24th World Mining Congress

MINING IN A WORLD OF INNOVATION

October 18-21, 2016 • Rio de Janeiro /RJ • Brazil

24th World Mining Congress **PROCEEDINGS**

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Created in 2009 with the purpose of stimulating innovation, competitiveness and sustainability in Vale's operations, Vale Institute of Technology (ITV) is a non-profit organization that develops research activities, with emphasis on H2 and H3 horizons as well as training of resources human at post-graduate level. ITV has two locations: one in Belém in the State of Pará, focused on matters related to Sustainable Development, and the other in Ouro Preto, MG, dedicated to Mining and Mineral processing topics.

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Luiz Mello

ITV also provides Specialization courses in Mining for Vale's employees and other courses for professional qualification, as well as research activities comprising levels from scientific research to post-doctoral degree.

In partnership with Capes, Vale offers academic postdoctoral scholarships for Brazilians and foreigners to researchers who are selected to work at Vale Institute of Technology units, further bringing together the academic community and Vale, expanding the potential generation of innovation and wealth for Vale and Brazil.

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It is a pleasure for us to participate in the 24th edition of the World Mining Congress - WMC 2016, being held for the first time in Brazil, and we can introduce you to some of the technological, research and innovation solutions in the Mining Sector. It is our commitment to share knowledge, innovation and technology towards the sustainable development of the operations and processes in global mining.

I hope that everyone enjoys the most of the World Mining Congress!

Luiz Mello
CEO of Vale Institute of Technology
Technology and Innovation Executive Manager of Vale

José Fernando Coura

On behalf of the Brazilian Mining Association - IBRAM and its associates, I would like to offer a warm welcome to all the participants of the 24th edition of the World Mining Congress - WMC 2016. This is the first time that the WMC, recognized as one of the most important world mining events, is being held in Brazil. The central theme of this congress is "Mining in a World of Innovation", one of the most current and important issues in the management of mining-sector businesses.

The 24th WMC began to take shape in 2012 when representatives from businesses and entities of the mining sector, as well as the Brazilian government, joined forces to support the country's bid, before the International Organizing Committee, to host the congress (IOC). This was well-deserved, given Brazil is one of the international exponents of mining.

The presentation of the Brazilian bid was made by IBRAM's presidency in conjunction with our Director of Mineral Issues, Marcelo Ribeiro Tunes. It fell to him to deliver the speech underlining the qualities that make IBRAM suitable to organize such an event, of the city of Rio de Janeiro (RJ) to attract and host event participants, and the Brazilian mining industry; factors which proved decisive in convincing the IOC members to choose Brazil as the host of the event in 2016.

With this significant vote of confidence, we are certain that the 2016 WMC will be the stage of an intense diffusion of knowledge, of discussions on the best way forward, and deep analyses of the current and future landscape of the mining industry. Without a doubt, it will also serve as a way to strengthen relationships and enable dialogue between the most diverse actors of the sector's extensive production chain on an international level.

We know that the last few years have been challenging for the mining industry and "innovation" is the key word for new business and the future of the sector itself. The economic environment has altered the rhythm of supply and demand, impacting ore prices and making it more difficult for mining companies to outline their next steps both locally and globally. Nevertheless, this moment offers an opportunity for mining to lay the way for a return to greater productivity in the future.

This is the proposal of the 24th edition of the WMC, amongst others. We also intend to technically and scientifically promote and support cooperation to develop more stages in the sustainable development of operations and processes in the mining sector.

With an optimistic vision of the prospects of the mineral sector, I hope that IBRAM, via this grand event, can awaken the public interest to debate the future of mining and identify innovative actions to further strengthen the mining industry around the world.

We wish everybody an excellent World Mining Congress!

José Fernando Coura
CEO of the Brazilian Mining Institute

Murilo Ferreira

Brazil has a historic vocation for mineral extraction activities, and since the mid-18th century they have practically dominated the dynamics of its economy. Rich in world-class minerals, the country has emerged as one of the leading global players in the mining industry, and it is now the second largest iron ore producer and one of the most significant agents in international trading and exports of this commodity.

The mining industry has become one of the most important pillars of Brazil's development. Despite the decline in iron ore prices and demand in the international markets, especially due to the slowdown in Chinese consumption, and despite the end of the super-cycle, the mining sector has continued to play a key role in maintaining Brazil's balance of trade surplus.

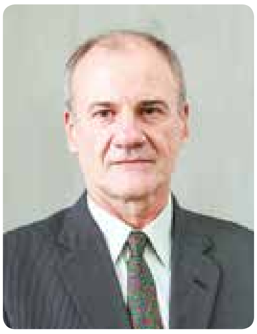
In addition to its positive impacts in the macroeconomic sphere in Brazil, mining has also become a driver of social development, particularly as it has a multiplier effect on other economic activities, contributing to the expansion of various production chains and consequently to the generation of jobs and income. It is noteworthy that in the municipalities where mining companies operate, Human Development Index ratings have been higher than the average figures for their respective states, and much higher than in non-mining municipalities.

In a country like Brazil, whose economic growth, as already mentioned, is strongly dependent upon the expansion of mining activities, the creation of the Brazilian Mining Association, which will turn 40 in December, was essential and absolutely necessary. This is a date to be celebrated, above all because IBRAM has played its role to support and strengthen mining activities with dynamism, efficiency and innovative practices. The sector's companies and organizations can count on a body that assertively and competently represents, coordinates and integrates them, defending their interests and generating conditions conducive to the sustainable development and competitiveness of their businesses.

The holding in Brazil of the 24th edition of the World Mining Congress, organized by an entity of IBRAM's quality, is a milestone and an excellent opportunity for the sector to share ideas, discuss, reflect and find stimuli and feasible ways forward at a time when we need to face the end of the mining super-cycle. The theme of the Congress could not be more appropriate, and I am sure that by its end, promising directions will have been mapped to strengthen the mining industry across the world.

Murilo Ferreira
Chief Executive Officer, Vale S.A.

Professor Jair Carlos Koppe



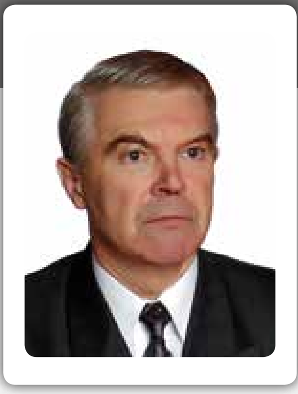
Mining has been extremely important to the World's economic growth and prosperity for centuries. The mining industry is currently facing an economic and social crises that can impact strongly the mineral production and productivity. In this scenario several challenges must be addressed, among them complex mineral deposits of low grades, water, social and environmental issues as well as declining commodity prices. Considering that the world is changing dramatically in all aspects this is the moment for innovation in mining. The WMC 2016 is under the umbrella of Mining in a World of Innovation in the proper moment. This is a nice opportunity to change our ways in mining technology considering the new evolving technologies such as automation, sensors, cloud computing, data analytics that can increase the mining production and efficiency in the entire value chain. Let's take this moment to spread our experience among academy, industries, practitioners and professionals of the mining sector focusing in the future of a world in constantly innovation.

