A Combined Multivariate Approach Analyzing the Geochemical Data for Knowledge Discovery: The Vazante – Paracatu Zinc District, Minas Gerais, Brazil

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1. Introduction

- Mineral exploration: deeper targets, higher cost per discovery
- Multivariate methods can improve performance & data utilization to understand the mineral systems.
- Vazante – Paracatu Zinc District hosts world-class hypogene zinc silicate deposits and several Pb-Zn sulfide deposits.
- A recent study revealed the pre-orogenesis zinc occurrence in underlying siliciclastic rocks [1].
- These siliciclastic rocks were considered as potential sources for the orogenic fluids that former the economic mineralization hosted in the carbonate-rocks [3].

Objectives

Using unsupervised multivariate analysis methods in rock geochemistry to:

(1) Gain insights about the geochemical processes which may have implications in exploration,

(2) Test the hypothesis that underlying siliciclastic rocks served as source of metals for the mineralizing fluids [3].

2. Study Area

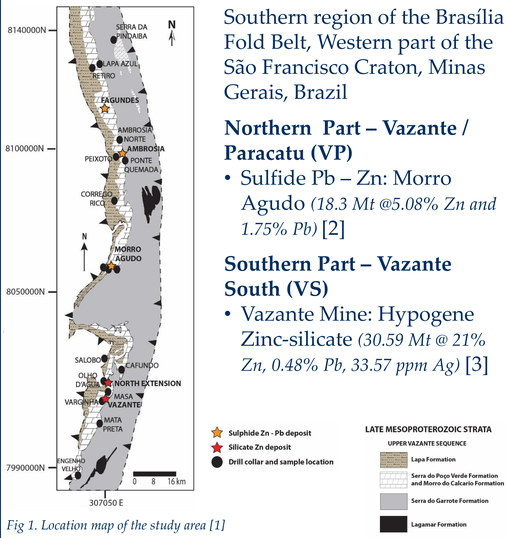

Fig 1. Location map of the study area [1]

Southern region of the Brasília Fold Belt, Western part of the São Francisco Craton, Minas Gerais, Brazil

Northern Part – Vazante / Paracatu (VP)

- Sulfide Pb – Zn: Morro Agudo *(18.3 Mt @5.08% Zn and 1.75% Pb)* [2]

Southern Part – Vazante South (VS)

- Vazante Mine: Hypogene Zinc-silicate *(30.59 Mt @ 21% Zn, 0.48% Pb, 33.57 ppm Ag)* [3]

Acknowledgments

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References

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[2] Cordeiro, P. F., Oliveira, C. G., Paniago, L. N., Romagna, G., & Santos, R. V. (2018). The carbonate-hosted MVT Morro Agudo Zn-Pb deposit, central Brazil. Ore Geology Reviews, 101, 437-452.
[3] Olivo, G., Monteiro, L., Baia, F., Slezak, P., Carvalho, I., Fernandes, N., ... & Moura, M. (2018). The Proterozoic Vazante Hypogene Zinc Silicate District, Minas Gerais, Brazil: A Review of the Ore System Applied to Mineral Exploration. Minerals, 8(1), 22.

Biography

Ilkay S. Cevik has a B.Sc. in Geological Engineering from Middle East Technical University, Ankara, Turkey. After five years of experience in mineral exploration in West Africa and Europe he became an M.Sc. student at Queen's University in September 2018, under the supervision of Dr. Julián M. Ortiz and Dr. Gema R. Olivo.

