Effect of Geological Models on ML/ARD Characterization Program Design at the KSM Project

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ABSTRACT

The effect of different geological classification systems on a ML/ARD characterization program is investigated for the KSM Au-Cu porphyry project in northwest BC, Canada. Geological models enable predictive modeling of the ML/ARD potential of material during excavation and long term storage of waste rock by allowing the representation of a large mass of material by a relatively small mass of sampled material. A robust sampling plan typically attempts to collect samples in proportion to the mass of material to be excavated. Geological models developed during advanced exploration are often used during the geochemical characterization program; however, biases towards ore at the expense of waste rock and future pit walls frequently exist. Perceived uncertainty introduced through "lumping" or "splitting" of datasets can be carried into ML/ARD prediction and water quality models and regulatory approvals. Therefore, the choice of geological model is essential as a geochemistry baseline program advances to determine quantities of potentially acid generating (PAG) and not-PAG waste rock for waste rock and water management planning and to address stakeholder and government concerns.

Three geological models of the KSM project were assessed: Lithology, Alteration, and a hybrid Mine Model. Using the proportion of samples classified as PAG in each model unit, the material to be excavated was classified as PAG or not-PAG.

These results were then compared to an ABA block based on each of the three geological models. Differences in the proportions of PAG material were identified and the underlying cause of the differences is presented.

Keywords: ML/ARD; KSM; Model

INTRODUCTION

The KSM (Kerr-Sulphurets-Mitchell) Project is located in northwestern British Columbia, Canada (Figure 1). Gold and copper mineralization is hosted in a cluster of porphyry related, deformed, and dismembered deposits. The deposits are spread over an area of roughly two by ten kilometers and contain a 2.16 billion tonne resource with an average grade of 0.55 g/t Au, 0.21 % Cu, 2.74 g/t Ag, and 44.7 ppm Mo.

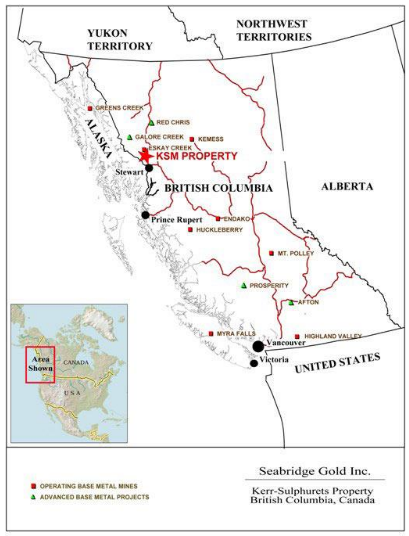

Figure 1 Location of the KSM Project

The work presented here focuses on the material that will be exposed during development of the Kerr open pit. The structural dismemberment of the deposit hinders the use of a pure alteration or lithology model, therefore a hybrid model has been used during the exploration program. This hybrid model (Mine Model) uses predominantly lithological terms above the major thrust faults, where protolith is more easily recognized, and alteration below the thrust faults where pervasive alteration has obliterated primary minerals and structures.

METHODOLOGY

To characterize the acid rock drainage (ARD) potential of the KSM Project each sample was analyzed to obtain its acid generating potential (AP) and acid neutralizing potential (NP). Standard acid-base accounting (ABA) methods (Sobek et al., 1978) were used to determine the sulfide sulfur content and the Sobek neutralization potential.

The neutralization potential ratio (NPR) is the NP:AP ratio. In this paper a generic NPR value of 2.0 was used as a cut-off for the designation of potentially acid generating (PAG; NPR < 2.0) or not-PAG.

PROJECT GEOLOGY

The setting provided in this report is a summary of previously completed descriptions of the regional geology (Ditson, Wells, and Bridge 1995; Fowler and Wells 1995; Kirkham and Margolis 1995; Lechner 2008). A detailed description of the local lithologies, alteration, mineralization, and structures can be found in the 2011 Pre-Feasibility Study Update (Wardrop 2011), this information was summarized in *2012 KSM (Kerr-Sulphurets-Mitchell) Prefeasibility Study* (Tetra Tech 2012).

