Appendix A. Relatively low-grade gold concentrates resulted from the processing of BG 1, concentrates from the Superpanner have a combined gold assay of 25 wt%. This represents only 10 wt% of the gold present in the sample; the remainder was lost to the middling & tailing products. By combining the concentrates with the middling products it is possible to increase the amount of gold recovered, to 38 wt%; however the combined gold assay is very low (0.11 wt%).

A lower grade gold concentrate resulted from the processing of BG 5, the concentrate from the Superpanner has a gold assay of 8 wt%. However, this represents 60 wt% of the gold present in the sample. By combining this concentrate with the Wilfley concentrate (which is classified as a middling product due to its low gold assay) and the middling products it is possible to increase the amount of gold recovered, to 80 wt%; however the combined gold assay is very low (0.02 wt%).

The results of the large-scale trials using the BGS-designed table are summarised in Table 6 and are given in full in Appendix B. Relatively low-grade gold concentrates resulted from the processing of BG 1, concentrates from the Superpanner have a combined gold assay of 10 wt%. This represents only 20 wt% of the gold present in the sample; the remainder was lost to the middling & tailing products. The BGS table produced results very similar to those achieved using the commercial Wilfley table.

Table 5. Summary of Wilfley shaking table trials, BG 1 & 5, Philippines

Product	Yield wt %	Gold assay grams/tonne	Gold assay wt %	Gold recovery wt %
BG 1 : Milled sluice feed, Acupan Benguet Gold Operation, Baguio, Luzon				
Concentrate	0.003	251310	25.131	9.97
Middling	3.208	803	0.081	28.15
Tailing	96.789	59	0.006	61.88
Total	100.000	91	0.009	100.00
BG 5 : Milled sluice feed, Kias Creek, Baguio, Luzon				
Concentrate	0.02	75472	7.547	59.95
Middling	6.97	60	0.006	19.65
Tailing	93.01	5	0.0005	20.40
Total	100.00	11	0.001	100.00

N.B. Concentrate = Notional combination of Superpanner concentrates; Middling = Notional combination of all middling product (BG 5 includes Wilfley Pass 3 concentrate); Tailing = Notional combination of all tailings products and slimes; See Appendix A.

Table 6. Summary of BGS-designed table trials, BG 1, Philippines

Product	Yield wt %	Gold assay grams/tonne	Gold assay wt %	Gold recovery wt %
BG 1 : Milled sluice feed, Acupan Benguet Gold Operation, Baguio, Luzon				
Concentrate	0.02	100178	10.018	20.80
Tailing	99.98	81	0.008	79.20
Total	100.00	91	0.009	100.00

N.B. Concentrate = Notional combination of Superpanner concentrates; Tailing = Notional combination of all tailings products and slimes; See Appendix B.

4.4. Small-scale mineral processing trials

4.4.1. Methods

Small-scale processing trials were mainly carried out to determine the effectiveness of physical separation methods for recovering the fine-grained gold (effectively 'lost' during sluice box processing) that is present in tailings. The trials involved the use of a Superpanner to remove the gold from these samples (this is akin to the use of a gold pan). The shaking table cannot be used for small sample volumes, but should produce similar results from a larger sample with the same characteristics.

The Superpanner is similar to the Wilfley table in that it is an efficient gravity separator, but designed for smaller samples where close control leads to very effective separation. The Superpanner consists of a tapering triangular deck with a 'V' shaped cross-section. The table mimics the concentrating action of a gold pan. Initially the sample is 'swirled' to stratify the minerals. The heaviest minerals settle to the bottom and come to rest on the deck surface. Whereas, the less-dense minerals migrate to the top, overlying the heavy minerals. The operation of the deck is then changed to a rapid reciprocal motion, with an appropriate 'end-knock' at the broad, upslope end and a steady flow of wash water is introduced. The 'end-knock' causes the heavy minerals to migrate to the upslope end of the deck whereas the wash water carries the light minerals to the narrower, downslope end of the deck.

4.4.2. Results

The results of the small-scale trials using the Superpanner are summarised in Table 7 and are given in full in Appendix C. No visible gold was observed in any of the products resulting from the processing of BG 2 (the tailings from Acupan). However, the gold assay of the combined concentrate and middling products is considerably higher than the feed, showing that some gold has been removed; although the gold content is still less than 0.1 wt%. This combined product only represents 17 wt% of the total gold present in the sample; the remainder being lost to the tailings.

A small proportion of visible gold was observed in the Superpanner concentrate resulting from the processing of BG 6 (tailings from Kias Creek) but no visible gold was observed in the middling and tailing products. The gold assay of the combined concentrate and middling products is also less than 0.1 wt%. However, this combined product represents 68% of the total gold present in the sample.

Table 7. Summary of results of processing trials using Superpanner, BG 2 & 6, Philippines

Product	**Yield** wt %	**Gold assay** grams/tonne	wt %	**Gold recovery** wt %
BG 2 : Tailings from Acupan Benguet Gold Operation, Baguio, Luzon				
Conc + mid	0.67	661	0.0661	17.40
Tailing	99.33	21	0.0021	82.60
Total	100.000	25	0.0025	100.00
BG 6 : Tailings from Kias Creek, Baguio, Luzon				
Conc + mid	2.12	434	0.0434	67.91
Tailing	97.88	5	0.0004	32.09
Total	100.00	11	0.0011	100.00

N.B. Conc + mid = Notional combination of Superpanner concentrate & middling products: Tailing = Notional combination of Superpanner tailings product and slimes; See Appendix C.

4.5. Product evaluation

The gold content of the products was determined by chemical assay and visual examination (as described in section 2.2.).

5. FIELD TRIALS

The BGS shaking table was shipped to the Philippines and taken to Baguio, the mining area from which the samples for the laboratory tests had been obtained. Field trials were carried out in collaboration with counterpart staff from the Mines and Geoscience Bureau (MGB), from both the headquarters in Manila and the Baguio regional Office. The trials were held in two areas with the participation of the local Small-scale Miners Associations. This was arranged by Mrs B Daisa (MGB), the Baguio Small-scale Mines Advisor and she also took part in the trials. There were severe water shortages in the Philippines at the time of the visit due to the drought caused by the El Niño weather disturbances and in the Baguio area there was little water running in streams. Trials could only be carried out at the small-scale mine 'processing plants' were a piped water supply was available. Water was rationed in Manila with no water available between 8 am and 6pm and hence we were unable to demonstrate the equipment to the MGB staff at the Headquarters in Manila.

5.1. Existing practices

Ore from small mines is carried in sacks to the 'processing plant' where the ore is crushed in a ball mill (approximate mill charge of 100-200 kg) powered by a diesel engine. After wet milling for a long period, 2-3 hrs, the slurry is emptied into a 'washing' tank (3m by 2m and 50cm deep), where the slurry is agitated by a miner with a wooden paddle to separate the mud from the heavier minerals. After stirring for about an hour the muddy water and 'washed' milled ore are passed over a shallow sluice, with no riffles, covered with blanket cloth. A heavy, gold bearing, concentrate collects on the cloth and this is removed periodically by washing the cloths in a large bowl. The tailings were collected for further processing (cyanidation). At Kias the miners no longer use mercury in the recovery of gold from the ground ore but are now experimenting with cyanide extraction of gold from tailings, both by heap leach and CIP separation in an oil drum. Disposal of the tailings from cyanidation was by dumping them in the creek. At Acupan the main procedures were the same as at Kias, except that the tailings are sold to Benquet Mining Company (for gold recovery by cyanidation).

5.2. Kias area

5.2.1. Field tests

These tests were carried out with the Kias Explorers Association and arranged with Mr Robert Faldo, the Association President. The small-scale mines are situated in Kias Creek, about 1km from the road and some 300 metres below road level, accessed via a steep path. The prototype shaking table was easily carried to the site by a miner (Plate 3a), which demonstrates both its portability and robustness, which is very useful feature for a demonstration model. Samples BG5- BG7 from the laboratory trials had been taken from this area.

The shaking table was set-up on the wall of the washing tank. Water was obtained from a hosepipe connected to an oil drum header tank, that gave a water head of about 2m. The drum was continually refilled and was normally used by the miners for their various processing operations. Ore material was not immediately available, as their routine was to mine ore in the morning and mill it in the afternoon. Rather than waiting for several hours for milled ore to be available, tests were carried out on the **tailings material** from the previous days operations.

It took about 15 minutes to set up the table; by setting the base plate level and adjusting the side slope of the table by wedging it with various pieces of wood that were available. A good point about a shaking table is that one can immediately see if it is working correctly; if it is not separating a small black heavy concentrate (Plate 2), adjustments are required. After this setting up a good separation of heavy minerals was achieved and after about 1 hr around 2kg of tailings had been processed. The resulting concentrate was then evaluated by hand panning which revealed a significant quantity of very fine gold. This elicited a great deal of interest from the small-scale miners, some of whom took notes and sketches of the design of the separator (Plate 3b). Samples of the concentrates and starting material were collected for laboratory examination in the UK.

5.2.2. Laboratory tests

The concentrates from the table were further separated using a Superpanner to upgrade the gold to make examination easier. These 'superconcentrates' were examined under a binocular microscope to observe the amount of gold, the shapes of the grains and to measure the sizes of gold particles that were being recovered by the table. The concentrate contained a considerable amount of gold, with a few 'coarse' grains around 0.2-0.4mm that are generally flattened and flaky due to the crushing (Plate 4a). Most of the grains were much finer with the dominant population around 30-50μm (Plate 4b), but grains as small as 10μm had also been recovered. This is quite remarkable as most of the grains recovered are in the size range where shaking tables are generally not considered to be effective. The shape of the gold grains may be an important factor as it can be seen from the photograph that most of the fine gold is equant, which makes separation more effective compared to flaky grains. It appears that very small gold grains do not get flattened during the crushing process. The concentrates only contained a very small proportion of coarser grains because the material processed was tailings and most of the coarser gold would have been removed on the sluice by the miners.

5.3. Acupan Benquet Mine area

5.3.1. Field tests

These trials were carried out at the Upper Camps Community Association, arranged by the Vice Chairman Mr Tony Olimpo. There are around 120 active small-scale miners who live at, and were previously employed by, the large Benquet Mine prior to its closure in the early 1990's. They have concessions from the Benquet Mine to carry out small-scale mining and sell their tailings to Benquet Mine for further processing in the cyanidation plant.

