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## THE PROCESSING OF ALLUVIAL GOLD DEPOSITS FROM SAMPLING TO COMMISSIONING

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### ABSTRACT

Alluvial gold deposits require careful evaluation to determine correct methods of mining and processing. In the initial evaluation bulk sample plants and metallurgical testing are recommended. The information generated is then used for the design of mining and processing plants for the recovery of alluvial gold.

### INTRODUCTION

Historically the evaluation of alluvial gold deposits was carried out by limited drilling and/or sampling and assaying. The testing and evaluation techniques used were often somewhat dubious in both the reliability of the results obtained, and their interpretation in terms of processing requirements.

For an alluvial gold operation, the measure of processing efficiency was considered to be more a function of tonnage treated and gold produced, rather than percentage recovery rates of the absolute values contained in the ground being mined. Indeed, the common lack of any tailings sampling and assaying was a sign of the prevalent, presumptive attitude that gold metallurgical recoveries were at or near 100%.

It is now well known that for many of the older generation alluvial gold operations, significant losses of fine gold did occur. However, these gold losses were not recognised due to the inefficiency of recovery technologies available at the time for both sample evaluation, and bulk processing.

The historical non-scientific approach to alluvial gold deposit evaluation could be considered excusable due to the relatively high ore grades and coarser gold being available in the virgin ground being exploited. However, the relatively low grades of alluvial gold deposits now being considered for mining necessitate

the fullest application of modern sampling theory and use of sample processing and evaluation techniques in order to ensure that the best available relevant information is obtained. Such information can then provide a sound basis for evaluation of the deposit from both technical (mining and processing) and economic view-points.

The theory of sampling has been well expounded by Gy. (1979), and the need to extract and process bulk samples to evaluate alluvial gold deposits is now well accepted. Bulk samples are necessary to achieve some reasonable semblance of representivity for alluvial gold deposits in which grades now considered for exploitation are as low as 0.2g/tAu.

The use of small process (or pilot) plants for the treatment of bulk samples derived from alluvial gold deposits is now common practice and this technique, if properly managed, provides a relatively reliable means to evaluate:

- i) the metallurgical characteristics of the ore,
- ii) a first order assessment of recoverable values, and
- iii) the requirements for processing the ore to recover the gold.

## DEPOSIT CHARACTERISATION

### ORE GRADE

The absolute gold content is clearly one of the prime economic determinants in the evaluation of an alluvial gold deposit. However, the gold content of the ground, in terms of grams of Au per tonne (or cubic metre) alone, is insufficient information to characterise the gold as a mineable resource. Other factors of varying significance include aspects associated with the gold particles and the bulk ore.

### GOLD CHARACTERISTICS

#### Size Distribution

The generally accepted phenomenon that alluvial gold is coarser than lode gold has been explained in terms of alternative theories, physical accretion and chemical precipitation. (Wenquian & Poling, 1983). There are also conflicting theories and examples of bimodal and unimodal size distribution in alluvial gold deposits. Furthermore, there is good evidence that gold will both degrade and accrete in river environments. (Fricker 1984).

Whatever the theories, or reasons for gold sizing in alluvial deposits, determination of the correct gold particle size distribution is critical to the selection of processing equipment in order that optimum gold recoveries are achieved.

#### Shape

Particle shape has been interpreted in a variety of ways (Fricker & Minehan, 1986) and the influence of the "flatness factor" in the recovery of alluvial gold is well documented (Cook & Rao, 1979; Lashley, 1983). In essence the malleability of gold results in individual particles assuming a flattened or flakey shape. The flatness factor is also clearly related to absolute particle size determination.

Furthermore, in general, alluvial gold particles become more flakey as the gold gets finer in size. These phenomena reduce the advantage of the high relative density of alluvial gold in conventional gravity separation systems, and some knowledge of gold particle shape is important for the realistic assessment of potential process recoveries.

### Surface Characteristics

The porosity and hydrophobicity of gold particles also increase the difficulty of separation of gold by gravity separation.

The natural hydrophobicity of metallic gold is often enhanced by oils used in machinery and/or derived from vegetation. Such hydrophobicity results in the flotation of gold particles, which escape recovery by gravity separation processes.

Another surface characteristic that can change the effective density of a gold particle is the presence of surface coatings. Surface coatings can be organic or inorganic in nature.

