EVALUATING THE COST & IMPACT OF RAMPS IN OPTIMAL PITS

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INTRODUCTION

The benefits of optimal pit design are well understood and accepted. However, the cost of inserting a ramp into such a design is often underestimated. This paper discusses ways of inserting and evaluating approximate and detailed ramp designs around an optimal pit.

Given an optimal pit design, there are an infinite number of ramps (or haulroads) which could be implemented. The methodology and benefits of being able to set up and evaluate different ramp configurations including width, gradient and direction are presented. In every case, the ability to check the dollar value of the modified design against the initial Whittle design is important.

In this paper the process of evolution of a **mathematically optimal** pit into a **practically mineable** pit is emphasized. This evolution can only be achieved by using the Whittle pit optimizing software in close combination with a full mine design software package.

First, there is a discussion of theoretical vs practical pits and a suggested procedure for generating a good practical and economic pit around an optimal pit.

The ideas in this study are illustrated by means of an example project or data set. Most of the data is fictitious, although it does resemble a real project. Results from several ramp alternatives are compared. It is concluded that an iterative approach is likely to yield the best design in a reasonable time frame. For any iterative procedure, the time for each cycle is important. If the time per iteration is prohibitive, the procedure will likely be prematurely terminated yielding a poor final result.

THEORETICAL VS PRACTICAL PITS

The Whittle Three-D and Four-D programs provide pit outlines which are mathematically optimal. This is done by providing a list of blocks which are feasible to mine and a time when they should be mined in the case of Four-D. However, there is little information on how to mine the blocks. In the context of this paper, a Whittle pit is considered to be a "theoretical pit" which is theoretically mineable but not very practical. The trick is to convert the theoretical pit into a practical pit without deviating too much from the mathematical optimum in terms of dollars. The evolution from theoretical to practical pit could take place in several stages, but often some of these stages will be omitted due to time constraints.

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It is useful to refer loosely to a "practicality" index for any pit. This is an index of how easy or practical it is to mine a pit. A value of zero would be difficult to mine, while an index of one would be very practical. Many (if not most) pits based upon the extraction of a whole number of blocks from a block model will have an index close to zero. A very good pit design with smooth ramps and constant gradients and ready access to relevant portions of the pit will have an index close to 1. In this paper, the index is used in a purely qualitative manner.

Very often, the transition from theoretical to practical pit is done as a single step process (single iteration). Contours from the optimal pit are plotted out and the mine planner spends from a few days to several weeks designing a detailed pit with appropriate ramp access. Often, after this exercise is complete, there is little time remaining to test various "what if" scenarios and even less will on the part of the mine planner to do this. The final design can be evaluated in dollar terms and compared against the Whittle optimal pit dollar value. However, with a single iteration, there is little way of knowing precisely how good the design is in dollar terms. It may be great aesthetically and practically, but would likely have a relatively poor dollar value. This situation is shown schematically in figure 1.

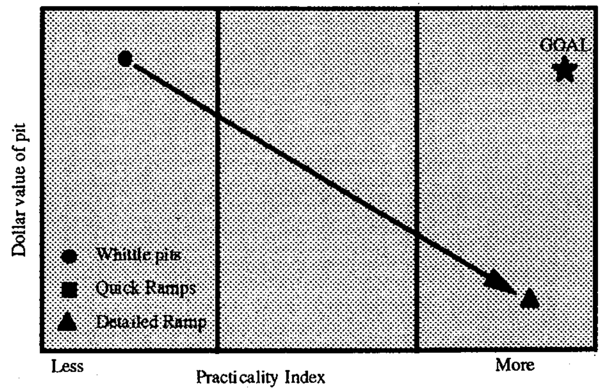

FIGURE 1 **Schematic of Pit value vs Practicality Index**
Case 1 : Single iteration

If the mine planner is a little luckier and has access to computerized ramp design software, then he may conduct various what if scenarios. However, the time for each design can still be quite long. A general trend is that as the ramp generation process becomes more automated, the ability of the user to make fine adjustments for local irregularities is reduced.

A METHOD FOR RAMP INSERTION

The PC-MINE system of GEMCOM Services Inc. offers a slightly different approach to that described above. It has two forms of ramp generation. The first is a block based ramp generation algorithm, which inserts a ramp into a grid representation of a pit using a digitized centreline as starting point. This is done by adjusting block elevations affected by the ramp so that geotechnical slope angles are reasonably maintained. The second is the more rigorous detailed process with full toe, crest and ramp outline modelling. The first method is quick but less accurate, while the second is slower but much more precise.

• CENTRELINE RAMP GENERATION

The block based ramp generation algorithms in PC-MINE are derived from a simple variable angle pit generation algorithm described by Diering, J.A.C. (1982, p.113). The pit, before and after ramp insertion is represented by a regular rectangular surface elevation grid. Grid elevations represent the amount of material remaining in each row and column of the block model. A polyline is digitized representing the centreline for desired ramp location. The only other input required by the user is a ramp width, bottom and top elevation for the ramp.

The algorithm then tries (iteratively) to adjust the surface elevations of each grid point to best honour the ramp location and local geotechnical angles. In places where an impossible ramp configuration has been specified, local irregularities in the resulting pit will be noted, but will not affect other areas of the design. Usually, with the first one or two tries, these overlaps will occur, showing the user that one portion of the ramp is too close to another portion of the ramp. However, fixing the problem is very simple. The user simply edits or moves the ramp centre-line polyline and repeats the process.

With this approach, the generation and evaluation several centre-line based ramps is quick, taking from 15 to 30 minutes, depending upon the amount of thinking and checking done in between stages. In some cases, only one or two polyline points need to be edited to yield another ramp alternative.

The main advantages of this method are:

- Speed
- Ease of use
- Compatibility with Whittle pits and block models
- Ease of implementing slight changes in the ramp position.
- Ability to easily model average pit slope angles including variations to rock type changes.

The main disadvantages of this method are:

- Accuracy and resolution depend upon the underlying block size.
- Toes, crests and detailed ramp information are not modelled explicitly.

• DETAILED RAMP GENERATION

In contrast with the above procedure, in which the entire ramp is generated from a single polyline, a detailed ramp design procedure uses hundreds or thousands of polylines. Each toe, crest or edge of the ramp as well as pre-mining topographic surfaces are represented by three-dimensional polylines. The user is provided with a tool-box of utilities for generating new lines progressing from one bench or level to the next (either upwards or downwards). At each level, the user should inspect the toe and crest positions against the available guidelines from previous ramp or Whittle pits and against level plans showing ore blocks. Lines can be edited locally as the generation process progresses. If done properly, this almost invariably ends up taking a fair amount of time. However, the final result is a pit design which is precisely defined (independently of the size of the underlying block model) and which is also very realistic and presentable for three-dimensional viewing and plotting. These designs can also be used for production layouts.

