

MINERAL PROCESSING DEVELOPMENTS FOR  
DREDGE MINING APPLICATIONS

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INTRODUCTION

Mineral Deposits Limited commenced operating in the mineral sands industry in 1940.

In these early days the Company operated as a syndicate producing rutile and zircon minerals from very high grade deposits. Due to the high grade nature of deposits, only small amounts of upgrading were necessary by a mining plant before separation into rutile and zircon products.

Naturally these deposits did not last for ever and eventually mining plants or wet plants were necessary to handle increasing tonnages of lower grade feed material. This led MDL into a number of areas:

1. Dredge technology.
2. Design, manufacture and supply of mineral processing equipment.
3. Design, construction and commissioning of mineral processing plants.

Initially, all three of these areas were pursued to satisfy the needs of the MDL Mining Division and are still pursued today. This was quickly altered to satisfy the needs of the mineral sands industry in Australia and, very soon after, the mineral sands industry worldwide and to many other minerals in most parts of the mining industry. This paper will examine two specific areas:

1. Mineral Processing Equipment
2. Mineral Processing Plant

Both these will be examined for dredge mining applications for three main areas; mineral sands and alluvial gold.

MINERAL SANDS

- Mineral Processing Equipment -

The processing equipment used in the mineral sands industry in Australia since the 1940's is tabulated below. This is a very general table to show the major trends in the equipment being used at various times.

Australia - Mineral Sands Industry

<u>Time</u>	<u>Process Equipment Mining Plant</u>
Before 1940	No processing - direct mining and processing of high grade minerals
1940-1950	Shaking Tables, small use of spiral separators, type 1
1950-1960	Spiral separators, type 1, numerous designs of tray separation systems
1960-1970	Spiral separators, type 1, numerous tray systems and Reichert cone concentrators
1970-1980	Reichert cone concentrators, tray systems, spiral separators, type 1 and spiral separators, type 2.
1980's	Spiral separators, type 2, and Reichert cone concentrators

Note:

Spiral separators, type 1, refer to spirals that use added wash water and spiral separators, type 2, refer to spirals that do not have added wash water.

The table above is very general and refers to the major mineral processing equipment used in the time periods indicated.

## Gravity Separation Equipment

### Reichert Spiral Separators

The first spirals manufactured by MDL were constructed in concrete. Spirals then moved to fibreglass construction with rubber lining and, in the late 1970's, to fibreglass construction with a polyurethane lining.

A significant number of the components used for the assembling of spirals are also manufactured from fibreglass and polyurethane castings.

Spirals began as single start units with wash water and today's spirals are sold in multiple starts with no wash water.

The competitive nature of the spiral manufacturing industry together with the spread in application areas for spiral separators from the mid 1970's has led to several innovative aspects being introduced to spiral design over the past ten years. The use of wash water has been dispensed with in many spiral models, and the introduction of compound trough profiles and continuous changing profiles has effected significant improvements in metallurgical performance and increases in unit capacity. Furthermore, the availability of spirals in multi-starts per column has reduced plant floor area/tonnage requirements.

The availability of a wide range of spiral separators suitable for selective duties has re-popularised the spiral and several existing plants in Australia have recently revamped by the incorporation of spiral separators for duties previously carried out by other equipment.

The concept of using spiral separators in areas previously considered for much higher capacity devices like the cone concentrator has led to the development of spiral separators as a system instead of an individual unit.

For example, a 2000 tph mining plant would require 936 spiral starts as a rougher stage. These spirals could be supplied as 26 banks of 12 triple start spirals. One of these banks is supplied as a spiral system complete with the following:

- a) 36 outlet static feed distributor
- b) 2 steel spiral frames capable of supporting these triple start spirals in a double row.
- c) Product launder system capable of collecting 3 products; concentrate, middlings and tailings from the spiral separators.

- d) A spiral subframe that can position the spirals at a convenient height for operation.

A general arrangement drawing of such a system is included with this paper. This is shown in Fig. 1.

### Reichert Cone Concentrators

The Reichert cone concentrator still has its place in the mineral sands industry but is now being used in conjunction with spiral separators.

The 2 metre cone concentrator developed in the late 1950's and continuously improved to the present time has been widely used since the 1960's to the present time.

The cone concentrator has a number of configurations that allow its employment as a rougher/scavenger and as a cleaner/recleaner/finisher.

In the early 1980's a 3.5 metre cone concentrator was developed and will become a significant piece of mineral processing equipment for future plants. This particularly applies as plants become larger with heavy mineral deposits becoming lower in grade.