The table was initially set up on two thick planks that straddled the washing tank as the miners thought this would give plenty of space for the person doing the hand winding and was convenient to drain away the water. Water was supplied from a piped system that was at considerably higher pressure than that at Kias and was controlled by a valve, but was also used by other miners for other processes. The table tends to move during operation due to the recoil of the end-knock mechanism and it proved very difficult to obtain effective separations as the table was not sufficiently stable. After about 30 minutes and several attempts to achieve stability this situation was abandoned. The table was then moved to the wall of another washing tank that was no longer being used and put in an arrangement very similar to that which had been used so successfully at Kias. It still proved more difficult to set up as the top of the wall was not flat and the geometry of the table would only stay constant for a few minutes at a time compared with perhaps 30 minutes at Kias. A further problem was that the water pressure was varying as other miners were using the same supply. The milled ore tested here was much muddier than the tailings processed at Kias and this also makes separation more difficult. Concentrates were collected from both freshly milled ore and tailings from previously sluiced material. When the concentrates were briefly examined on site they did not appear to contain much gold. The trials here demonstrated very clearly how crucial stable conditions are for the table to work effectively. Valuable insight was gained about the operation of the table and features needing design improvements were identified, particularly a leveling mechanism.

5.3.2. Laboratory tests

The concentrates were further processed with the Superpanner and the product examined with a binocular microscope. The concentrate from ore material contained gold with a wide range of grain sizes, with several around 0.5mm (Plate 5a), many around 0.1-0.2mm (Plate 5b), much very fine gold around 50μm (Plate 6a) and some down to 20μm. The concentrates were not as rich as those from Kias but contained far more than was expected from the field examination. The concentrate from tailings contained a few ‘coarse’ grains around 0.2mm but most was less than 60μm with many around 30μm (Plate 6b). The trials at Acupan, though not as successful as at Kias, had actually been far better than was realised at the time. This is possibly because in the field it was difficult to see the gold due to Fe-oxide coatings on the coarser grains and the finer grains being hidden in the fine muddy material.

5.4. Participants reaction to the trials

The miners at Kias were very impressed by the trials as they had seen fine gold recovered from the tailings from their current operation. Although they no longer use mercury to try to recover this gold they were aware that cyanidation also has associated problems and hazards and could see that a simple gravity method that only used water was preferable. This was both from a pollution point of view and also because they did not need to buy relatively expensive reagents. They studied the table in great detail and made sketches of it, and asked if it could be made larger to increase the throughput. The prototype table was small to make it portable and be capable of hand operation, but shaking tables can be scaled-up in size to increase the throughput. In commercial mines tables several metres in size are used and these can have a throughput of 1 ton per hour. The limiting factor in the small-scale mining would be cost and the power available for operation.

They suggested some modifications to the design and in particular thought that it could be powered by a belt drive from the ball mill shaft so that it could be run continuously for long periods without a need for hand winding. Once we had started the trial several other miners from nearby mines brought samples of their tailings for testing and similar good results were obtained. The miners would be very keen to have a table in regular use if it could be produced at a price they could afford

The miners at Acupan had been involved in the problems setting-up the table and were unfortunately unable to see the effectiveness of the table that was only revealed by laboratory examination. They were interested to try it further, particularly due to the reports of successful trials at Kias the previous day. They were unsure whether this might violate their concession agreement, which definitely precluded the use of chemical extraction

The MGB staff who were involved in the trials were impressed by the simple construction but effective operation of the table. It was unfortunate that we were unable to demonstrate it to a greater number of staff in Manila due to the water shortage. The shaking table has been donated to MGB and they plan to carry out further trials and particularly in the mining areas on Mindanao, much further from Manila, where mercury amalgamation is widely used. For time and logistical reasons it was not possible to test the table in these areas during a short visit.

6. DISCUSSION

The primary aim of the work described in this report was to construct, and evaluate, a simple shaking table to be used for the recovery of fine-grained gold. The use of an efficient physical separation method would not only enable a higher recovery of gold but it would, as a consequence, reduce the reliance on chemical methods for gold recovery, such as mercury amalgamation and cyanidation. The secondary aim of the work was to determine whether the fine-grained gold present in tailings could be recovered using a simple form of gravity separation.

The mineral processing trials conducted using the gold-bearing samples from the Philippines reinforced the effectiveness of shaking tables for recovery of gold, down to a particle-size of approximately 50 µm. Both of the samples used for the large-scale trials contain a significant proportion of gold finer than 50 µm. Sample BG 5 is coarser than BG 1 with a higher proportion of gold between 125 and 500 µm. This accounts for the dramatic difference in the processing results. The concentrate produced from BG 1 has a relatively low gold assay and also only represents a tenth of the gold in the sample. This is probably due to its fine grain size; the small gold grains were probably entrained within the tailings and swept over the riffles. In contrast, the concentrate produced from BG 5 has a much higher gold recovery, albeit at a lower gold assay, due mainly to its coarser particle-size.

Processing of BG1 using both the Wilfley and BGS-designed shaking tables produced markedly different results (as given in Table 5). The Wilfley table concentrate has a gold assay of 25%, but this only represents 10% of the gold present in the sample; whereas the BGS-designed table concentrate has a gold assay of only 10%, which represents 20% of the gold present in the sample. The BGS-designed table has therefore removed a higher proportion of gold from the original samples, albeit at a lower gold content, but this indicates that it is more effective than the Wilfley table.

Another means of comparing the performance of the two tables is to ignore the results of the final upgrading by Superpanner. The performance of the BGS-designed shaking table is then seen to be comparable to the Wilfley shaking table. The gold assays and recoveries prior to final upgrading by Superpanner can be seen in Table 8.

Table 8. Comparison of Wilfley and BGS-designed shaking table, BG1, Philippines

Product	**Yield** wt %	**Gold assay** grams/tonne	wt %	**Gold recovery** wt %
Wilfley shaking table				
Concentrate	2.79	1867	0.187	56.96
BGS-designed shaking table				
Concentrate	2.48	2305	0.230	61.59

The combined concentrate produced using the BGS-designed shaking table resulted in a product very similar to that produced by the Wilfley shaking table. This indicates that for gravity separation the BGS-designed shaking table is as effective as the Wilfley shaking table.

Processing of the tailings samples (BG2 & BG6), using the Superpanner, yielded similar results to those produced by processing of the corresponding feed samples (BG1 and BG5 respectively) using the Wilfley table. The proportion of gold recovered from BG6 is approximately four times that recovered from BG2. This is probably due, as with the difference between BG5 and BG1, to the coarser grain size of the gold present in the samples from Kias Creek. However, the relatively high proportion (68 wt%) of gold recovered from BG6 demonstrates that simple methods of gravity separation can be used to extract fine-grained gold from tailings, provided it is coarser than 50 μm.

The results of the investigation have shown that a relatively high proportion of gold can be recovered using simple gravity methods. However, the gold content of the products has generally been low, less than 1%. In these studies a Superpanner was used to make higher concentrations with around 10% gold as the concentrates were only small volumes. It should be possible to upgrade these concentrates using the table if sufficient material were available, as it can be set with settings that achieve a finer separation of the heavy minerals once all the light minerals have been removed. For example at a mine the concentrates collected during a whole day could be reprocessed once a day to produce a concentrate with several percent gold. There is still a need to establish whether the table could be used to clean the concentrate to a purity suitable for sale. In some places this is done by very careful hand panning but it is possible that another method for this final stage is still required. The volume in question at this stage is very small, much less than 1% of the original ore and a controlled amalgamation process using retorts could be used.

The throughput from the small prototype table is around 3kgs per hour but a table around four times the size, with a motor driven mechanism should be capable of around 15-20kg/hr. The small mines in the Philippines process relatively small amounts of ore every day, 100-200kg. On this basis it would be feasible to process all the ore by a shaking table.

The cost of a commercial Wilfley table, similar in size to the prototype BGS table is around £5,000 (US$ 8,000) and one to achieve the throughput outlined above around £8,000 (US$ 13,000). The parts for the prototype BGS table cost around £100 (US$ 160) and labour costs for construction in the UK would give a total price around £500 (US$ 800). Production costs in a developing country would be very much lower.

The findings of the investigation have reinforced the value of characterisation prior to mineral processing. Mineralogy, particle-size and texture all have an influence on the performance of mineral processing trials. For example, the proportion of gold finer than 50 μm in an ore has a significant effect on the proportion of gold recoverable using simple gravity methods. Therefore a determination of the particle-size distribution of gold could be used to indicate the likely success of using gravity methods for the recovery of gold from a given ore.

7. RECOMMENDATIONS

1. The use of a shaking table can increase the amount of fine-grained gold recovered during processing of ore. Figure 9 illustrates the recommended sequence of process stages, incorporating a shaking table, for the recovery of fine-grained gold.
2. It is assumed that most small-scale miners have little knowledge of the particle-size distribution of the gold present in their ore. Therefore the most practical method of establishing the effectiveness of a shaking table for the recovery of gold from a given ore would be to perform processing trials.
3. It is also unlikely that the use of mercury amalgamation for the final concentration of gold from gravity concentrates will be easily replaced. However, its use could be restricted to this stage only and hopefully, by demonstrating the effectiveness of simple gravity techniques, the use of mercury in trommel mills, sluice beds and other process equipment could be significantly reduced if not eliminated.

8. CONCLUSIONS

I. Laboratory characterisation of gold bearing ores and tailings from the Philippines established the grade and grain size distribution of gold within the samples. This showed that they contained dominantly fine-grained gold with one of the main samples studied having 60% <63μm. References in the literature suggest that shaking tables are only effective on grain sizes down to about 50μm.

II. Laboratory separation test using a commercially produced laboratory-scale Wilfley table recovered only 10% of the gold from the finest-grained sample but nearly 60% from one that was slightly coarser.

III. A simple, hand-powered, shaking table was designed and constructed of cheap materials that are available in developing countries. It was particularly aimed at the recovery of fine-grained gold. Laboratory trials showed that this table appears to be as good as the commercial Wilfley table for the separation of fine-grained gold.

IV. The simple shaking table was taken to the Philippines for field trials. Field trials showed that it is remarkably good at recovering fine-grained gold when properly set-up and recovered considerable gold from miners tailings where the grain size was only around 40µm. The trials also showed how important and sometimes difficult it can be to adjust the table to the correct settings.

V. The small-scale miners were impressed by the performance of the table and were keen to test it further and possibly produce a larger version for regular use as an alternative to cyanidation (for ore containing gold coarser than 30 microns).

VI. A simple shaking table can be very effective for the recovery of fine-grained gold down to a grain-size of around 20µm and hence could play an important role in providing an alternative to the use of mercury in the extraction of gold from bulk samples. The heavy mineral concentrates produced contain several % gold and still require further processing to remove the remaining impurities. This might be possible with the table but this has not yet been demonstrated and controlled amalgamation using retorts might still be required.

9. REFERENCES

Mitchell, CJ, Evans, EJ & Styles, MT (1997) A review of gold particle-size and recovery methods. *British Geological Survey Technical Report* **WC/97/14**, 32 pp.

Williams, TM (1997) Visit to the Philippines and Thailand. *British Geological Survey Technical Report* **WP/97/1**.

