A retro-review

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Mining Geostatistics

Journel, A G and Huijbregts, Ch J
Academic Press, 1978

In his *Foreword* to Journel and Huijbregts's 1978 *Mining Geostatistics*, Professor G Matheron sets the stage by stating, *"...zones of rich and poor grades always exist, and this is possible only if the variability of grades possesses a certain degree of continuity."* He clarified this observation by restating with circular logic, *"...this degree of continuity will be more or less marked, but it will always exist."* His proclivity to spurious logic leads Matheron to declare, "*...even though mineralization is never so chaotic as to preclude all forms of forecasting, it is never regular enough to allow the use of deterministic forecasting techniques."* It was Matheron himself who proposed the term *geostatistics* because geologists *"stress structure"* and statisticians *"stress randomness"*. Is this peculiar dichotomy between orderliness and randomness really the *raison d'être* for Matheron's *noveau* science of geostatistics? Strangely enough, *Mining Geostatistics* has much less in common with mathematical statistics than Matheron's contrived dichotomy suggests.

Matheron predicts that a specialist in mathematical statistics *"would not find much more than variances, covariances, optimal linear estimators, etc"*. As luck would have it, a mathematical statistician could not possibly find any true variances or covariances of sets of independently measured values but plenty of pseudo variances and covariances of sets of distance-weighted averages-*cum*-kriged estimates. Matheron's statement, *"A statistician who is not familiar with mining may well be discouraged before he can even get a good idea of the problem at hand"*, confirms that his Centre de Géostatistique paid scant attention to mathematical statistics. In those days a statistician would have found out in short order that Matheron's problem with his new science of geostatistics is that it violates the fundamental requirement of functional independence and ignores the concept of degrees of freedom. In the simplest of terms; computing more data from measured data is impermissible.

Matheron conferred the first krige-inspired eponym on Professor D A Krige who found the infinite set of distance-weighted averages but lost the infinite set of variances of distance-weighted averages. Matheron and the authors of *Mining Geostatistics* failed to notice that the infinite set of variances of distance-weighted averages had vanished without a trace. And so it came about that the distance-weighted average was the first and only weighted average to shed its variance even before it was reborn as an honorific kriged estimate. Ironically, no other weighted average could have lost its variance as inconspicuously as the distance-weighted average-*cum*-kriged estimate did.

In mathematical statistics, one-to-one correspondence between variances and central values (the arithmetic mean and all sorts of weighted averages) is *sine qua none*. In geostatistics, however, one-to-one correspondence between variances and distance-weighted averages is null and void. Overlooking the variances of distance-weighted averages may well be a classic example of a human error that will be recorded in the history of science. In contrast, any inferences from pseudo variances and covariances of sets of kriged estimates transgress from human error into a true scientific fraud.

Given that two or more independently measured values of a stochastic variable, when determined in samples selected at different coordinates in a sample space, define an infinite set of distance-weighted averages, it follows that the infinite set of variances of ***single*** distance-weighted averages was lost somewhere in South Africa a short while before the pseudo variance and covariance of a ***set*** of distance-weighted averages-*cum*-kriged estimates was found and became the quintessence of Matheron's novelty science.

The authors of *Mining Geostatistics* seem unaware of the irrefutable fact that distance-weighted averages converge on the arithmetic mean, and variances of distance-weighted averages on the central limit theorem when variable and equal weights converge. It is highly improbable indeed that these authors understood more than a modicum of mathematical statistics. How otherwise could pseudo variances and covariances of **subsets** of **infinite** sets of distance-weighted averages become the cornerstones of geostatistics as it evolved at Matheron's *Centre de Géostatistique* where mathematical statisticians would have been as popular as black flies on field trips?