The Sulphurets District is located along the eastern side of the Coast Mountains, approximately 25 km east of the Coast Plutonic Complex, a north-northwesterly trending belt of Cretaceous to Early Tertiary intrusions and high grade metamorphic rocks. The area lies near the western edge of the middle Jurassic to Cretaceous age Bowser Basin within the Stikine Terrane, also known as Stikinia, which was possibly accreted to the North American continental margin in the Middle Jurassic Period. Stikinia is interpreted as Triassic and Jurassic volcanic arcs resting on Palaeozoic basement (not present at site) and overlain by Jurassic basinal sedimentary rocks.

The upper Triassic Stuhini Group has two major subdivisions. A lower, dominantly sedimentary sequence consisting of turbidites and sandstones. Overlain by an upper dominantly volcanic sequence of volcanic pillowed flows and volcaniclastic breccias.

The Lower Jurassic Hazelton Group is inferred to represent a volcano-sedimentary island arc and back arc complex. The sedimentary sequence consists of a coarse basal sedimentary sequence overlain by a lower volcanic/volcaniclastic sequence, an upper felsic volcanic-pyroclastic unit (Mount Dilworth Formation), and an uppermost marine sedimentary sequence containing subaqueous mafic volcanic flows. The upper contact of the Hazelton Group is gradational with the Bowser Lake Group.

The Hazelton sedimentary sequence is intruded by a suite of porphyritic, Early Jurassic (189 to 195 million years) rocks including alkali feldspar granite, quartz monzonite, syenite, and granodiorite collectively referred to as the Mitchell Intrusions or Texas Creek Plutonic Suite. Below the Sulphurets and Mitchell thrust faults (STF and MTF), pre- and intra-mineral intrusions have historically been exploration targets. A conceptual summary of the evolution if the Project is presented in Figure 2.

There are two main structures at the project (Figure 3) – the Mitchell Thrust Fault (MTF) and the Sulphurets Thrust Fault (STF). The STF can be identified as the primary structure at the Kerr Deposit. The footwall of each deposit is usually more altered and more sheared than the hangingwall. In most instances this alteration and shearing has obliterated primary textures making identification of the protolith difficult. Where evident the protolith is classified as either volcaniclastic or sedimentary belonging to the Stuhini Group. The host rocks have been intruded by multi-phases of the Mitchell Intrusions.

The project fits within a broad porphyry alteration model. Weak hornfelsed alteration assemblages are evidence of contact metamorphism during the emplacement of the Mitchell Intrusions. There is a broad and pervasive propylitic halo characterized by chlorite alteration with variable secondary carbonate. More proximal to the intrusions and along hydrothermal conduits phyllic (QSP; quartz-sericite-pyrite) and intermediate argillic (IARG; clay minerals) alteration dominates, generally destroys primary mineral assemblages and structures. The more intense QSP and IARG alterations are the primary targets for gold and copper exploration. Potassic alteration has been noted but is volumetrically minor in waste rock. The pyrite halo is most intense within the QSP and IARG alterations and pyrite contents can reach 20 %.

