1st International Geometallurgy Conference (GeoMet 2011)

# Geometallurgical Modelling Techniques Applicable to Pre-Feasibility Projects: La Colosa Case Study

*Paula A Montoya[1], Luke Keeney[2], Rudi Jahoda[3], Julie Hunt[4], Ron Berry[5], Udo Drews[6], Vaughan Chamberlain[7]*

Reference Number (XXX)

Contact Author
Paula A Montoya L
Professional Senior Geologist
AngloGold Ashanti Colombia
116 Avenue Number 7 – 15 Cusezar Building Floor 8, Bogota D.C
Office Number +67 6 57 9100
Mobile +61 305 455 72
Email: pmontoya@anglogoldashanti.com

# Geometallurgical Modelling Techniques Applicable to Pre-Feasibility Projects: La Colosa Case Study

*Paula A Montoya*[1], *Luke Keeney*[2], *Rudi Jahoda*[3], *Julie Hunt*[4], *Ron Berry*[5], *Udo Drews*[6], *Vaughan Chamberlain*[7]

1.
Professional Senior Geologist, AngloGold Ashanti Colombia
116 Avenue Number 7 – 15 Cusezar Building Floor 8, Bogota D.C
pmontoya@anglogoldashanti.com

2.
Research Fellow JKMRC, Julius Kruttschnitt Mineral Research Centre
40 Isles Road, Indooroopilly, QLD, 4068.
l.keeney@uq.edu.au

3.
Geology Manager, AngloGold Ashanti Colombia
116 Avenue Number 7 – 15, Cusezar Building, Floor 8, Bogota D.C
rjahoda@anglogoldashanti.com

4.
Research Fellow, GeM$^{III}$ Group, CODES - University of Tasmania, Hobart, TAS, Australia.
julie.hunt@utas.edu.au

5.
Associate Professor, CODES – University of Tasmania, Hobart, TAS, Australia.
ron.berry@utas.edu.au

6.
Metallurgical Manager, AngloGold Ashanti Colombia
116 Avenue Number 7 – 15 Cusezar Building Floor 8, Bogota D.C
udrews@anglogoldashanti.com

7.
Vice-President-Geosciences, AngloGold Ashanti Limited
Johannesburg, South Africa.
vchamberlain@anglogoldashanti.com

# ABSTRACT

La Colosa is a world-class porphyry Au project located in Colombia, currently undergoing pre-feasibility analysis. As part of collaboration between AngloGold Ashanti and the AMIRA P843A GeM$^{III}$ Project, the application of emerging geometallurgical characterisation testing and modelling tools has been incorporated in early stages of project development. The aim of the geometallurgical study is to map inherent comminution variability across the La Colosa deposit providing information critical for mine/mill design and optimisation. In this study, site-based data incorporating multi-element assays, QXRD bulk mineralogy measurements, EQUOtip rebound hardness data, and routine geological logging information from 59 diamond drill holes has been integrated with a range of geometallurgically specific comminution test (i.e. GeMCi, A*b, BMWi). The work in this paper demonstrates the integration techniques used at La Colosa to link routine data acquisition methods with comminution test results through the development of proxy support models. The integration incorporates a range of statistical techniques including principal component analysis and regression modelling. By creating proxy models, comminution index estimates can be propagated into the geological database enabling comminution processing domains to be defined. These domains provide the first spatial representation of comminution performance and variability at La Colosa and can be compared against traditional geological domains. This study provides the foundation for ongoing comminution characterisation as the La Colosa project evolves through project cycles into an operational mine.

**Keywords: Geometallurgy, Comminution Modelling, Comminution Mapping, Orebody Knowledge, La Colosa**

# INTRODUCTION

The La Colosa copper-poor porphyry gold system, located in the middle part of the Cordillera Central of Colombia (Figure 1), is part of the Miocene calc-alkaline volcano-plutonic arc of Colombia (Sillitoe, 2008), and consists of diorites, quartz diorites, and dacites that intruded schist of the Paleozoic Cajamarca Complex. La Colosa is genetically associated with Miocene (8 m.y.) porphyritic intrusive centers intruded into Paleozoic schists. The highest grade gold mineralization is closely associated with a suite of early porphyry intrusions/breccias with potassic and sodic-calcic alteration, pyrite and traces of chalcopyrite and molybdenite. The coherent body suffered little dilution by intermineral/postmineral phases or fault propagation.

Diamond drill hole information indicates mineralization follows a ~2,500m NNW strike length, is ~600m wide and extends to a maximum vertical depth of ~600 m. Hornfels exist at the intrusive contact and schists form the boundary of mineralization to the west. Late and intra-mineral diorite and dacite rocks exist on the eastern margins of La Colosa (Figure 2). Currently, the southern limit of the main mineralized zone is open with soil sample information suggesting mineralization continues for ~1,000 m toward the south of the currently defined resource. Based on 59 diamond drill holes, it is estimated that La Colosa contains ~12.5 Moz of gold (Jahoda, 2008).

La Colosa is currently in pre-feasibility and through collaboration with the AMIRA P843A GeM$^{III}$ project; a study focused on developing early predictive capabilities for identifying comminution variability across the La Colosa deposit has been implemented. This is critically important as porphyry deposits operate as large tonnage high throughput operations with comminution frequently being the rate limiting stage during processing. The aim of the work described in this paper is to obtain an early understanding of inherent comminution variability at La Colosa, which can assist future mine/mill design as the feasibility study develops.

# METHODOLOGY

As part of the collaboration between AngloGold Ashanti and the AMIRA P843A GeM$^{III}$ Project, the application of emerging geometallurgical characterisation testing and modelling tools has been incorporated into early stages of project development. The methodology applied for La Colosa follows the integrated geometallurgical method (IGM) outlined in Keeney and Walters (2011) and consists of the following components:

- Geometallurgical Characterisation and Testing:

Quantitative continuous data available for analysis included multi-element assays, EQUOtip hardness results, and density measurements. In addition to the continuous data, QXRD mineralogical information was conducted on 278 samples. Using the multi-element assay and QXRD data, a model was developed to convert assay results into estimated mineralogy. This model enabled continuous mineralogical information to be obtained for all diamond drill hole intervals. Comminution test work incorporated GeMCi, JKRBT Lite and Bond Ball Mill index tests. Table 1 summarizes the characterisation test work conducted at La Colosa.