Tonnages and volumes can be computed once the polylines have been used to create a triangulated surface representation for the design. This allows the design pit to be re-evaluated against the grade and economic block models and the dollar value compared with other alternatives.

• THE ITERATIVE PROCEDURE

Using this approach, the following steps would then define the overall iterative cycle.

1. Carry out a Three-D or Four-D run.
2. Do initial sensitivity analysis by modifying the Whittle slope angles to allow for various forms of ramp access. At this stage, you would have a pit shape which makes allowance for a ramp, but has NO detailed information on the POSITION of the ramp. For example, with a spiral type ramp, this stage would not define whether the ramp runs clockwise or counter-clockwise.
3. Import the results of the Whittle runs into PC-MINE.
4. Smooth these pits so that reasonable graphical representation of the pits may be obtained. Smoothing using a fairly simple moving average formula has been found to work quite well. It is important to evaluate these smoothed pits to check that valuable ore has not been smoothed out of the pit. This is particularly important if a high degree of re-blocking has been used for the Whittle runs. The smoothed pit will have a higher index of practicality than the un-smoothed pits. Also, they will be a lot easier to work with for subsequent ramp design work.
5. Choose the best one or two results from step 4 and conduct a number of quick (but approximate) designs looking for the best option in terms of dollar value. It is quite feasible to generate and evaluate 10 to 20 alternatives in a day. By noting the dollar value of each, an improved understanding of the sensitivity of different areas of the ramp will be gained. For example, if a ramp covers some of the highest grade material, there should be a noticeable dip in the dollar value. If you notice that the dollar values are significantly different from those in step 2, then you likely need to adjust the slope angles and repeat steps 2 - 5 or move the ramp.
6. Choose the best result from step 5 and conduct a detailed ramp design including precise ramp gradients, all toes, crests, safety berms etc.
7. Evaluate the detailed design. If the dollar value is as expected relative to the quick ramp designs and initial Whittle pits, you are done. Otherwise, you need to assess where the dollars are going and go back to step 5 or 2.

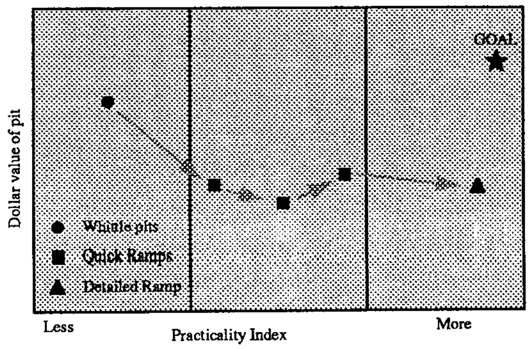

FIGURE 2 **Schematic of Pit value vs Practicality Index**
Case 2 : Single Whittle, many ramps

In carrying out a single iteration, the objective and hope is to achieve a good detailed pit design which is both practical and close to being optimal in dollar terms. This is shown schematically in figure 2.

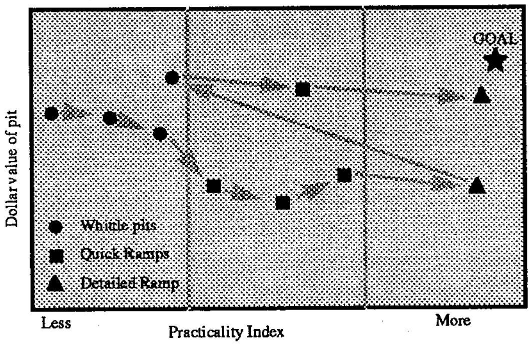

FIGURE 3 **Schematic of Pit value vs Practicality Index**
Case 3 : Many Iterations

Experience has shown that one iteration is insufficient and that several iterations will likely be better as shown schematically in figure 3. Put another way, there are two points to note:

- If you only do a single ramp design, it may look good, inducing a false sense of security and an erroneous belief that a much better design is not likely to exist.
- If you do several alternatives, you can pick the best one AND see how much better it is compared with alternatives and how sensitive the design is to slight changes. Usually it will be quite insensitive, but this is not always the case.

THE TEST PROJECT

For the purposes of this paper, a test project, based upon a real project was chosen. The main elements of interest from the pit design perspective have, however, been retained. Figure 4 shows contours of the pre-mining surface topography in the area of interest. The following items are of interest or relevance to this study:

- The orebody lies in the saddle portion between two hills.
- The orebody is high grade and quite steeply dipping, but requires a high strip ratio for open pit mining.
- The orebody has an in-situ resource 83.8 million tons @ 1.16 % Cu at a cut-off of 0.4% Cu .
- The rockmass is quite strong, so that inter ramp slope angles of 55 degrees are feasible.
- In order to mine a significant portion of the orebody, it is necessary to strip a substantial portion of both hillsides. Thus the economics of the final pit are quite sensitive to the ramp configuration.
- The relatively large pit, steep slopes and narrow steeply dipping orebody results in a deep pit with a long ramp for access to the deepest level.
- Typical mining and processing costs, recovery factors and metal prices were used.

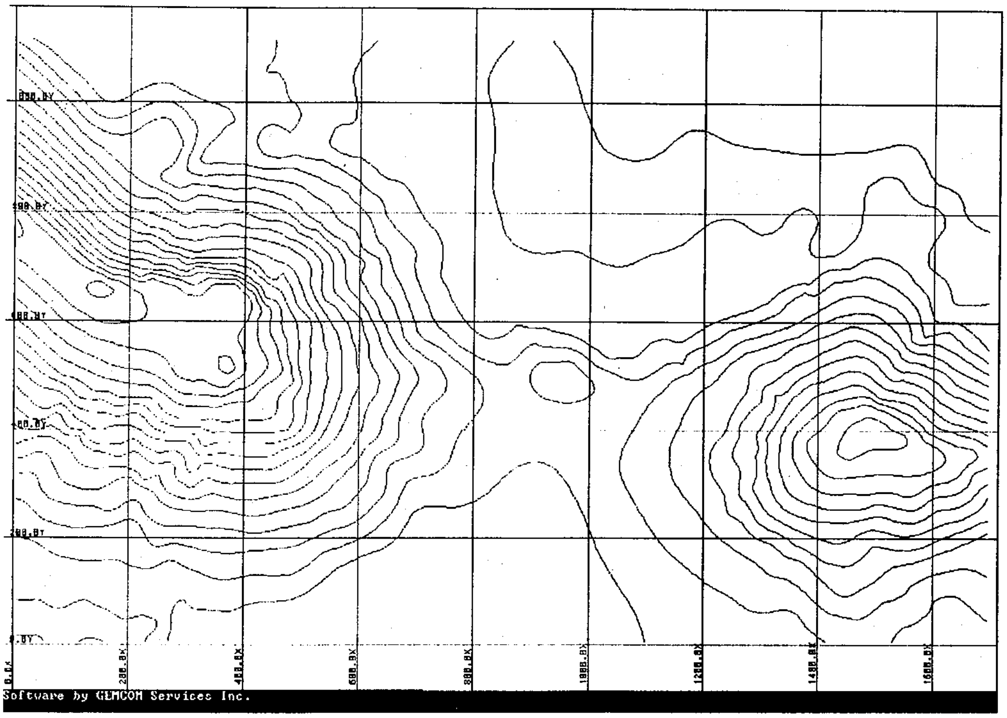

Figure 4 : Pre-mining surface topography.