APPENDIX A. Large-scale mineral processing trials : Wilfley shaking table

BG1

Product	**Yield** (wt %)	**Gold assay** (troy oz / short ton)	**Gold assay** (grams/ tonne)	**Gold assay** (wt %)	**Gold recovery** (wt %)
Head	100.00	2.7¶	91	0.009	100.00
Feed (deslimed)	98.45	2.7¶	93	0.009	99.74
Slimes (<10 µm) *	**1.55**	0.5†	15	0.002	**0.26**
First Wilfley table pass (P1)					
- Concentrate	0.19	546.1¶	18723	1.872	39.90
- Middling + Tailings	98.26	1.6¶	56	0.006	59.84
First Superpanner pass (SP1)					
- Concentrate *	**<0.01**	8974.3#	307692	30.769	**6.44**
- Middling *	**0.03**	1132.7¶	38835	3.883	**13.73**
- Tailings *	**0.16**	327.7¶	11234	1.123	**19.74**
Second Wilfley table pass (P2)					
- Concentrate + Middling	36.30	3.2¶	109	0.011	43.09
- Tailings *	**61.95**	0.7†	25	0.002	**16.75**
Third Wilfley table pass (P3)					
- Concentrate	2.59	17.5¶	602	0.060	17.06
- Middling *	**1.83**	3.5†	121	0.012	**2.41**
- Tailings *	**31.88**	2.0†	68	0.007	**23.62**
Second Superpanner pass (SP2)					
- Concentrate *	**<0.01**	6749.3#	231405	23.140	**3.53**
- Middling *	**1.35**	23.8¶	815	0.082	**12.01**
- Tailings *	**1.24**	3.2†	111	0.011	**1.51**

NB * = Final products (yield & recovery data, highlighted in bold, total 100%)
Remaining products were used as feed material for subsequent processing stages.
Processing flowsheet given in Figure 3.
Assay determined by : † = chemical analysis; # = visual estimation; ¶ = back-calculation

APPENDIX A. Large-scale mineral processing trials : Wilfley shaking table

BG5

Product	**Yield** (wt %)	**Gold assay** (troy oz / short ton)	**Gold assay** (grams/ tonne)	**Gold assay** (wt %)	**Gold recovery** (wt %)
Head	100.00	0.3†	11	0.001	100.00
Feed (deslimed)	98.99	0.2†	8	0.001	99.53
Slimes (<10 μm) *	**1.01**	0.1†	4	0.000	**0.47**
First Wilfley table pass (P1)					
- Concentrate	3.89	25.1¶	432	0.043	78.67
- Middling + Tailings	95.10	0.1¶	5	0.000	20.86
First Superpanner pass (SP1)					
- Concentrate *	**0.02**	2201.0	75472	7.547	**59.95**
- Middling *	**0.25**	29.2¶	1000	0.100	**11.56**
- Tailings *	**3.63**	1.2†	42	0.004	**7.15**
Second Wilfley table pass (P2)					
- Concentrate + Middling	49.52	0.2¶	7	0.001	15.44
- Tailings *	**45.58**	0.1†	3	0.000	**5.42**
Third Wilfley table pass (P3)					
- Concentrate *	**1.14**	3.4†	117	0.012	**6.23**
- Middling *	**5.58**	0.2†	7	0.001	**1.86**
- Tailings *	**42.80**	0.1†	4	0.000	**7.35**

NB * = Final products (yield & recovery data, highlighted in bold, total 100%)
Remaining products were used as feed material for subsequent processing stages.
Processing flowsheet given in Figure 3.
Assay determined by : † = chemical analysis; # = visual estimation; ¶ = back-calculation

APPENDIX B. Large-scale mineral processing trials : BGS-designed shaking table

BG1

Product	**Yield** (wt %)	**Gold assay** (troy oz / short ton)	**Gold assay** (grams/ tonne)	**Gold assay** (wt %)	**Gold recovery** (wt %)
Head	100.00	2.2¶	77	0.008	100.00
Feed (deslimed)	98.54	2.7¶	93	0.009	99.75
Slimes (<10 μm) *	**1.46**	0.5†	15	0.002	**0.25**
First BGS table pass (P1)					
- Concentrate	0.82	173.9¶	5961	0.596	53.33
- Tailings	97.72	1.3†	43	0.004	46.42
First Superpanner pass (SP1)					
- Concentrate	**<0.01**	14583.3#	500000	50.000	**13.91**
- Tailings *	**0.82**	128.9#	4420	0.442	**39.42**
Second BGS table pass (P2)					
- Concentrate	27.75	3.6†	124	0.012	27.14
- Tailings *	**69.97**	1.0†	35	0.003	**19.28**
Third BGS table pass (P3)					
- Concentrate	1.66	14.5†	499	0.050	8.26
- Tailings *	**26.09**	2.1†	72	0.007	**18.88**
Second Superpanner pass (SP2)					
- Concentrate *	**0.02**	1458.3#	50000	5.000	**6.89**
- Tailings *	**1.64**	2.9#	100	0.010	**1.36**

NB * = Final products (yield & recovery data, highlighted in bold, total 100%)
Remaining products were used as feed material for subsequent processing stages.
Processing flowsheet given in Figure 3.
Assay determined by : † = chemical analysis; # = visual estimation; ¶ = back-calculation

APPENDIX C. Small-scale mineral processing trials : Superpanner shaking table

Product	Yield (wt %)	Gold assay (troy oz / short ton)	Gold assay (grams/ tonne)	Gold assay (wt %)	Gold recovery (wt %)
BG2					
Head	100.00	0.7†	25	0.003	100.00
Feed (deslimed)	99.03	0.7¶	25	0.003	99.41
Slimes (<10 µm) *	**0.97**	0.4†	15	0.002	**0.59**
Superpanner Pass					
Concentrate + Middling *	**0.67**	19.3¶	661	0.066	**17.40**
Tailings *	**98.36**	0.6†	21	0.002	**82.01**
BG 6					
Head	100.00	0.3†	10	0.001	100.00
Feed (deslimed)	99.32	0.4†	14	0.001	99.82
Slimes (<10 µm) *	**0.69**	0.1¶	4	0.000	**0.18**
Superpanner Pass					
Concentrate + Middling *	**2.12**	12.7¶	434	0.043	**67.91**
Tailings *	**97.20**	0.1†	4	0.000	**31.91**

NB * = Final products (yield & recovery data, highlighted in bold, total 100%)
Remaining products were used as feed material for subsequent processing stages.
Processing flowsheet given in Figure 4.
Assay determined by : † = chemical analysis; # = visual estimation; ¶ = back-calculation

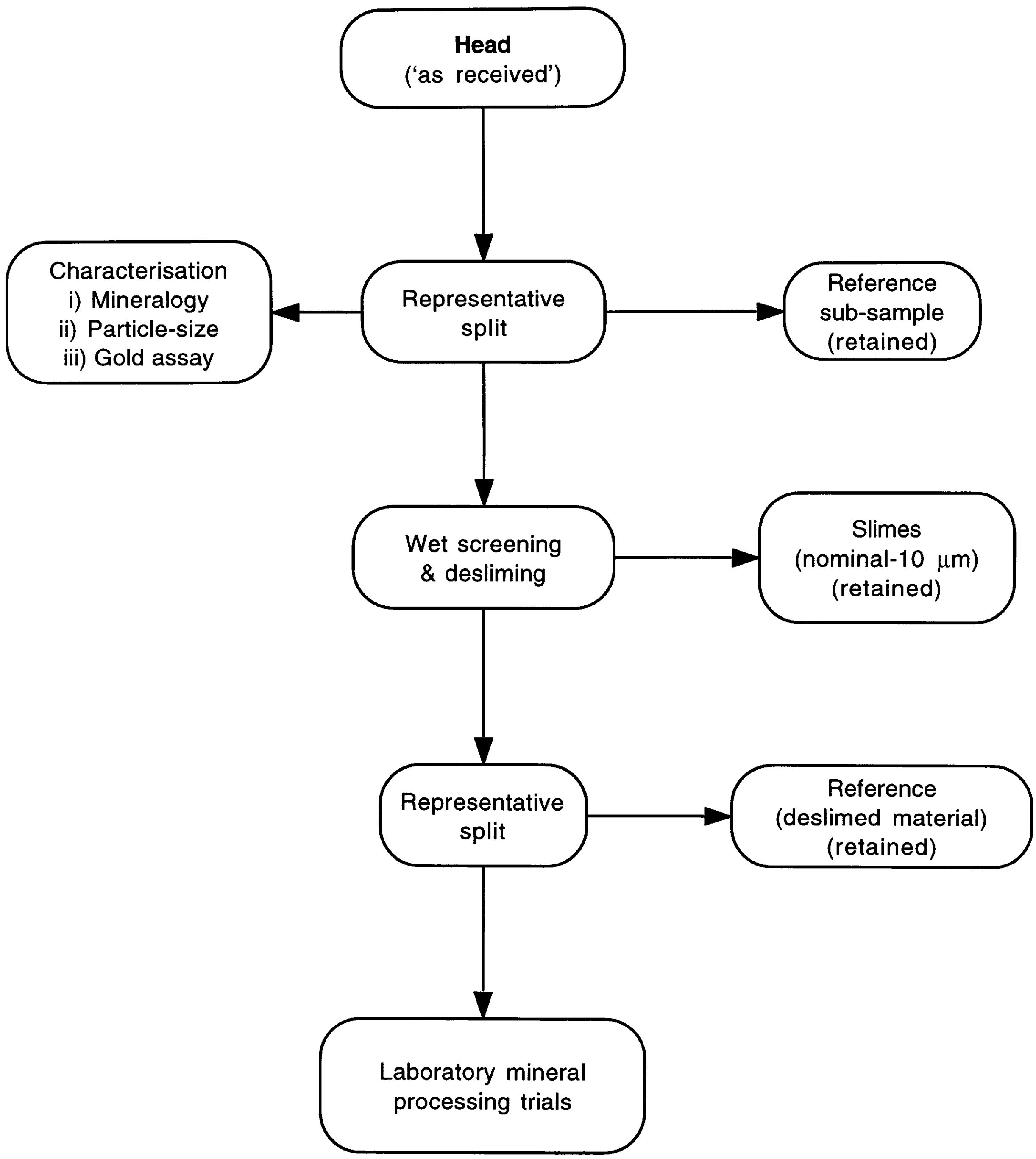

Figure 1. Flowsheet for characterisation and preparation for mineral processing trials