- Class-Based Analysis:

Class-based analysis aims to investigate and constrain geologic variability in a non-spatial way. Selected mineralogy calculated from assay and density measurements were used in the principal component analysis (PCA). The results of PCA allow development of mineralogical classes for La Colosa, with each class being mineralogically constrained. This is critical for facilitating development of proxy support models of comminution indices.

- Predictive Modelling:

Class-based analysis facilitates the development of predictive proxy support models of comminution indices producing large quantities of estimated indices. This enables deposit scale mapping of comminution variability to be undertaken, which is not possible from only 278 physical measurements. For La Colosa, A*b (impact breakage) and BMWi (grindability) indices have been modelled to investigate comminution variability.

- Process Performance Domaining:

Based on estimated indices of A*b and BMWi, it is possible to identify comminution domains as a high degree of data support exists. The DomAIn algorithm (Nguyen and Keeney, 2010) has been applied to convert continuous down hole estimated comminution indices into spatially continuous down hole processing domains. The creation of these processing domains enable a three dimensional model to be created which maps the inherent comminution response and variability across La Colosa.

## RESULTS / DISCUSSION

The first stage of analysis consisted of modelling BMWi and A*b values from GeMCi test results (Kojovic et al, 2010). The reason for this was only 45 A*b and 25 BMWi physical test results currently exist, which is insufficient for developing predictive models. The calibration models between A*b, BMWi and GeMCi results had associated errors of 10.6% for A*b and 6.9% for BMWi. It is important to note that although the values for A*b and BMWi derived from the GeMCi contain error; this is still useful for identifying broad scale comminution domains at the pre-feasibility stage of project development. The calibration models produced 278 estimated A*b and BMWi numbers which can be used for further detailed analysis.

Traditionally, rock type is used as the primary control for distributing comminution indices. This is only valid if the rock type defined constrains the comminution response. For La Colosa, initial analysis indicates that rock type, alteration and gold grade do not directly correlate and constrain variation in comminution responses (Figure 3). The IGM applied in this study uses class-based analysis and predictive modelling to overcome this problem.

The aim of PCA is to constrain variability within the dataset making it easier to predict comminution response. For this approach to work, the data used in the PCA has to be linked to comminution performance. Bulk gangue mineralogy is the primary control on comminution performance in a porphyry deposit. This information was obtained from the mineralogy calculated from assay dataset. A comminution footprint diagram (i.e. A*b versus BMWi scatterplot) enables this analysis to be conducted. Different groups were created covering the range of comminution responses and the mineralogical variations between each group was identified (Figure 4). The broad mineralogical variations associated with comminution response at La Colosa are:

1. Feldspar, chalcopyrite and pyrite abundance increase in soft rocks.
2. EQUOtip hardness, magnetite, chlorite, albite, and density increase in hard rocks.

These input variables formed the initial parameters incorporated into the PCA. Through a process of iteration where redundant parameters were removed based on eigenvector results (Keeney and Walters, 2011), the final set of input parameters were albite, chlorite, magnetite and density (Table 2). The eigenvalues indicate principal component 1 and 2 capture 70% of the data variability.

A scatterplot of principal component 1 and 2 provides a simple two dimensional representation of multivariate data. It is important to note that this diagram does not indicate spatial distribution but rather, a relative multi-dimensional mineralogical distribution in multivariate space. Through a process of interactive examination of this diagram, an understanding of why data points plot in a particular region of the graph is obtained. Figure 5 displays defined classes and the mineralogical characteristics of each class. Principal component 1 is dominated by increased pyrite, chalcopyrite, feldspar into lower right regions, and principal component 2 displays a clear distinction in chlorite and magnetite abundance. The class boundaries were constructed manually around clusters of high point densities, with 7 classes defined each containing discrete hardness, density and mineralogy characteristics. Assessing the mineralogical variability discrimination diagram in this way allows mineralogy to be associated with different regions of the graph, which is critical in obtaining a geometallurgical understanding. This classification is the basis for predictive model creation.

The aim of the current analysis is to map comminution variability at La Colosa. It is impossible to do this with only 278 results, therefore models need to be created to increase the number of data points. Multiple linear regression proxy support models were created on a class by class basis using mineralogy from assay, EQUOtip and density information. This enables an order of magnitude increase in the quantity of comminution data available for mapping comminution variability. The modelling results (Figure 6) show the applied methodology works for creating proxy support models, and enables each assay data point to be assigned estimated values for A*b and BMWi. Using the estimated results a comminution footprint diagram (Figure 7) enables the overall comminution signature of La

Colosa to be investigated. Results indicate that La Colosa contains a zonation in both crushing and grinding response, rather than discrete clusters of significantly different comminution performance. This signature is typical of a porphyry deposit. At La Colosa, the initial modelling suggests the dominant variability within the deposit is in the A*b range of 25 to 40 and BMWi range of 15-20 kWh/t. It is important to note that the comminution footprint does not provide a spatial representation of comminution variability, but rather a signature of inherent variability. It is important to convert this information into a spatial representation to investigate the spatial distribution and variability of comminution indices.

Using the modelled down hole A*b and BMWi results, a DomAIn analysis (Keeney and Walters, 2011) was conducted to define spatially continuous processing domains. The results indicate that four A*b and nine BMWi domains exist at La Colosa (Table 3). The most abundant A*b domain at La Colosa has a mean of 33.21 and a standard deviation 3.03. More variability is observed in BMWi response with the two most abundant domains having a mean of 17.3 kWh/t and 18.6 kWh/t and a standard deviation of 1.2kWh/t and 1.4 kWh/t respectively. Using Leapfrog, wireframes of each processing domain was created enabling the first visual three dimensional representation of comminution variability at La Colosa (Figure 8 and 9). This is a significant result which can be improved through further analysis and exploited when mill design work commences in the feasibility stage of La Colosa development.

# CONCLUSIONS

The work in this paper demonstrates the IGM method provides a good mechanism for mapping comminution variability at La Colosa, which significantly aids deposit understanding. This knowledge can be exploited in future mill design, mine planning and economic modelling of the resource as the project life cycle advances. Several factors are critical to achieving the results demonstrated in this paper:

- Before working with data it is necessary to have good QA/QC protocols.

- Integration of all data analysis and logging is fundamental to identifying linkages between data acquisition and comminution indices.

