Geology and statistics -- striking the balance in the real world

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Introduction

As potentially mineable deposits become more complex geologically and more marginal economically, they become more difficult to quantify in terms of mineral resource evaluation and quantification of confidence in the predictions. With the recent advances in computer technology and available software, geological complexity can be included in orebody modelling with ever increasing efficiency.

However, there has been a tendency to look towards more sophisticated mathematical methods to solve valuation problems. In this presentation we provide case studies in actual mine and project valuation where a combination of simple and proven techniques have been used to evaluate complex situations. Amongst the cases presented will be:

- A base metal deposit in Southern Africa, hosted in several rock types, of debatable genesis and consisting of at least three mineralisation phases;
- A shear enhanced gold deposit in Western Australia;
- A copper/cobalt tailings dump in Central Africa.

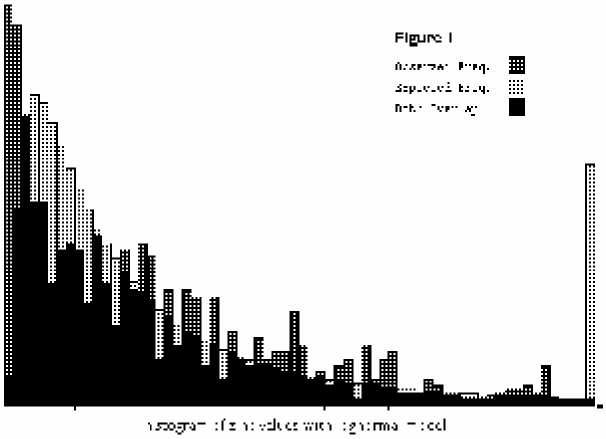
The intention of the presentation is to show that – in many cases – complexity can be adequately managed by a combination of relatively robust estimation techniques, geological interpretation and sheer common sense.

Geology versus mathematics

Over the last twenty years the advances in speed and availability of personal computers has inspired a plethora of computer packages for mine planning and project evaluation. The geological interpretation of a deposit can now be carried out almost totally on high-quality interactive graphics facilities. Plans and sections and, in many cases, full three dimensional views of the geological structure can be inspected, interpreted and corrected interactively. Mine plans can be drafted and tested for many different scenarios until an optimum is found. Open pits can be optimised automatically with modern packages. So where does our problem lie? In the gap between the geological interpretation and the "block model" used by the mine planners.

Almost all mine planning packages now contain geostatistical estimation capabilities. Some are more restricted than others and the facilities tend to depend on the origins of the package – both geographically and geologically. For example, some packages will offer multiple indicator kriging and some will offer simple as well as ordinary kriging. Few mining packages have the capability to handle drift or trend. Some will handle skewed data with "gaussian anamorphosis" of various types. What tends to be forgotten in practice is that most of these approaches rely on one basic assumption: *that the behaviour of the mineral is consistent throughout the study area*. In this paper, we present cases where the automatic approach of: transform data, calculate semi-variogram, model and krige just did not work in practice.

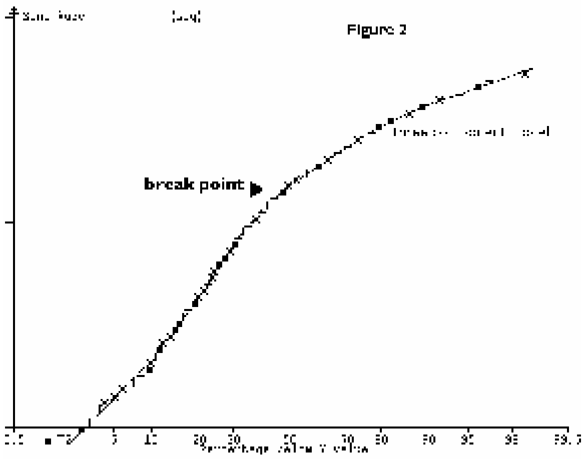
Case study 1: Zinc in Southern Africa



Borehole drilling was carried out in a valley between two ridges in southern Namibia. The cores were logged and photographed on-site as drilling proceeded. Several rock types were noted as well as general grade content. Several host rock types contained economic zinc mineralisation. There were also several zones separated by major faulting.