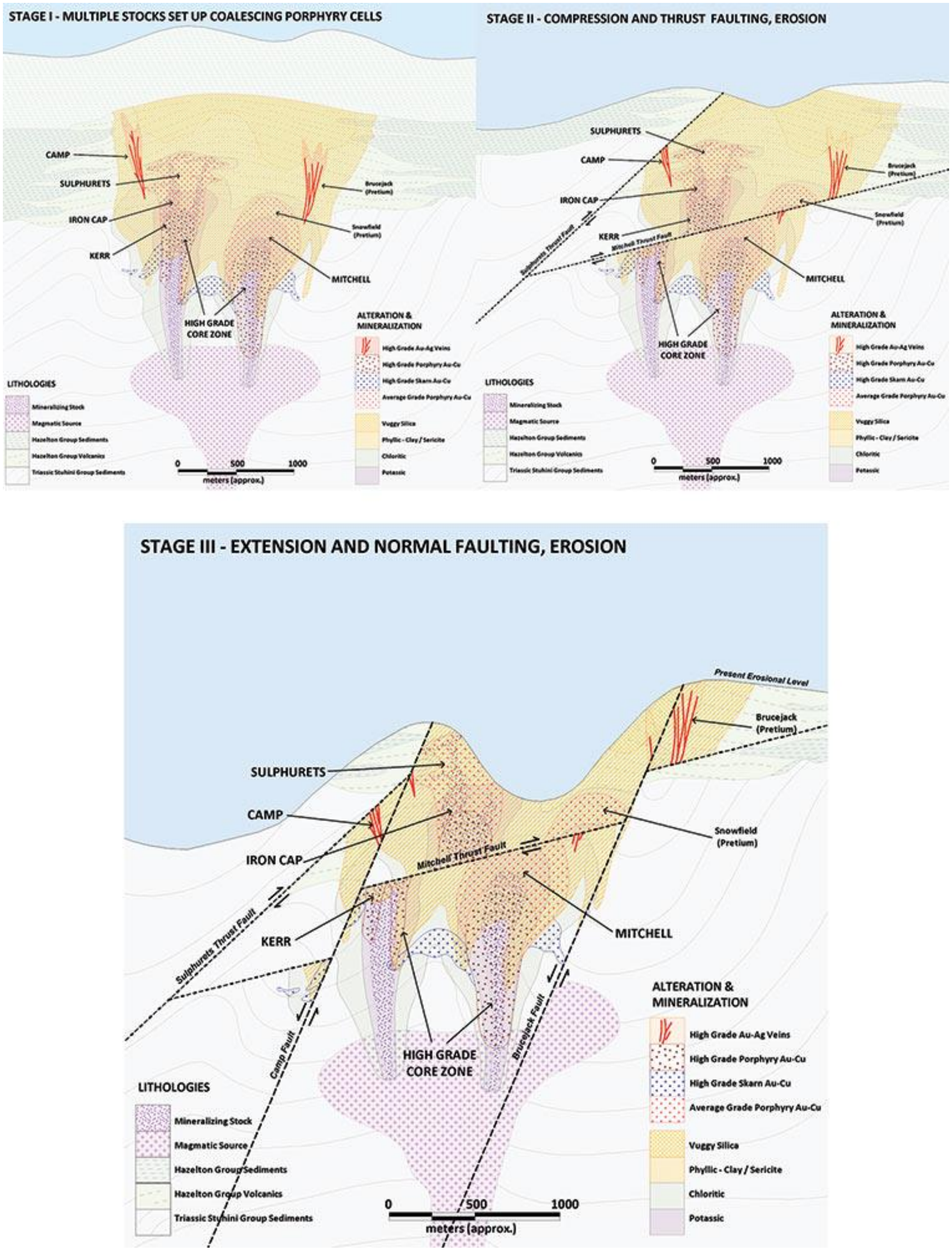

Figure 2 Conceptual geological evolution of the KSM deposits

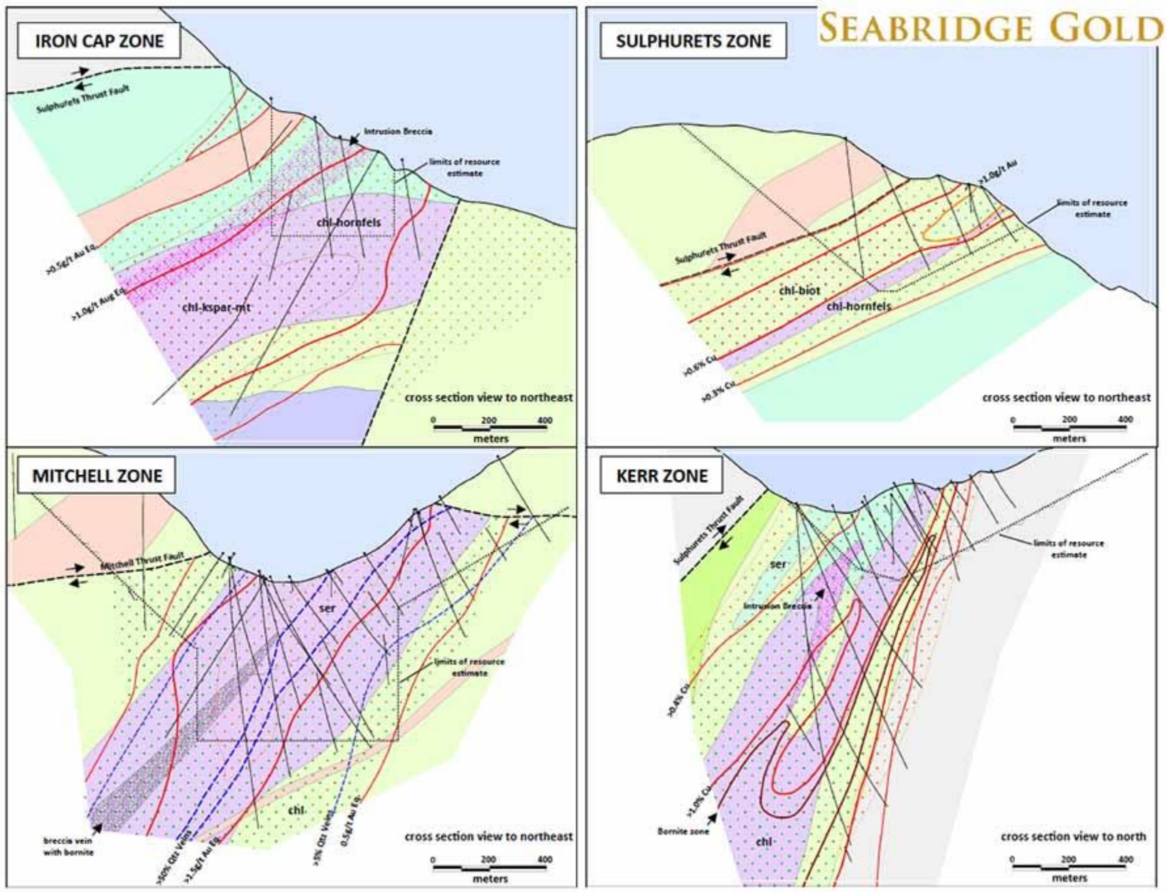

Figure 3 Schematic cross sections through KSM Project deposits

BLOCK MODEL

ABA block models were constructed for the KSM project in 2010, 2011, and 2012. Those models were updated in 2014 with additional static ABA sample data and refined geological models. The ABA block models were constructed with data collected from relatively wide-spaced drill holes from materials thought to be representative of "ore" and "waste". The resolution of individual model blocks is 25 m x 25 m x 15 m, which should allow for large excavators to segregate materials on a pit-bench scale. A general outline of the method used to generate the ABA block model is given below:

The ABA models are based on samples collected from existing drill hole assay pulps. Basic descriptive statistics were tabulated for AP and NP based on block model rock types, alteration types, degree of mineralization, and stratigraphic position relative to major thrust faults.

The models were constructed using three distinct methods outlined below and simplified in Figure 4:

- direct assignment of ABA values to blocks "pierced" by ABA samples;
- two-pass inverse distance estimation methods; and

- assignment of ABA values based on average values calculated by rock/alteration/mineralization type.

Individual model blocks pierced by an ABA sample were assigned NP and AP values from the sample and flagged as being estimated and off limits for subsequent estimation methods.