The area of interest was modelled with a regular block model with dimensions 10 m X 10 m X 12m with 112 rows, 170 columns and 60 levels. Thus the plan dimensions are 1.7 Km by 1.12 Km with elevations ranging from the hilltop at elevation 670m to deepest ore at 42m.

The ore blocks on level 40 (towards the pit bottom) are shown below as an example.

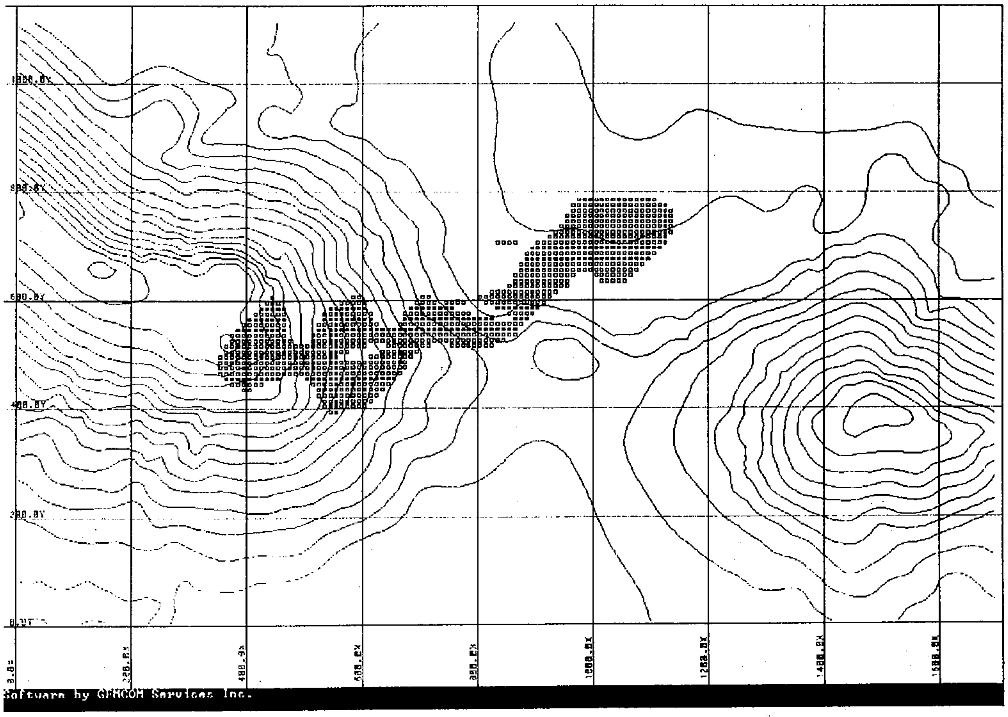

Figure 5 : Level plan for level 40. Shaded blocks represent Cu > 0.4%.

The ramp exit elevation at the South side of the pit was set at 475m. For a ramp gradient of 10% this gives a ramp length of 4330m. A ramp width of 30m (including safety berm and drainage ditches) was desired. Even before doing any optimization, it is useful to estimate the approximate volume or tonnage of material associated with the ramp.

The following formula for estimating the additional tonnage associated with the addition of a ramp into a pit (without a ramp) is quite useful. It assumes that no exposed ore in the pit would be covered up by the ramp insertion process:

$$\text{Tons} = 0.5 \times \text{Density} \times \text{Width} \times \frac{\text{Height}}{\text{Gradient}}$$

In our example, this works out as:

$$\text{Tons} = 0.5 \times 2.7 \times 30 \times 433 \times \frac{433}{0.10} = 76 \text{ million Tons}$$

This is a rough estimate of the tonnage required to insert a ramp into a simple pit with an otherwise flat topography. This is clearly quite a substantial tonnage. A 20% variation of this figure with a mining cost of $1.00 per ton equates to + or - 15 million dollars! This simple calculation hopefully demonstrates that due care is called for. Of course, the picture is quite likely to be not so bleak. Some of the newly uncovered material for a ramp may to be revenue generating ore. Also, a variable topography may make a substantial difference to the quantity of waste to be moved.

THE INITIAL WHITTLE RUNS

In setting up the input for some Whittle Three-D runs for this example, the following parameters and input were used.

- Reblocking factor 2 X 2 X 2
- Slope angle with no ramps = 55 degrees
- Slope angle including one ramp pass per 150m vertical = 48 degrees
- Slope angle including two ramp passes per 150m vertical = 42.3 degrees
- No ramps above 475 elevation. It is assumed that the ramp access to upper benches is mined out as part of the waste stripping.

This situation was handled in Three-D by using two subregions. The upper subregion consisted of 55 degree slopes in all directions, while lower subregion consisted of a variety of combinations of the 55, 48 and 42.3 degree slope angles according to the type of run. In all, four different Three-D runs were carried out as follows:

Run	Comment	Slopes				Average
		West	North	East	South	Error
1	Spiral ramp	48 deg	48	48	48	0.6 deg
2	Switchbacks in North and South areas	55	42.3	55	42.3	0.5
3	Switchbacks in South area only	55	55	55	42.3	0.5
4	No ramps	55	55	55	55	0.6

• WHITTLE RUN 1

This was the first run with slope angles estimated to allow for a simple spiral type ramp. A contour plot of this pit is shown as figure 6. A smoothed pit is shown in figure 7.