We would like to thanks all the contributions done by the authors invited speakers and participation of delegates that will make WMC 2016 a very successful meeting. Special thanks to the members of the Scientific Committees that helped in the paper analysis ensuring the quality of the conference.

Welcome to the WMC 2016.

Professor Jair Carlos Koppe
Congress Chairperson

Józef Dubiński


Hermínio Oliveira

The 24th World Mining Congress is one of the most important mining events worldwide and is going to be held in Rio de Janeiro, Brazil, from October 18 to 21, 2016. The premiere of the World Mining Congress took place 58 years ago, in September 1958, in Warsaw, Poland. Currently, the WMC organization gathers 45 mining nations from all over the world.

Each World Mining Congress, which takes place in a different host-nation, is always a great mining occasion for the international community that represents science and industry figures involved in the exploration of mineral assets. We can assert that this congress points to the most significant directions for global mining development and determines priorities for the activities of all institutions related to mineral activity. The same approach is going to be adopted during the 24th World Mining Congress, which is going to concentrate on the theme of "Mining in a World of Innovation". Nowadays, and increasing number of countries hold great knowledge potential on mining. The challenges aforementioned demand mutual cooperation, exchange of technical knowledge and professional experience, as well as assistance to those in need. Personally, I believe that our generation of the world mining society – the heirs of our illustrious ancestors – will follow their accomplishments and guide the organization of the World Mining Congress into a new direction, to assure many more years of effective services to global mining and to the people who have taken part in this challenging activity, yet still necessary for all humankind.

Józef Dubiński
Professor and Doctor of Engineering
Corresponding Member PAS
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Summary

A SYNTHESIS OF THE STRUCTURAL EVOLUTION OF THE PEDRA LAVRADA MINING DISTRICT, SERIDÓ PEGMATITIC PROVINCE, NE BRAZIL

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A SYNTHESIS OF THE STRUCTURAL EVOLUTION OF THE PEDRA LAVRADA MINING DISTRICT, SERIDÓ PEGMATITIC PROVINCE, NE BRAZIL

ABSTRACT

The Pedra Lavrada mining district is located in the Paraíba state, NE Brazil. This region is known by the intense exploration of industry minerals such as white mica, potassic feldspar and quartz, which are mainly extracted from pegmatitic rocks. These bodies are part of the Seridó Pegmatitic Province, an area in northeast Brazil that is composed by several pegmatitic intrusions and important mineralizations, such as the famous Paraíba Tourmaline. In the study area, these pegmatites are intrusive in biotite schists and garnet-biotite schists of the Seridó Formation, Seridó Fold Belt. Mesoscopic analysis revealed that this area was subjected to polydeformation including the D_n, D_{n+1} and D_{n+2} structural phases. D_n and D_{n+1} has a ductile rheology, which the former represented by tangencial tectonites being restricted to Nova Palmeira town region, and the latter associated with vertical tectonites, that represent the main structural framework of the region. Both tectonics control the trend of regional foliation and the shape of most of pegmatitic and granitic rocks of the region. At last, D_{n+3} is ductile-brittle and brittle, and is represented by fractures that are filled or not by pegmatitic and aplitic dykes in the NNW-SSE and E-W directions. Detailed geological mapping revealed that these pegmatites have internal mineral zoning which is typical of heterogeneous pegmatites, besides being controlled by a main NE-SW regional trend. The combination of these data indicates that these pegmatites were emplaced in the continental crust by a transtensive regime, which is related to the Pedra Lavrada and Picuí-João Câmara NE-SW strike-slip shear zones, resulting in the interaction between D_{n+2} and D_{n+3} deformational events.

KEYWORDS

Structural evolution, Seridó Pegmatitic Province, Pedra Lavrada mining district

INTRODUCTION

Granitic pegmatites are well known rocks because they are source of strategic metals to several industry segments, such as Ta, Nb, Be, W and rare-earth elements (Linnen et al., 2012). The Seidó region in northeast Brazil is characterized by a plenty of pegmatite stocks, in which its economic potential is known worldwide for Nb-Ta minerals, common industry minerals such as muscovite and feldspars and important gemstones, including elbaite tourmalines such as the famous Paraíba Tourmaline.

Recently, petrology and gemology-related research has strongly contributed to the knowledge of these pegmatites. Nevertheless, the tectonic setting and the nature of magma emplacement, besides structural relationships with the wall-rocks has not been addressed, except by few regional approaches such as that presented by Araújo et al., (2001).

In this paper we present structural and stratigraphic relationships between the Alto do Feio and Alto da Serra Branca pegmatites and regional wall-rocks and major structures of the area. These pegmatites are part of the Pedra Lavrada mining district, which is fairly important for this region, thus we intend to contribute to future mineral research projects in the region as well as the mining workers of this region.

GEOLOGICAL SETTING

The Pedra Lavrada mining district is located in the southern portion of the Seridó Pegmatitic Province (Santos et al., 2014). This province is inserted in the Seridó Fold-belt of the Rio Grande do Norte Domain (Figure 1), which is located in the northern part of the Neoproterozoic Borborema Province.

Regionally, the Rio Grande do Norte Domain is composed by several sequences of Archean to Paleoproterozoic gneissic and migmatite sequences, including the Rio Piranhas, São José do Campestre and Jaguaribeano terranes. In addition, these terranes are intruded by several Ediacaran-related granitic intrusions (Brito Neves et al., 2000; Santos et al., 2000).

The Seridó Fold-belt is formed by several segments of supracrustal rocks that locally host important Au and W-related deposits and is Neoproterozoic in age (Van Schmus et al., 2003). On a stratigraphic point of view, it is composed by the Jucurutu, Equador and Seridó formations. In the region of the Pedra Lavrada mining district, this unit is mostly composed by biotite-schists and garnet-biotite schists of the Seridó Formation. This formation trends to NE-SW and host several mineralized pegmatitic intrusions including the Roncador, Capoeira, Serraria, Alto Serra Branca and Alto do feio pegmatites.