The benefits of the cone concentrator are still based on the smaller number of units required when compared to spiral separators and the ease of changing the performance of the cone concentrator, and thereby the total plant.

In addition to the gravity separation equipment which is principally spiral separators and cone concentrators, some use is being made of classification equipment to enhance recovery of valuable minerals and rejection of non-valuable minerals from gravity separation equipment.

Such equipment includes hydrocyclones and upstream classifiers. Hydrocyclones are being used for the removal of slime material and upstream classifiers are used for the rejection of fine silica and some low specific gravity minerals.

### - Mineral Processing Plant Flowsheets -

A mineral sands plant being fed by a dredge comprises a number of elements, these include:

- dredge mining
- feed preparation circuit
- mineral recovery circuit
- tailings disposal/concentrate storage

- water supply
- services

- c) Pulp density control or a combination of all three

The two elements to be covered in this paper are:

- a) Feed preparation circuit
- b) Mineral recovery circuit

Both of these circuits are obviously important but often the attention is based on the mineral recovery circuit and not enough attention is given to the feed preparation circuit.

#### Feed Preparation Circuits

The name states the purpose, that is, prepare the feed for heavy mineral recovery and separation.

The mining method in the case of dredging provides to the feed preparation circuit a pulp stream containing water, sand, mineral, rock, clay, slimes, organic material, fibrous material, shell, gravel, timber, etc.

The mineral recovery circuit requires a feed material that contains the mineral fraction and the sand fraction supplied at a controlled feed rate, feed density and, if the mining system allows, at a controlled feed grade.

The function of the feed preparation circuit is to achieve this purpose in an effective manner with the minimum number of maintenance problems and the minimal mineral loss.

The components of the feed preparation circuit which begin at the dredge discharge are: (and not necessarily in this order)-

1. Coarse screening - using a trommel/vibrating screen.
2. Scrubber, either as part of trommel or as a separate unit for mineral liberation from clay.
3. Fine screening, either by trommel, sieve bend screen or vibrating screen.
4. Surge bin - used for pulp density control, feed rate control and providing surge capacity for smooth plant operation.
5. Hydrocyclones - these are used for three potential functions:
  - a) Desliming of surge bin overflow and desanding for mineral recovery
  - b) Desliming of mineral recovery circuit feed

The choice of the elements used for a feed preparation circuit obviously depends on the nature of the mined material. For example, MDL at its Viney Creek operations in New South Wales uses a circuit which comprises:

- a) Trommel screen for the removal of tramp oversize including rock and fibrous material.
- b) A surge bin for primary feed density and control of desliming.
- c) Hydrocyclones for removing sand from surge bin overflow.

In the case of Sierra Rutile in Sierra Leone a feed preparation circuit comprises two stages of scrubbing to liberate mineral from clay, a number of screening stages and a number of hydrocyclone stages for desliming and density control.

The evaluation of the material to be mined is obviously essential from the mining point of view and even more essential with regard to the effective recovery of valuable minerals.

The feed preparation circuit must be considered as important, if not more important, than the mineral recovery circuit because of the dramatic effect it can have on mineral recovery and also on plant operating time.

#### Mineral Recovery Circuits

Metallurgical process circuits that are being used today are designed on numerous parameters. In all cases we can assume that the feed preparation circuit is presenting the mineral recovery circuit with a pulp stream at a controlled feed rate, and a controlled pulp density.

Since a feed preparation circuit is being used we can also assume that all of the tramp oversize has been removed and that the slimes (very fine particles) have been reduced to an acceptable level.

Parameters that would need consideration are:

1. Size of minerals - both high SG, that is, greater than 3.8 and low SG, that is, less than 3.8 but greater than 3.
2. Size of gangue particles.
3. Percentage heavy mineral, greater than 3.0  
Percentage heavy mineral, high SG greater than 3.8

Percentage heavy mineral, low SG less than 3.8 but greater than 3.0.

In simple terms, how well will the high SG heavy minerals separate and concentrate from the low SG minerals and gangue minerals using the mineral processing equipment that is available. Metallurgical testwork has to be designed to answer these questions, either in a laboratory or a pilot plant or a combination of both.

Assuming that the valuable minerals can be recovered and concentrated, consideration has to be given to the metallurgical circuit design. Consideration must now be given to the variability of the three parameters mentioned earlier as to:

1. How frequently do they vary?
2. What is the duration of variation?
3. By what amount do they vary?

A lot of this information is gained from deposit drilling and mine planning. Metallurgical circuits have to be designed to accommodate these variations and the equipment selection also has to accommodate these changes. This process equipment has to be designed to allow the minimum number of equipment changes as the incoming feed changes.

