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Some Thoughts on the Nugget Effect in Multi-Mineral Geological Samples

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Abstract

The nugget effect for a multi-element geological sample like rock represents differing geochemical concentrations occurring in each subsample (or "nugget"). However, there are differing, and sometimes contradictory, definitions and explanations of the nugget effect, including witchcraft. Some argue the nugget effect cannot be eliminated, and others say it can be. These differences can be resolved by recognizing that the nugget effect can involve at least seven issues or facets, which are rarely all considered and addressed. For full-scale minesite components, the full-scale nugget effect can be a major determinant in whether acid rock drainage (ARD) eventually appears in spite of any average-value-based prediction.

1. Introduction

Seemingly unresolvable conundrums are great challenges, especially when they appear to involve relatively simple concepts. They are fun to think about, but can also be frustrating such as when professional liability is involved. Welcome to the "nugget effect".

A relatively simple explanation of the nugget effect begins with a sample of rock, soil, or tailings with each particle in the sample composed of a different mineral. Upon the geochemical analysis of each particle (or each subsample or each "nugget" in a sample), different geochemical concentrations of elements will be obtained among the particles because each is a different mineral. Thus, each nugget in a sample has a different concentration of an element, called the "nugget effect".

This leads to the question of "What is the real concentration in a multi-mineral geologic sample?" Interesting debates can then be had when further asking, "Will additional sampling and analysis of the other subsamples and nuggets resolve the nugget effect?" Such debates are interesting because the answer is both "yes" and "no". This is because the nugget effect is not a single thing.

Here are some simple definitions of the nugget effect taken from the Internet:

> *"nugget effect = sum of geological microstructure and measurement error"*
> http://www.statios.com/resources/04-variogram.pdf
>
> *"The nugget effect is affected by the volume of sampling, decreasing in value as the volume*

> *increases.*" https://geostatisticslessons.com/lessons/nuggeteffect

More elaborate explanations say:

> *"The Nugget Effect simply is the product of the clustering of metals in a given deposit. Where metals are very tightly clustered (nuggety), then finding the nugget will give a wild overestimation of the amount of metal, inversely missing it will underestimate the amount of metal."*
> https://www.geologyforinvestors.com/the-nugget-effect-what-is-it-and-how-to-recognize-it/
>
> *"Anomalously high precious metal assays resulting from the analysis of samples that may not adequately represent the composition of the bulk material tested due to nonuniform distribution of high-grade nuggets in the material to be sampled."* https://www.mindat.org/glossary/nugget_effect
>
> *"The nugget effect can be attributed to measurement errors or spatial sources of variation at distances smaller than the sampling interval or both. Measurement error occurs because of the error inherent in measuring devices. Natural phenomena can vary spatially over a range of scales. Variation at microscales smaller than the sampling distances will appear as part of the nugget effect. Before collecting data, it is important to gain some understanding of the scales of spatial variation."*
> https://pro.arcgis.com/en/pro-app/latest/help/analysis/geostatistical-analyst/understanding-a-semivariogram-the-range-sill-and-nugget.htm

Explanations of the nugget effect can also be based on geostatistical parameters like the variogram in kriging:

> *"The nugget is the y-intercept of the variogram. In practical terms, the nugget represents the small-scale variability of the data. A portion of that short range variability can be the result of measurement error."*
> https://vsp.pnnl.gov/help/Vsample/Kriging_Variogram_Model.htm
>
> *"In the context of estimating a variogram, a nugget allows for the variogram to assume a non-zero value for two observations having a distance of zero... Presence of a nugget means that any two observations sampled arbitrarily closely will not necessarily have the same value."*
> https://stats.stackexchange.com/questions/324825/what-is-the-nugget-effect

A humourously honest explanation of the nugget effect can involve witchcraft and sacrifices.

> *"Unfortunately, I'm not going to tell you what's the right nugget constant to use today, that's a topic for another post and might or might not involve witchcraft and offering sacrifices on the altar of the god(dess) of Chaos."*
> https://lazymodellingcrew.com/post/post_21_nugget_effect_ta/

2. A More Rigorous Definition of the Multi-Faceted Nugget Effect

Chapter 1 above contains some explanations and definitions of the nugget effect, with some being unrelated and even exclusive or contradictory. This is usually a sign that a topic is more complex than generally thought. Fortunately, some authors and researchers have thought this through in more detail.