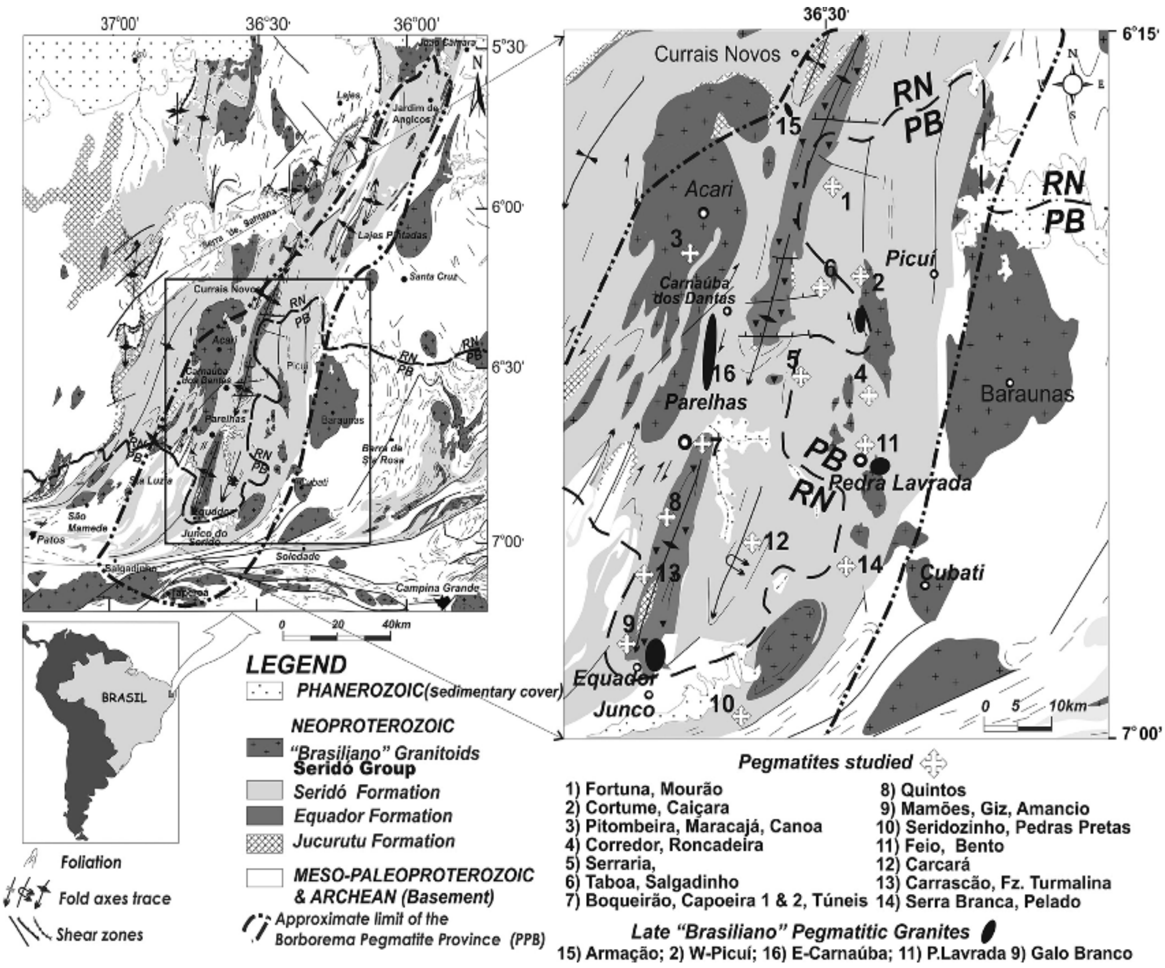

Figure 1 – Regional geological map of the Borborema Pegmatitic Province and the location of the main pegmatitic bodies, after Beurlen et al., (2014).

STRUCTURAL ANALYSIS OF THE STUDY AREA

This research was conducted combining aerial photographs, Landsat ETM satellite images and mesoscopic field measurements of the main structures that are related to the Pedra Lavrada mining district, including the studied pegmatites. This region is strongly affected by ductile strike-slip shear zones on the NNE-SSW directions, defining the main geological trend of the Rio Grande do Norte Domain as shown by Archanjo et al., (2008).

We defined three main deformation styles, which are called Dn, Dn+1 and Dn+2. The Dn deformation is marked by structural elements that are concentrated in the NE portion of the area, being defined by a series of mylonitic and schistosity planes. In the vicinity of the Nova Palmeira town, is common the presence of low-angle foliation with E-SE direction. Other associated structures include open and closed Fn folds which vertical and sub-vertical axial planes or overturned ones. Kinematic markers which are easily observed in the XZ plane of the deformation ellipsoid are mainly represented by asymmetric folded micas and deformed quartz and potassic feldspar porhyroclasts (σ type), which suggest up-dip tectonic vergence to WNW (Figure 5a).

On the other hand, Dn+1 deformation corresponds to the most important structural regime, being responsible by the mainly trend of the region. This deformation determines the elongated shape of the rocks in a preferentially NNE-SSW trending, formed by planar S-L type tectonites. The main associated structural markers include gneissic banding which is vertical associated with an important stretching lineation which is mainly horizontal or forming axial lines in related overturned folds (Ln+1b).

The main associated structures related to this deformation include the dextral Pedra Lavrada and Picuí João Câmara strike-slip shear zones. In outcrops, there are several kinematic criteria that can be easily observed including S-C and asymmetric folded foliation as a consequence of a non coaxial structural regime. The asymmetric shapes of the main mineralized pegmatites of this district are attributed to this vertical regional foliation.

The last identified tectonic regime is the Dn+2 stage is strongly important for mineralization control in the area. It is characterized by the changing in rheologic regime from a ductile brittle. Several faults and joints are observed in schists and intrusive pegmatites, that can be sub-vertical and horizontal. We mapped three main families of fractures related to this stage, which has NNW-SSE, E-W and NE-SW directions. These structures cross-cut the main pegmatites and are frequently responsible for the concentration of ore minerals, such as elbaite tourmaline, cassiterite and amblygonite, besides punctual gemstones occurrences such as beryl.

These phases are commonly concentrated in quartz veins, aplitic dykes and later pegmatitic dykes in directions related to the main mapped families. The geological mapping of these fractures represents an important contribution for prospective works for economic minerals in the area.