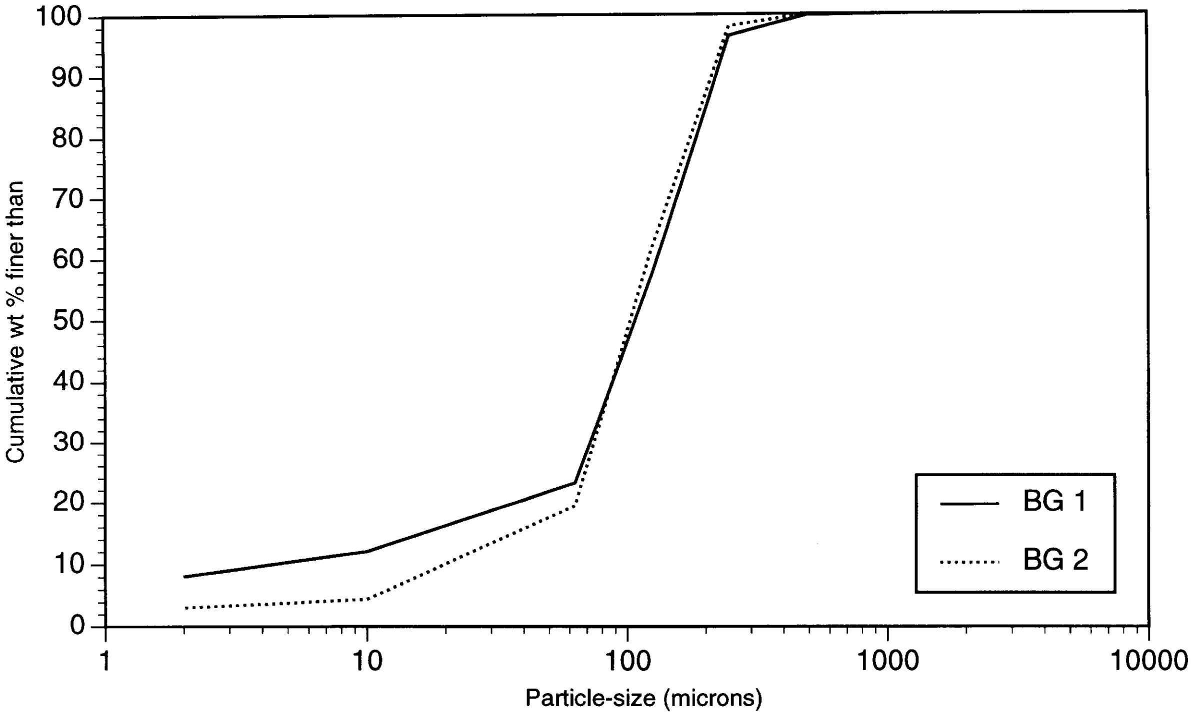

Figure 2. Particle-size distribution of feed (BG 1) and tailings (BG2) from Acupan Benguet Gold Operation (BGO) concession, Baguio, Luzon, Philippines

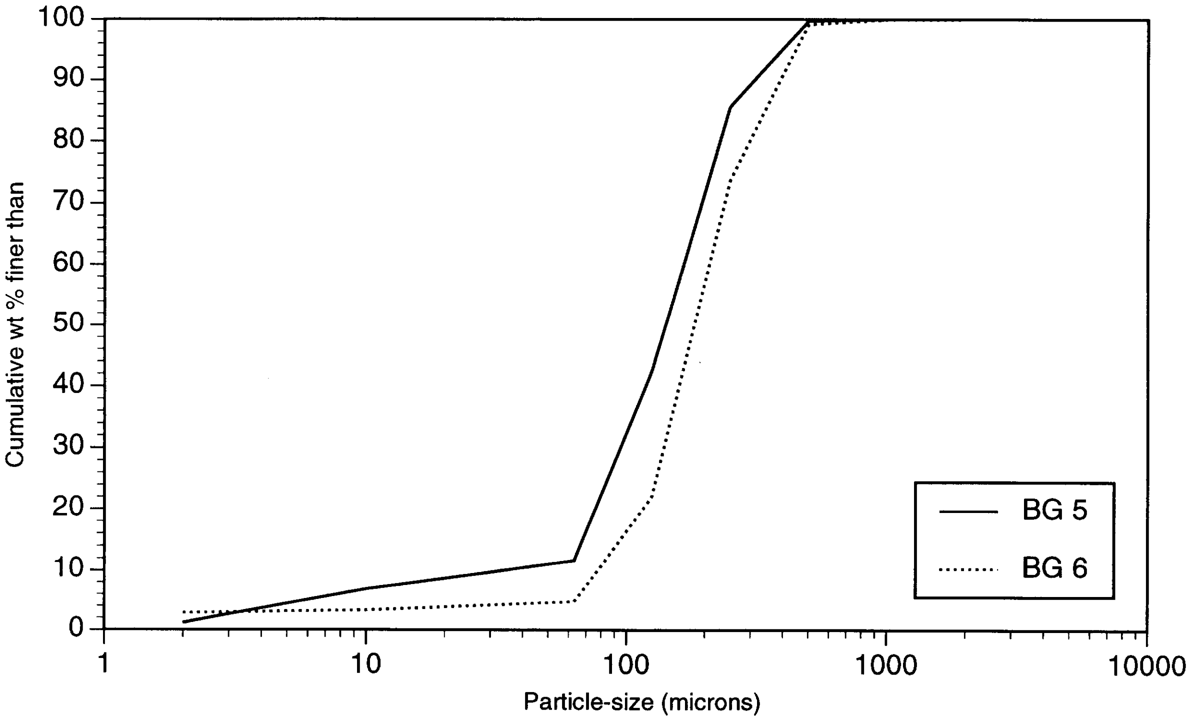

Figure 3. Particle-size distribution of feed (BG 5) and tailings (BG6) from Kias Creek Gold Operation, Baguio, Luzon, Philippines

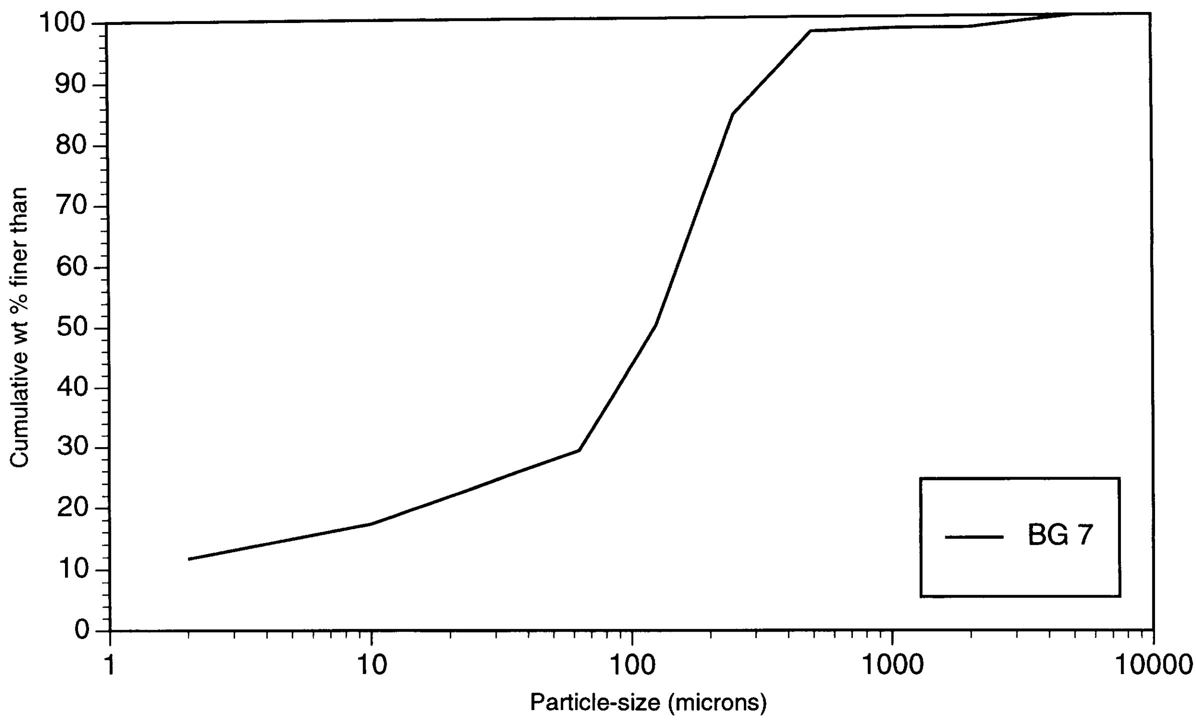

Figure 4. Particle-size distribution of feed (BG 7) from Gold Operation similar to Kias Creek, Baguio, Luzon, Philippines

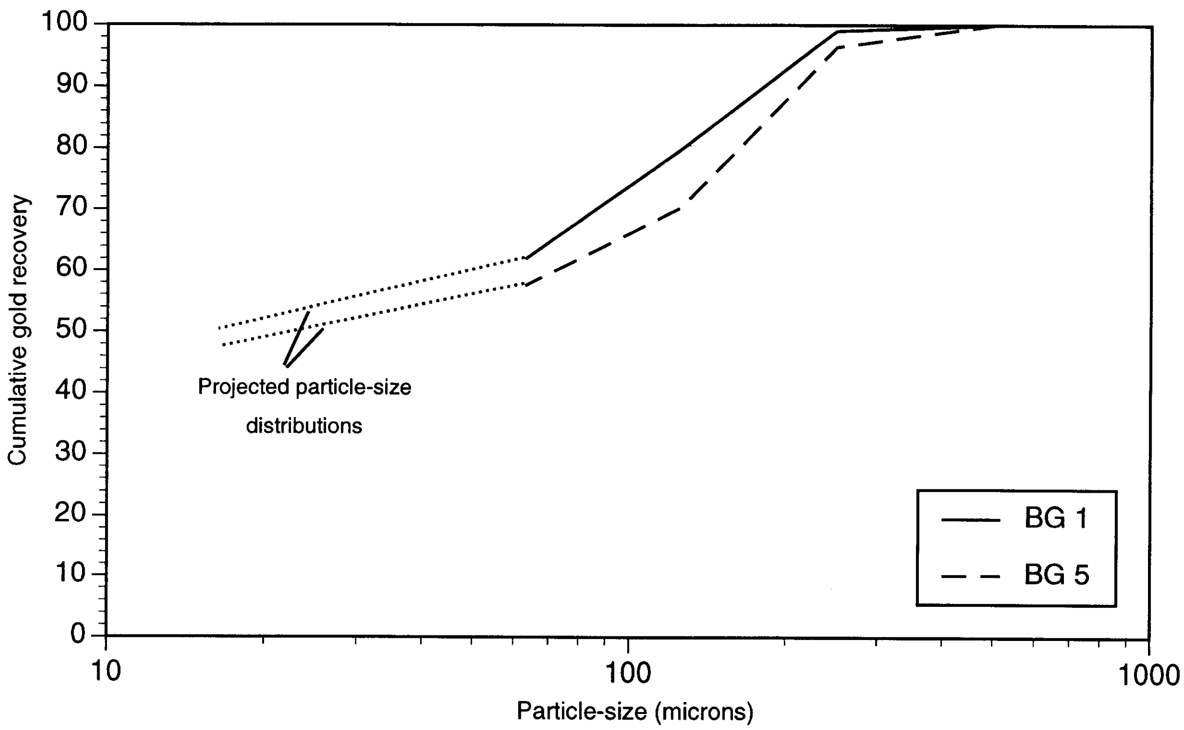

Figure 5. Particle-size distribution of gold present in feed (BG 1) from Acupan Benguet Gold Operation (BGO) concession & feed (BG 5) from Kias Creek Gold Operation, Baguio, Luzon, Philippines

