Using Geostatistics as a Tool in Fine Tuning of Iron Ore Resource Modelling

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ABSTRACT

The aim of this paper is to demonstrate the importance of using variography for grade interpolation in multi-element environments and to illustrate how variography can assist in the understanding of geological controls on mineralisation.

Variography codes mineralisation continuity numerically and it is one of the first links between geology and mine planning, since it guides the choice of the interpolation technique. Owing to advances in computer technology and new visualisation techniques, semi-variogram analysis is becoming more of a routine procedure during both feasibility studies and on operating mines.

It is a complex and challenging task to produce a high quality model for an iron ore deposit as iron and the numerous contaminants all have different grade distributions, different spatial orientations and different degrees of variability. In addition, even within a single well-defined geological domain, several populations of mineralisation are often found. Because of these complexities, resource modelling often requires the application of non-parametric interpolation methods.

The spatial continuity of two contaminant elements in 'N' domain was carried out for an iron ore deposit (mineralised banded iron formation). Grade values for the both contaminants form positively skewed data distributions with evidence of mixed populations. Directions of maximum continuity were interpreted for each population percentile for both contaminants. Structural controls affecting the levels of both contaminants were confirmed or established.

INTRODUCTION

A semi-variogram is a graph summarising variability of mineralisation between pairs of samples within a certain orientation*.

If this relationship can be described by the sample's grades then it can be used by the geostatistical interpolation to estimate grade at locations not directly sampled. Generally, as the distance between the samples increases, the difference in grade values will increase as well. However, as Banded Iron Formation (BIF) is characterised by its fine layering, hole effect semi-variograms may point to discrete lenses of high values of a particular element in a certain direction.

Iron ore deposit grade continuities often show anisotropy, that is they are rarely regular in all directions for most of the modelled elements, and have a longer range of influence along strike than they do across strike. The directions associated with maximum grade continuity can be described as dip and strike of mineralisation of a particular element as opposed to dip and strike in purely geological terms.

In order to produce a reliable resource model and confirm or investigate geological controls it can be advantageous to establish the direction of maximum continuity of certain element grades experimentally. The first stage of this analysis involves generating a horizontal semi-variogram fan$^{\Delta}$ (Figure 3).

The direction of greatest continuity within this fan is referred to as the strike. To ascertain the apparent dip, a fan in the vertical direction perpendicular to the established strike direction is generated. Once the strike and dip directions are established, a variogram fan can be generated in the plane passing through the strike and dip directions in order to determine the direction of maximum continuity of mineralisation (pitch).

As the BIF has undergone a complex geological history, several populations of mineralisation could be found within a single well-defined geological domain (Figures 1 and 2). Application of non-parametric methods, allowing modelling of the mixed distributions of the grades, involves interpreting directions of maximum continuity at several indicator grade values.

STATISTICAL ANALYSIS

The study of the spatial continuity of two contaminant elements (Contaminant 1 and Contaminant 2) in 'N' domain was carried out.

Values for both contaminants form positively skewed grade distributions close to lognormal with evidence of mixed populations (Figures 1 and 2).

VARIOGRAPHY

An example of a variogram fan is presented in Figure 3. Orientations of mineralisation continuity are presented in Table 1 (Contaminant 1) and Table 2 (Contaminant 2).

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* More detailed information on variography is summarised by Coombes (1996)

Δ Horizontal semi-variogram fan is comprised of a number of individual semi-variograms in all horizontal directions commonly at 10° intervals, with contoured variability.

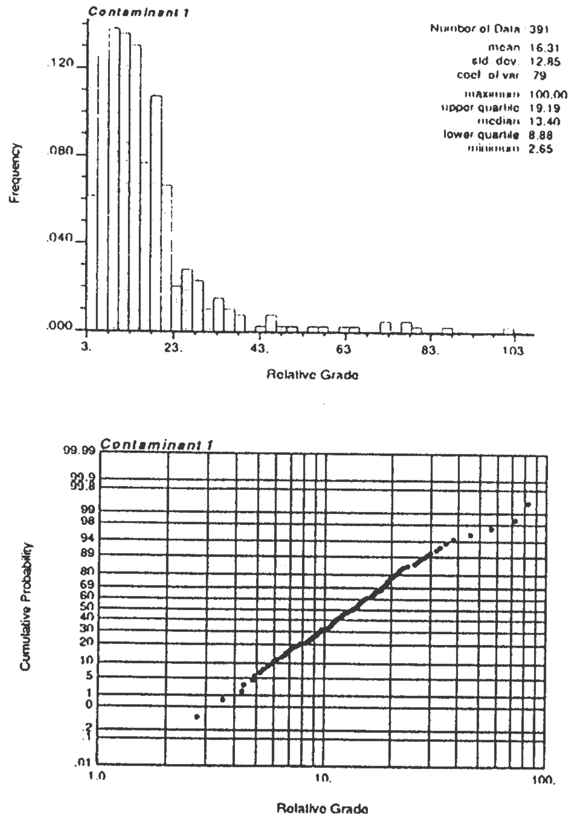

FIG 1 - Log scale histogram and log scale probability plot for Contaminant 1.