- Mineralogy from assay and A*b/BMWi estimates from GeMCi tests are useful for providing initial results suitable for mapping comminution variability in pre-feasibility stages of project development at La Colosa.

- Using classed-based analysis has significant benefit in constraining deposit variability enabling predictive model creation.

- A*b, BMWi processing domains can be created and transferred into three dimensional space which preserve natural inherent deposit scale variability.

## ACKNOWLEDGEMENTS

This research is part of a major collaborative geometallurgical project (AMIRA P843 & P843A GEM$^{III}$ Project) being undertaken at CODES (University of Tasmania), JKMRC, BRC and CMLR (Sustainable Minerals Institute, University of Queensland) and Parker Centre CRC (CSIRO). The authors acknowledge financial support and permission to publish from AngloGold Ashanti and for the assistance provided by the La Colosa project team.

## REFERENCES

Sillitoe, R, 2000, Gold rich porphyry deposit: descriptive and genetic models and their role in exploration and discovery, Economic Geology, chapter 9:315-344

Jahoda, R, 2008, La Colosa mineral resource statement, Bogota D.C., 30 November.

Rodriguez, J, 2010, Igneous petrology of the Colosa gold-rich porphyry system (Tolima – Colombia), Arizona.

Keeney, L., Walters, S., 2011 The development of a novel method for integrated geometallurgical mapping and orebody modelling, September.

Kojovic, T., Groves, L., Walters, P. and MaCasker, R., 2010. Comminution update. Technical report 4, Febraury, paper 4:24pp.

Berry, R., Hunt, J., Mcknigth S., 2011 Estimating mineralogy in bulk samples, Brisbane, 5 – 7 September.

Nguyen, K., and Keeney, L., 2010. The development of domain definition software. Technical report 4, Febraury, paper 11:16pp.

# FIGURE CAPTION

Figure 1. Tectonic map of Colombia and regional location of the La Colosa porphyry deposit. WC = Western Cordillera; CC = Central Cordillera; EC = Eastern Cordillera. (Gil-Rodríguez, 2010).

Figure 2. : W-E cross section for lithologies identified at La Colosa.

Figure 3. Distribution of comminution indices and gold grade for different logged lithologies at La Colosa.

Figure 4. Mineralogical variations associated with comminution variability at La Colosa.

Figure 5. La Colosa class diagram and associated mineralogical and EQUOtip signatures for discrete classes identified.

Figure 6. Results of class-based multiple linear regression models for BMWi and A*b.

Figure 7. Global comminution footprint for La Colosa based on regression model results.

Figure 8. Spatial representation of A*b processing domains mapping inherent rock variability at La Colosa.

Figure 9. Spatial representation of BMWi processing domains mapping inherent rock variability at La Colosa.

# TABLE CAPTION

Table1. Data available for analysis.

Table2. Results of principal component analysis

Table3. La Colosa comminution domains

# FIGURE

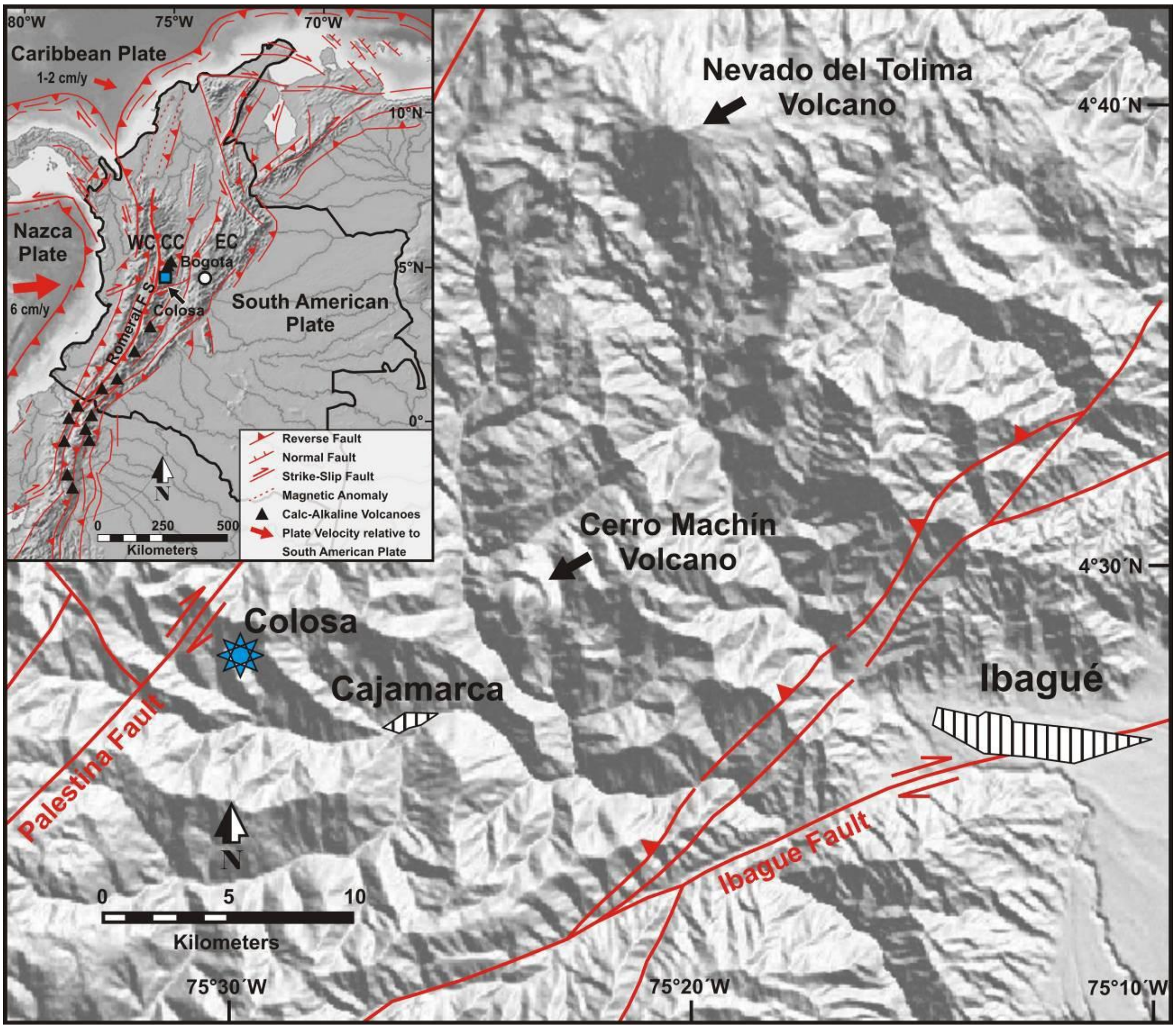


Figure 1. Tectonic map of Colombia and regional location of the La Colosa porphyry deposit. WC = Western Cordillera; CC = Central Cordillera; EC = Eastern Cordillera. (Rodriguez, 2010).