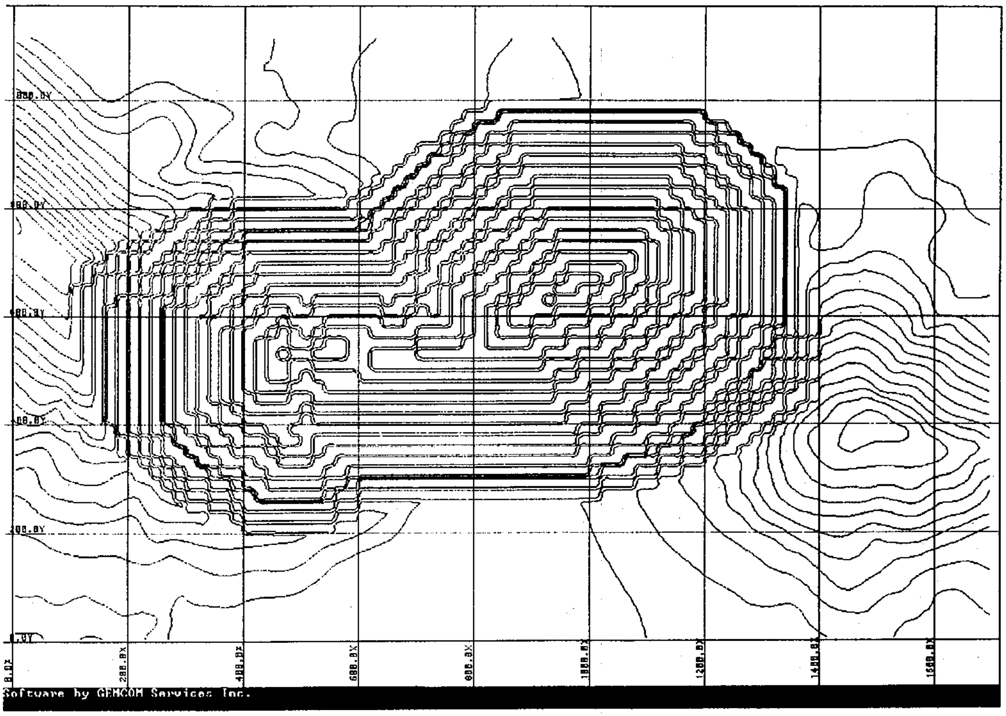

Figure 6 : Whittle pit 1 before smoothing.

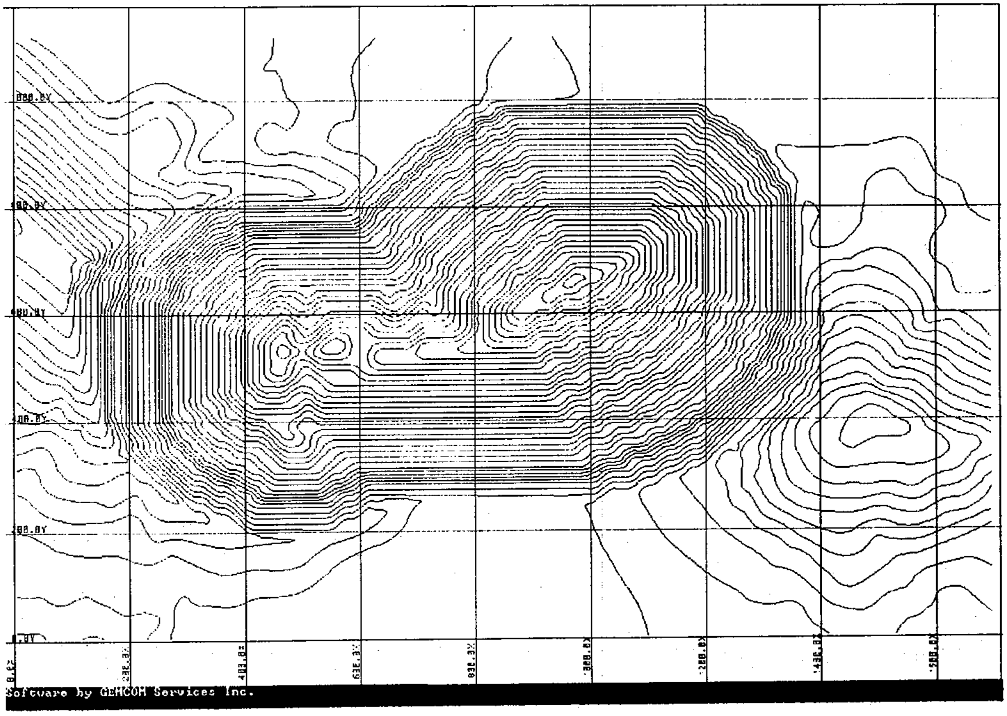

Figure 7 : Whittle pit 1 after smoothing

The effect of the 2 X 2 X 2 reblocking is quite obvious in figure 6 and it also masks the overall shape of the pit to some extent. For this reason, smoothing of Whittle pits is carried out, yielding more attractive looking plots, with very little change in dollar value. The smoothed pit is shown in figure 7.

- **WHITTLE RUN 2**

  This run (which was subsequently discarded) tried to allow for most of the ramp to be located in the North and South "limbs" of the pit, avoiding the West and East limbs which is where the hills are located. The logic here was to try to leave steeper average slopes where these are highest (i.e. under the hillsides). However, the results from this run didn't show any natural bridge connecting the North and South sides, so it was discarded

- **WHITTLE RUN 3**

  This run used a relatively shallow South slope angle to accommodate a ramp with multiple switchbacks on the South side of the pit with minimal interference with the hillsides. A contour plot of this pit (after smoothing) is shown in figure 8.