Although such coatings can influence hydrophobicity, of perhaps greater significance is their detrimental effect on the amalgamability of the gold.

### ORE CHARACTERISTICS

#### Size Distribution

The relative proportions of various size fractions in the ore are significant in determining the appropriate mining method and processing requirements. Specifically the presence and proportion of coarse (lump) material will dictate design requirements for the oversize handling facility. The presence of significant levels of fine clays and silt material (nominally  $-50\mu\text{m}$ ) will affect water quality and may necessitate a classification (desliming) stage in the processing with subsequent attention to tailings disposal requirements.

#### Bulk Density

Attendant to the size distribution is the bulk density of the in situ ore. Knowledge of this factor is critical to determining volumetric tonnage and also to the correct specification of mining equipment.

#### Liberation

The presence of clays in alluvial ores often results in the agglomeration of larger sand-size and lump particles. Such cementation commonly occludes gold particles and/or results in inorganic coatings on the gold particles. Knowledge of the degree of agglomeration and the energy and water requirements necessary to achieve liberation of the gold is necessary for correct process plant design.

### Mineral Assemblage

Heavy minerals such as magnetite, ilmenite, rutile, zircon, cassiterite, etc. are commonly associated with alluvial gold. Knowledge of the overall heavy mineral content, mineral composition, and size distribution is important as it will affect not only the selection of process equipment in the primary processing plant, but also the gold room circuit and sizing, together with the probable transport method of the plant concentrate to the gold room.

Bulk sample processing and further laboratory investigations of concentrates derived from bulk samples can provide the data outlined above. Once established, these data are the bases for determining the most appropriate mining method and the processing systems for the recovery of gold from alluvial deposits. Apart from establishing base data for each bulk sample, however, it is perhaps just as significant to determine the range and variability of each of the factors throughout the deposit.

### Deposit Size

The total volume of ore available together with the recoverable values content in any mineral deposit usually determines the maximum mining rate. In addition, consideration must be given to:

- i) The Depth of the deposit (both maximum and minimum) and the associated water table levels. These aspects are of prime consideration in the selection of mining equipment and for materials handling/tailings disposal methods.
- ii) The Width of the deposit. This aspect is significant in terms of the need to ensure that a reasonable working face can be established.
- iii) The Length of the deposit, for which consideration is required as regards both the mining method, and type of process plant, e.g. floating or land-based; and if land-based, whether fixed, mobile or relocatable. Furthermore, this aspect is significant in terms of the requirements and costs for any reticulated services.

### Deposit Cross-Section

Alluvial deposits can be notoriously variable both laterally and throughout their depth. Variation of grade with depth is a necessary consideration as stripping of barren overburden ahead of the ore may be feasible. If overburden stripping is desirable, it

is important to establish the existence and consistency of a clear interface between the overlying vegetation/soil and /or barren superstrate and the ore.

A common characteristic of alluvial gold deposits is a concentration of gold at the interface of alluvium and the basement. If this phenomenon occurs, the need either to remove the top section of the basement rock and/or to carefully cleanse the basement and any crevasses within it will influence the mining method selected.

Clay layers within an alluvial deposit can be significant to the processing requirements of the ore. Even though the overall clay content can be relatively low, the "balling" effect that can occur during screening when clays are present may result in gold losses.

The presence of timber and/or other large objects at depth within the alluvium, and the stability of trench/pit walls should be assessed as both of these factors can be significant in the selection of a mining method.

### LOCAL CONDITIONS

Apart from the deposit characteristics, which, for any particular deposit, will normally be the basic determinants of the mining method selected and the processing requirements for gold recovery, local conditions are usually also significant to the overall technical and/or economic feasibility of establishing an alluvial gold operation.

#### Water Supply

The continuous availability of water at the requisite quality, quantity and cost is one of the most critical aspects for alluvial mining operations.

#### Meteorological and Seismological Conditions

Precipitation (rain/snow) and temperature data are important for final plant design in the scheduling of construction activities and in establishing services.

Wind data can determine the design of plant structures and, in particular, winch manoeuvring systems for floating plants.

Earthquake loading data are necessary for building/structural specifications.

#### Energy Supply

The source of power can be significant in terms of both capital and operating costs. If power is available from a national supply the reliability, consistency and costs need to be established. The reliability of power supply is critical to overall plant operating availability, and locally generated power may prove cost effective on this basis alone.