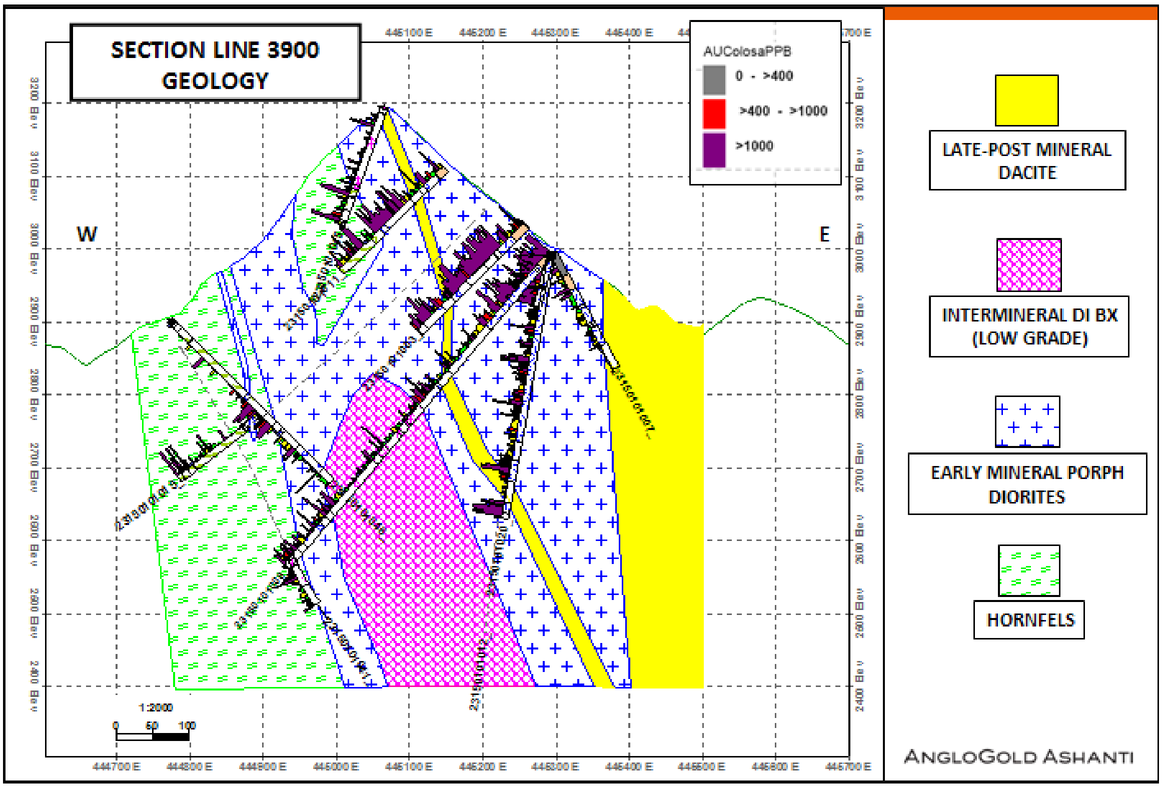


Figure 2: W-E cross section for lithologies identified at La Colosa.