Spirals systems developed by MDL are designed to be forgiving of changes in feed rate, feed grade and feed density.

Modern spiral separators are potentially high efficiency devices, but this efficiency can only be achieved if the complete spiral package, including the necessary peripheral equipment, is capable of keeping the spiral separators in that part of their operating characteristic in which high levels of efficiency are achievable.

Highly developed spirals with limited number of splitters and no separate wash water supply can operate reliably due to limited need or opportunity for operator adjustment. However, it is then necessary to match the spiral closely to the duty since the performance characteristics are inherent in the shape and pitch of the volute and these can only be optimised for a limited range of operating conditions.

It is important that the spiral separators should not have too limited a range of optimum operation since, in practice, it is unrealistic to expect that the spiral can consistently be held in such a restricted envelope of operating conditions. Higher levels of overall plant performance can often be achieved with

more flexible spirals if compared with spirals that can demonstrate greater efficiency but only over a more limited range of operating conditions.

In developing complete spiral separation packages, MDL therefore adopts the following principles:

- a) Spirals should be as efficient as practical but over a realistic range of operating conditions.
- b) A wide range of different spirals is required so that for particular operating conditions a suitable spiral may be chosen.
- c) The adjustment facilities of the spiral should be suitable for its intended application.
- d) The spiral volutes must be accurately constructed with the designed shape being accurately reproduced and maintained in service.
- e) The spiral should be very well protected against wear both to limit maintenance costs and also to preserve the designed performance characteristics. Parts subject to high wear should be readily replaceable.
- f) Accurate distribution between spiral volutes is essential if the spirals are to operate within their preferred envelope.
- g) Laundering should be immune to incorrect direction of products from the spiral. This can be a major problem in large plants.
- h) The operator should have excellent access at all points at which adjustment, visual monitoring or cleaning is required.
- i) Easy access should be available for spiral replacement in the event of damage.

The parameters considered so far are characteristics of the ore body. Consideration also has to be given to the economic and operational needs of the metallurgical circuit, such considerations include:

1. Cost of producing mineral.
2. Cost of transportation of heavy mineral concentrate from mine site to mineral separation plant.
3. Effect of heavy mineral recovery on quality of final products.

These types of considerations are dependent on the mineral assemblage and the final product requirements. Each mine operation/deposit will have its own set of parameters which will have to be

evaluated. Some of these parameters will be common to other deposits and some will be unique.

Metallurgical testwork as part of a feasibility study will consider numerous questions that arise with regard to mineral assemblage, process circuits and final products.

A number of technical papers have been written on mineral recovery circuits. The articles are listed at the end of this paper. Some of these circuits are not being fed by a dredge but after feed preparation circuits, the philosophy for treating sand and mineral fractions is the same.

In the mineral sands industry in Australia today, mineral recovery circuits are being expanded to carry out more functions than just recovery and concentration of heavy minerals. These functions include:

1. Quartz rejection by upstream classification.
2. Rejection of light heavy minerals by expanded gravity circuits using high grade mineral spirals.
3. Cleaning of concentrates to remove slimes particles. This is carried out by attritioning cells and classification stages either hydrocyclones or upstream classifiers.
4. Magnetic separation to remove both magnetite and ilmenite.

These steps are in reality feed preparation stages for the mineral separation plant and are being incorporated in the mine plant for reasons of cost, product quality and environmental considerations.

## ALLUVIAL GOLD

### - Mineral Processing Equipment -

The processing equipment traditionally used for the recovery of alluvial gold has been covered in numerous articles and books beginning when man started to print. A considerable amount of equipment used at the start of this century is still being used today.

For all the correct reasons emphasis on alluvial gold operations has always been on the mining of the deposits because it is in this area that the operational money is spent. For this reason the processing equipment and processing plant has not always received the necessary attention.

The general philosophy in the past has been that gold is easy to recover by basic gravity separation techniques because of its high SG and its particle size. For these reasons jigs and sluices or other equivalent equipment have been adequate for the recovery of gold.

An alluvial gold operation of a medium size, that is, up to 600 tph now has a mining tool in the dredge (non bucket line) that has low mining cost and relatively low capital cost. Therefore, lower grade deposits, that is, lower than normal from previous experience can be exploited. These lower grade deposits are sometimes more difficult in terms of gold recovery due to grade and particle size.

This change in philosophy with regard to alluvial gold operations leads to closer examination of the following:

1. Deposit sampling techniques.
2. Use of bulk sample plants to evaluate cell deposits.
3. Metallurgical process equipment.
4. Metallurgical process plants.