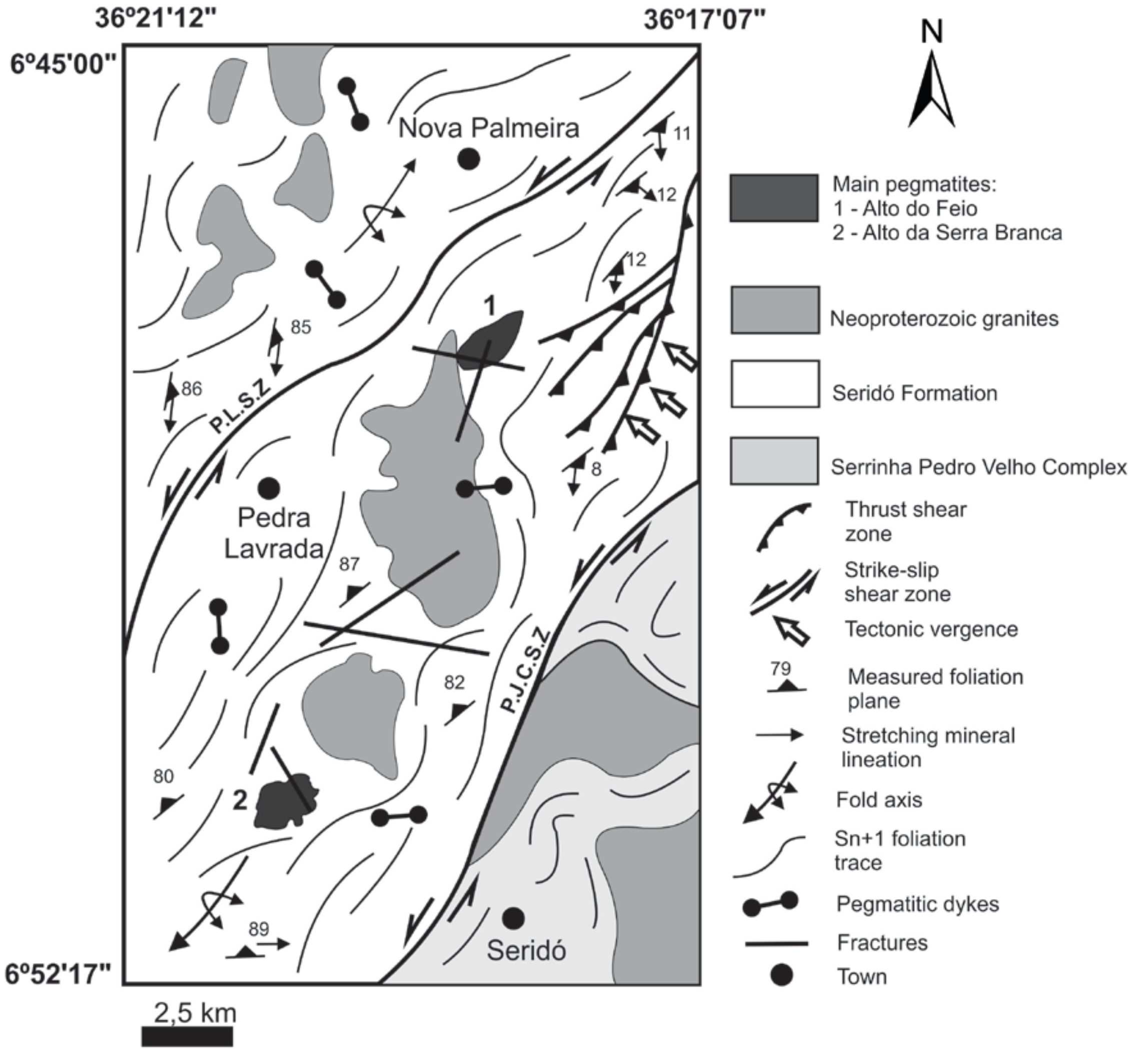

Figure 2 – Geological map of the Pedra Lavrada mining district.

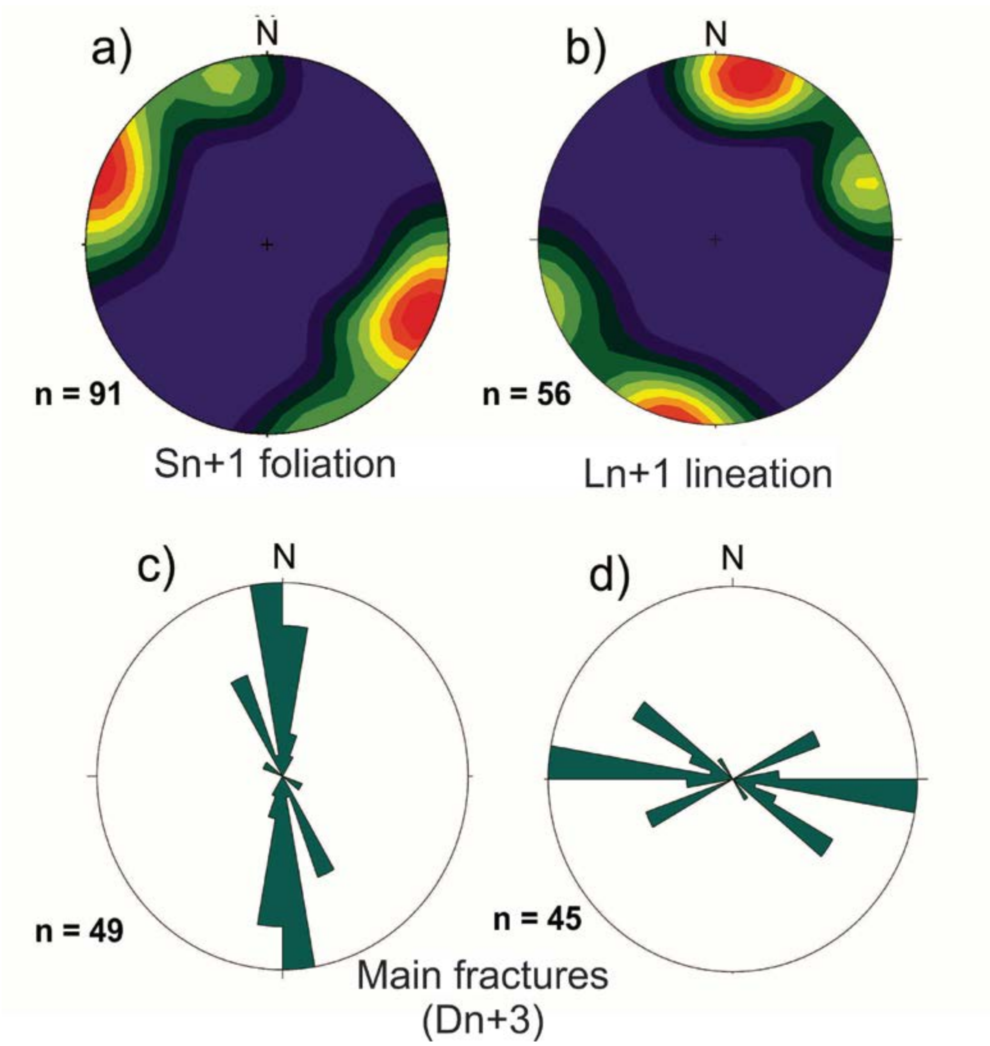

Figure 3 – Stereograms with measures of the main foliation and lineation trends, besides the main mapped of fractures related to Dn+3 deformation on rose diagrams.

DISCUSSIONS AND CONCLUSIONS

Our study aims to demonstrate the main structural elements and evolution of deformation in the Pedra Lavrada mining district, an important region of mineral resources and exploration in NE Brazil. This district is inserted in the Seridó Pegmatitic Province, which concentrates several mineralized pegmatites of NE Brazil, being a strategic region for industry minerals in Brazil.

This region is affected by at least three distinct structural events which are called Dn, Dn+1 and Dn+. Dn event is responsible by the development of a low angle dipping foliation associated with high rake lineation that dips to SE. This deformation is concentrated in the NE portion of the area affecting mainly the wall-rocks of the mineralized pegmatites, which are mainly schists. This stage can be correlated to a huge thrusting event described in the Seridó Fold-Belt by Hackspacher et al., (1993) during the Brasiliano orogeny.

On the other hand, Dn+2 deformation produced the most prominent structures, which are related to vertical mylonites that can gentle dip to SE or NW and are always associated with horizontal lineation with low pitches. This deformation is mainly non coaxial and is represented by the transcurrent dextral Picuí-João Câmara and Nova Palmeira shear zones. In addition, it strongly control the elongated form of the Alto do Feio and Alto Serra Branca mineralized pegmatites.

At last Dn+2 deformation is brittle and is characterized by faults, fractures and joints that cross-cut all the study area. These structures can be mapped in three main families, which follows three main structural trends, which are: NNW-SSE, E-W and NE-SW. They can be sterile or contain important ore minerals, such as elbaite tourmalines, gemstomes, cassiterite, amblygonite, among others. Usually, the main ore stages are concentrated in aplitic, quartz and pegmatitic veins and dykes.

The strong structural control on pegmatites of the Seridó Pegmatitic province and its mineralizations was shown by Agrawal (1992) and Araújo et al., (2001), who defined the main stages of pegmatites emplacement in the region. In general, our data suggest that these pegmatitic bodies were injected in continental crust through a transtenssive tectonic regime. In this sense, the definition of main structural stages in the region shall represent an important contribution to understand the geological evolution of the Pedra Lavrada mining district.