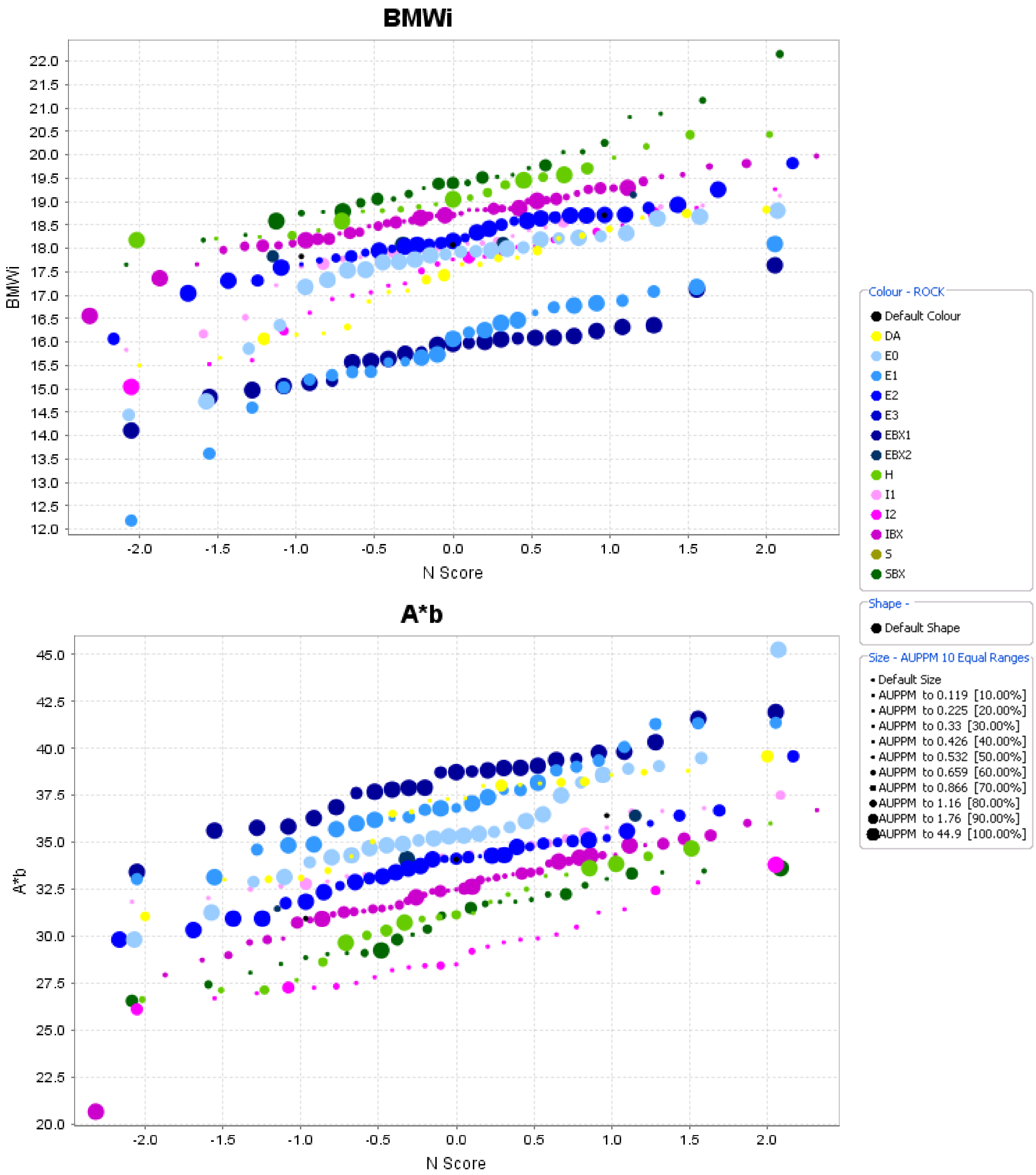


Figure 3. Distribution of comminution indices and gold grade for different logged lithologies at La Colosa.

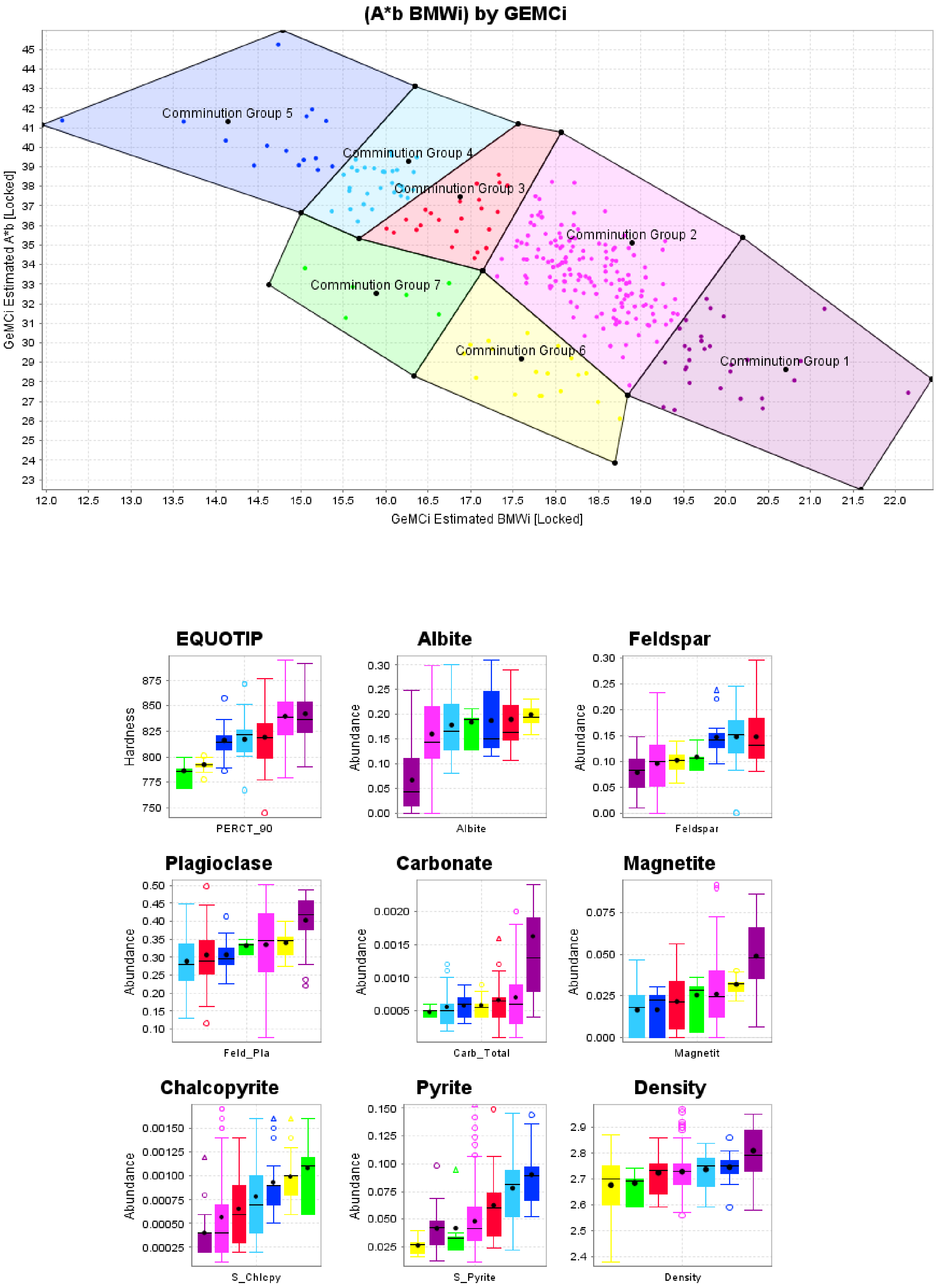


Figure 4. Mineralogical variations associated with comminution variability at La Colosa.