These elements have been covered in the paper by Roger G. Richards - "The Processing of Alluvial Gold Deposits From Sampling to Commissioning".

This change in philosophy with regard to mining techniques has been translated from the mineral sands industry to alluvial gold. The mineral sands industry also brings to the alluvial gold industry the same approach with regard to equipment and processing plants.

The information contained earlier in the paper with regard to spiral and cone separators is applicable to alluvial gold.

### - Mineral Processing Plant Flowsheets -

The same elements as outlined for mineral sands apply to alluvial gold. Again the two points of interest are:

1. Feed preparation circuit
2. Mineral recovery circuit

#### Feed Preparation Circuit

The same comments written for the mineral sands industry apply to alluvial gold. Within alluvial gold two areas are of particular interest as they can dramatically effect the recovery of gold:

1. Scrubber/Trommel - Used for the breakdown of clay and therefore gold liberation.
2. Surge Bin Overflow - this is a major area of concern particularly for high clay deposits where gold losses have to be minimised.

#### Scrubber/Trommel

If the deposit contains clay either with or without gold, care has to be taken in the design of the scrubber system. When the clay has entrained gold the scrubber has to provide sufficient time to break the clay down into its constituent particles so that the gold can be liberated. Therefore, retention time in the scrubber, the design of internal lifters and overall power requirements are most important.

If the clay does not contain entrained gold it is still necessary for scrubbers to be used as gold particles will attach themselves to the clay and therefore need to be liberated.

#### Surge Bin Overflow

Most dredge fed plants require a surge bin between the dredge and the mineral recovery plant. This is necessary for the provision of controlled feed rate to the process equipment.

Alluvial gold deposits that contain clay normally generate considerable quantities of slimes particles, that is particles less than 10 microns in size. These particles become part of the water. They are carried in suspension and can have a significant effect by increasing the viscosity of the water.

The effect of this increase in viscosity is to greatly increase the solids carrying capacity of the surge bin overflow. The surge bin overflow can therefore have two things that are detrimental to gold recovery; one is volume of overflow and the other is viscosity of the overflow.

The feed preparation circuit between the dredge and the mineral recovery plant requires slimes and water to be removed from the pulp. This is normally carried out at the surge bin by overflowing the bin directly back to the pond.

With the increased viscosity of the water, solids will be carried over with the water, this will include gold particles. This gold loss can be overcome in a number of ways either by mining areas with a small amount of clay but unfortunately this is not always possible.

The second alternative is to collect the surge bin overflow and pump to hydrocyclones to recover the solids. This alternative is sometimes difficult if the volume of surge bin is too high. In this case the problem can be alleviated by pumping a large percentage of the surge bin overflow to hydrocyclones and not the total volume.

#### Mineral Recovery Circuit

A number of alluvial gold circuits are enclosed with this paper. There is no standard gold recovery circuit, there are only standard elements which can be combined to provide the best circuit to suit a particular ore body. The different elements are based on the general flowsheet attached with this paper. All alluvial gold recovery circuits should consider both coarse gold and fine gold as separate entities.

#### 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 1.0-0.4mm and would normally incorporate several stages of spiral separator. 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 illustrates all the above stages in alluvial gold processing. This is shown in Fig. 2.

#### 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. Gold room flowsheets for coarse and fine gold concentrate upgrading are illustrated in Fig. 3.

#### Examples

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

#### P.T. Monterado Mas Mining, Kalimantan, Indonesia

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 gold present requires little liberation but the presence of a wide size range of particles 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. Flowsheet is shown in Fig. 5.

#### Indo-Pacific Resources, Marisa, Sulawesi, Indonesia

This is a low grade (0.3-0.5g/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 throughput 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 gravitates 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. Flowsheet is shown in Fig. 4.

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

#### Philosophical Note - Alluvial Gold

The advent of the low operating costs mining tool, the bucketwheel dredge, has led potential alluvial gold process into lower grade and more difficult ore bodies with regard to recovering the gold. In this paper some of the potential problem areas have been highlighted.