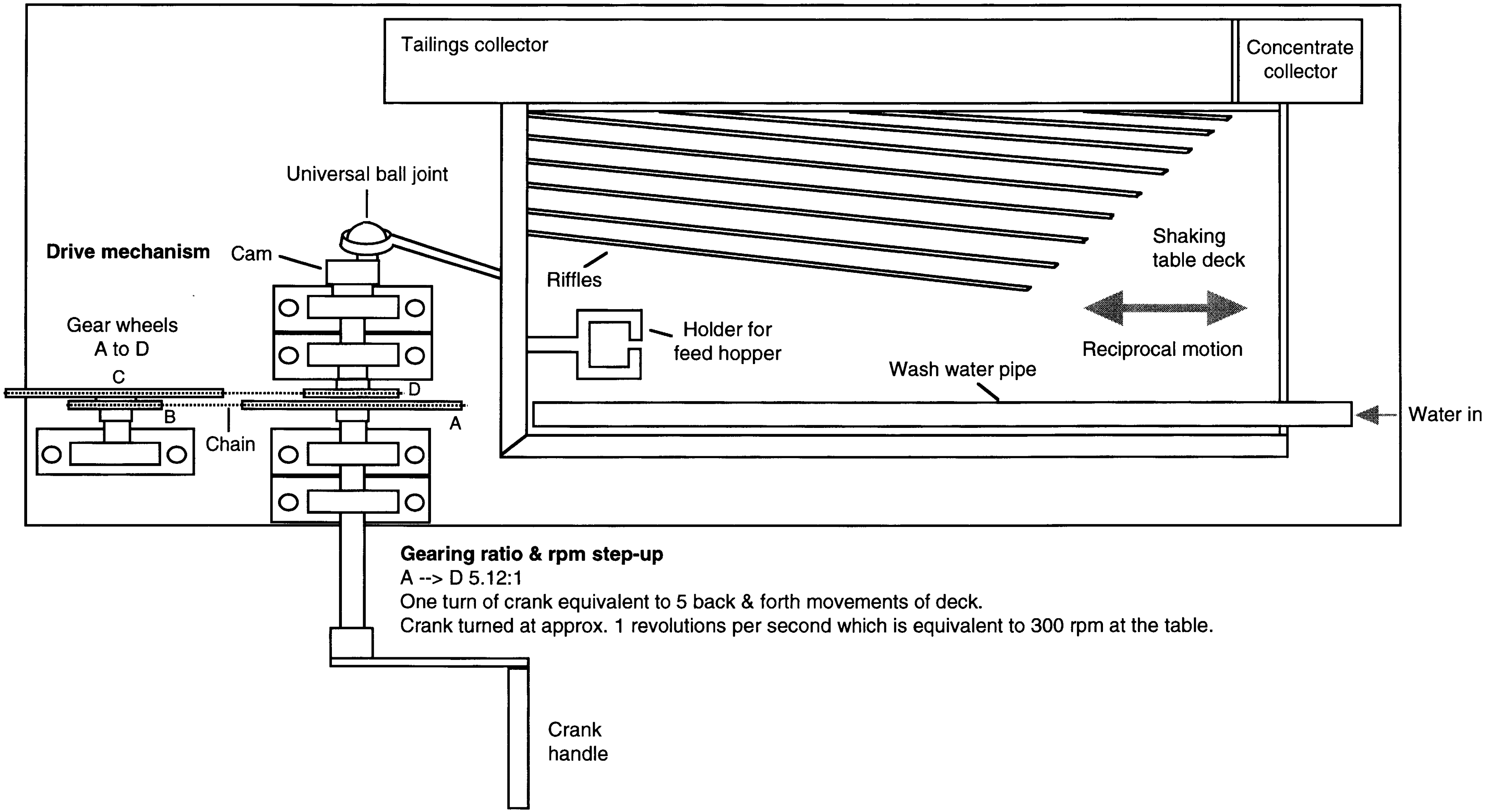

Figure 6. Plan view of BGS-designed shaking table (one-fifth scale)

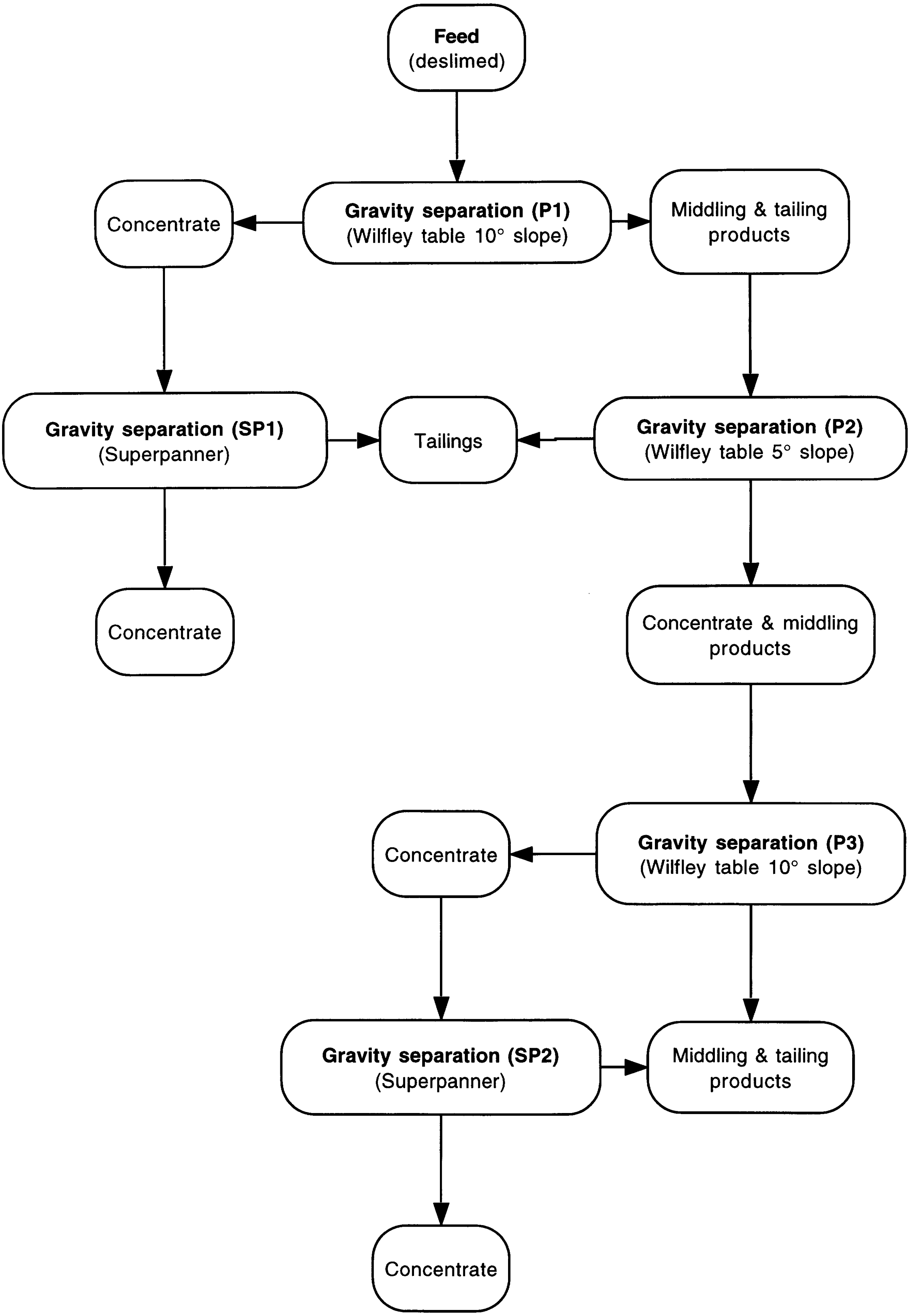

Figure 7. Flowsheet for large-scale mineral processing trials (BG1 and BG5)

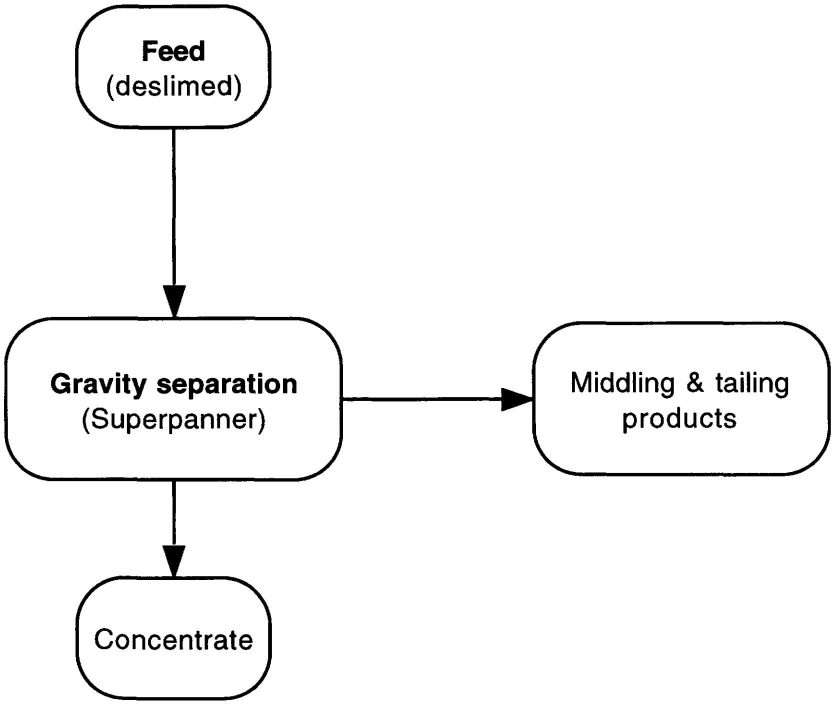

Figure 8. Flowsheet for small-scale mineral processing trials (BG2 and BG6)