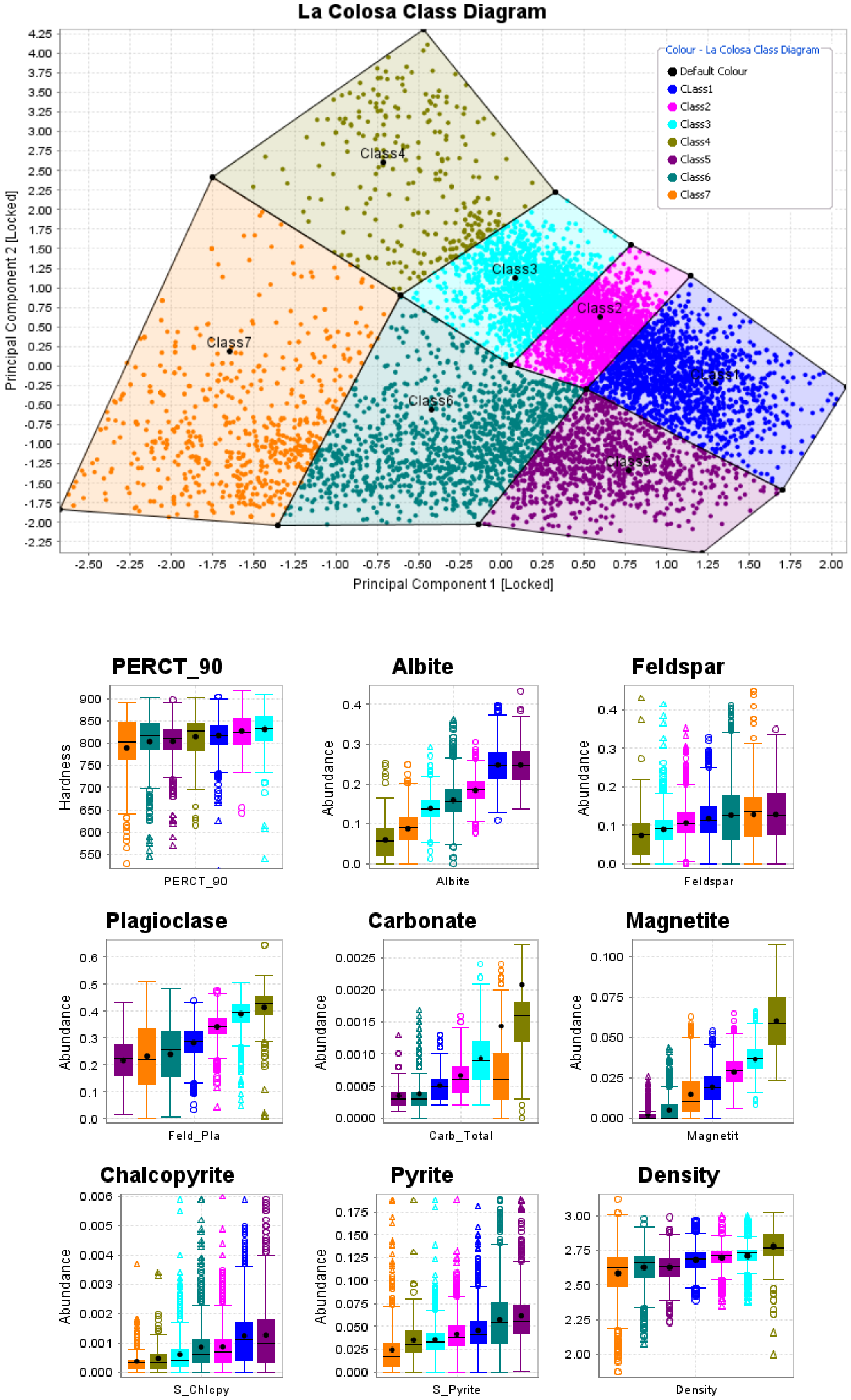


Figure 5. La Colosa class diagram and associated mineralogical and EQUOtip signatures for discrete classes identified.

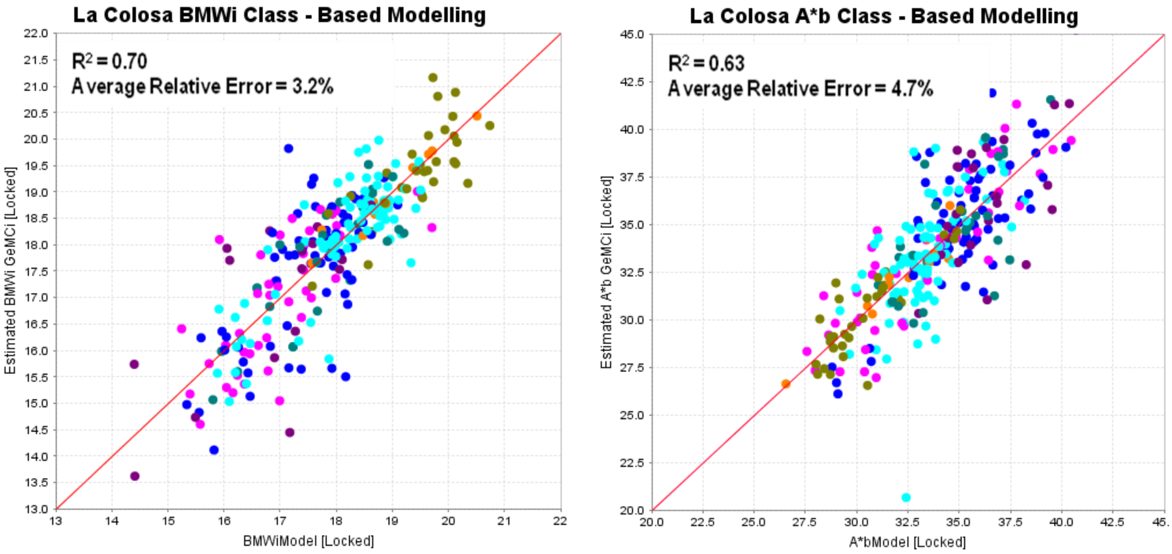


Figure 6. Results of class-based multiple linear regression models for BMWi and A*b.