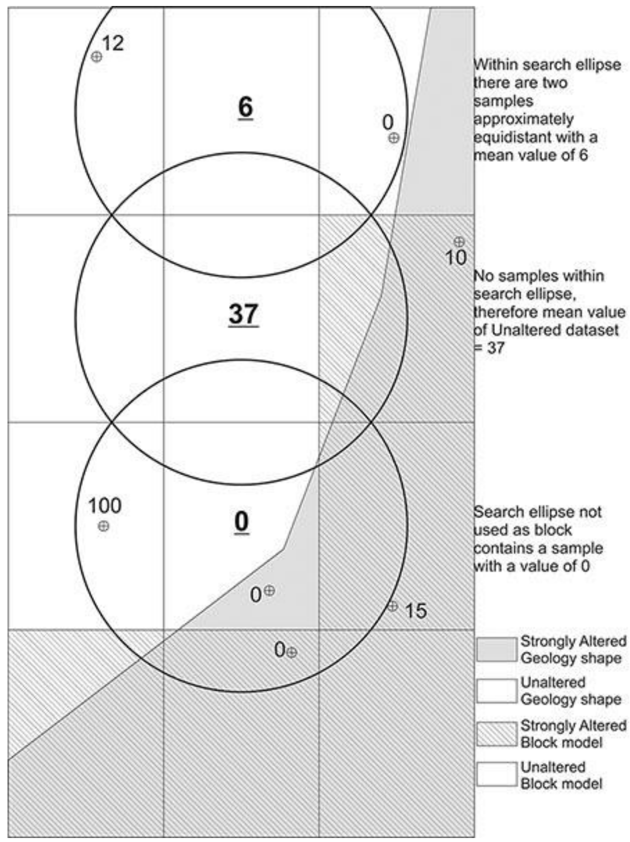

Figure 4 Conceptual diagram showing three methods for assigning a value to a block

After direct ABA assignment was completed, a two-pass inverse distance estimation method was implemented. The first pass used a 100 m x 100 m x 60 m search ellipse to locate eligible ABA samples. A minimum of one sample was required with a maximum of 8 samples used to interpolate NP and AP values. Blocks estimated by this method were flagged as being estimated and not subjected to subsequent estimates. The second estimation pass used a 200 m x 200 m x 120 m search ellipse with the same sample selection used for the first pass. Strict block/sample matching was used in both inverse distance estimation passes. This means that blocks of a certain rock type could only be estimated by samples with the same rock type. Unique search ellipse orientations were used for the Kerr, Sulphurets, and Mitchell zones. A minimum of 1 sample was required, with a maximum of 8 samples allowed with no more than 2 samples from each drill hole. An inverse distance weighting power of 2 was selected.

For blocks beyond 200 m of ABA sample data, class average values were assigned to blocks based on rock, alteration, or mineralization codes. The average values for NP and AP for these static samples are influenced by mineralization intensity. Typically, as gold and/or copper grades increase NP values decrease and AP values increase. Commingling mineralized and unmineralized

ABA samples has provided a certain degree of conservatism because most of the mineralized material will be processed and not sent to a waste rock disposal area. After the estimate and assignment of block ABA values was completed, the NPR was calculated.

RESULTS AND DISCUSSION

Lithology Model

The primary difference between the two approaches is the large difference in predicted PAG material from the heavily altered and uncategorized material below the STF (Table 1). The result is that the two approaches have an approximately 28 % difference in the total mass of predicted PAG material.