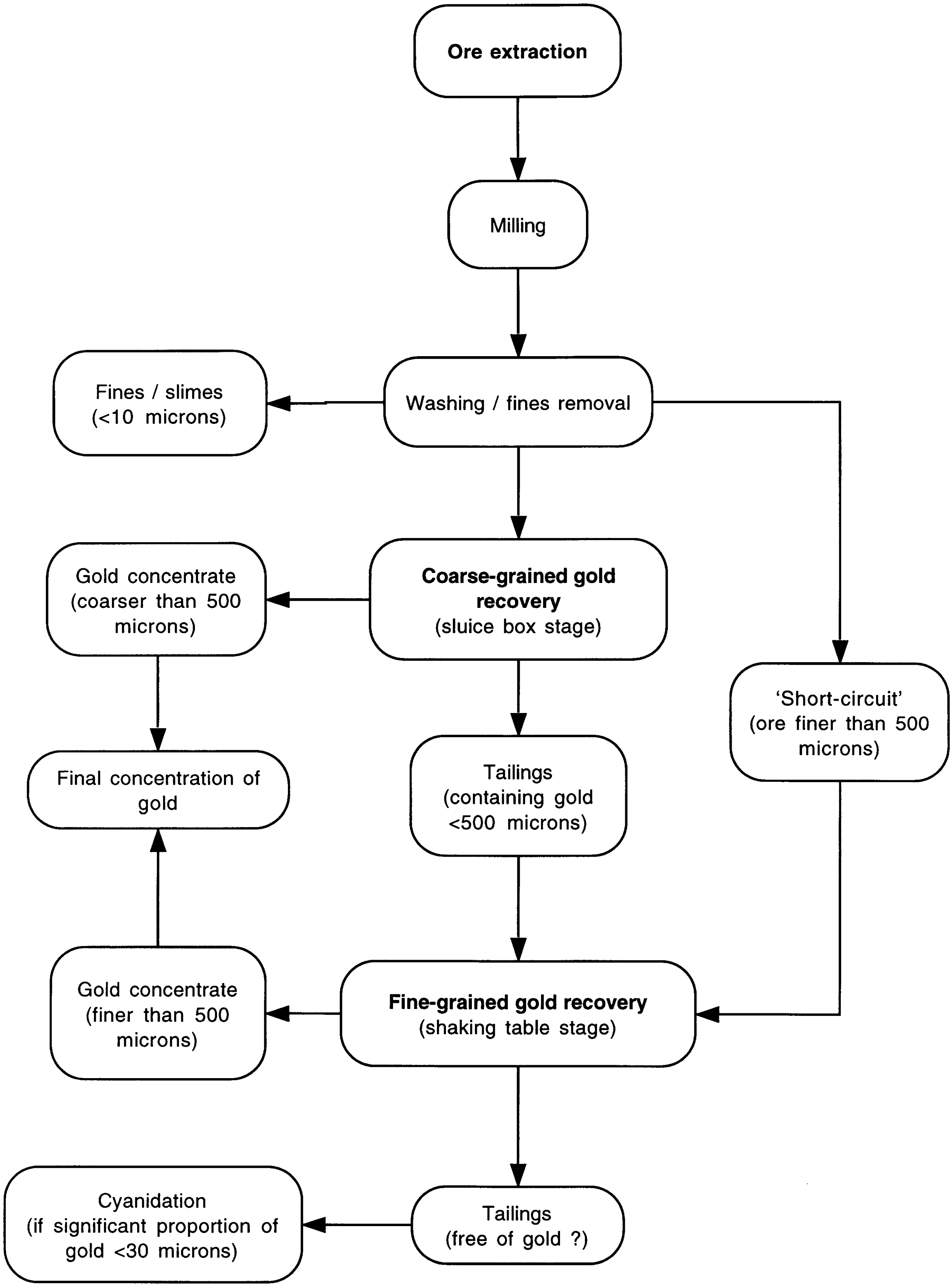

Figure 9. Flowsheet illustrating recommended small-scale gold recovery process route

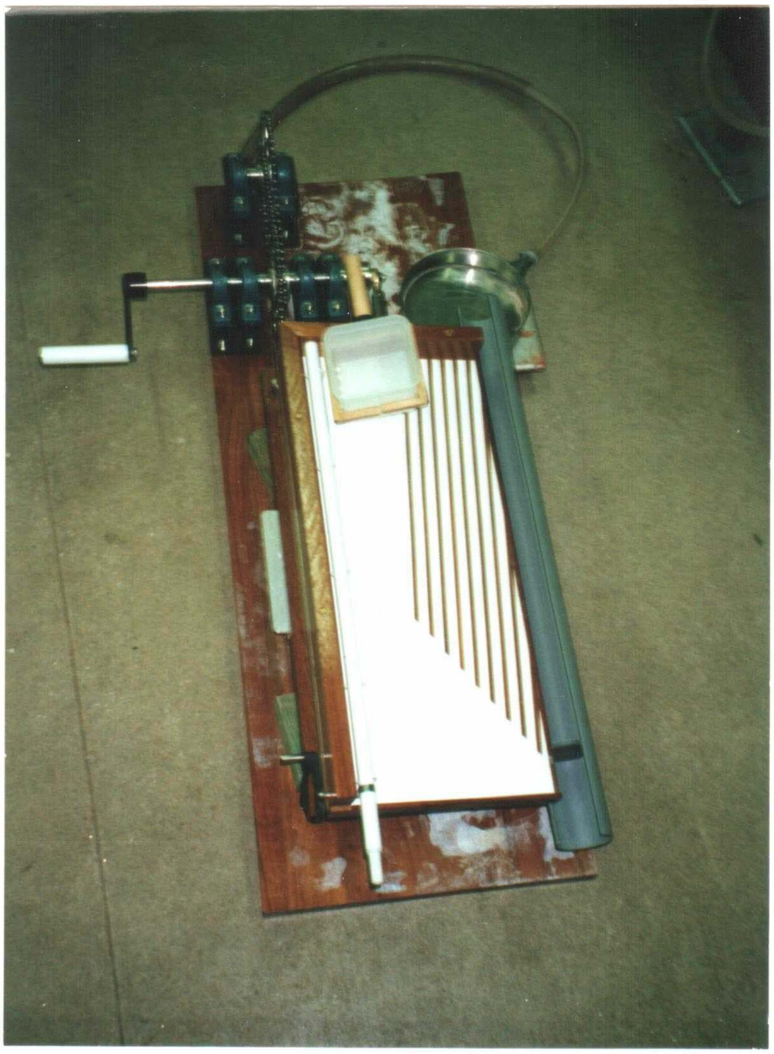

Plate 1a. The BGS shaking table showing the riffled deck, sample feed, drive mechanism and drain-pipe, concentrate collector. The rubber band knock-effect is on the front left corner.

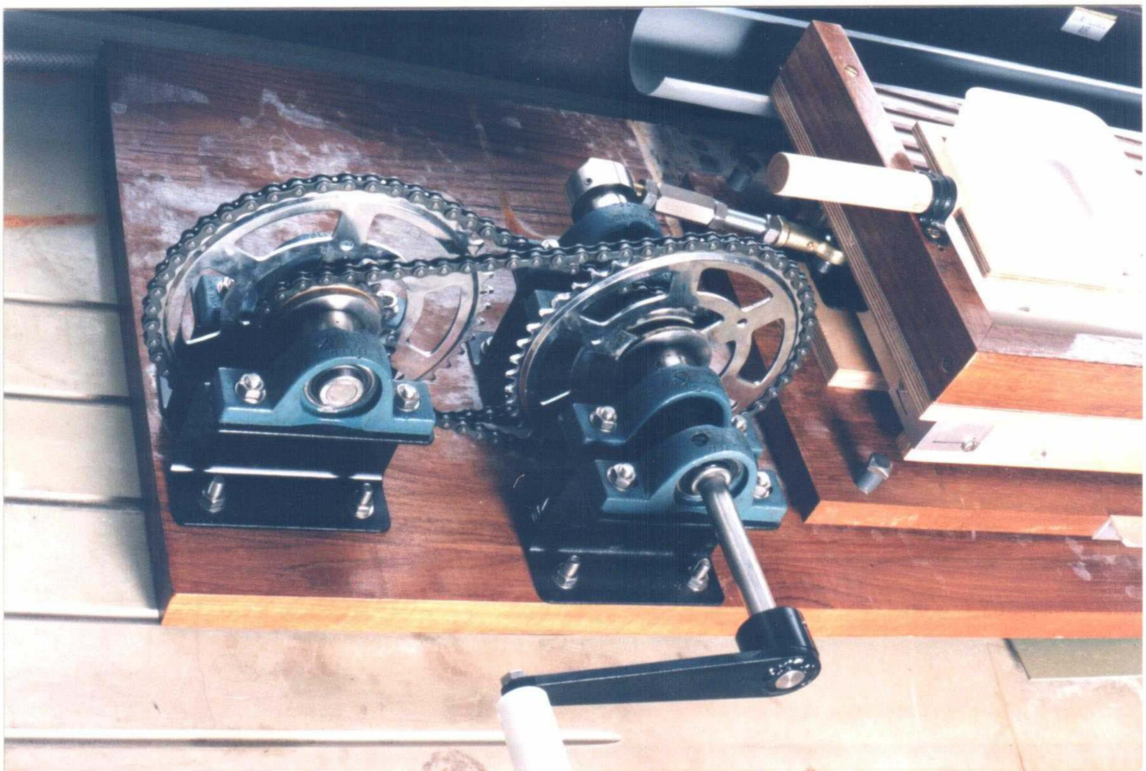

Plate 1b. Close up of the drive mechanism showing the two sets of bicycle sprockets, each producing a gearing of 2.5:1 to give the overall ratio of 5:1, to give the required table movement.

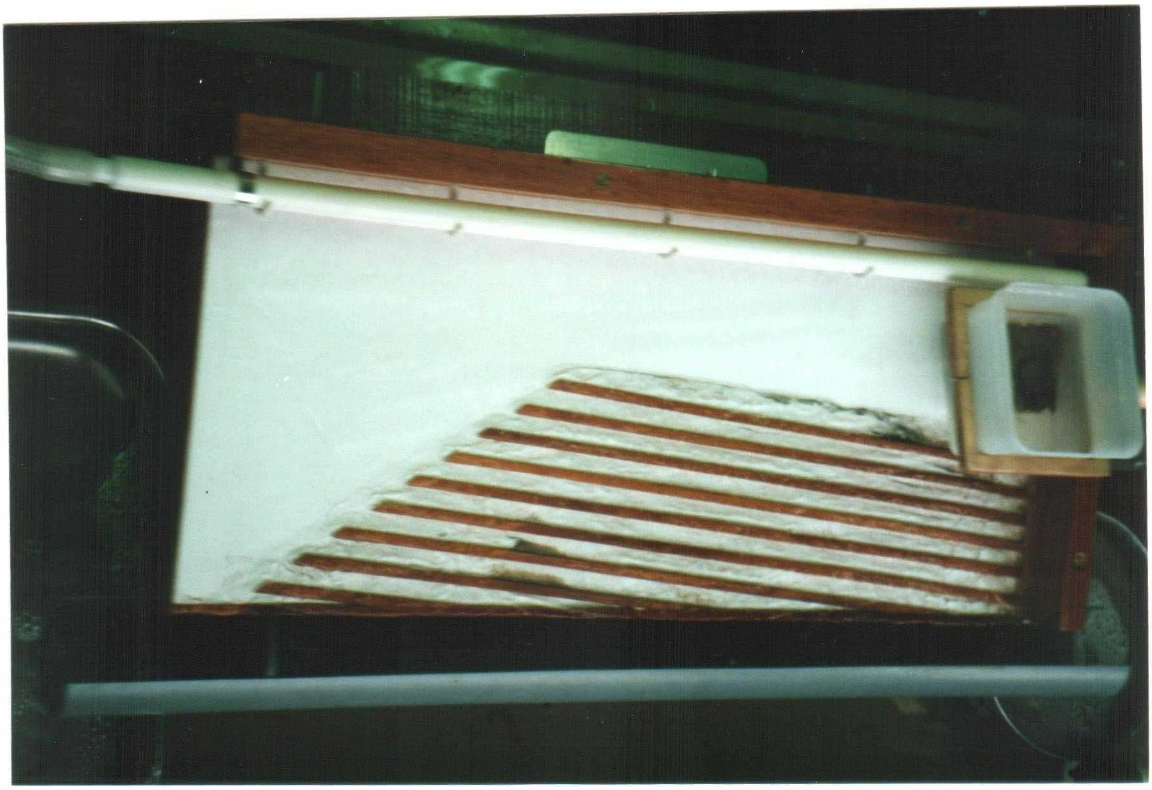

Plate 2a. The shaking table during operation, the heavy black minerals (and gold) are moving across above the top riffle.