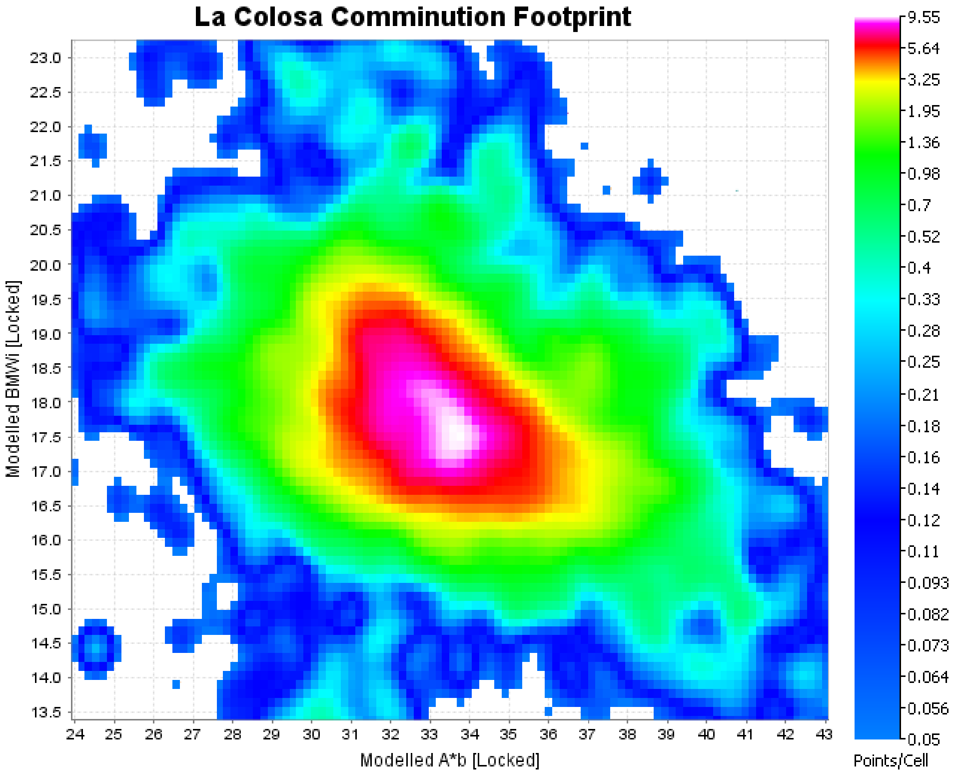


Figure 7. Global comminution footprint for La Colosa based on regression model results.

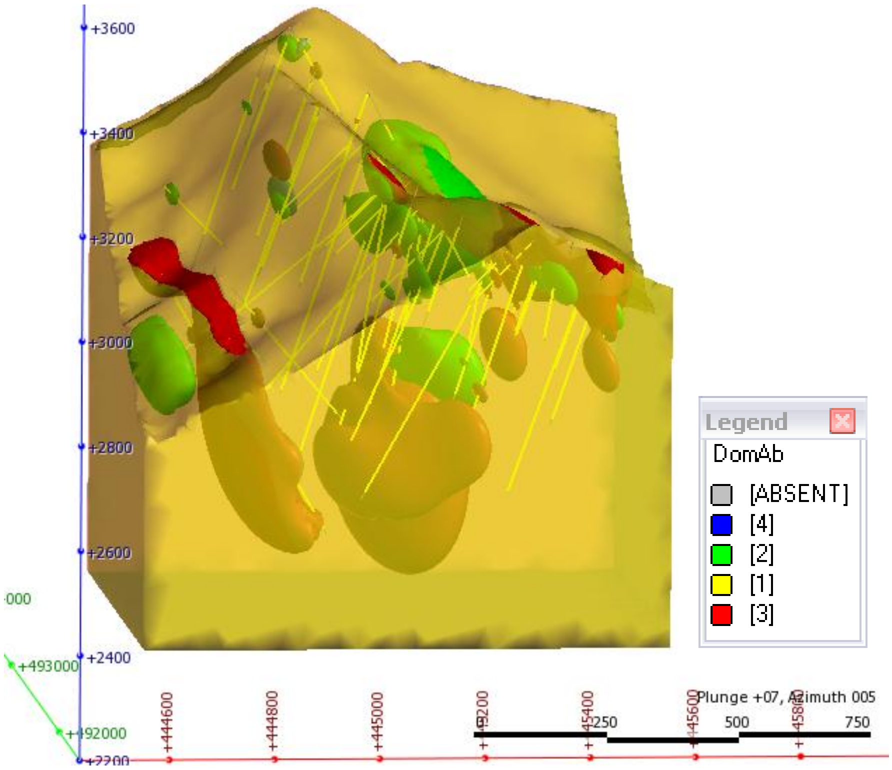


Figure 8. Spatial representation of A*b processing domains mapping inherent rock variability at La Colosa.

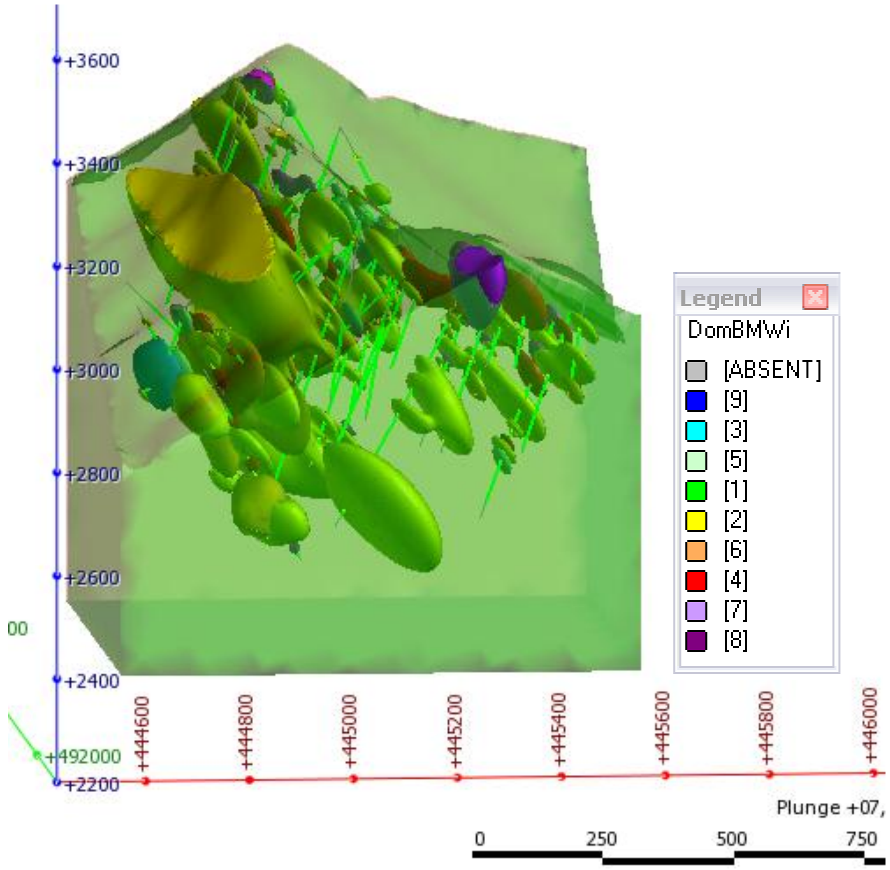
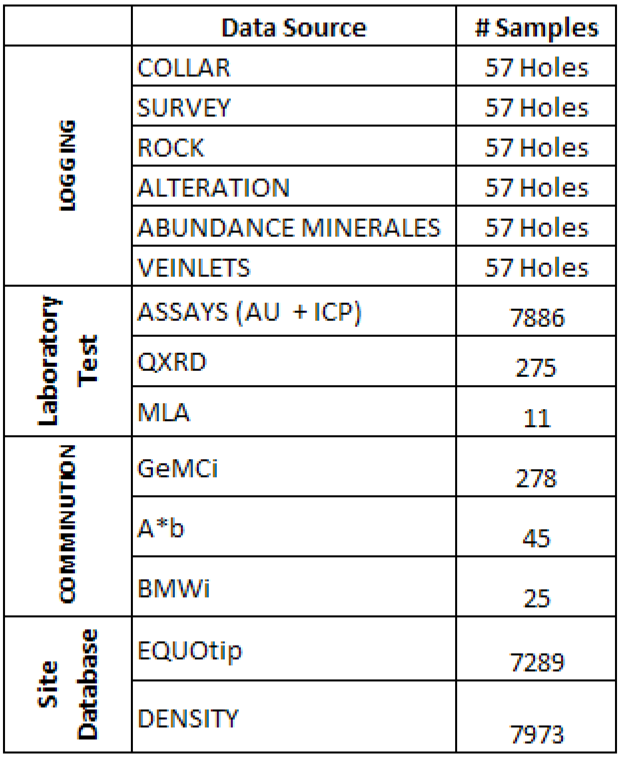