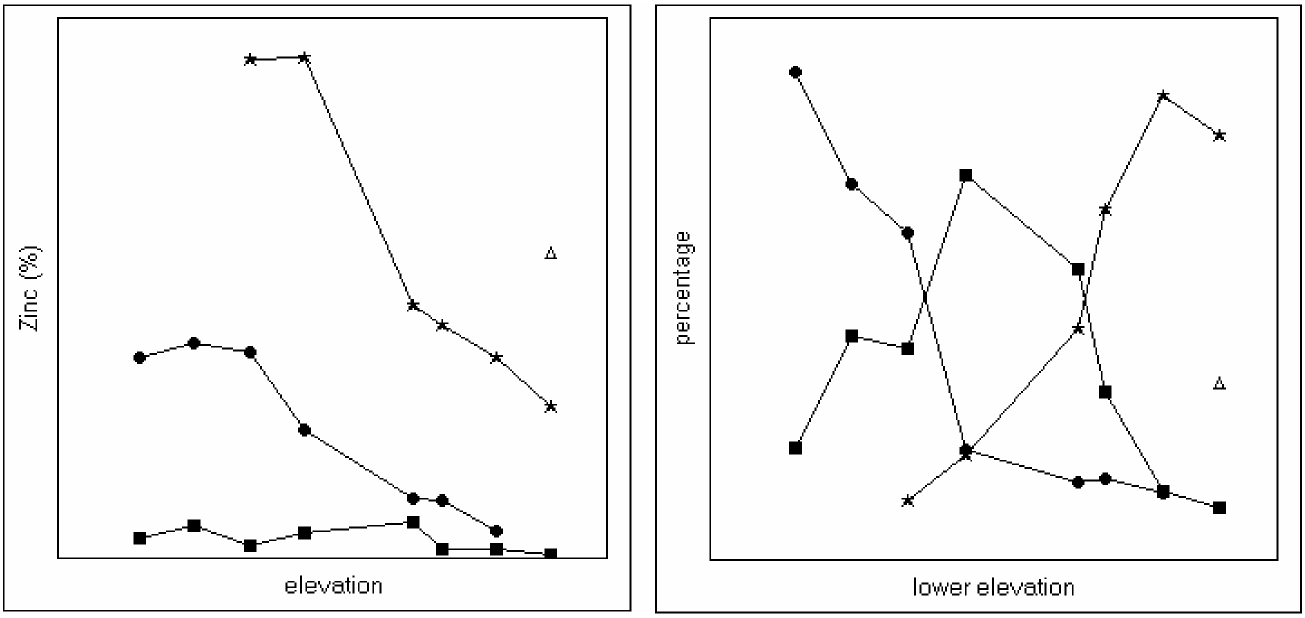
When the 'geostatistical' study was undertaken, samples were separated by rock type and by fault block before any analysis was undertaken. The resulting histograms were rather difficult to interpret. Smaller and smaller sub-regions within the deposit were taken. The histogram shown as Figure 1 and the probability plot in Figure 2 are from samples taken in a 200 by 200 by 40 metre block from the centre of the centre fault block. This was as small a unit as we could take and still get a histogram.

Figure 1 shows a highly positively skewed set of data with the best lognormal fit which can be achieved. It is fairly obvious that the data is not lognormal. Taking logarithms of the data does not result in a symmetrical histogram or in a straight line on the probability plot. The only parametric model which fits this data is one composed of *three lognormal components*. In our experience, this only happens when there are three phases of mineralisation or some similar difference in geological populations. In this case the genesis of the deposit is under heated discussion, but it would seem fairly clear that the zinc deposited here was introduced by three separate mobilisations.