The conclusion to be drawn is that an alluvial gold deposit has to be correctly assessed from the outset. This assessment must cover:

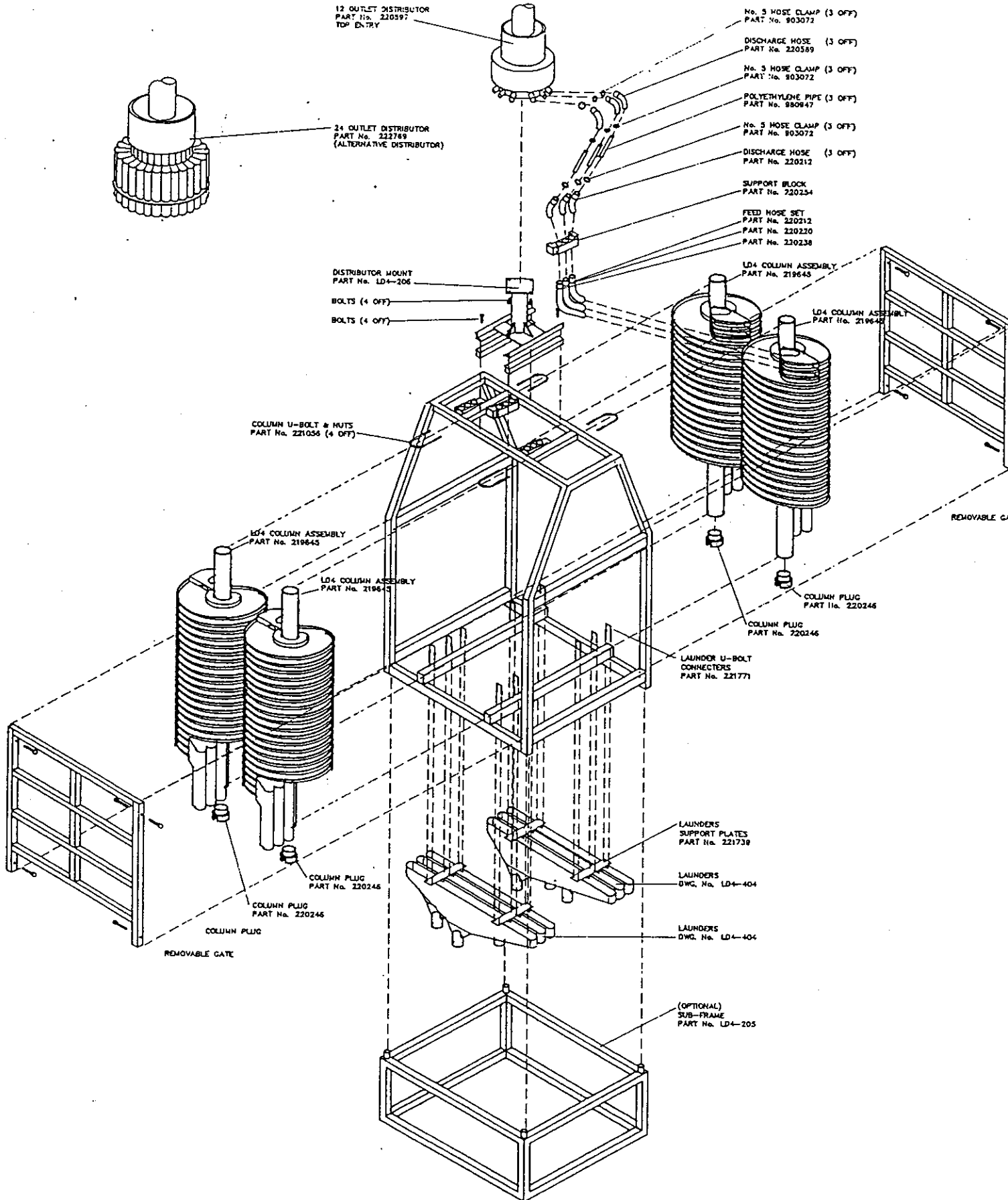
1. Size of orebody including location.
2. Grade of orebody and this means recoverable grade. From the experience MDL has gained the most effective way to determine this correctly is by drilling or equivalent method, followed by bulk sampling. Bulk sampling will provide the information on the size and grade of the orebody as well as

information on the mining of the orebody and the processing of the orebody which will provide the required gold recoveries.