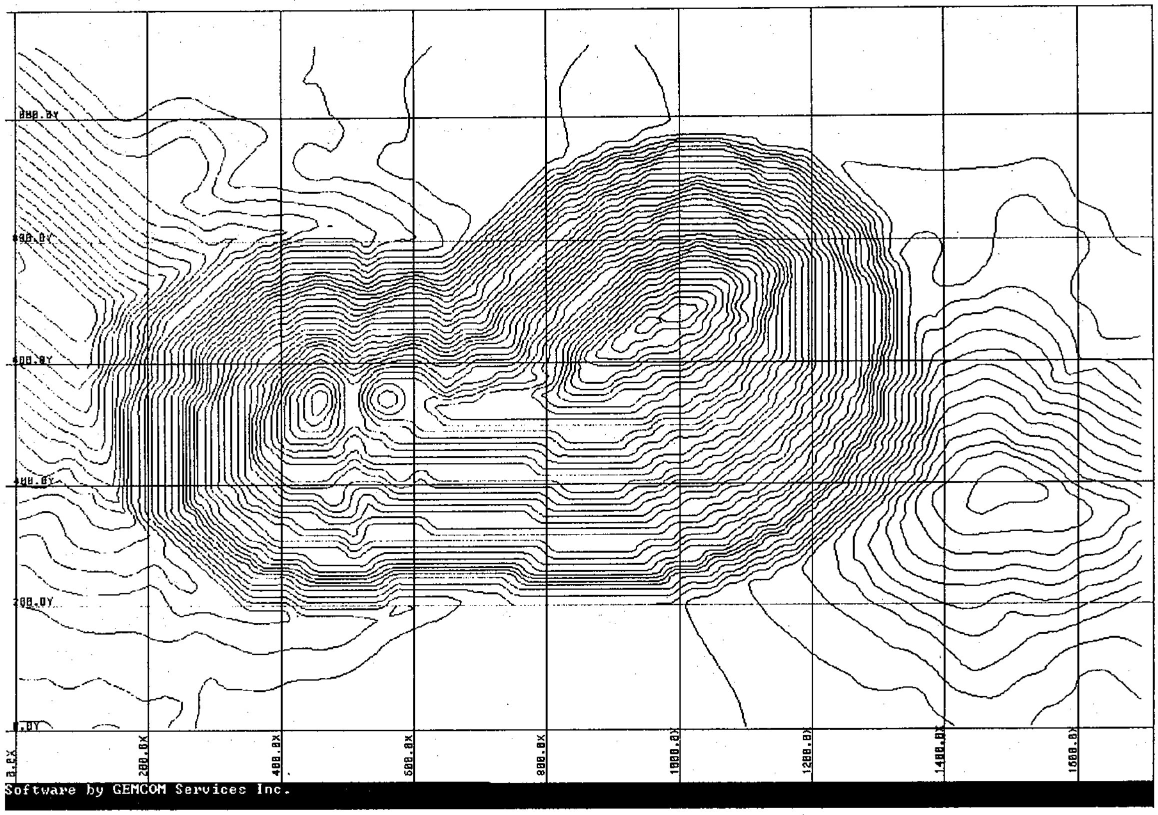

Figure 8 : Smoothed Whittle pit 3.

• WHITTLE RUN 4

This run would yield an optimal pit without any allowance for a ramp in the final pit. Such a pit would be technically mineable, but you would not be able to use trucks to remove the ore and waste in the lower levels. (You could use underground access or even helicopters to remove the material, although this would clearly be very expensive and very impractical) . A contour plot of this pit (after smoothing) is shown as figure 9.

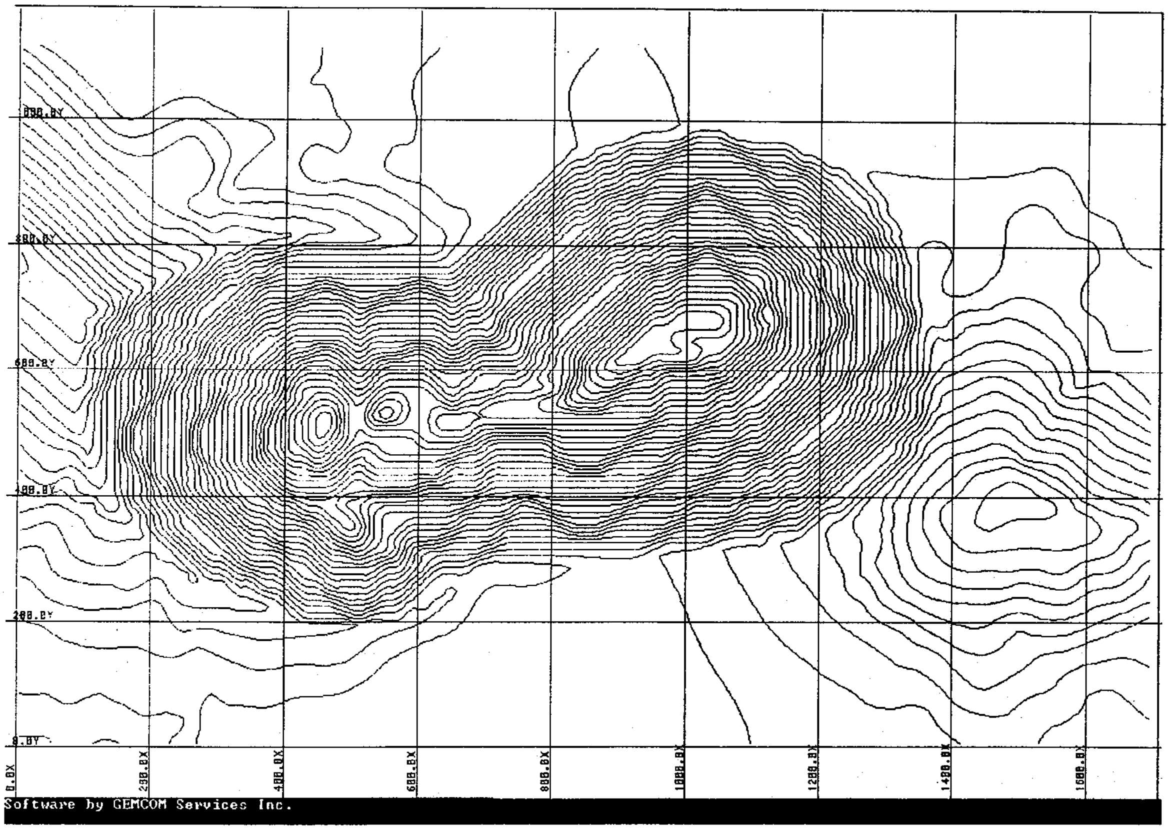

Figure 9 : Smoothed Whittle pit 4.

RESULTS

For this paper, a total of 16 pit surfaces were generated and evaluated against the original pre-mining topography, namely, 4 Whittle pits, 4 smoothed pits, 7 quick centreline alternatives and one detailed design. The pit and pre-mining surface together with the dollar value evaluation of each pit and figure numbers are shown in the table below:

Run	Description	Dollar value (Millions)	Figure
1	**Pre-mining surface**	**n/a**	**4**
2	**Whittle run 1**	**706**	**6**
3	**Smoothed Whittle pit number 1**	**705**	**7**
4	**Bottom portion of first ramp**	**703**	**-**
5	**First ramp - First Whittle pit**	**681**	**10**
6	**Second ramp - First Whittle pit**	**688**	**-**
7	**Third try - First Whittle pit**	**683**	**11**
8	**Second Whittle Pit**	**687**	**-**
9	**Third Whittle Pit**	**729**	**-**
10	**Smoothed Third Whittle Pit**	**727**	**8**
11	**Ramp with many switchbacks - try 1**	**701**	**-**
12	**Ramp with many switchbacks - try 2**	**701**	**12**
13	**Fourth Whittle pit (no place for ramp)**	**790**	**-**
14	**Smoothed fourth Whittle pit**	**788**	**9**
15	**First try, fourth Whittle pit**	**687**	**-**
16	**Second try, fourth Whittle pit**	**683**	**13**
17	**First try for Detailed pit design**	**654**	**14**

Some of the more interesting ones are shown below:

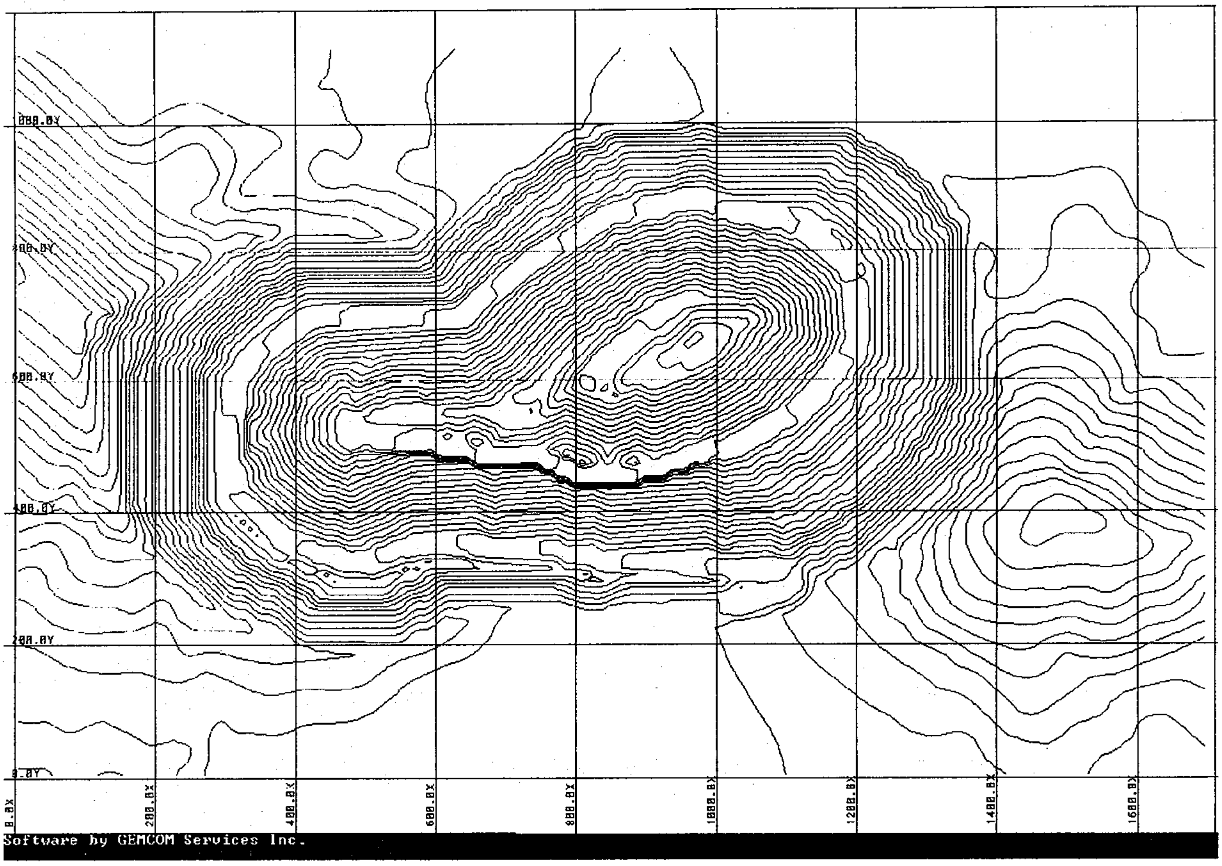

Figure 10 : Pit # 5 - Whittle pit 1, first ramp attempt. Note ramp and slope conflicts.

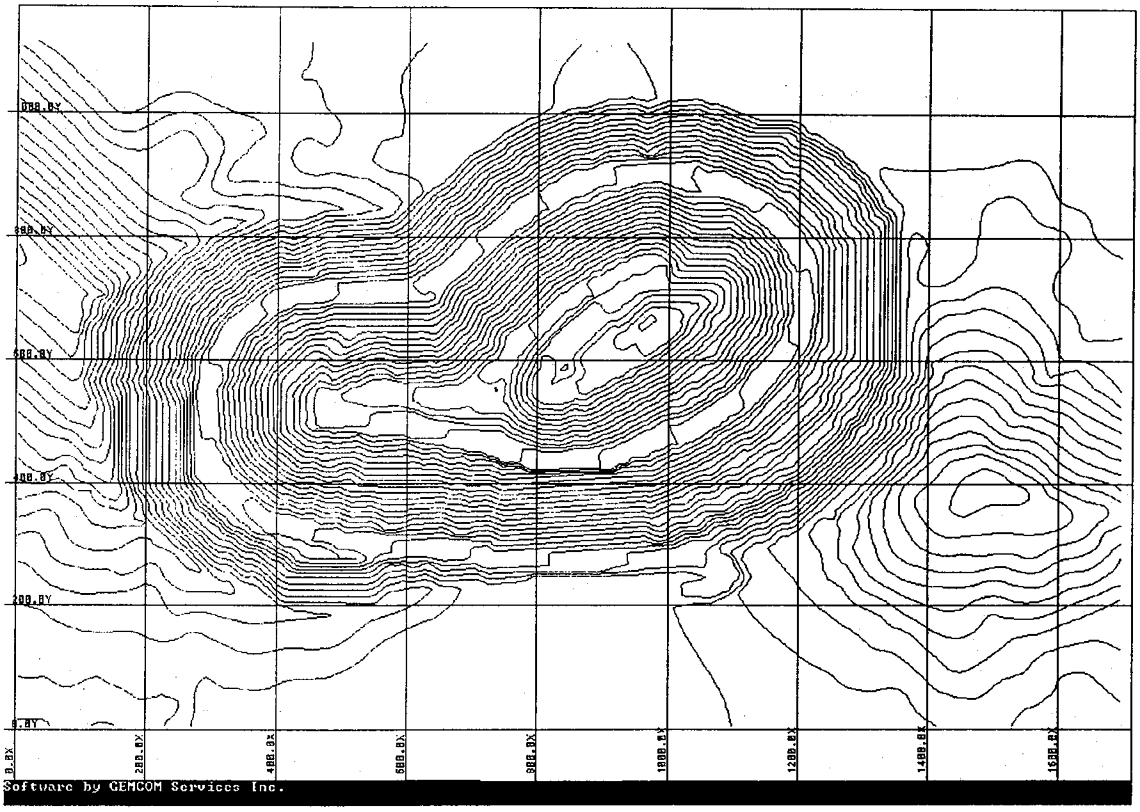

Figure 11 : Pit # 7 - Whittle pit 1, third ramp.