Table 1 Lithology model comparison

	From Block Model		From ABA Samples		Tonnage of waste
Lithology Model Code	PAG	not-PAG	PAG	not-PAG	(Mt)
Kerr					
Overburden	100 %	0 %	26 %	74 %	20.3
Stuhini Group	0 %	100 %	0 %	100 %	70.4
HW Intrusive Rock	97 %	3 %	64 %	36 %	51.1
Premier Dike	100 %	0 %	100 %	0 %	9.3
Hornblende Dike	100 %	0 %	N.S.	N.S.	0.1
HW Mixed	98 %	2 %	82 %	18 %	32.9
FW Mixed	100 %	0 %	82 %	18 %	11.0
HW Uncategorized	**100 %**	**0 %**	**91 %**	**9 %**	**200.5**
FW Uncategorized	**99 %**	**1 %**	**50 %**	**50 %**	**240.6**
Unclassified	100 %	0 %	N.S.	N.S.	25.6
Kerr Total Mass	585.7	76.1	401.9	234.2	661.8

N.S. = no sample collected

Major units are represented by bold font

Alteration Model

The two Alteration Model approaches predict a 24 % difference in the mass of PAG material (Table 1). The two major units have much higher predicted masses of PAG material through the block model approach compared to the ABA samples.

Table 2 Alteration model comparison

Alteration Model Code	From Block Model PAG	not-PAG	From ABA Samples PAG	not-PAG	Tonnage of waste (Mt)
Kerr					
CL-PR	100 %	0 %	93 %	7 %	18.5
QSP	**99 %**	**1 %**	**86 %**	**14 %**	**208.2**
Weak CL-QSP	100 %	0 %	86 %	14 %	110.4
Premier Dike	100 %	0 %	86 %	14 %	13.3
Hornblende Dike	100 %	0 %	N.S.	N.S.	0.3
Uncategorized/unaltered	**79 %**	**21 %**	**43 %.**	**57 %**	**311.0**
Kerr Total Mass	596.0	65.7	436.9	224.5	661.7

N.S. = no sample collected

Major units are represented by bold font

Mine Model

In the Mine Model the difference between the block model and the ABA samples can be large for major units (Table 3). Using just the ABA samples the volume of PAG material would be underestimated by approximately 129 Mt at Kerr, approximately 21 % of the mass of waste rock produced.

Table 3 Mine model comparison

Mine Model Code	From Block Model PAG	not-PAG	From ABA Samples PAG	not-PAG	Tonnage of waste (Mt)
Overburden	100 %	0 %	100 %	0 %	20.3
Premier Dike	100 %	0 %	100 %	0 %	1.3
Chlorite-propylitic alteration	100 %	0 %	93 %	7 %	15.5
QSP alteration	**99 %**	**1 %**	**85 %**	**15 %**	**175.2**
Weak chlorite-QSP alteration	100 %	0 %	91 %	9 %	91.1
Stuhini Volcanics	0 %	100 %	0 %	100 %	63.0
HW Intrusive Rock	95 %	5 %	60 %	40 %	0.0
FW Weak QSP alteration	99 %	1 %	88 %	12 %	33.3
FW Propylitic Hornfels alteration	99 %	1 %	42 %	58 %	51.4
HW Propylitic Hornfels alteration	**100 %**	**0 %**	**64 %**	**36 %**	**175.0**
Kerr Total Mass	560.8	65.3	431.3	194.8	626.1

Major units are represented by bold font

DISCUSSION

The differences between the proportions calculated from the ABA samples and the proportions calculated from the Block Models are a function of block model edge effects and the influence high AP values. Blocks near the periphery of the Kerr open pit have AP and NP values assigned by either inverse distance estimation or average value of model unit. Both methods favor higher AP assignment, as both methods are influenced by the drilling and sampling focused in the mineralized and highly altered footwall. The average value assignment method is not responsible for as many assigned values as inverse distance estimation.

Figure 5 uses fictional data to illustrate the difference in calculated proportions of PAG material based on using the ratio of ABA samples (left grid) or using inverse distance estimation (right grid). In the example five samples are identified with varying NP and AP values and placed in a two dimensional grid to simulate a block model. When just the ABA sample data are used (left grid) the example predicts 60 % of the material to be not-PAG (shaded grey); based on three of five samples having a NPR more than 2.0. This result indicates that the bulk of the material in the block is not-PAG. Note that using the ratio of PAG to not-PAG samples from an ABA database does not take into account the spatial layout of samples.