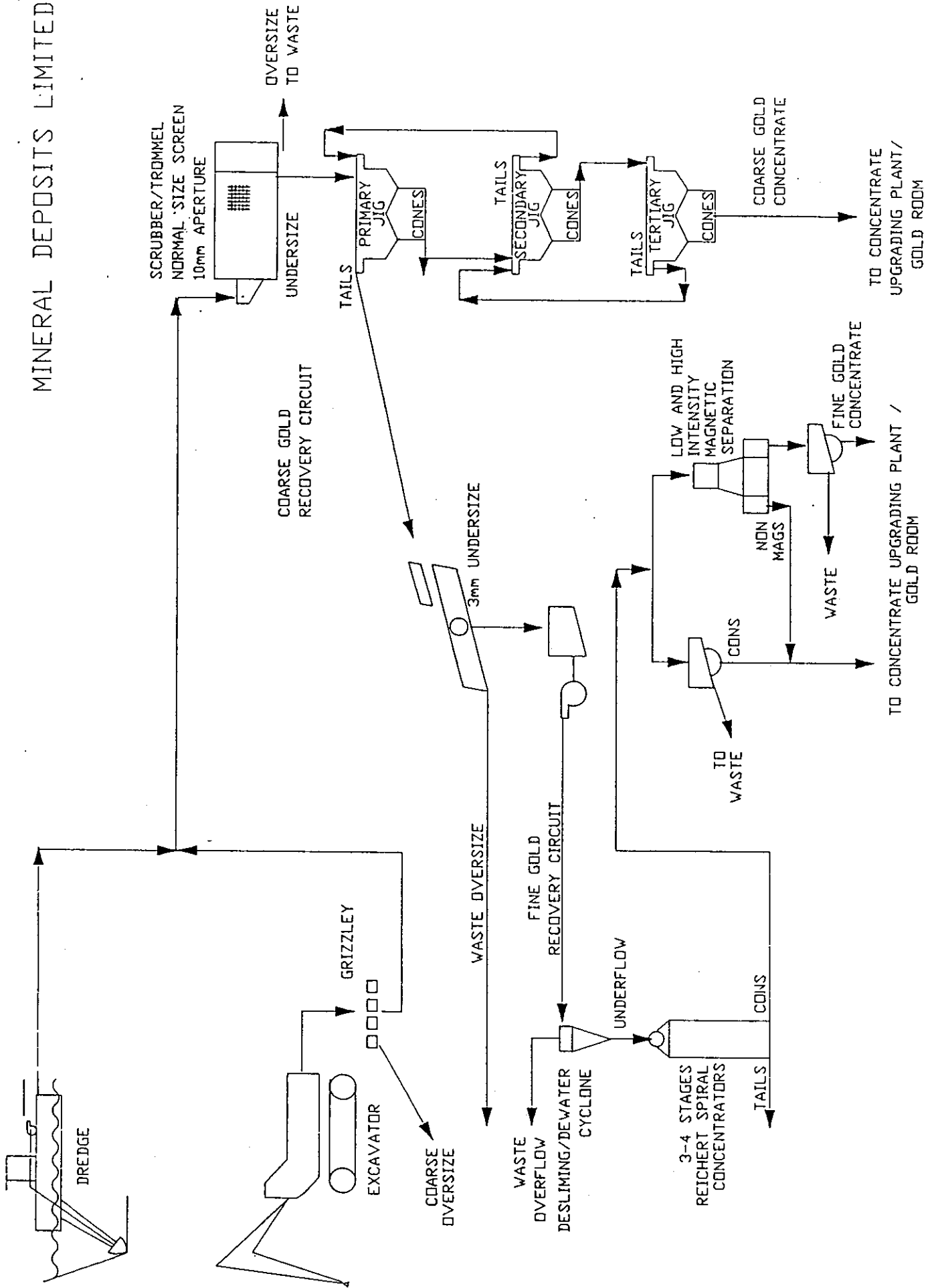
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FIGURE 1 SPIRAL ASSEMBLY DIAGRAM