#### Transport and Communications

Information on access to the proposed mine site by existing roads, railways and/or waterways, and definitive data on the maximum dimensions and loadings which can be transported via these systems from shipping ports and airports can be critical in determining project costs.

The existence and reliability of communications facilities (telephone, telefacsimile, telex) is significant to the efficiency of an operation, especially during construction and commissioning, but also during subsequent normal production.

#### Statutory Requirements

Satisfying legal requirements can cause more delay in a project than any other aspects. Care must therefore, be taken to ensure the necessary correct approvals and/or settlements are obtained from the appropriate regulatory authorities with adequate time allowances. Statutory constraints can cover a diversity of aspects, including land use, water rights, environmental aspects, land ownership, taxation and royalties, importation restrictions, design standards, industrial awards.

### FINANCE

The financing of gold ventures has historically been at the extreme of entrepreneurial endeavour. High financial risks were taken by investors stricken by gold "fever." The risks were often associated however with the lack of background information of the types outlined above. This information is now

recognised as necessary for the launch of a sound mining venture and, indeed, the financial institutions are now requiring "bankable" documentation inclusive of sound technical and economic argument in favour of the feasibility of a mining operation.

Current world activity in gold is related largely to the gold price, however, the availability of "gold loans" (whence repayments are made in gold) has made investment in gold ventures particularly attractive in third world countries where hard currency investment is a scarce commodity.

### TRADITIONAL TECHNOLOGY FOR GOLD RECOVERY

The high specific gravity of gold compared with the gangue minerals makes gravity separation attractive for the recovery of gold from alluvial deposits. Primary concentration by gravity separation followed by amalgamation has always been the mainstay of gold recovery from alluvial deposits. Sluices were the first type of gravity concentrator with any significant capacity used in alluvial gold operations. Their simplicity reflected the ease of recovery of coarse gold which was the primary objective of earlier processing systems. The later adoption of screening systems to remove gross oversize and the transition to the more effective strakes improved the probability for recovery of finer gold. But losses of gold sized below 0.25mm were significant and frequently not fully recognised.

The introduction of jigs, having the advantage of allowing continuous processing, resulted in increased metallurgical efficiency and reduced the potentially recoverable gold size to 0.1 - 0.2mm.

The inherent shortcomings of the techniques available and/or the methods used to assess the metallurgical efficiency of alluvial gold separations in the past (as outlined above) resulted at times in dramatically understated levels of gold occurring at finer sizes (particularly less than 0.1mm) in alluvial deposits.

### CURRENT TECHNOLOGY FOR GOLD RECOVERY

Gravity separation remains the almost exclusive primary concentration system for gold recovery from alluvial deposits. However, the incorporation of fine gold recovery unit processes is now commonplace in alluvial gold operations. These fine-gold

recovery circuits utilise technology, some of which has been a spin-off from the Australian mineral sands industry, and other hardware developed specifically for gold recovery.

The applicable size range for the most common wet gravity concentrators is indicated in Figure 1.

**Jigs**

Jigs are still considered the most appropriate technique for the recovery of alluvial gold down to approximately 0.2mm. The real advantage of jigs is their tolerance of a wide feed size range and fluctuations in feed tonnage, operational aspects which are often intrinsic within alluvial gold operations.

The relatively recently-developed circular jig is marginally more efficient than the rectangular style in that the diminishing radial velocity enables the outer portion of the jig to perform a scavenging function (Nio & van Muijen, 1988). However, the relatively high cost and sophistication of control associated with circular jigs has mitigated against their popularity for alluvial gold operations.

**Cone Concentrators**

The Reichert cone concentrator is a high capacity, low cost gravity concentrator designed for the treatment of particulate material generally finer than 2mm in size and to recover fine heavy mineral particles down to 0.04mm (Ferree & Terrill, 1978). For effective operation, cone concentrators require well-controlled feed tonnage and density, requirements that are often not feasible in alluvial gold operations. Notwithstanding the foregoing comment, cone concentrators have been successfully utilized in alluvial operations (Robinson & Ferree, 1983).