Examining the deposit on any scale (within rock type, within fault block) gives similar histograms. To test whether the three mineralisations (or whatever) were consistent over the study area, we took this same 200 by 200 metre area and sliced the block into 40 metre 'benches'. Starting at the bottom of the available drilling, we took a 40 metre bench. We then moved up 20 metres and took another 40 metre slice. This was repeated until the last slice at the surface, which was only 20 metres thick. In each case a histogram was constructed and a multi-component model was fitted.

After many attempts at 'joining the dots' on various graphs, we came up with those shown in Figure 3. These represent *four* components which change in character and composition as we approach the surface. The fourth component is the oxidation layer in the top 20 metres and would seem to be an enrichment of the medium value component. Apart from this, all components reduce in value as they approach the surface. So the first complexity introduced into any evaluation is that the average value of each geological population increases with depth. This could be handled by including a 'drift' into our kriging system.



average zinc content for each component

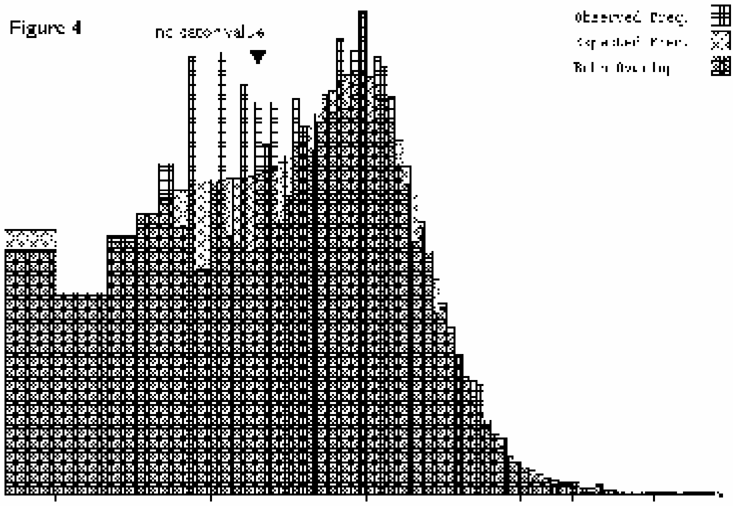
percentage contribution of each component

Figure 3

The real problem arises from the second graph in Figure 3 – the percentage contribution of each component to the final ‘ore’. The low value component increase in ‘presence’ towards the middle elevation sand then drops off again. The medium and high value components seem to be almost complementary. The moderate grade predominate at depth and drop off consistently under the middle elevations. The high grade component doesn’t exist at depth and increases in contribution (but drops off in grade) towards the surface.

It is pretty obvious that any mine planning, production or evaluation which is to take place here will have to reflect these changes in the nature of the ore with depth. The medium and high grade components cannot be separated by statistical or geostatistical methods for evaluation purposes. The low grade can be filtered out with an indicator approach, since it is extremely consistent in value – if not in proportion. Exercising grade control in this mine will take a combination of detailed geological study, statistical analysis and stable geostatistical methods featuring a combination of indicator and lognormal kriging.

Case study 2: shear enhanced gold in Australia



Our second case study is chosen to illustrate how the combination of geology and geostatistics can significantly improve the evaluation of a deposit. In this case we consider an open pit which had been in production for some years before the study was undertaken. Geostatistics had been used to produce a block model which was then used to design the open pit and to guide production. Drilling was carried out on a routine basis at very close spacing to control the gold produced. However, there

were still some local problems with production not meeting expectation.
Inspection of the histogram revealed the apparent presence of two geological populations. This was not unexpected, as the gold deposition is heavily influenced by the presence of massive quartz shear zones. In similar cases, where the gold is shear-hosted, we usually have two quite separate populations – almost barren host rock plus highly mineralised shears. The histogram above does not conform to these expectations, however.