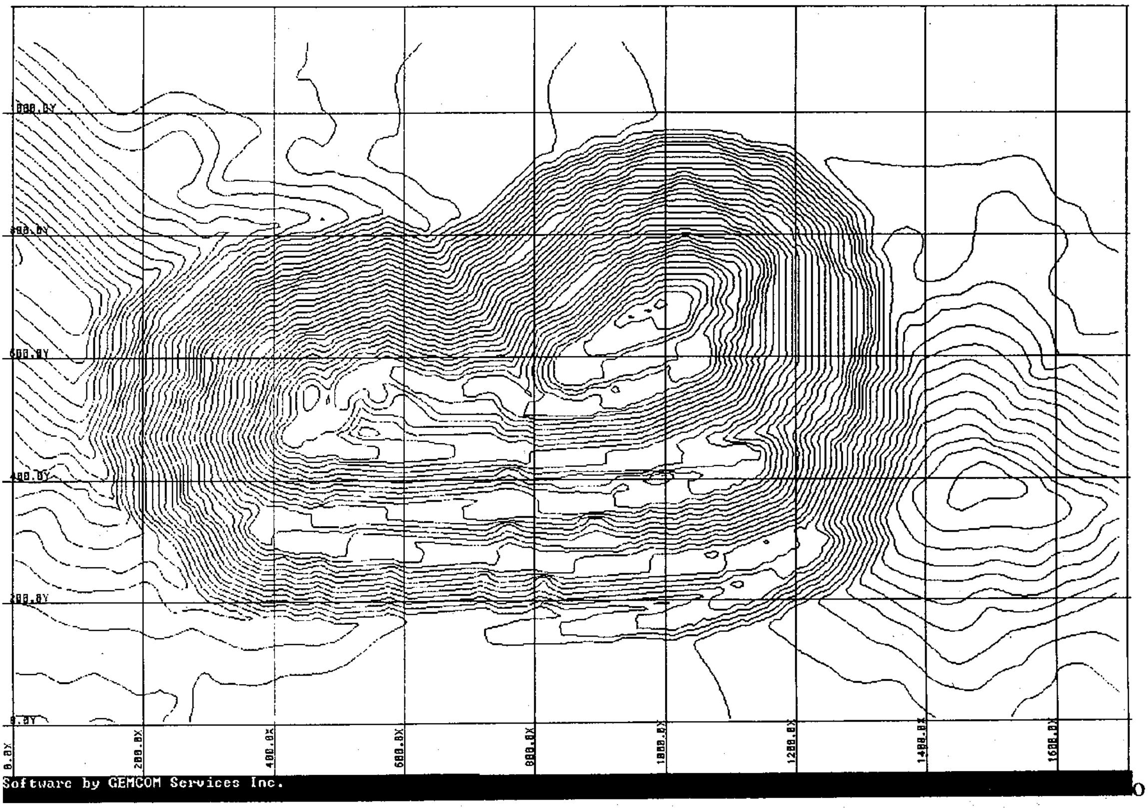

Figure 12 : Pit # 12 - Whittle pit 3, try 2.

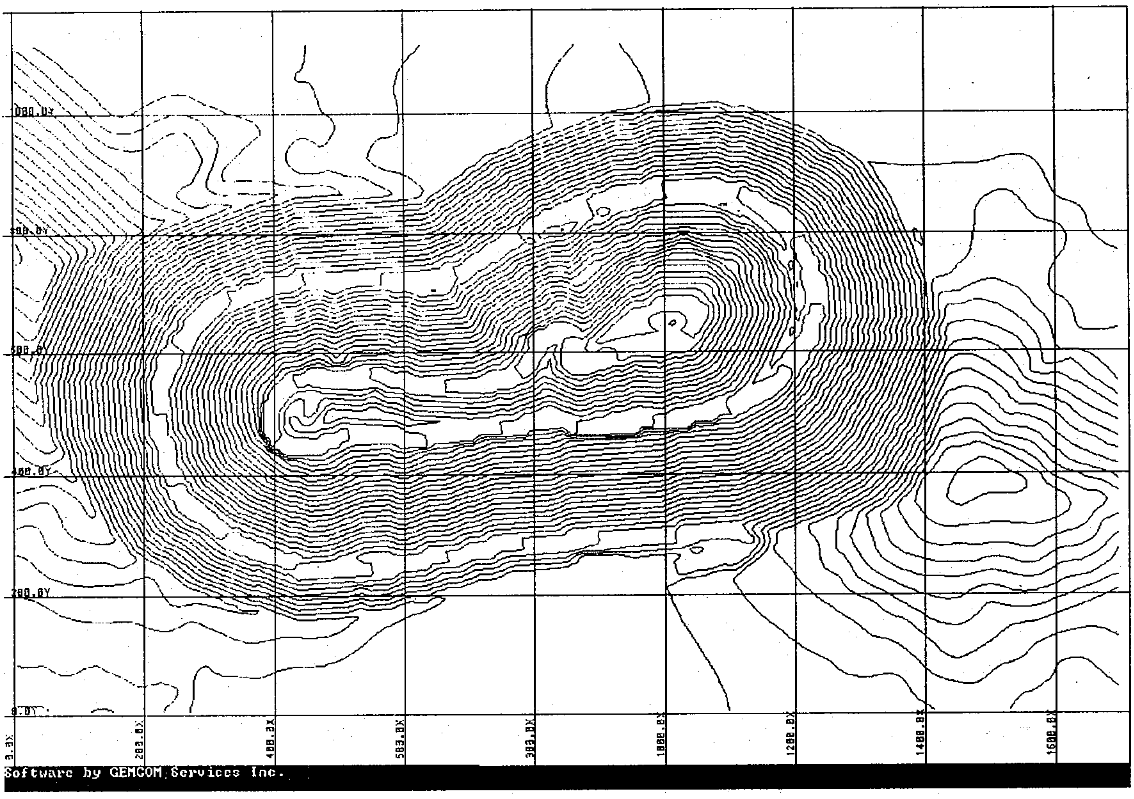

Figure 13 : Pit # 16 - Whittle pit 4, try 2.