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3. Data

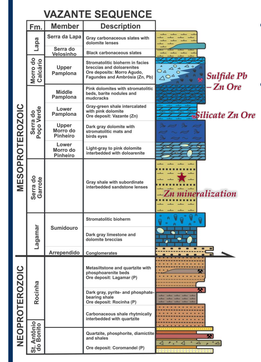


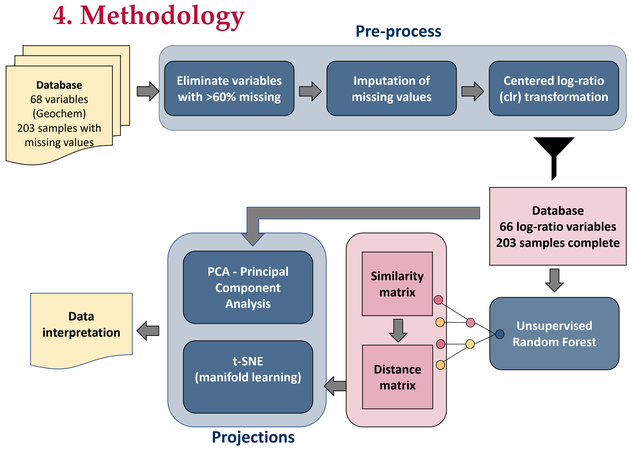
Fig 2. Stratigraphic section of the Vazante sequence [2]

- A geochemical database with 203 samples from Serra do Garrote Fm.
- Total of 68 variables (*Table 1*)

Table 1. *Summary of the available variables separated by analysis method*

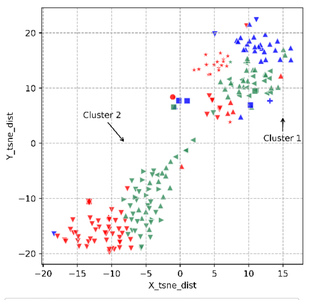
Data	Details
Major Oxides (%) - XRF	Al_2O_3, BaO, CaO, Cr_2O_3, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, SrO , TiO_2 , Loss on Ignition (LOI)
Multi Element (ppm) – Acid digestion, ICP-MS	Ba, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, La, Lu, Nb, Nd, Pr, Rb, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, V, W, Y, Yb, Zr
Multi Element (ppm) *– Aqua Regia, ICP-MS*	As, Bi, Hg, In, Re, Sb, Sc, Se, Te, Tl
Multi Element (ppm) - Four-acid digestion, ICP-AES finish	Ag, Cd, Co, Cu, Li, Mo, Ni, Pb, Sc, Zn
LECO Analyzer (%)	Total Carbon (C), Total Sulfur (S), Total Organic Carbon (TOC)

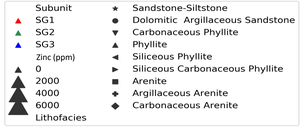
4. Methodology

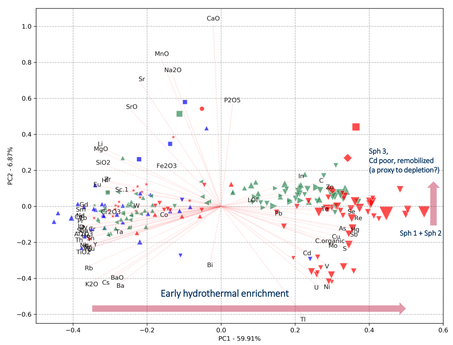


5. Results

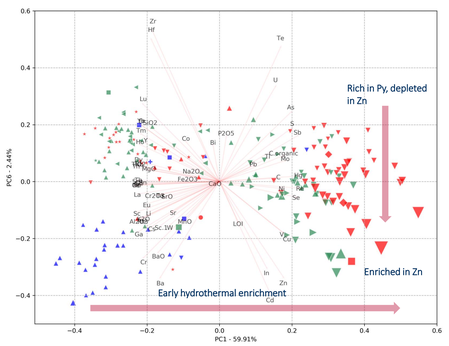
t-SNE projection showing the local structures in the data