ACKNOLOWDGEMENTS

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CHARACTERIZATION OF THE INTRUSIVE BODIES FROM THE GOIÁS ALKALINE PROVINCE USING GEOPHYSICAL INVERSIONAND SELF-ORGANIZING MAPS

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CHARACTERIZATION OF THE INTRUSIVE BODIES FROM THE GOIÁS ALKALINE PROVINCE USING GEOPHYSICAL INVERSION AND SELF-ORGANIZING MAPS

ABSTRACT

Alkaline intrusive rocks have physical and mineralogical characteristics related to their composition and origin that differentiates them from the hosting environment, resulting in magnetic and gravimetric anomalies coming from the contrast of their physical properties of magnetization and density. At the Northern border of the Parana Basin, in the Goiás State, Brazil, there are two alkaline provinces: 1) Goiás Alkaline Province in the Southeast and 2) Alto Paranaíba Province in the East, including a portion in the Minas Gerais State. The Goiás Alkaline Province (GAP), study object of this work, is located along the Brasilia Belt, with some of the main alkaline complexes concentrated in the South of the Goiás Magmatic Arch. Several alkaline complexes, dykes and local volcanic products characterize its intrusions. In the GAP area, systems of long sub-vertical faults also occur hosting alkaline intrusions and sometimes recognized as rifts or *en echelon* systems. The crossing of faults system, where structural NW-SE directions predominates, could have influenced the site of the intrusions. In this work, we have used existing geological and geophysical information to characterize and differentiate the mineral systems that originated the main alkaline occurrences in the GAP area situated between the Montes Claros and Pirapora cities, in the centre-west of the Goiás State. The methodology included the creation of thematic maps, geophysical inversions (gravity and magnetic data) besides the Self-Organizing Maps (SOM) method applied to the Magnetization Vector Inversion result to differentiate the intrusive systems. The integration of the geophysical and geological data in the GAP area enabled the identification and characterization of the surficial geology (gamma), characterization and delimitation of the enclosing rocks (satellite gravity) and alkaline intrusions (magnetic thematic maps and geophysical inversions), and differentiation of the mineral systems that originated the intrusions (SOM).

KEYWORDS

Magnetization Vector Inversion, SOM, Goiás Alkaline Province.

INTRODUCTION

Alkaline intrusive rocks have physical and mineralogical characteristics related to their composition and origin that differentiates them from the hosting environment, resulting in magnetic and gravimetric anomalies coming from the contrast of their physical properties of magnetization and density. At the Northern border of the Parana Basin, in the Goiás State, Brazil, there are two alkaline provinces: 1) Goiás Alkaline Province in the Southeast and 2) Alto Paranaíba Province in the East, including a portion in the Minas Gerais State.

The Goiás Alkaline Province (GAP), study object of this work, is located along the Brasilia Belt, with some of the main alkaline complexes concentrated in the South of the Goiás Magmatic Arch. Its intrusions are characterized by having several alkaline complexes, dykes and local volcanic products (Rocha, 2013), that have been studied by many authors in recent years. In the GAP area, systems of long sub-vertical faults also occur hosting alkaline intrusions and sometimes are recognized as rifts or *en echelon* systems. The crossing of faults system, where structural NW-SE directions predominates, could have influenced the site of the intrusions (Dutra, 2011).

The goal of this work was the integration of existing geological and geophysical data to characterize and differentiate the mineral systems that originated the main alkaline occurrences in the GAP area situated between the Montes Claros and Pirapora cities, centre-west of Goiás State. With this objective, we have created and used thematic maps, geophysical inversions (gravity and magnetic data) besides the Self-Organizing Maps (SOM) method applied to the Magnetization Vector Inversion result to differentiate the intrusive systems.

METHODOLOGY

The airborne geophysical survey including magnetic and gamma spectrometric data used in this work correspond to the Area 1-GO acquired by Lasa Engenharia e Prospecções S.A in 2004 for the Secretaria de Minas-GO. The flight height of the survey was 100 m, with flight lines in the N-S direction with 500 m spacing and Tie lines in the E-W direction with 5000 m spacing. The gravity and digital terrain model grids were obtained from the public Geosoft DAP server (http://dap.geosoft.com/Flamingo/). We have used the Bouguer anomaly from the Marine Gravity in mGal/10 with 1080 m cell size (http://topex.ucsd.edu/WWW_html/mar_grav.html) and the SRTM World Elevation with 90 m cell size (http://www2.jpl.nasa.gov/srtm/). The geology and structural data used correspond to the Brazilian millionth Geological chart from 2004 generated and made available by the Brazilian Geological Survey (CPRM, 2004).

The magnetic data was corrected, micro levelled and interpolated to generate the themes used for interpretation such as Total Magnetic Intensity (TMI), Analytic Signal (AS), Upward continuation 300 m minus Upward continuation 200 m, amongst others. The gamma spectrometric data, after correction and interpolation, was displayed as a ternary image (RGB = KThU). All the mentioned themes combined with the Bouguer anomaly and geological map were integrated and analyzed to interpret the area (figure 1).