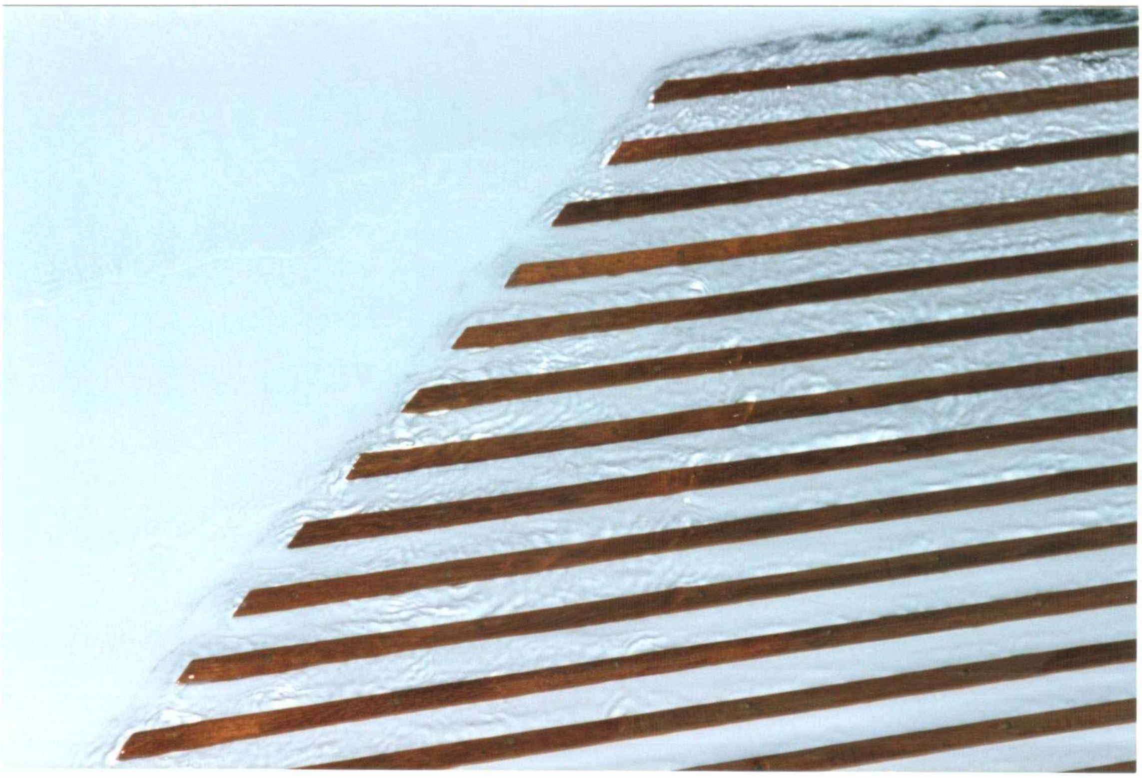

Plate 2b. Close-up showing the heavy minerals moving across to the concentrate collector in the bottom left corner.

Plate 3a. Carrying the table to the small mine test site in Kias Creek, Baguio mining district, Philippines.

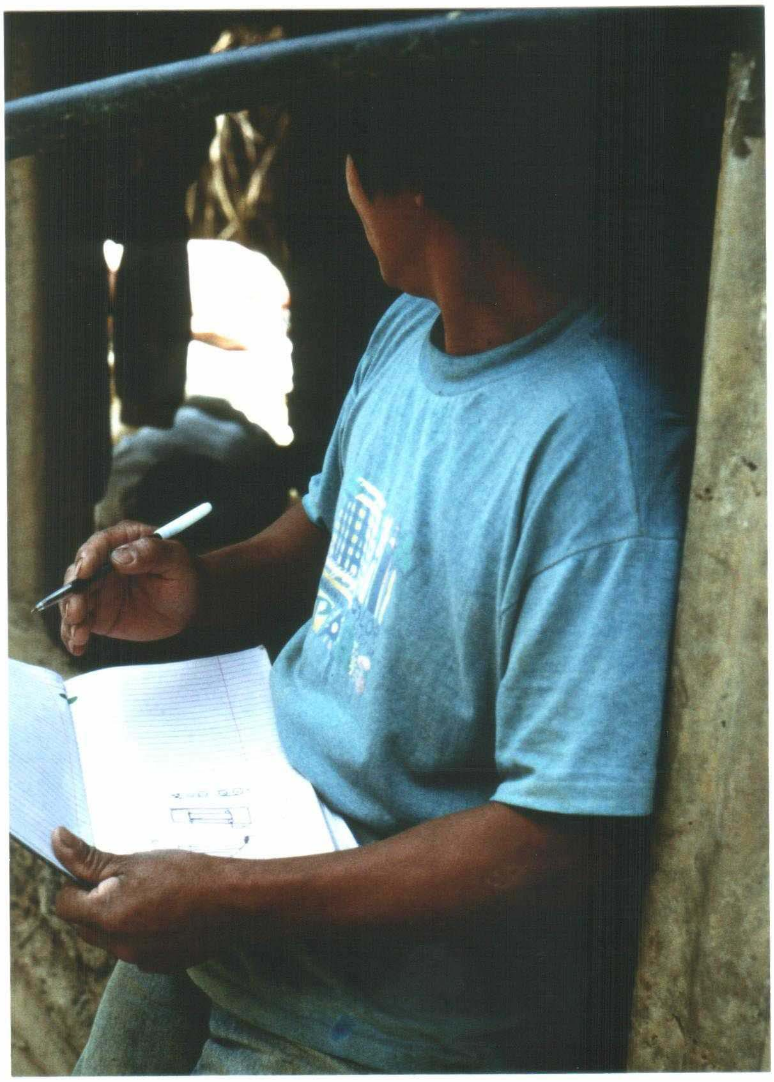

Plate 3b. Small-scale miner in the Philippines making detailed sketches of the table after successful field trial.

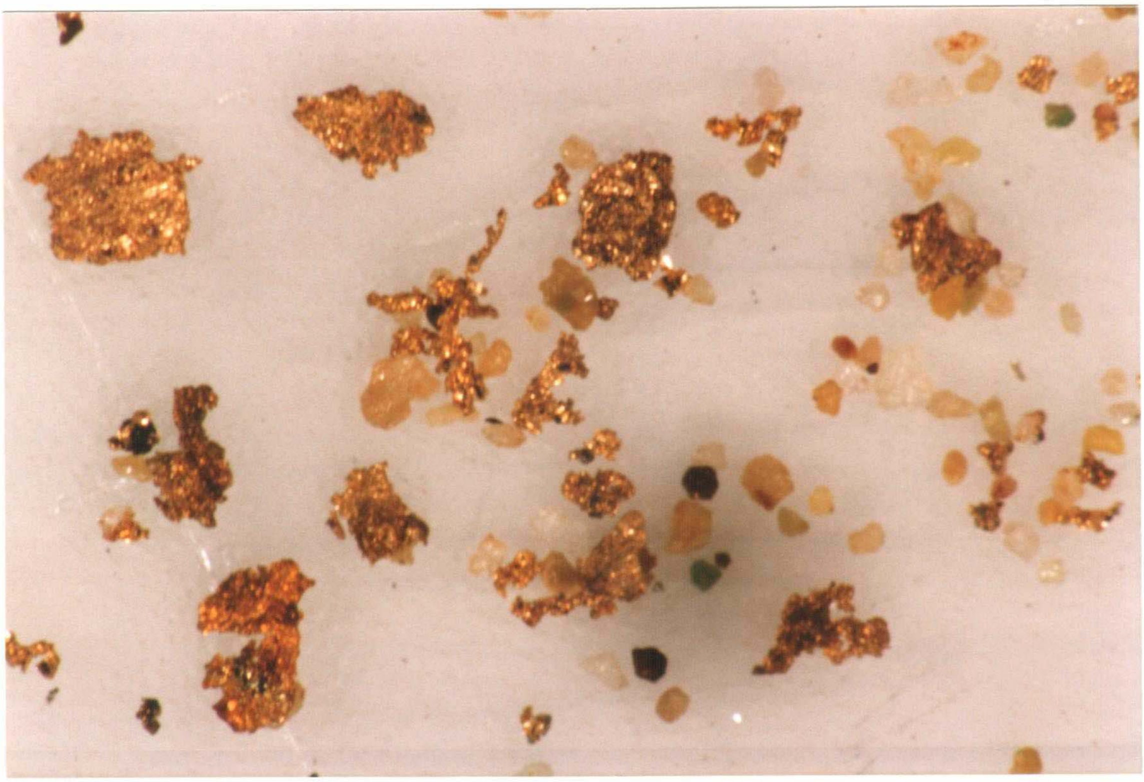

Plate 4a. Rare grains of coarse gold separated from miners tailings at Kias Creek during field trials. Scale 1cm = 0.5mm