Not surprisingly, the authors of *Mining Geostatistics* do not explain how to select the least biased and most precise subset of an infinite set of distance-weighted averages. What the authors did do is introduce scores of confounding neologisms and *krige*-inspired eponyms such as *kriging, kriging matrix, kriging plan, kriging process, kriging system, cokriging, disjunctive kriging, linear kriging, lognormal kriging, random kriging, simple kriging, universal kriging, kriging variances, kriging covariances* and *kriging estimators*. All that kriging muscle must have had a seductive ring of innovation for those who fail to grasp that Matheron's new science is a fundamentally flawed variant of mathematical statistics because it violates the requirement of functional independence and ignores the concept of degrees of freedom.

Index A. Geostatistical Concepts, in *Mining Geostatistics*, does not list *variability*, *degree of continuity*, or *continuity* for that matter. Nor does it list *central limit theorem, coefficient of variation, coefficient of determination, degrees of freedom*, *independently measured values, functionally dependent values, spatially dependent values*, *sampling variogram, analysis of variance*, *Fisher's F-test*, *Bartlett's* χ^2*-test,* or *Student's t-test*.

Under *Sill and dispersion variance*, in Chapter III *Structural Analysis*, the authors failed to link geostatistics to its tenuous roots in mathematical statistics by specifying that a randomly distributed set of $\boldsymbol{n}$ independently measured values has $\boldsymbol{df_r=n-1}$ degrees of

freedom. They could have pointed out under I.B.2. *The variogram*, in Chapter I. *Geostatistics and Mining Applications,* that an *in situ* ordered set of ***n*** independently measured values has $\boldsymbol{df_o=2(n-1)}$ degrees of freedom. Another statistical fact that eluded these authors is that the number of degrees of freedom is a positive integer for a set of independently measured values with identical weights, and a positive irrational for a set of independently measured values with variable weights.

The authors appear unfamiliar with the sampling variogram, as defined in several ISO Standards including those developed by ISO Technical Committee 69–*Applications of statistical methods*, which show where orderliness in sample spaces dissipates into randomness. A sampling variogram is a visual interpretation of Fisher's F-test, obtained by plotting the variance terms of the *in situ* or temporally ordered set of independently measured values of the stochastic variable of interest against the variance of the randomly distributed or randomized set and the lower limits of its asymmetric 95% and 99% confidence ranges.

Nowhere in *Mining Geostatistics* is credulity stretched more than in Chapter V *The Estimation of In Situ Resources*, under Section *V.A. Theory of Kriging, Remark 2, (ii) a zero kriging variance,* $\sigma^2_K=0$. Logically, infinite sets of kriged estimates entail infinitesimal distances between them, and, thus, give zero kriging *"variances"*. The zero kriging *"variance"* did not concern these authors in 1978 as much as the shrinking of kriging *"variances"* troubled Armstrong and Champigny in 1989 when they cautioned against oversmoothing. It defies belief that causality between the rise of pseudo covariances, the fall of pseudo variances and the requirement of functional independence in mathematical statistics, stymied scores of geostatistical scholars.

Index B. *Quoted Deposits*, does indeed quote a veritable ABC of deposits but *Mining Geostatistics* is remarkably devoid of practical examples pertaining to any of those deposits. The authors, to their credit, did as much as they could with what little statistics was allowed at Matheron's *Centre de Géostatistique* at Fontainebleau, France. While it is tempting to sympathize with those who toiled for ten years under Matheron's stifling tutelage, the authors share some blame because their work has been reprinted without any corrections. Journel carries most of the blame because he would rather prevaricate about spatial dependence, degrees of freedom and *"Fischerian"* (sic) statistics than investigate infamous failures of Matheron's new science such as Hecla's Grouse Creek crash and Bre-X's Busang salting scam.

Professor Dr A G Journel, the lead author of *Mining Statistics*, accepts pseudo variances and pseudo covariances of sets of kriged estimates. Journel, a prominent member of the geostatocracy, has yet to respond to the fundamental question; does or doesn't each and every distance-weighted average-*cum*-kriged estimate have its own variance? To have or not to have a true variance! That's a simple question! Just the same, Journel, one of Matheron's most gifted students and a renowned member of the first generation of geostatistical scholars, remains silent.