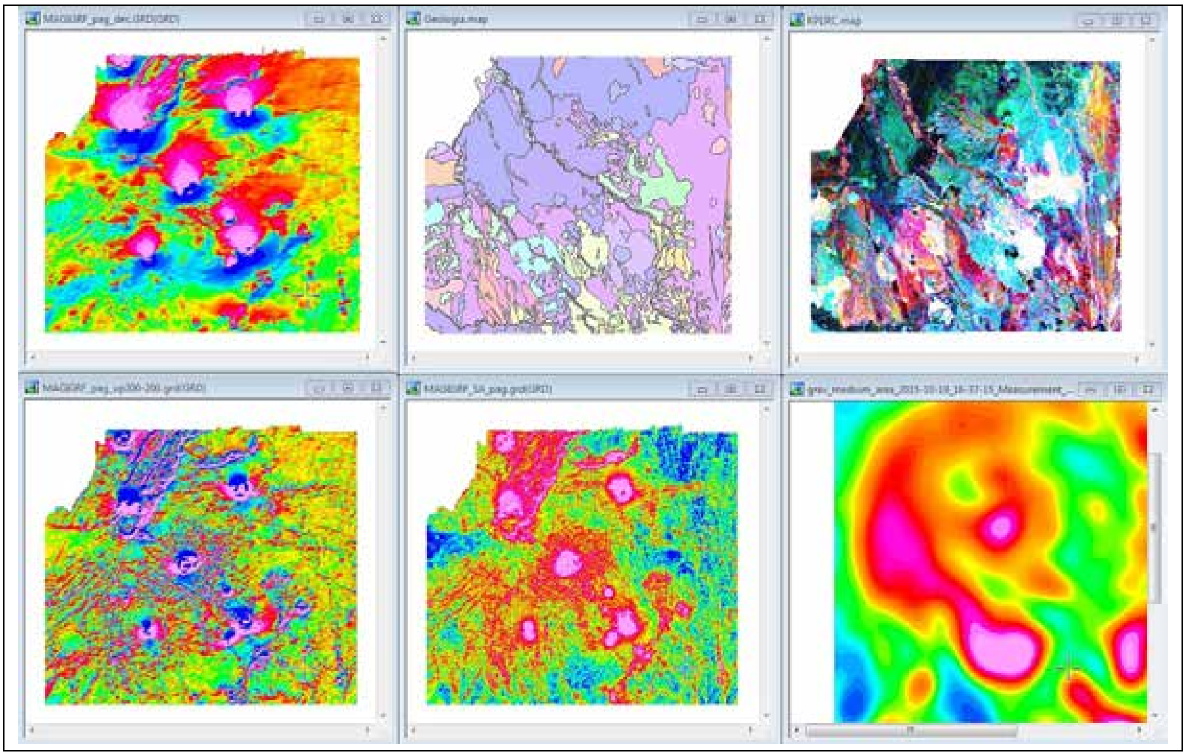

Figure 1: Top from left to right: Total Magnetic Intensity (TMI), Geology (CPRM, 2004) and Gamma ternary image. Bottom from left to right: Analytic Signal (AS), Upward Continuation 300m minus Upward Continuation 200m and Bouguer Anomaly grid

The magnetic and gravity data were also inverted using VOXI (Aisengart, 2013, 2015; Barbosa & Pereira, 2013; Ellis, Wet, & MacLeod, 2012; Ellis, 2015; Pereira, Ando, Barbosa, Aisengart, Pardal, & Rech, 2014) generating density, susceptibility, and magnetization vector models. The SOM technique (https://en.wikipedia.org/wiki/Self-organizing_map; MacLeod & Ellis, 2015) was applied to the spatial coordinates (X, Y, and Z) and the Cartesian components of the magnetization vector (Mx, My, and Mz) in order to differentiate the mineral systems.

RESULTS

The ternary image generated with the gamma spectrometric data helped the geological characterization and the identification of main intrusive bodies. The analysis of this data combined with the magnetic thematic maps allowed the identification of the intrusions named as: Morro do Engenho, Araguaia, Montes Claros, Arenópolis, Iporá, and Santa Fé (figure 2).

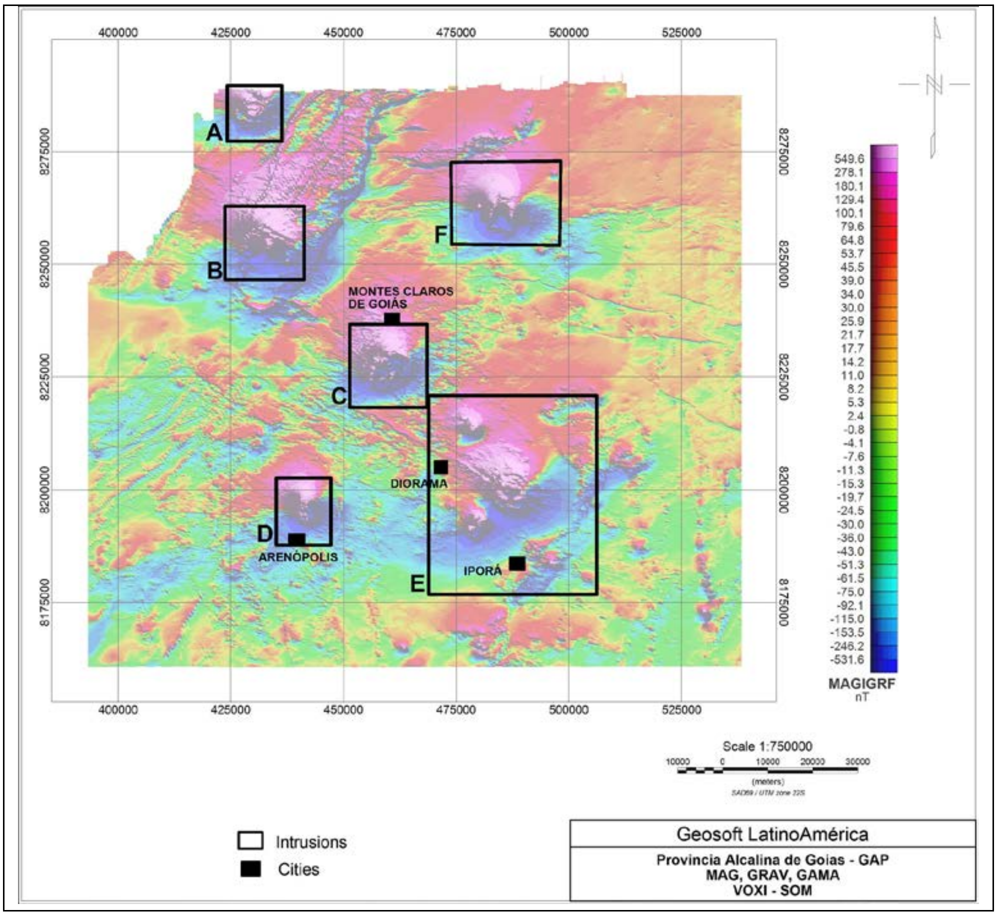

Figure 2: Intrusive bodies: (A) Morro do Engenho, (B) Araguaia, (C) Montes Claros, (D) Arenópolis, (E) Iporá, and (F) Santa Fé

After some tests, we have noticed that the Magnetization Vector Inversion (MVI) provided better results than the susceptibility inversion. For this reason, the MVI was selected as the method to invert the whole area and each intrusion named above. In the inversion of the total area (145x130 km) the model cell size was 300x300x150 meters and for the smaller models was 200x200x100 meters (figure 3). The inversion results indicated presence of remanence and/or magnetic anisotropy and allowed a better characterization of the intrusions. For the gravity regional data inversion (cell size 1000x1000x100 meters), the total extension of the inversion area was 230x280 km, bigger than the study area, enabling a better visualization of the anomalies edges (figure 4).