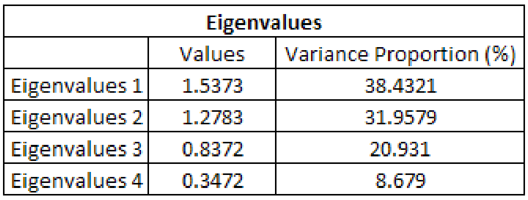
Figure 9. Spatial representation of BMWi processing domains mapping inherent rock variability at La Colosa.

# TABLE CAPTION

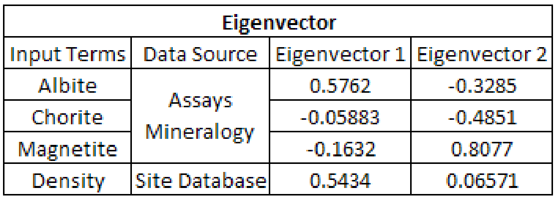


| | Data Source | # Samples |
|---|---|---|
| LOGGING | COLLAR | 57 Holes |
| | SURVEY | 57 Holes |
| | ROCK | 57 Holes |
| | ALTERATION | 57 Holes |
| | ABUNDANCE MINERALES | 57 Holes |
| | VEINLETS | 57 Holes |
| Laboratory Test | ASSAYS (AU + ICP) | 7886 |
| | QXRD | 275 |
| | MLA | 11 |
| COMMINUTION | GeMCi | 278 |
| | A*b | 45 |
| | BMWi | 25 |
| Site Database | EQUOtip | 7289 |
| | DENSITY | 7973 |

Table1. Data available for analysis.

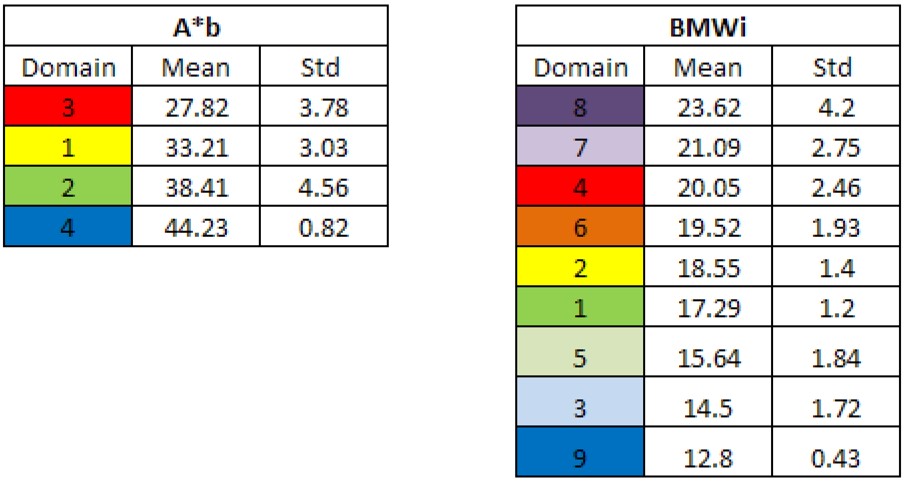


| Eigenvalues | | |
|---|---|---|
| | Values | Variance Proportion (%) |
| Eigenvalues 1 | 1.5373 | 38.4321 |
| Eigenvalues 2 | 1.2783 | 31.9579 |
| Eigenvalues 3 | 0.8372 | 20.931 |
| Eigenvalues 4 | 0.3472 | 8.679 |



| Eigenvector | | | |
|---|---|---|---|
| Input Terms | Data Source | Eigenvector 1 | Eigenvector 2 |
| Albite | Assays Mineralogy | 0.5762 | -0.3285 |
| Chorite | | -0.05883 | -0.4851 |
| Magnetite | | -0.1632 | 0.8077 |
| Density | Site Database | 0.5434 | 0.06571 |

Table2. Results of principal component analysis.



| A*b | | |
|---|---|---|
| Domain | Mean | Std |
| 3 | 27.82 | 3.78 |
| 1 | 33.21 | 3.03 |
| 2 | 38.41 | 4.56 |
| 4 | 44.23 | 0.82 |

| BMWi | | |
|---|---|---|
| Domain | Mean | Std |
| 8 | 23.62 | 4.2 |
| 7 | 21.09 | 2.75 |
| 4 | 20.05 | 2.46 |
| 6 | 19.52 | 1.93 |
| 2 | 18.55 | 1.4 |
| 1 | 17.29 | 1.2 |
| 5 | 15.64 | 1.84 |
| 3 | 14.5 | 1.72 |
| 9 | 12.8 | 0.43 |

Table3. La Colosa Comminution Domains.