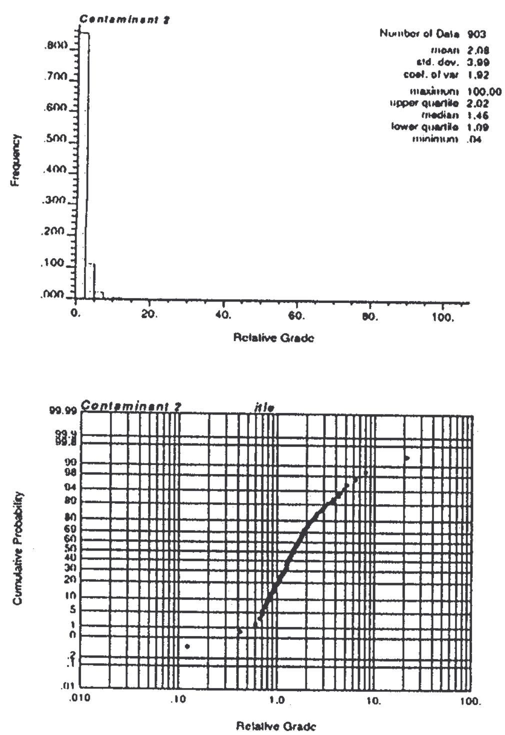

FIG 2 - Log-scale histogram and log scale probability plot for Contaminant 2.

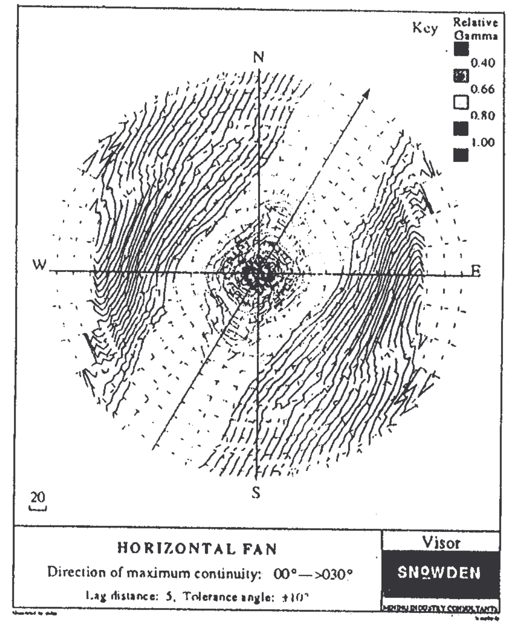

FIG 3 - Horizontal semi-variogram fan for Contaminant 1.

TABLE 1

Contaminant 1 - orientations of continuity.

Percentile	Strike direction	Dip direction[4]	Maximum continuity
20 %	030°	-80°/120°	-10°/208°
30 %	040°	-80°/130°	-20°/216°
40 %	060°	-80°/150°	-20°/236°
50 %	080°	-80°/170°	-20°/256°
60 %	080°	-80°/170°	-20°/256°
70 %	080°	-80°/170°	-20°/256°
80 %	090°	-80°/180°	-10°/268°
90 %	090°	-80°/180°	-09°/265°

TABLE 2

Contaminant 2 - orientations of continuity.

Percentile	Strike direction	Dip direction[4] (limb 1)	Maximum continuity (limb 1)	Dip direction[4] (limb 2)	Maximum continuity (limb 2)
30%	070°	-80°/340°	00°/250°	-80°/160°	00°/250°
40%	070°	-80°/340°	00°/250°	-80°/160°	00°/250°
50%	070°	-80°/340°	00°/250°	-80°/160°	00°/250°
60%	070°	-80°/340°	00°/250°	-80°/160°	00°/250°
70 %	070°	-80°/340°	-10°/252°	-80°/160°	00°/250°
80%	070°	-80°/340°	-29°/256°	-80°/160°	00°/250°
90%	070°	-80°/340°	-20°/254°	-80°/160°	-10°/240°

[4] Expressed as dip/dip azimuth.

DISCUSSION

Analysis of spatial continuity of Contaminant 1 shows that the direction of high contamination (indicators 80 per cent and 90 per cent) strikes east and dips steeply south. The lower contamination directions appear to strike north-east (from 030° to 080°) and dip steeply south-east at 80°. It is concluded that there is rotating anisotropy for the different element ranges and that the higher values display a rotation in the strike towards the east.