We chose an ‘indicator’ value in an attempt to try to separate the two component populations. All samples below the indicator were coded as ‘0’ and all above the indicator coded as ‘1’. If the populations are well defined spatially, we should get a decent semi-variogram from these 0/1 values. The calculated semi-variogram for the horizontal, north/south direction (along the pit) is shown as Figure 5a.

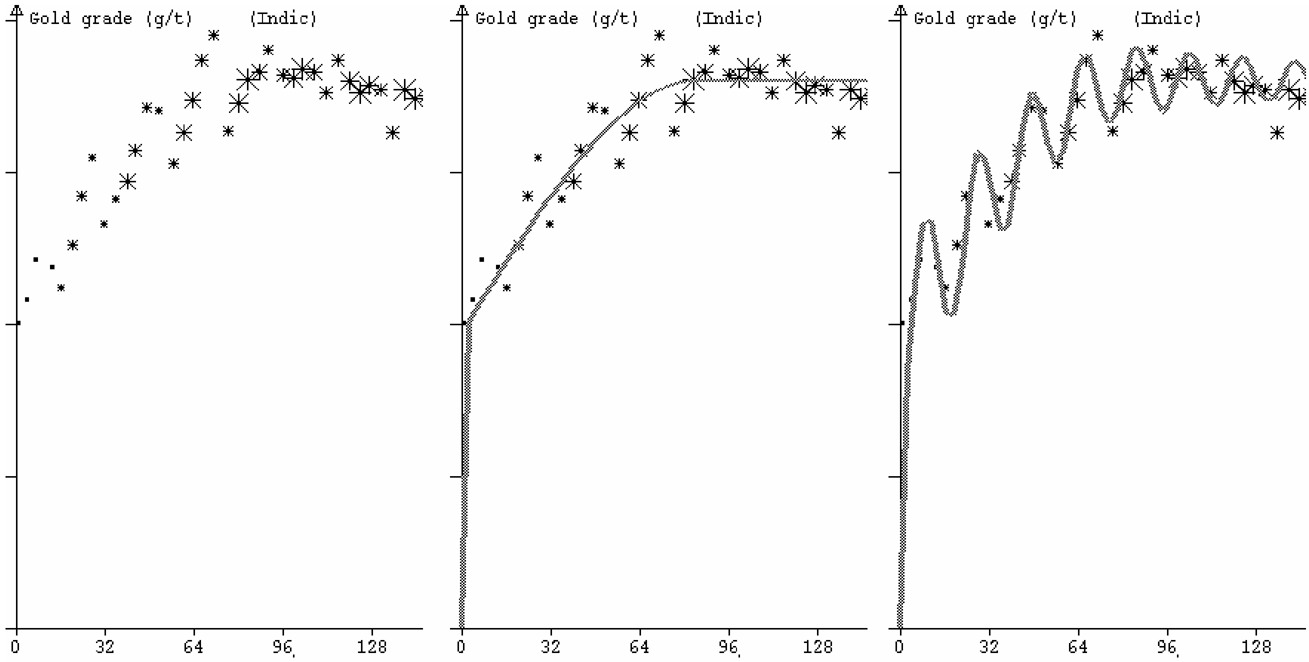


Figure 5a: calculated semi-variogram **Figure 5b: fitted spherical model** **Figure 5c: final fitted model**

Figure 5b shows the semi-variogram model type which was in use at the mine. This is a standard spherical or Matheron model with a nugget effect of just over 50% and a range of about 85 metres. If this mineralisation was shear hosted we would expect a hole effect type of model. If it was not affected by the shears, we would expect a spherical or similar type of model.

In fact, this mineralisation is “shear enhanced”. That is, there is gold everywhere within the host rock, but there tends to be more of it close to the shear zones. Figure 5c shows a combination of spherical and hole effect components which more than adequately fits the experimental semi-variogram in the north/south direction. Adding the cyclic component, with a repeat of around 20 metres, reduces the nugget effect by almost 30 percent. Including a spherical comopnent helps to stabilise the mathematics for the kriging.