**Spiral Separators**

Significant developments and refinements to spiral separators since the original Humphreys unit have resulted in a number of spiral models now being available, several of which are appropriate to the recovery of gold generally in the size range -1.0 +0.04mm (Balderson, 1982). Metallurgical performance data from several installations have reported (Robinson & Dolphin, 1984) gold recoveries of alluvial gold down to 0.04mm with diameter to thickness ratios of up to 20:1.

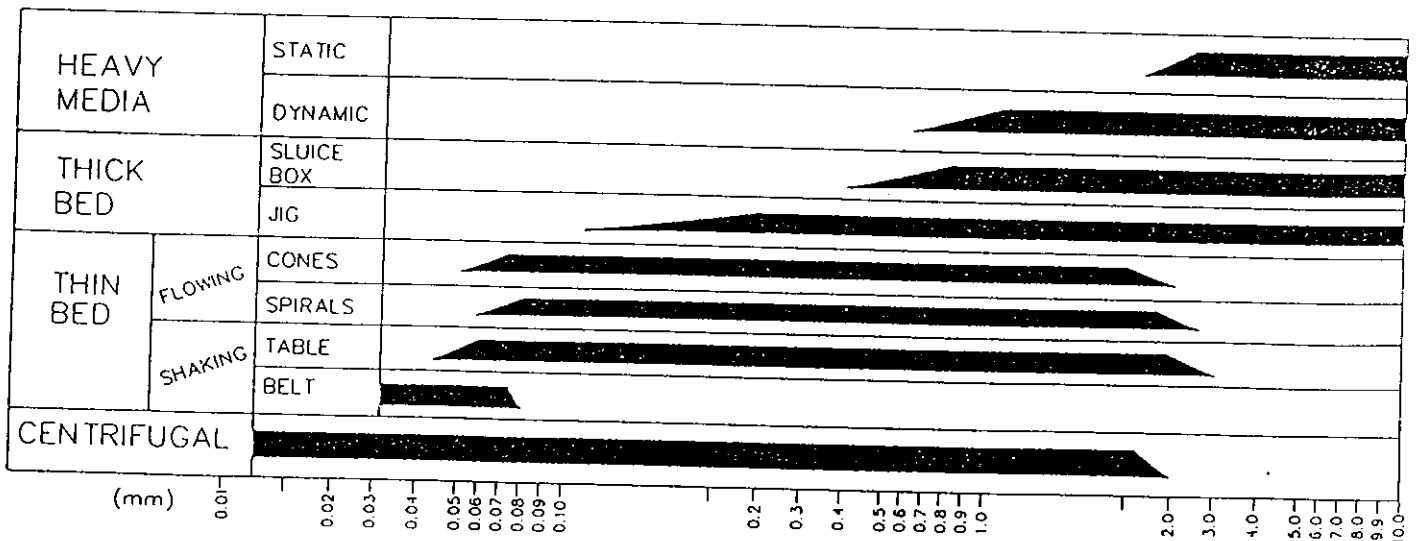


FIGURE 1 OPERATING SIZE RANGE FOR WET GRAVITY CONCENTRATORS

### Hydrocyclone Systems

Water washing cyclones have been proposed for gold beneficiation (Visman, 1966). Although their use in the Soviet Union is well-established (Mankov et al, 1988) the potential for such systems appears to be considered rather limited elsewhere. Dense medium separation cyclones and their derivative versions, including the "Dynawhirpool" (Willis & Lewis, 1980) and "Tri Flow" separator (Dessinibus, 1982) although accepted in the coal and tin industries, are also unlikely to find application in the treatment of gold ores. This is due to their cost effectiveness being limited to the treatment of material greater than 0.5mm.

### Centrifugal Separators

The concept of enhancing the density effect through spinning (centrifugal) gravity separation devices has a sound basis and has resulted in the development of number of devices claimed to recover gold at sizes finer than that recoverable by jigs and/or spirals.

More recently developed centrifugal separators range from relatively simple devices such as the Knelson concentrator (Harris, 1984) and the Knudsen bowl to the sophistication of the centrifugal (Kelsey) jig and the (Mozley) MultiG Separator.

### Shaking Tables

Wet shaking tables are one of the most efficient gravity separation devices for the recovery of heavy minerals in the size range  $-2 +0.04\text{mm}$ .