The best quality information on the directions of spatial continuity is obtained from the analysis of percentiles 30 per cent to 70 per cent. Within the dip plane there is evidence of a pitch component of 20° for these indicators. The remaining indicators have a pitch component of 10°.

Figure 4 illustrates stereonet plots of Contaminant 1 dip planes and directions of maximum continuity for the percentiles 30 per cent to 70 per cent. It was noticed that the three directions of maximum continuity are close to the plane -21°/236°. Direction -79°/151° is defined by the intersection of the three dip planes. Calculations of the planes defined by each of the three pairs of lineations are presented in Table 3. The directions of intersections of the three pairs of planes are in Table 4.

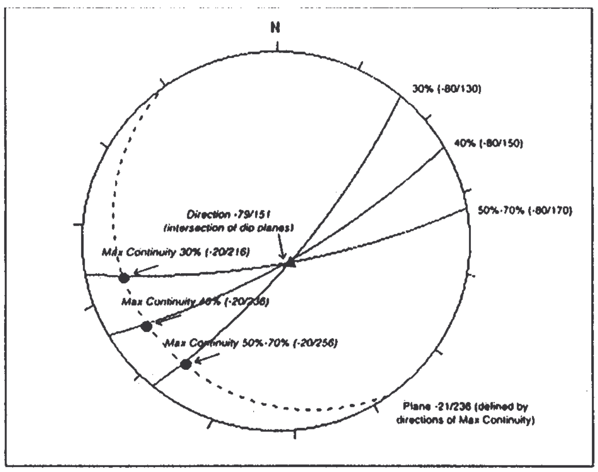

FIG 4 – Contaminant 1 mineralisation controls from variography.

TABLE 3

Contaminant 1 – planes defined by directions of maximum continuity (lineations).

Lineation 1	Lineation 2	Plane defined by 2 lineations
-20°/216°	-20°/236°	-20/226
-20°/236°	-20°/256°	-20/246
-20°/256°	-20°/216°	-21/236

Analysis of spatial continuity of Contaminant 2 demonstrates a constant north-north-east strike of 070° for all indicators. There is an indication of folding with two limbs dipping in different directions. The first limb dips steeply north-north-west (-80°/340°) and the second limb steeply dips south-south-west (-80°/160°). Within the dip planes for both limbs there are no pitch components, giving the same direction of maximum continuity.

TABLE 4

Contaminant 1 – directions obtained as intersections of dip planes.

Plane 1	Plane 2	Direction of intersection of 2 planes
-80°/130°	-80°/150°	-80°/141°
-80°/150°	-80°/170°	-80°/161°
-80°/170°	-80°/130°	-79°/151°

The best quality information on the directions of spatial continuity is obtained from the analysis of percentiles 30 per cent to 60 per cent.

Figure 5 illustrates stereonet plots of Contaminant 2 dip planes for the percentiles 30 per cent to 60 per cent. It was noticed that the axis of the fold coincides with the direction of maximum continuity of mineralisation (00°/250°).

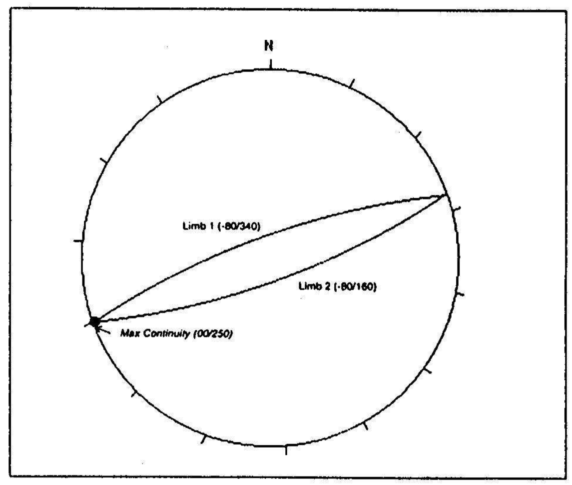

FIG 5 – Contaminant 2 mineralisation controls from variography.

CONCLUSIONS

It was concluded that use of geostatistics is highly beneficial both for geological modelling as well as for interpolation of block element values.

Analysis of spatial continuity of Contaminant 1 indicates that there could possibly be structural control defined by the direction of intersection of the dip planes and/or the plane, defined by the directions of maximum continuity. Folding has been demonstrated for Contaminant 2, with the axis of the fold coinciding with the direction of maximum continuity.

Search ellipse radii and orientations for contaminant interpolation were established both for Contaminant 1 and Contaminant 2. The necessity to divide domain 'N' into sub-domains for interpolation of Contaminant 2 was demonstrated as well.

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REFERENCES

Coombes, J, 1996. Latest Developments in visualising spatial continuity from variogram Analysis, in *Proceedings 1996 AusIMM Annual Conference*, pp 295 – 300 (The Australasian Institute of Mining and Metallurgy: Melbourne).