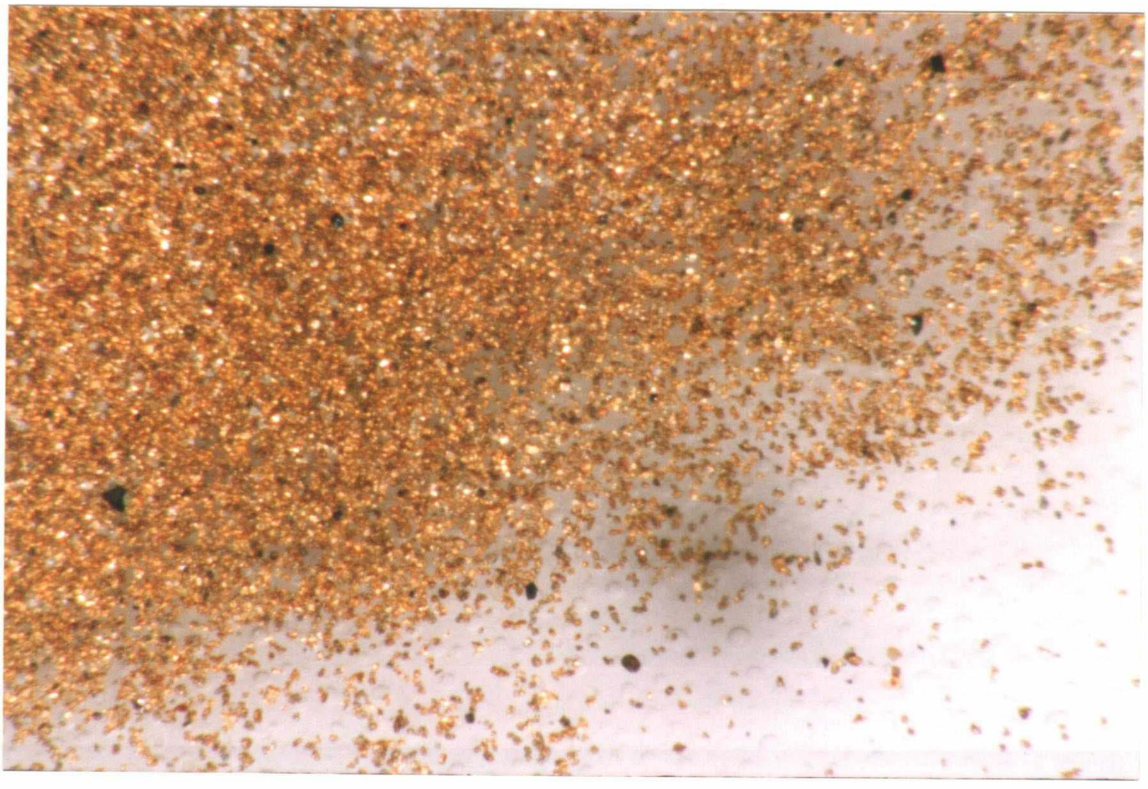

Plate 4b. Fine gold which forms the bulk of the concentrate separated from tailings at Kias Creek, most of the gold is 30-40 μm in size. Scale 1mm = 20μm

Plate 5a. Coarse gold separated from milled ore at Acupan small mines. Grains are flattened due to crushing and have Fe-oxide coatings. Scale 1cm = 0.22mm.

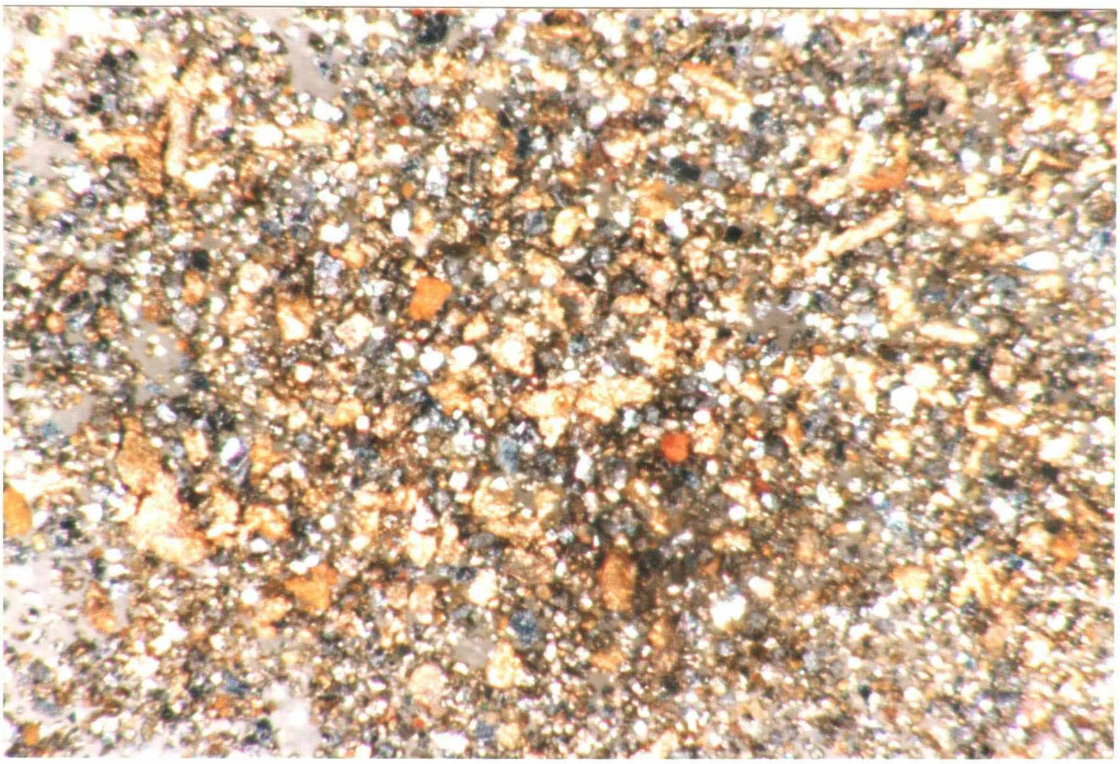

Plate 5b. Abundant 'medium' sized gold, around 100μm, from milled ore at Acupan. Scale 1mm = 22μm.

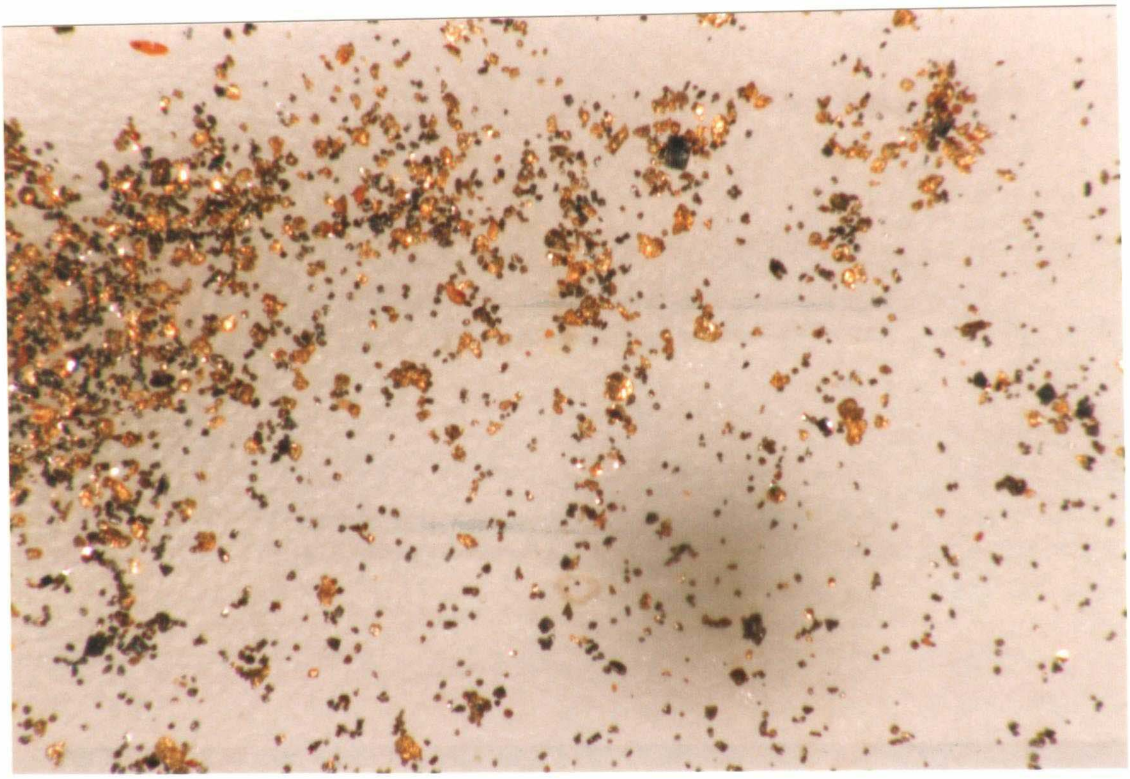

Plate 6a. Fine gold, 20-50μm, separated from milled ore at Acupan. Scale 1mm = 22μm.

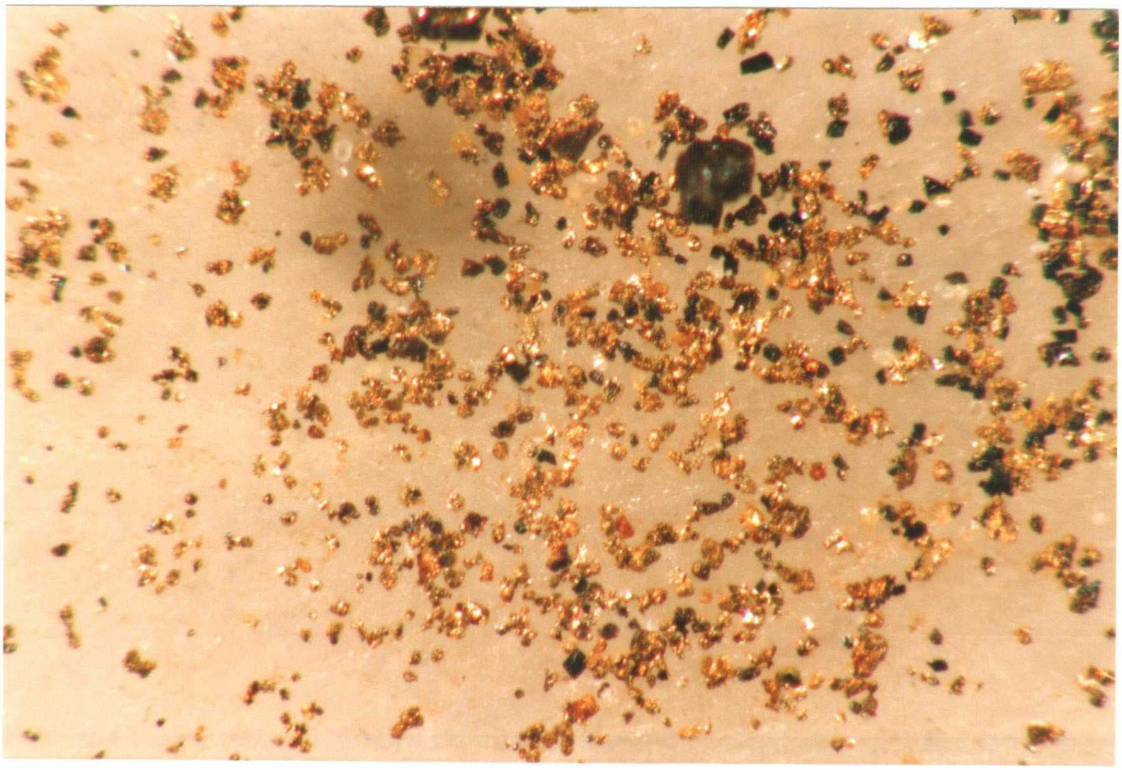

Plate 6b. Fine gold, 20-40μm, separated from tailings at Acupan. Scale 1mm = 14μm.