In the east/west direction, the cycles shorten to about a third of this distance. In the vertical direction the cycles are almost invisible in the calculated semi-variogram.

We call this combination of spherical and hole effect components the “paddington mix” and have used it successfully in other cases where a fairly consistent mineralisation is modified by structural or other rock characteristics. Examples are: fracture hosted mineralisations on a small scale, such as those at Palabora; pothole occurrences in platinum reefs, such as the Merensky in South Africa and at Stillwater Mine in Montana.

Case study 3: Copper/cobalt dump in Central Africa

In recent years, many 'new' projects have looked to reclaiming dumps and tailings ponds from previous mining activities. These often have quasi-geological structures and can be modelled by similar techniques to non-technogenetic deposits. One case that we looked at turned out to be more complex than the usual fairly coherent dumps.

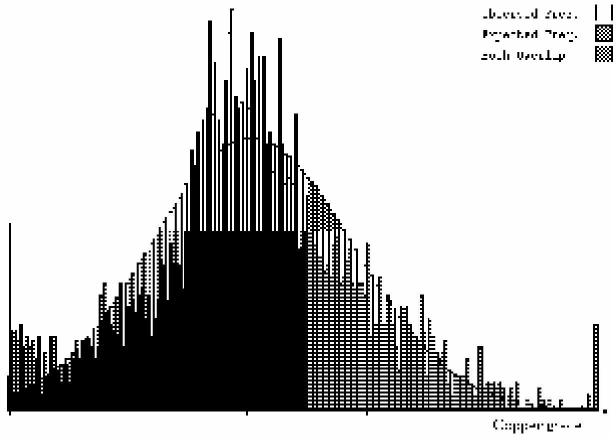


Figure 6: histogram of copper grades with best fit Normal distribution

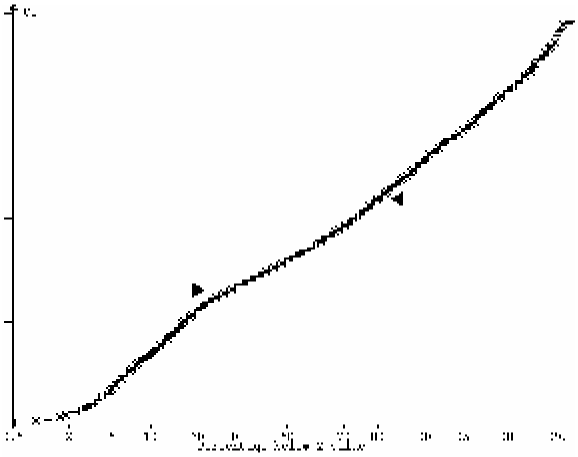


Figure 7: probability plot for copper values

When a histogram is drawn of the borehole cores, it appears to be a mixture of two Normal (Gaussian) components.

Around 75 percent of the samples seem to come from a relatively Normal distribution with an extensive standard deviation. The remaining 25% come from a much more cohesive, less variable component with a mean not much different from the wider component --- but a much smaller standard deviation.

The probability plot bears out this interpretation, showing predominantly straight line behaviour with a flattening out of the curve in the middle ranges of the plot. We have three parts to this distribution (not counting the flattened tail):

1. the lower tail (below 20%) which is all in the wide component;
2. the upper tail (above 80%) which is all in the wide component;
3. the centre of the range, in which samples are equally likely to be from either component population.

The simplest way to tackle this deposit is with two indicators, at the break points. Using maps kriged from these indicators, it should be possible to determine what is the *geological* difference between the two components in the deposition.

Conclusion

We have shown three cases where the mineralisation under study was deposited by more than one process. The different depositional mechanisms produce different statistical and geostatistical behaviour in the mineral values. Unless these are included in the evaluation process, unrealistic predictions will be made. This could lead to major grade control problems during production or even the total failure of the mining project. All of the methods discussed in this presentation have been in practical use for at least 15 years.