For alluvial gold, shaking tables can exploit the naturally and commonly occurring flat shape of the gold particles. The large surface contact area of the flattened particles enhances the drag forces on the table deck, thereby potentially improving gold recovery. Notwithstanding this factor, the natural hydrophobicity of fine gold particles can be more significant, with gold losses resulting from such particles floating across the top of the bed (Feather & Koen, 1973). Assuming the flotation problem can be controlled, shaking tables have an accepted place as normal gold room practice where their disadvantages of low unit tonnage and relatively high unit cost are outweighed by their metallurgical efficiency in the treatment of low tonnage high grade concentrates.

A recent addition to shaking table technology is the Gemini gold table, a low tonnage gravity separation device designed for the efficient and selective recovery of free gold particles from heavy mineral concentrates.

### Other Systems

The use of Johnson drum concentrators followed by continuous strakes for the recovery of coarse gold from grinding circuits for hard-rock gold ores has found favour in South Africa and to a limited extent in Western Australia. However, such systems have not proved popular for alluvial gold operations.

Ultrafine or slimes gravity separators such as the GEC duplex concentrator and the cross-belt separator have found limited application (Bradford, 1987) in fine alluvial gold recovery. However these devices are generally high-cost, low-throughput systems, and as such are not suited to low-grade alluvial gold ore.

## PROCESSING REQUIREMENTS FOR ALLUVIAL GOLD DEPOSITS

The recovery of gold from alluvial deposits can broadly be divided into three sequential aspects: mining, concentration, and gold room.

### MINING

Alluvial gold deposits can be mined either by wet or dry mining techniques. The choice of method is dependent on the scale of operations and the characteristics of the deposit. Detailed hardware mining options and their associated advantages and considerations are listed in Table 1 (after MacDonald, 1983).

TABLE 1

DRY VS WET ALLUVIAL MINING SYSTEMS (after MacDonald, 1983)

|                                   | Dry Mining  | Wet Mining   |
|-----------------------------------|---|--|
| APPLICATIONS                      | Shallow surface deposits, tightly compacted or indurated sands, irregular geometry, desert environment.   | All environments where ample water is available for mining and processing, including shallow deposits, high dunes mineral deposits.  |
| HARDWARE                          | Bulldozers, scraper loaders, front end loaders, draglines, hydraulic excavators, bucketwheel excavators.  | Suction dredges, bucketline dredges, bucketwheel dredges, clamshell dredges, jet-lift dredges, hydraulic excavators.   |
| CONTROLLING FACTORS FOR SELECTION | Scale of mining, minerals distribution and value, location and physical characteristics, slope and texture of mining floor surface and bedrock geometry, availability of water. | Scale of mining, deposit size and grade, location and physical characteristics, slope and texture of mining floor, bedrock geometry, amount of water available, position of water table. |
| ADVANTAGES                        | Ability to handle a group of small deposits, selective mining leads to feed grade control.  | Mining and processing can be incorporated on one unit, low unit mining costs, only possible method in excess water conditions.   |
| DISADVANTAGES                     | High unit operating costs, difficulties in handling occasional large volumes of water, requires firm base for vehicle movement, needs large on-site workshop facilities.        | Less mining selectivity, high capital cost, large water requirements.  |

\* \* \* \* \*

CONCENTRATION

Feed Preparation

Mined alluvial gold ores are usually treated initially by screening and/or classification to produce two or more sized/classified process streams.

Coarse oversize may be removed by rotating trommel screens to reject material nominally greater than 10mm. For dry mining a grizzly may be necessary to remove large oversize material (say greater than 250mm) prior to slurring with water and subsequent pumping to finer screening.

For clay-bound or otherwise cemented material, liberation is necessary prior to screening, the degree of cementation determining the amount of energy required to liberate the material and thence the unit processes to be used, which may include a rotary scrubber or attrition cells.

For ores containing significant levels of clay material, it may be necessary to remove the slime fraction by classification after liberation and coarse screening. This classification is normally carried out using hydrocyclones or screw classifiers.

Coarse Gold Recovery Circuit

For the recovery of gold from alluvial ore containing a significant amount of gold in the particle size range 0.5mm to 10mm, a process circuit incorporating jigs is normally employed. The jig circuit may incorporate up to three stages to ensure maximum recovery and upgrading is achieved.

For alluvial gold ores in which there are only a few particles of gold greater than 0.5mm, a reduced coarse gold recovery circuit can be used. Such a reduced circuit would use sluices or strakes or other gold trap-type devices.