Using the same example data in the same grid inverse distance estimations were used to calculate AP values for each block (Figure 5, right grid). The single high AP value in the center dominates an inverse distance estimation resulting in very few blocks being classified as not-PAG. The end result is less than 10 % not-PAG (shaded grey) by inverse distance estimation, compared with 60 % not-PAG by ABA sample. This result indicates that the bulk of the block is PAG and may require segregation or special handling.

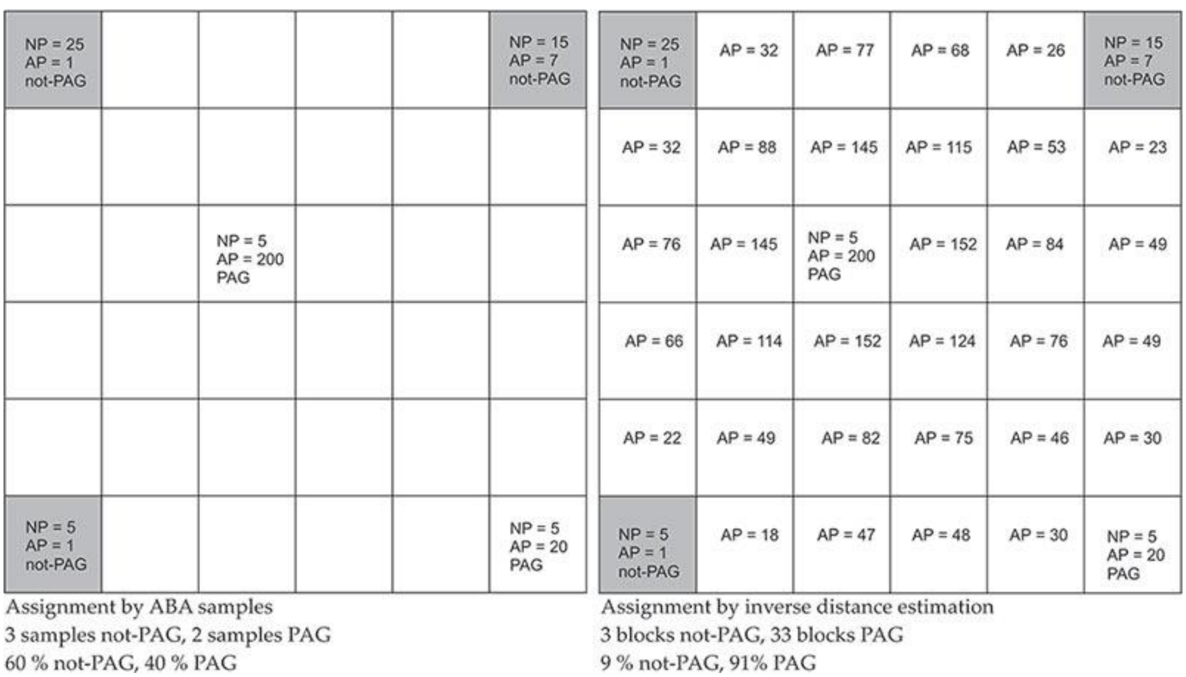

Figure 5 Conceptual diagram showing proportion of material estimated to be PAG by two differing methods

CONCLUSION

Differences were noted when comparing the proportion of PAG material predicted for the three Kerr block models to the proportions of samples classified as PAG. In the Lithology, Alteration, and Mine Models the block model predicted a higher proportion of PAG material than the ABA sample data. The primary reason for the difference is the overwhelming effect a single high AP value can have on surrounding blocks if NP and AP are usually moderate to low.

The results presented illuminate the need to consider Block Models and ABA datasets when predicting the proportions of PAG material. Additionally, the masses predicted by the deposit Block Models were quite similar irrespective of the geological model used to generate the Block Model. This result indicates that at the Kerr Deposit the Block Models are a robust and conservative approach to ARD prediction.

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