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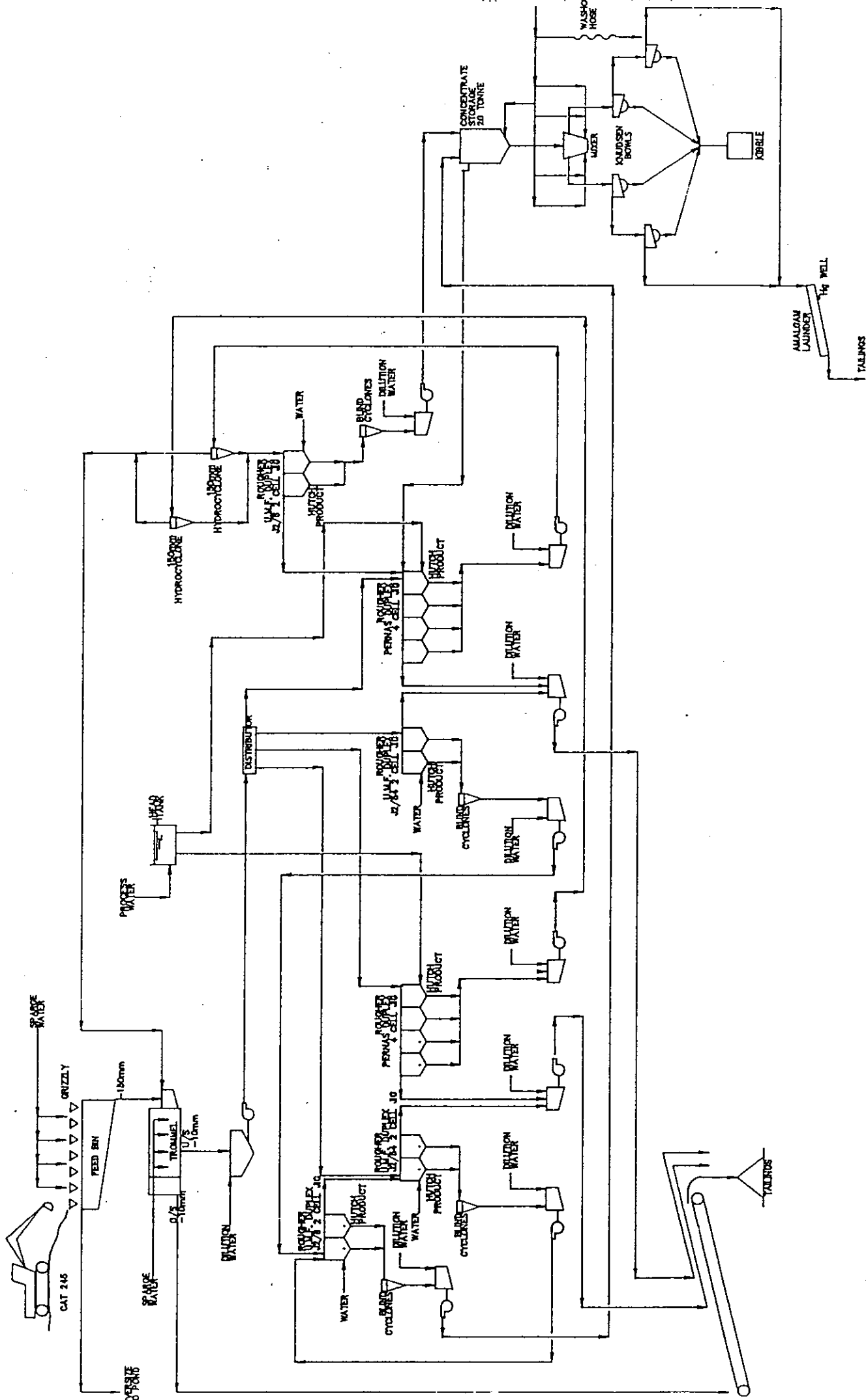