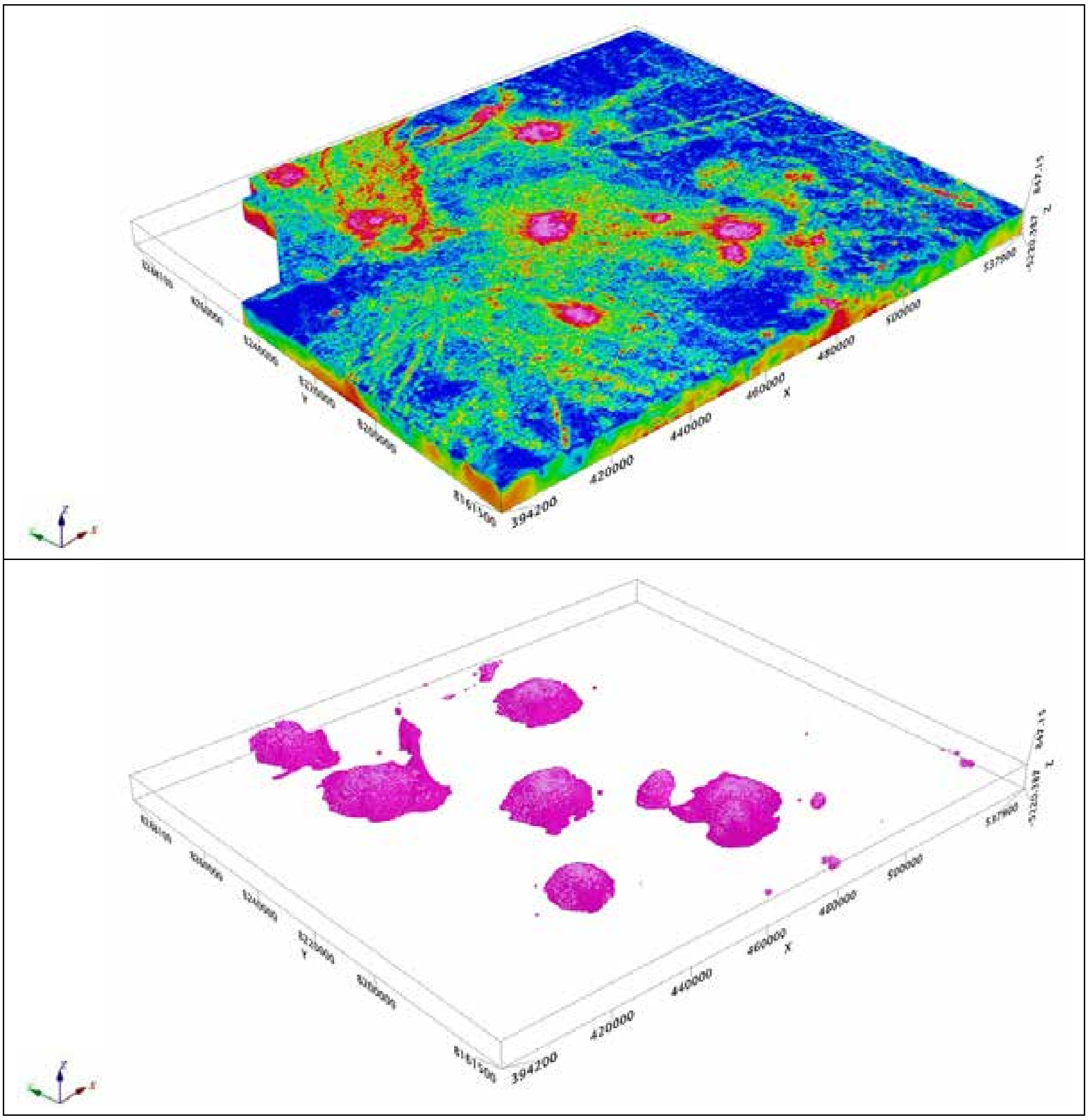

Figure 3: MVI model result for the total area (top) and clipped at 0.04SI (bottom)

Although the unconstrained model generated by the MVI (figure3) is a non-unique solution, it fits the measured data and because of that, it was used to individualize and characterize the alkaline bodies (figure 3 and 4). All intrusive bodies described as follow reached a maximum of 8 km depth except for the Iporá anomaly, which reached 10-12 km depth.

A. Morro do Engenho: located in the extreme north of the study area, was characterized as having an elliptic shape with major axis in NE-SW direction measuring 8 km.

B. Araguaia: located in the north of the study area, was characterized as a circular shape with diameter measuring 11 km.

C. Montes Claros: located in the central area was characterized as an elliptic shape with major axis in NE-SW direction measuring 12 km.

D. Arenópolis: located in the SW area was characterized as a circular shape with diameter measuring 8 km.

E. Iporá: located in the SE area is represented by two bodies. The bigger one was characterized as an elliptic shape with major axis in NE-SW direction measuring 20 km. The smaller one has a circular shape with diameter measuring 12 km.

F. Santa Fé: located in the NW area was characterized as a slightly elliptic shape with major axis in NW-SE direction measuring around 20 km.

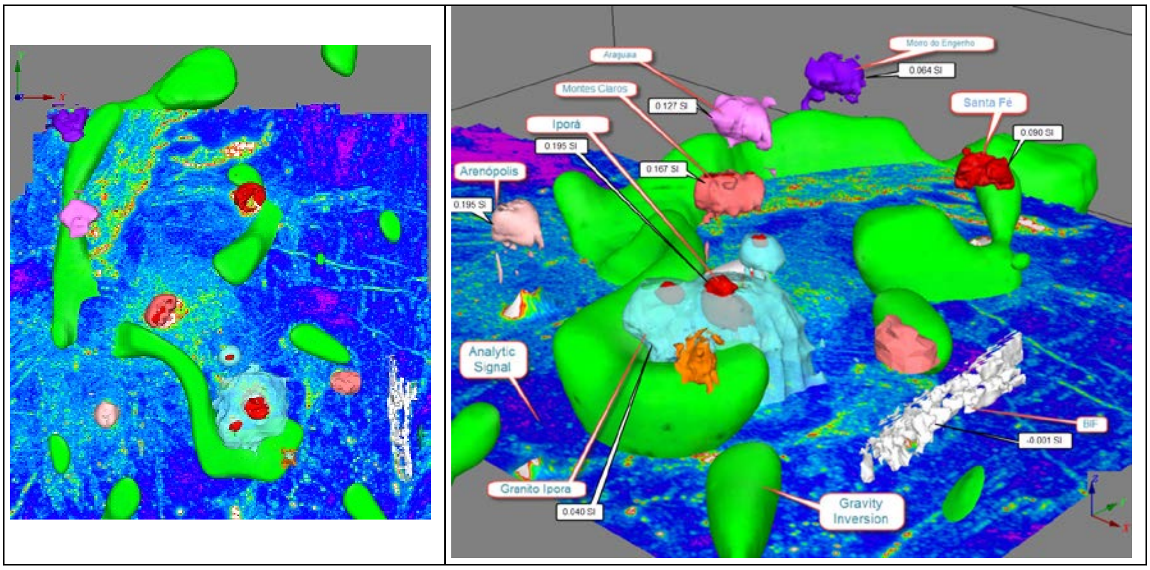

Figure 4: Gravity Inversion result (green isosurface at 0.429 g/cm^3) and the intrusive bodies (individualized as susceptibility isosurfaces from MVI model results). Top view on the left side and SE view on the right.

The MVI result of the total area was used as input for the SOM technique. First SOM was used to determine the background values to create a filter. This filter was applied in a new SOM analysis resulting in a differentiation of the magnetic anomalies in terms of its magnetic properties. In figure 5 the SOM technique result and the structural data for the area are presented.