### Fine Gold Recovery Circuit

Although a jig circuit will recover gold below 0.5mm in size, the presence of significant amounts of gold below 0.2mm will necessitate process circuitry specifically for fine gold.

For effective operation fine gold circuits, which generally utilize flowing film gravity separation devices, require good feed preparation.

Feed preparation normally involves screening (the jig circuit tailings) at 2-3mm, using a vibrating screen or sieve-bend the oversize being rejected. The screen undersize may need classification for slimes removal prior to gravity separation.

Fine gold recovery circuits are effective for recovering gold in the range 1.0-0.04mm and would normally incorporate several stages of spiral separators. Spiral circuit concentrates may provide direct gold room feed or be further concentrated using, for example, Knudsen bowls.

The presence of other heavy minerals (which are likely to include magnetite, ilmenite, zircon, cassiterite) can have a significant effect on fine gold recovery, and will influence the process circuit utilized. The selection of spiral models utilized is significant, and furthermore the removal of magnetic minerals may be desirable.

Magnetite is readily removed by low intensity magnetic separation, and ilmenite by high intensity magnetic separation.

A generalised flowsheet (Figure 2) illustrates all the above stages in alluvial gold processing.

### GOLD ROOM

Gold concentrates from the processing plant are normally removed to a separate facility for final upgrading to produce gold bullion. This approach is normally used for security reasons and to minimise gold losses. The gold room operations are carried out under close supervision and on a batch basis during a day shift schedule.

Coarse and fine gold concentrates can be treated separately or together depending on individual characteristics, including size and shape of the gold, and the presence of other heavy minerals. Similar processing stages are used whether the concentrate is

coarse or fine and would normally utilize gravity separation, amalgamation and smelting and bullion production. Example gold room flowsheets for coarse and fine gold concentrate upgrading are illustrated in Figure 3.

### EXAMPLES

The varying processing requirements outlined above are illustrated by a number of recently commissioned alluvial gold operations.

Monterado Mining Mas, Kalimantan, Indonesia (Figure 4)

This operation is a very low grade deposit in which gold occurs over a broad size range. The operation consists of 2 x 400tph bucket wheel dredges each feeding a separate floating concentration plant. The free-flowing ore requires little liberation, but the presence of a wide size range of gold necessitates both coarse (jig) and fine (multi-stage spirals) circuitry. The presence of significant levels of magnetic minerals (magnetite and ilmenite) necessitates the incorporation of magnetic separation. Knudsen bowl concentrators are used for final coarse gold recovery and for scavenging the fine magnetics fraction.

Indo-Pacific Resources, Marisa, Sulawesi, Indonesia (Figure 5)

This is a low grade (0.4-0.6g/m<sup>3</sup> Au) alluvial deposit located on an inland river flat. The gold occurs largely in the size range 5mm to 0.1mm at a depth of 5-12 metres. Only very low levels of heavy minerals are present.

The operation consists of dry mining by hydraulic excavator, and a floating concentration plant with a design throughout of 440 tph. A significant proportion of coarse material occurs, but the ore is very low in slimes. Processing incorporates prescreening at 240mm (grizzly). The screen undersize is slurried and pumped to a rotating trommel to be further screened at 10mm. All +10mm material is rejected, and the -10mm material is treated in a simple, two-stage jig circuit.

The concentrates from the secondary jigs are stored in a 20 tonne bin, and are treated on a day-shift basis only using two stages of Knudsen bowls. The Knudsen

bowl tailings are scavenged by an amalgamation launder.

The Knudsen bowl concentrate is transported in locked kibbles to the gold room, where it is further upgraded on a Gemeni table and subsequently amalgamated prior to smelting into bullion.