In a paper subtitled "Sampling error or nugget effect?", Clark (2010) explains:

> *"Arguments were put forward that 'sampling errors' actually exist at zero distance. Some geostatistical schools actually maintain that the 'nugget effect' is all sampling error. This would imply that 'perfect' sampling would eliminate the nugget effect entirely."*

In a thesis, Simmonds (2009) saw two parts to the nugget effect, one of which cannot be resolved:

> *"The nugget effect is composed of a geological component, which can be thought of as inherent, and a sampling component, which is not fixed... The geological contribution to the nugget effect cannot be removed... The nugget effect in variography [statistical modelling] is defined as the discontinuity seen at the origin where at negligible sample separation distances variability is still seen between sample pairs."*

An elaborate and detailed explanation of the many facets of the nugget effect was given by Pitard (1994), recognizing that "[t]he misunderstanding of all these variability component prevents the effective minimization of the errors they generate":

> *"Indeed, the 'Nugget Effect' is the result of at least seven types of variability:*
>
> 1. *The true in-situ, small-scale, random variability;*
> 2. *The variability introduced by Constitution Heterogeneity during all sampling and subsampling stages, which is function of fragment size and sample or subsample weight*
> 3. *The variability introduced by small-scale Distribution Heterogeneity during all sampling and subsampling stages which is a function of transient segregation as soon as the material has been broken up... because of the transient nature of distribution heterogeneity (i.e., segregation), there is no such thing as a constant bias in sampling;*
> 4. *The variability introduced by any deviation from an isotropic module of observation ensuring sampling equiprobability in all relevant dimensions, during all sampling and subsampling stages;*
> 5. *The variability introduced by selectivity and poor recovery during all sampling and subsampling stages;*
> 6. *The variability introduced by contamination, losses, alteration of physical or chemical properties, and human errors; and*
> 7. *The variability introduced by the analytical procedure."*

Thus, the nugget effect consists of at least seven different variabilities according to Pitard (1994)! Perhaps this is why the involvement of witchcraft is sometimes suspected (Chapter 1).

3. Some Simplified Thoughts on the Nugget Effect Related to Minesite-Drainage Chemistry

Based on Sections 1 and 2 above, there are a few additional observations that can be made about the nugget effect for minesite-drainage chemistry. To illustrate, a greatly simplified geologic sample consists of 10 pieces each of 10 minerals. All 10 pieces of a single mineral occur in a row forming a horizontal line of 10 boxes in Figure 3-1. The horizontal row of particles of a single mineral could be due to stratification, foliation, or some other process.

If a vertical subsample (a vertical slice in Figure 3-1) were to be sent to a laboratory for geochemical analyses, the elemental concentrations would be an average value of all 10 minerals and perhaps not representative of any of the 10 minerals. This is actually what analytical laboratories typically attempt to achieve by pulverizing solid-phase samples prior to analysis so that all subsamples theoretically contain the same averaged mixture of minerals.

On the other hand, if a horizontal subsample (a horizontal slice in Figure 3-1) were to be sent to a laboratory for geochemical analyses, the elemental concentrations would be only those of that single mineral. The concentrations in the remaining nine minerals would remain unknown.

A question: for the understanding and the prediction of full-scale minesite-drainage chemistry, metal leaching, and acid rock drainage (ARD), which of the two scenarios above (a vertical subsample or a horizontal subsample in Figure 3-1) is more important and representative? Answer: neither.

Figure 3-1 can be viewed in terms of ARD, with the lightest (uppermost) row containing the most Effective Neutralization Potential (ENP) and the darkest row containing the most Effective Acid Potential (EAP). The relevant question is: will Figure 3-1 release ARD at any time?

In addition to the relatively large error bars in Net Potential Ratios (= ENP/ EAP) caused by the ratio of the numerator and denominator (Morin, 2018a), the answer also depends strongly on scale. For a hand-sized geological sample, perhaps the averaged vertical slice in Figure 3-1 might tell whether any ARD might appear from the hand sample. However, this can be irrelevant for full-scale ARD.

Full-scale case studies show that a small percentage of ARD-releasing rock (e.g., <10% of total volume) can cause ARD to eventually flow from the entire minesite component (e.g., Morin and Hutt, 1997 and 2008; Morin, 2017a and 2018b). This is easy to envision, because on full scales the spatial orientations of water flowpaths and of the ARD-releasing rock determine whether ARD is released (see Figure 3-2 below, taken from Morin, 2017b).

In terms of Figure 3-1, the prediction of full-scale ARD is not related to the vertical (averaged) slice, but to each and every one of the 10 distinct mineralogical layers whose individual geochemical contents and spatial distributions are important to full-scale predictions. Thus, for reliable predictions in Figure 3-1 on the full scale, each of the 10 horizontal slices would require geochemical analysis. Another, unconventional way to say this is: the full-scale "nugget effect" can determine whether ARD eventually drains from a minesite component.