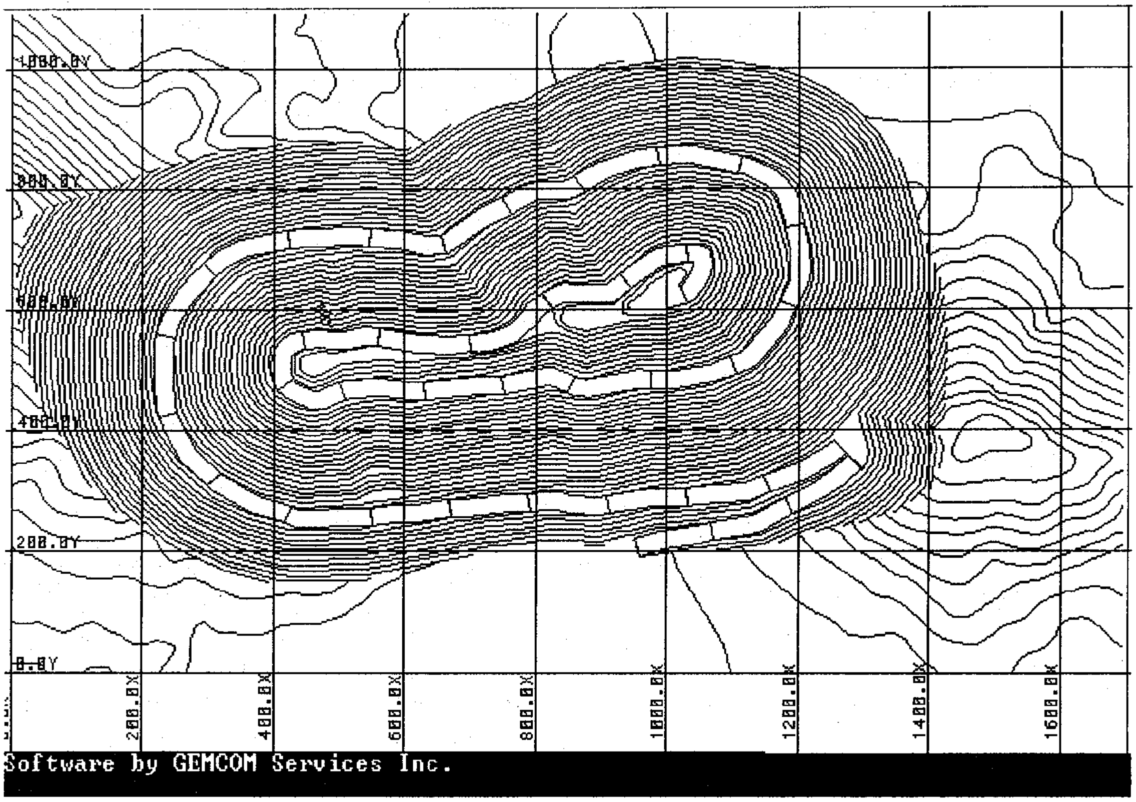

Figure 14 : Pit # 17 - Whittle pit 4, with detailed ramp (try 1).

The next table shows some tonnage figures for each of these runs. Tons of ore and waste are shown separately to give an idea of whether it is change of ore or waste tons which is primarily responsible for changing dollar value for the various runs.

Run	Description	Tons Waste (Millions)	Tons Ore (Millions)	Strip Ratio
1	**Pre-mining surface**	**n/a**	**n/a**	**n/a**
2	**Whittle run 1**	**340**	**61.7**	**5.51**
3	**Smoothed Whittle pit number 1**	**340**	**61.6**	**5.52**
4	**Bottom portion of first ramp**	**350**	**62.7**	**5.58**
5	**First ramp - First Whittle pit**	**327**	**59.0**	**5.54**
6	**Second ramp - First Whittle pit**	**346**	**61.7**	**5.61**
7	**Third try - First Whittle pit**	**356**	**62.3**	**5.71**
8	**Second Whittle Pit**	**351**	**59.8**	**5.87**
9	**Third Whittle Pit**	**332**	**62.6**	**5.30**
10	**Smoothed Third Whittle Pit**	**332**	**62.4**	**5.32**
11	**Ramp with many switchbacks - try 1**	**367**	**65.0**	**5.65**
12	**Ramp with many switchbacks - try 2**	**367**	**65.0**	**5.65**
13	**Fourth Whittle pit (no place for ramp)**	**298**	**64.2**	**4.64**
14	**Smoothed fourth Whittle pit**	**298**	**64.0**	**4.66**
15	**First try, fourth Whittle pit**	**422**	**70.0**	**6.03**
16	**Second try, fourth Whittle pit**	**428**	**70.2**	**6.10**
17	**First try for Detailed pit design**	**455**	**70.8**	**6.43**

All of the above pits were evaluated from the same basic grade and economic model. The range of dollar values between the highest pit at $790 million and the lowest at $654 million is substantial. The fourth Whittle pit (# 13) has steep slopes allowing no place for a ramp. Even if pit 13 is excluded from the results, the spread from highest to lowest value is still $75 million! There are several other points of interest from these results:

- The process of smoothing the Whittle pits using a moving average technique has very little effect of either dollar value or tonnages. This is as expected.
- It is likely that a ramp with several switch backs on the south side of the pit would yield the best dollar value. Pit # 12 above yielded a dollar value of $701 million, compared with the Whittle pit 3 used as a starting point, pit # 9 with a dollar value of $729 million. The difference in dollar value here is attributable to the slightly lower average slope angle which results from the ramp with switchbacks compared with the Whittle pit. (Note that pit 9 or 10 of figure 8 extends to southwards to Y=200, while the pit with ramps extends to Y=120. This would lend confidence that a final result between 700 and 720 million could be obtained. The improved dollar value for a ramp with several switchbacks would have to be compared against potentially higher truck operating costs over the life of mine.
- By contrast, pit numbers 13, 14, 16 and 17 provide an example of how not to do it. Pit 13 is the pit with steep (55 degree) slope angles and no allowance for a ramp. This results in a deeper pit

with more ore as shown in the table above. However, when the ramp is inserted, the dollar value goes from $790 million (pit 13) to $683 million (pit 16) to $654 million (pit 17).

- Pit 16 was produced from the quick ramp generation program. There are two areas of conflict between higher and lower portions of the ramp (380x, 360y) and (900x, 460y). These could be fixed quite easily and would not have much impact on the dollar value. Pit 16 was used as the basis for producing a more detailed design (pit 17). The drop in dollar value from $683 to $654 million did come as a surprise. More detailed investigation showed three reasons for the drop. First, there was some internal waste near the bottom of the left side of the pit base (500x, 480y) which was removed in the detailed design. Second, the ramp gradient was based upon 10% on the inside edge of the ramp instead of 10% along the centreline as for the other ramps. This resulted in a longer ramp requiring more of the hillside to be moved. Third, the overall slope angles were slightly less steep (between .5 to 1 degree) for the detailed design as compared with the quick method. However, even if the detailed design was modified to correct these three differences, the dollar value for this type of ramp would still be around $680 million compared with $700 million for the ramp with switchbacks.

CONCLUSIONS

Although the results presented above are for a fictitious deposit, they do show how important good ramp positioning can be. It is estimated that up to 10% of the value of a pit could be lost by poor positioning. Some of the factors which should be considered when designing a ramp are:

- Width. The cost of the ramp is roughly proportional to the width of the ramp.
- Gradient. Although this is usually dictated by equipment and local ground and weather conditions, the effect of ramp gradient is substantial. The cost benefits of a steeper ramp can be evaluated and compared with the higher equipment operating costs and ramp construction costs.
- Use of inside edge or centreline gradient should be carefully considered.
- Smoothness (in terms of corners and bends) of the ramp also has its price. This should be weighed against the benefits of easier construction and operation of the smoother ramp.
- LOCATION. This is likely the biggest factor.

There are three stages at which the impact of ramps can be studied. First is within the Whittle optimizers using average slope angles. Second is using a quick, but approximate ramp generator to study various alternatives to more closely define an ultimate ramp position. Third is the detailed and hopefully final procedure.

The process is certainly not as easy as it may seem. For this reason, several iterations are likely to be required. Having tools to do both quick, yet approximate designs and slower but more accurate designs should enable the dollar value of a final design to be improved by several percent.

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