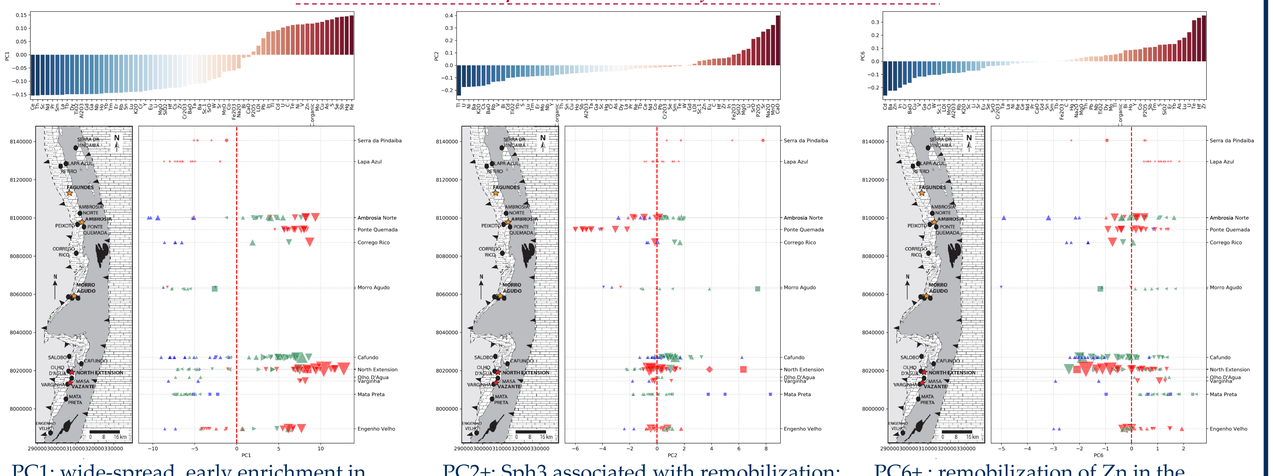


- **PC1** positive (PC1+) represents the ore-related elements associated with the pre-orogenic mineralization.
- **PC2** relates to the composition of the different generations of sphalerite; *Cd-poor Sph3 compared with Sph1+2.*



- **PC6** negative (**PC6-**) is associated with Zn, In, Cd (typical of sphalerite).
- **PC6+** is associated with As, S and Organic Carbon (typical of the pyrite-rich layers).

Spatial Distribution of PCs



PC1; wide-spread, early enrichment in ore related elements

PC2+: Sph3 associated with remobilization; PC2-: pre-orogenic sphalerite signature

PC6+ : remobilization of Zn in the pyrite-rich zone; PC6-: pre-orogenic ore signature

(inset geological maps are retrieved from Fernandes et al. [1])

6. Discussion

Serra do Garrote Fm. shows evidences to be considered as source of metals for the overlying deposits:

- PC1 captures a regional, sub-economic levels of pre-orogenesis enrichment event; presumably acted as a ground preparation process.
- PC2 separates different phases of sphalerite, i.e. Sph1 + Sph2 vs Sph3 *(Cd-poor)*; Sph3 is spatially associated with remobilization of ore related elements which is interpreted as evidence of dissolution of Sph1 and Sph2 and precipitation of minor Sph3.
- PC6 is interpreted to reveal the signature of the remobilization of Zn from the pyrite-rich layers.

Implications for Exploration

The PCA allows for identification of the zones of:

- Enrichments in the source rocks pre-to orogenesis,
- Depletion that are interpreted to be associated with the orogenic event that formed the economic mineralization in the carbonate rocks .

When integrated in the geographic context it can be use to define new targets for exploration as show in the Table 2:

Table 2. *Summary of favorable PCs and their occurrence in sections (see Figure 1 for location of the sections)*

Section	PC1+	PC2+	PC6+	Known Deposit
Serra da Pindaiba		●	●	
Lapa Azul		●	●	
Ambrosia Norte	●	●	●	**YES**
Ponte Quemada	●		●	
Correco Rico	●	●		
Morro Agudo		●	●	**YES**
Cafundo	●	●	●	**YES**
North Extension	●	●	●	**YES**
Olho D'Agua			●	
Varginha	●	●	●	**YES**
Mata Preta		●	●	
Engenho Velho	●	●	●	**NO** - *Exploration Potential*

7. Conclusion

- A multivariate analysis workflow for an exploratory study is presented.
- t-SNE projection improved understanding of the local structures and helped to formulate directed questions which are explored through different PCs.
- Principal component analysis allowed for the identification of multivariate patterns interpreted as the evidences for Serra do Garrote Formation to be considered as source rock for the overlying deposits.
- PC1+ represents the signature of metal enrichment throughout the basin during the pre-orogenesis event.
- PC2 + and PC6+ are interpreted to reveal the signature of depletion during the orogenic event, which is coeval with the formation of the economic zinc mineralization in the carbonate rocks.
- Spatial distribution of the multivariate signatures of pre-orogenic enrichment and syn-orogenic depletion can assist in identify the targets for exploration.
- An exploration target was identified in this study and is currently being tested by NEXA resources