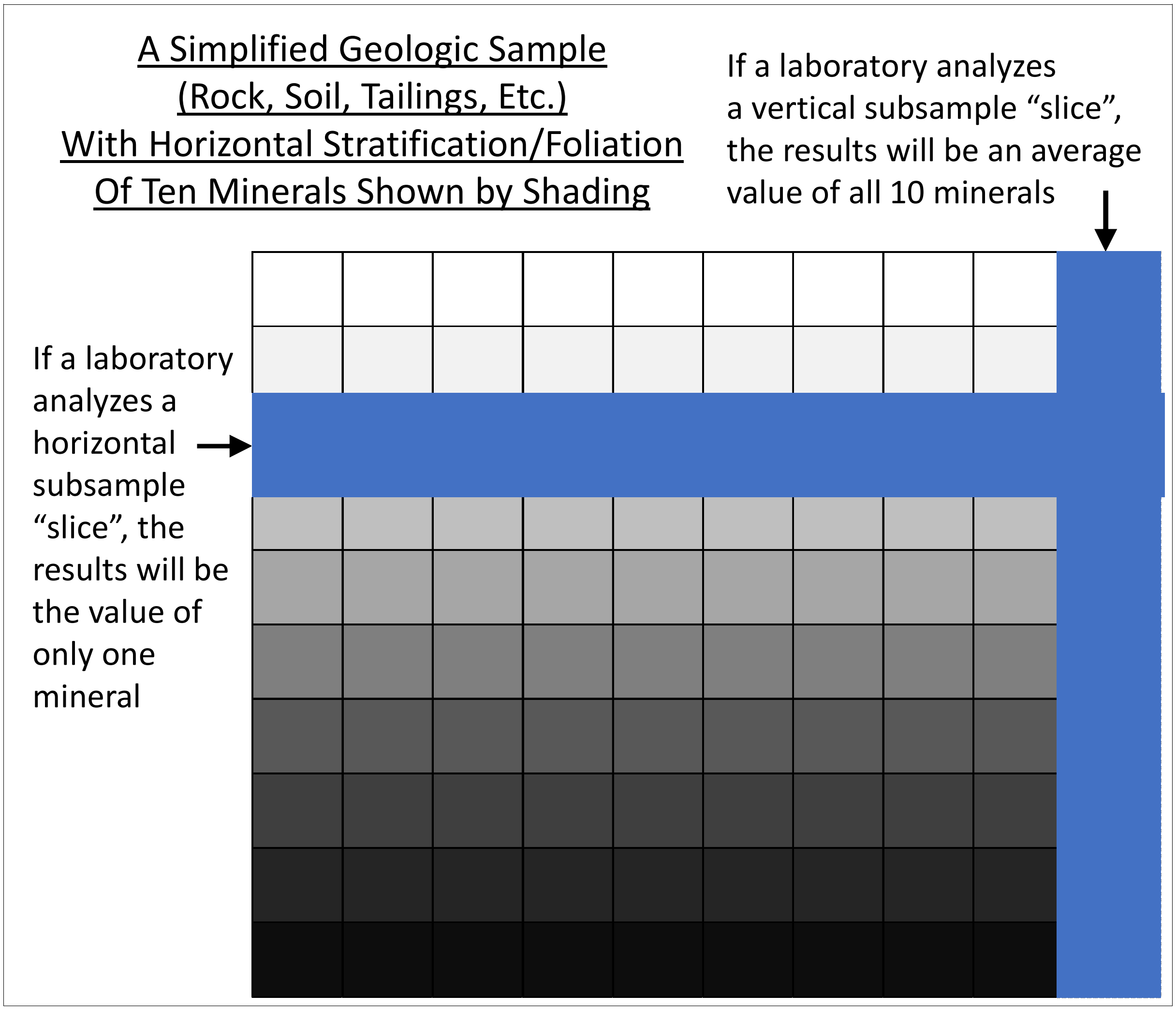

Figure 3-1. A greatly simplified geologic sample in two dimensions, with horizontal stratification or foliation occurring as 10 horizontal layers of distinct minerals.

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Figure 2-6. After five years, the acidic NAG cells have generated and released sufficient net acidity that NP in adjacent NAN cells has been consumed and they too have become acidic; these NAN cells, if any AP is left, become net acid generating themselves, and release additional acidity to adjacent cells.