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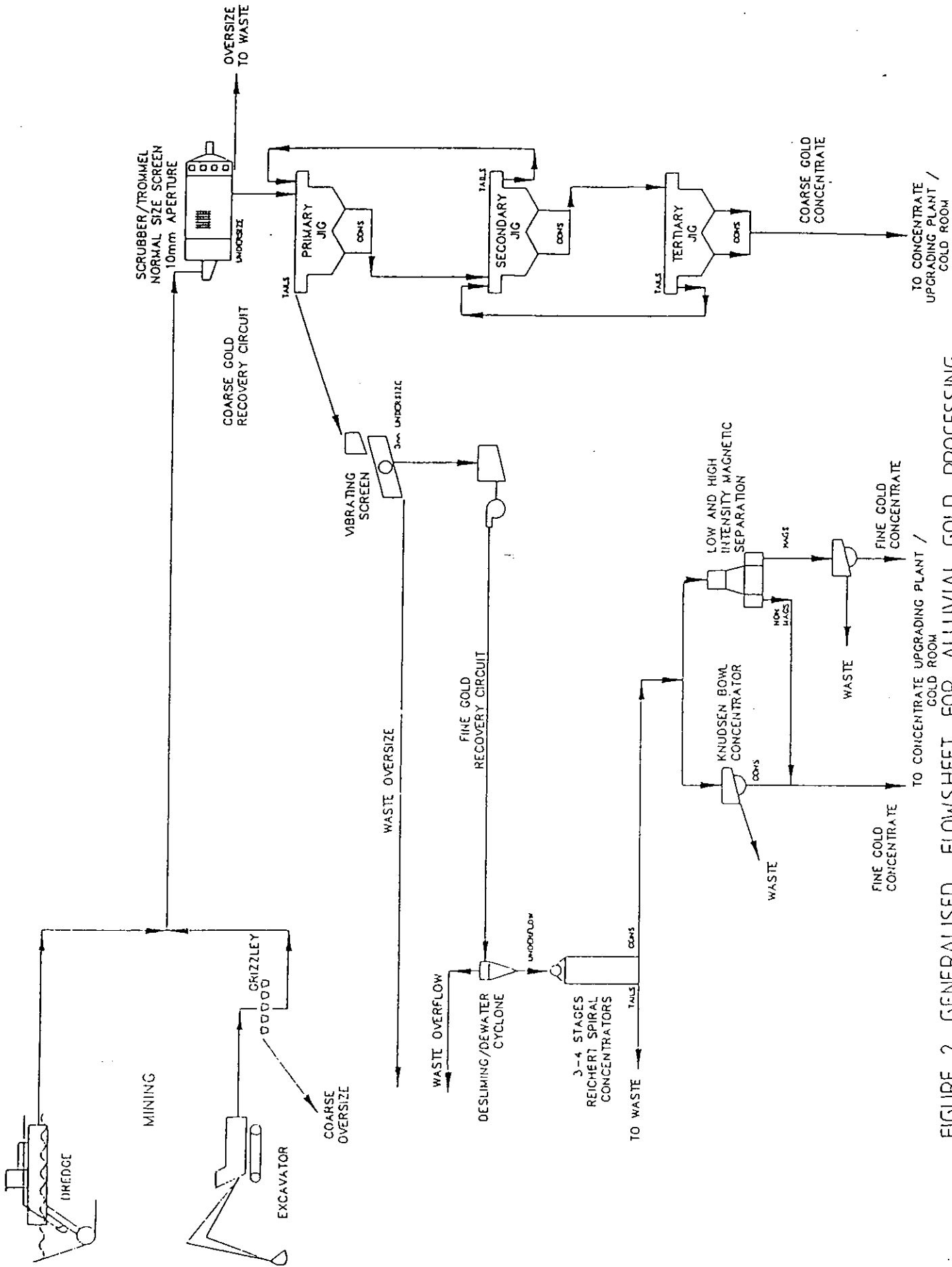