FIGURE 4 FLOWSHEET FOR ALLUVIAL GOLD PLANT, MARISA RIVER, SULAWESI

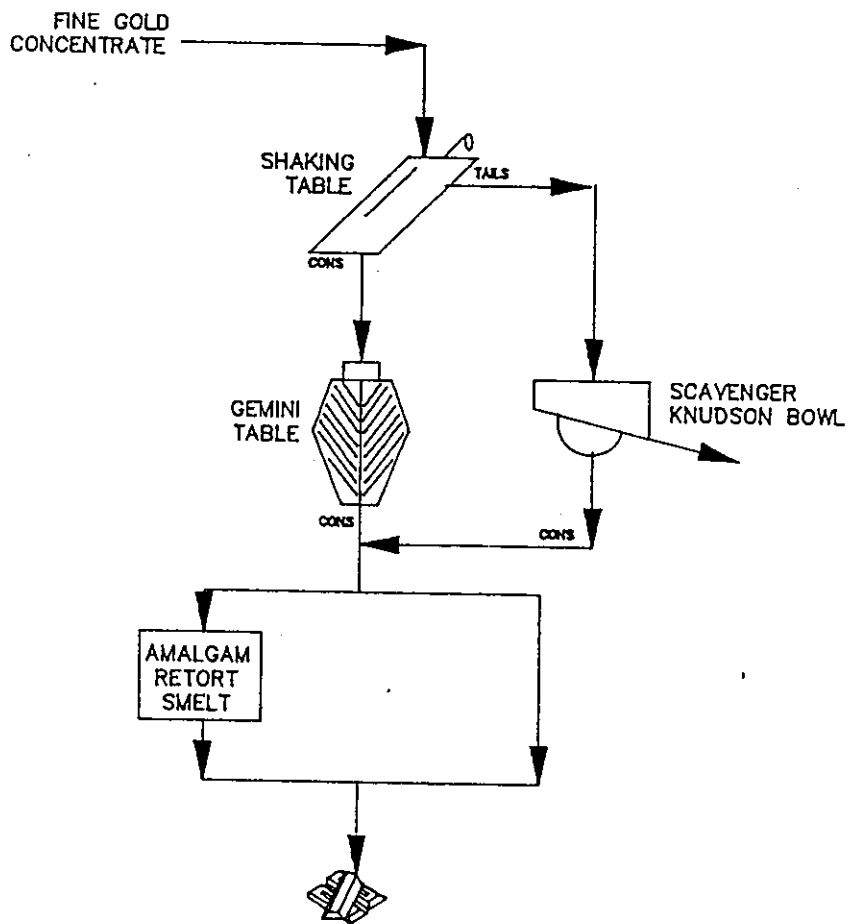
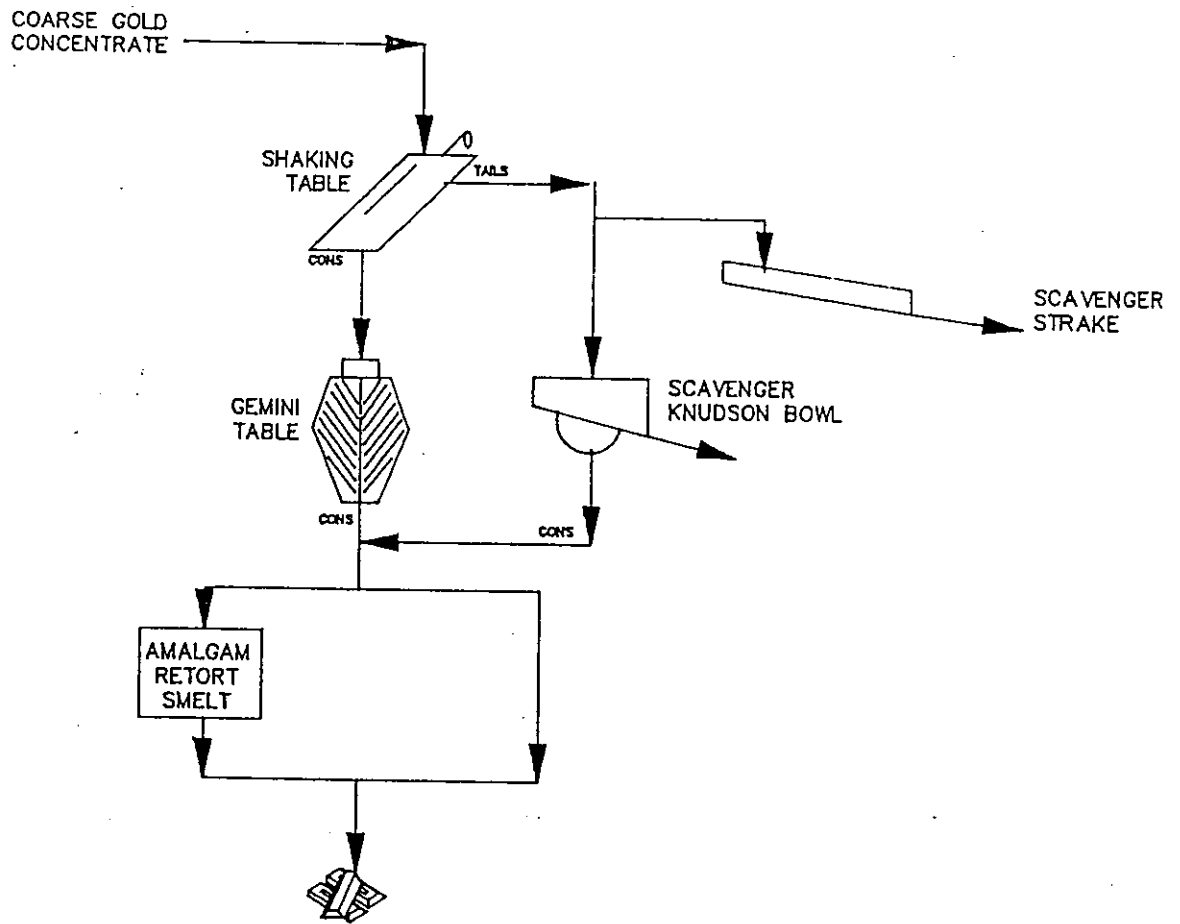


FIGURE 3