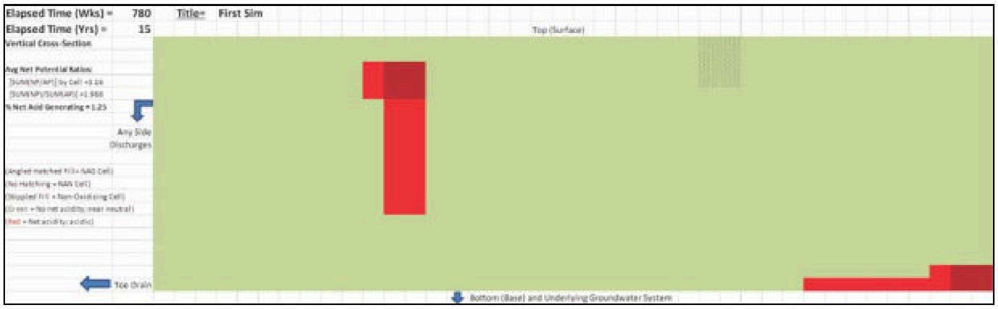

Figure 2-7. After 15 years, the acidic plumes moving downward and laterally to the left grow larger.

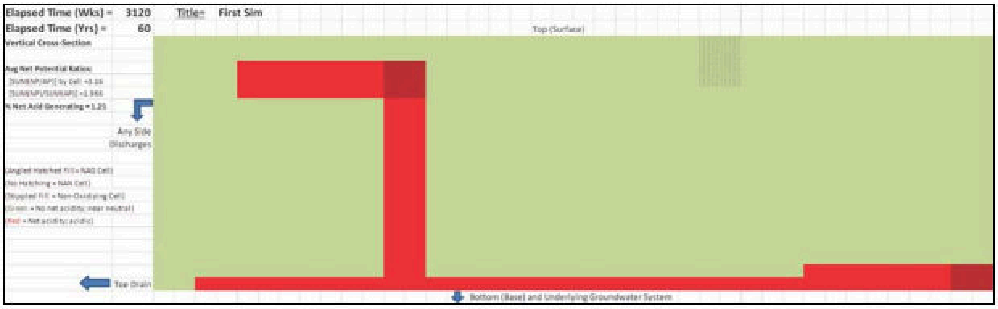

Figure 2-8. After 60 years, the basal acidic plume has merged with the wider, vertical acidic plume, has reached the underlying groundwater system long ago, and has almost reached the toe drain to the left; another acidic plume higher in the minesite component is approaching the side slope.

Figure 3-2. An example of how ARD can flow from a full-scale minesite component due to a small internal percentage of net-acid-generating (NAG) material (from Morin, 2017b).

4. References

Clark, I. 2010. Statistics or geostatistics? Sampling error or nugget effect? The Journal of The South African Institute of Mining and Metallurgy, 110, p. 307-312.

Morin, K.A. 2018a. Propagation-of-Uncertainty in Net Potential Ratios for Predictions of Acid-Rock Drainage. MDAG Internet Case Study #53, www.mdag.com/case_studies/cs53.html

Morin, K.A. 2018b. Two Case Studies Revisited of Full-Scale Co-placement of Net-Acid-Generating and Net-Acid-Neutralizing Geologic Materials. MDAG Internet Case Study #55, www.mdag.com/case_studies/cs55.html

Morin, K.A. 2017a. A Case Study Revisited of Full-Scale ARD from a Waste-Rock Pile with Abundant Reactive Neutralization Potential. MDAG Internet Case Study #47, www.mdag.com/case_studies/cs47.html

Morin, K.A. 2017b. The MDAG Dynamic ARD-Onset Simulator. MDAG Internet Case Study #48, www.mdag.com/case_studies/cs48.html

Morin, K.A., and N.M. Hutt. 2008. Field Study of Unavailable Neutralization Potential in Acidic Rock. MDAG Internet Case Study #31, www.mdag.com/case_studies/cs31.html

Morin, K.A., and N.M. Hutt. 1997. A comparison of AMD predictions with historical records. IN: Proceedings of the Workshop on Acid Mine Drainage, 15-18 July, Darwin, Northern Territory, Australia, Australian Centre for Minesite Rehabilitation Research, p.33-44.

Pitard, F.F. 1994. Exploration of the "Nugget Effect". IN: R. Dimitrakopoulos, ed., Geostatistics for the Next Century, p. 124-136. Kluwer Academic Publishers. Doi: 10.1007/978-94-011-0824-9_16

Simmonds, S-J. 2009. The Nugget Effect: In describing the variability of an ore deposit. M.Sc. Dissertation, Department of Geology, Rhodes University, South Africa, 104 p. Dated December 2009.