FIGURE 2. GENERALISED FLOWSHEET FOR ALLUVIAL GOLD PROCESSING

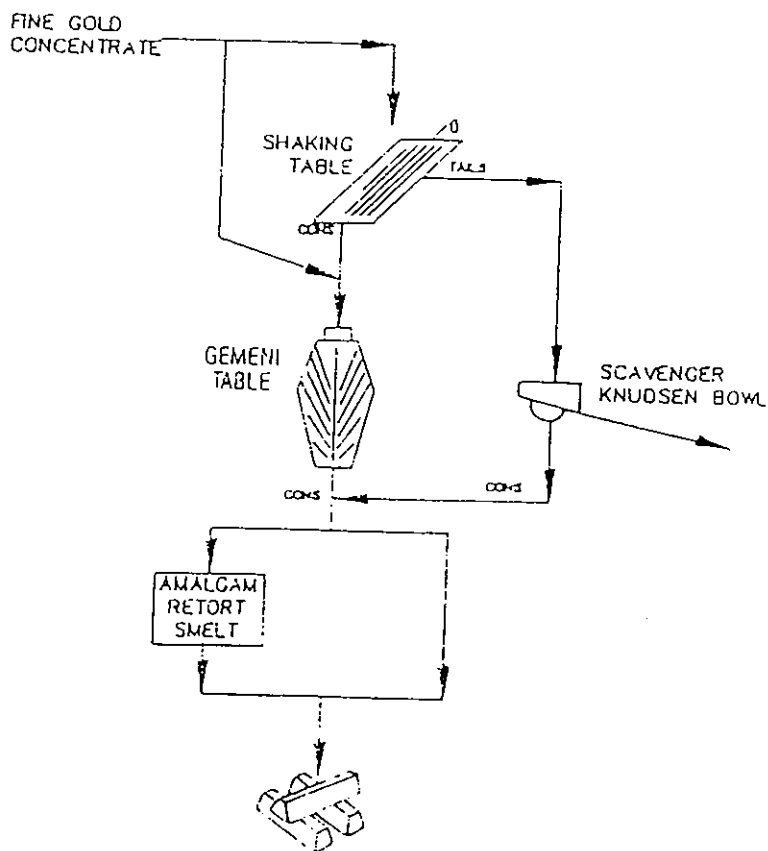
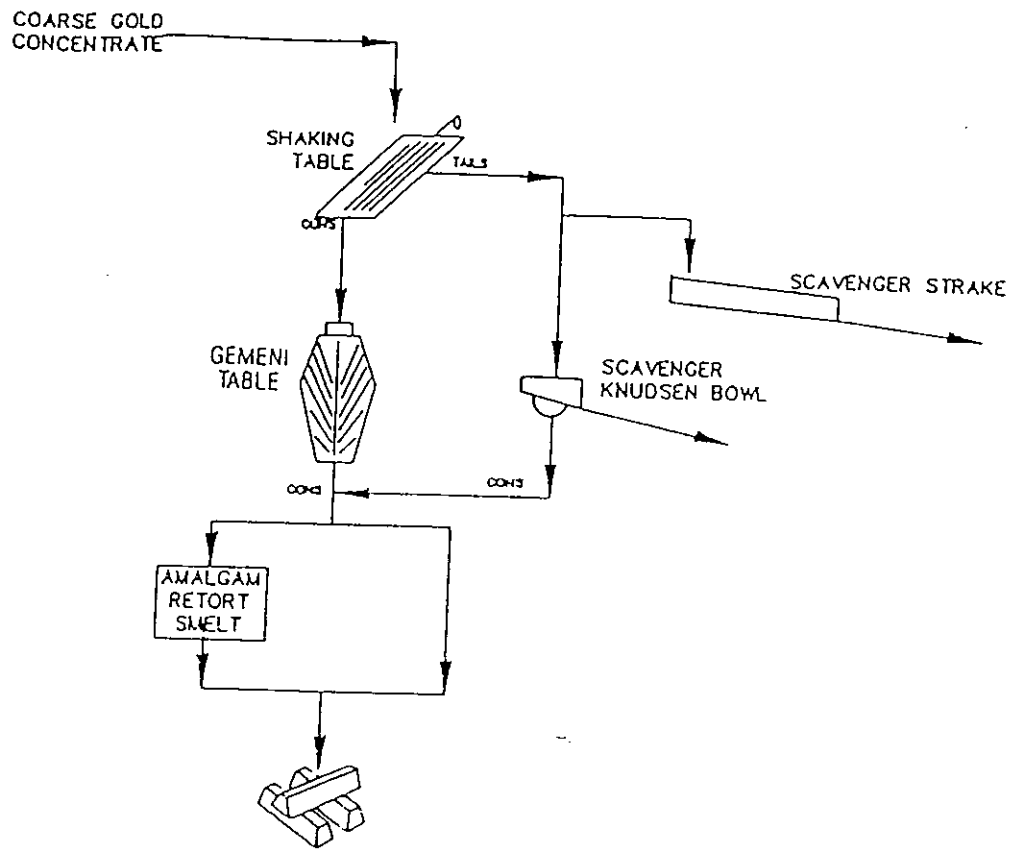


FIGURE 3. GOLD ROOM FLOWSHEET OPTIONS