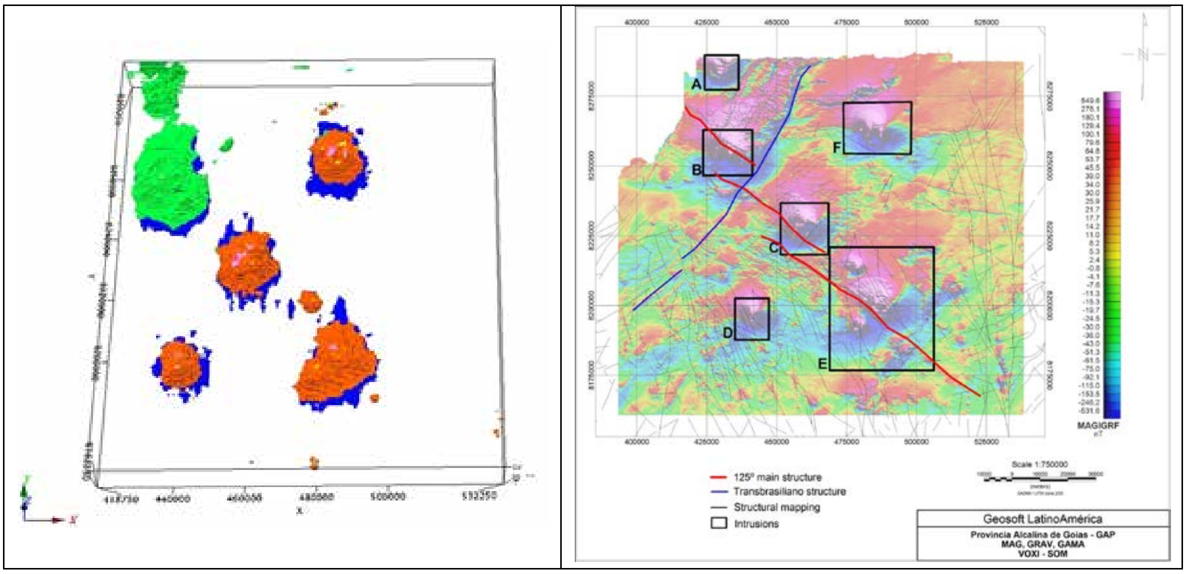

Figure 5: SOM technique Result (left) and structural data (right)

CONCLUSIONS

The models generated by the geophysical inversions helped to individualize and characterize the alkaline bodies (figures 2 and 3). The gravity data indicated the existence of a 125º linear trend accompanying the fracture zone (figure 1) which probably facilitated the magma intrusions (Dutra, 2011) and the density model also highlighted the granitic enclosing rocks from the region (figure 4).

The SOM technique suggested the existence of two distinct mineral systems forming the alkaline intrusions: one system englobing the Morro do Engenho and Araguaia anomalies and the other englobing Montes Claros, Arenópolis, Iporá and Santa Fé anomalies. Analyzing the structural map, we observe that the Transbrasiliano structure (Az. 40º) is the one that divides those two magnetic domains.

The integration of the geophysical and geological data in the GAP area enabled: (i) the identification and characterization of the surficial geology (gamma), (ii) the characterization and delimitation of the enclosing rocks (satellite gravity) and alkaline intrusions (magnetic thematic maps and geophysical inversions) and (iii) the differentiation of two mineral systems that originated the intrusions (SOM).

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CURRENT ISSUES OF THE LIGNITE DEPOSIT EXPLOITATION IN ROMANIA

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CURRENT ISSUES OF THE LIGNITE DEPOSIT EXPLOITATION IN ROMANIA

ABSTRACT

In Romania, there are significant lignite and brown coal reserves hosted by different regions of the country. The most important lignite bearing zone of the country is situated in the North – West part of Oltenia region and covers a surface area of 2,500 km^2 and host a total reserve of 3.0 billion tons of lignite, of which more than 95% can be exploited by open cast method. The paper deals with the existing geological and mining conditions of the zone, the distribution by mining basins, exploitation perimeters and the open cast working technologies. Years ago, for the improvement of the economic situation as a whole and in each unit, a large production reorganization, technology update and modernization process was started up.

We describe the rehabilitation measures of the technological lines (coal transport and sterile dumping) and modernization of the equipments. There are mentioned the equipments considered and the economic outcomes obtained after modernization. Future actions for the equipment modernization and perspectives of the lignite deposit exploitation to meet the national economy requirements of solid fuels are discussed.

KEYWORDS

Lignite deposit, surface exploitation, coal pit, flow sheet, Oltenia mining basin

LOCATION AND GEOLOGICAL CONDITIONS OF OLTENIA LIGNITE DEPOSITS

Romania has significant reserves of lignite, brown coal and hard coal, of which more than 3.0 billion tons of lignite geological resources. The lignite deposits of Romania are spread over 3 zones (Figure 1) and fifteen distinct mining basins among which the most important zone is Oltenia which includes as well 5 mining areas.

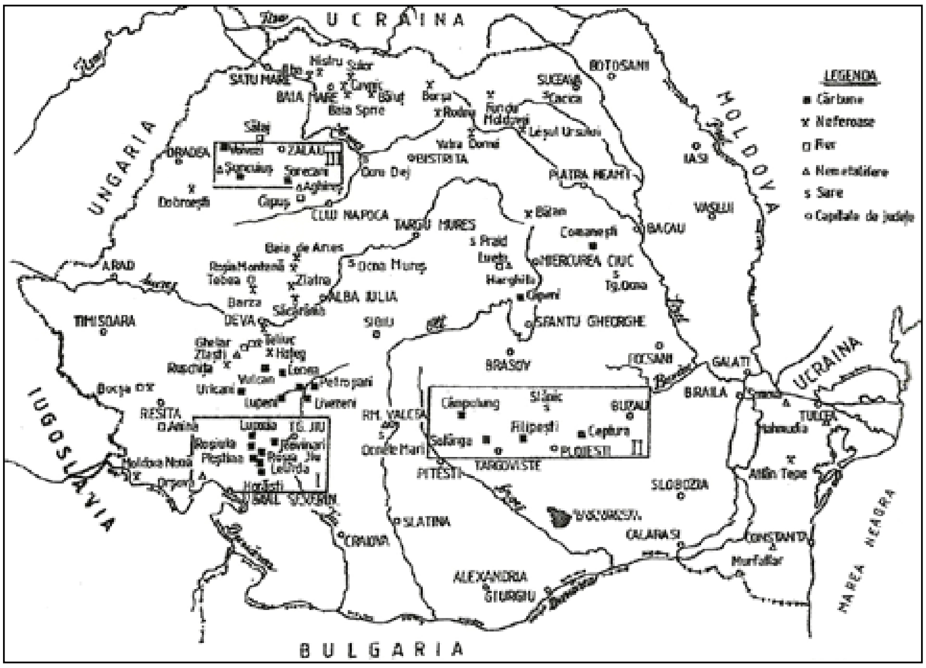

Figure 1. Localization of the main mining exploitation from Romania

The lignite deposits of North – West Oltenia (zone I) are comprised within the structural unit of the Sub-Carpathian depression, within the area between Danube and Olt rivers occupying a surface area of about 2500 km^2 of the territory of three counties: Mehedinţi, Gorj and Vâlcea [3].

The lignite geological reserves of Oltenia represent almost 90 % of the total reserves of the country and have the following grades:

- Average thermal power........... : 1700 - 2200 kcal/kg ;
- Anhydrous ash content …….. : 34 - 38 %;
- Humidity................................ : 39 - 45 %;
- Sulphur content..................... : 0,8 - 1,2 %;
- Volatile matters..........................: 17 - 23%.

The lignite deposits of Oltenia are grouped by geographic, geological and economic criteria in five mining basins.

Each mining basin to be exploited comprise several exploitation perimeters, depending on the zonal characteristics of the deposit and exploitation possibilities (Figure 2).

Figure 2. Oltenia's mining basins with the exploitation perimeters which are highlighted and in exploitation in the present day

The contribution of the Romanian lignite production to the power production of the country is over 35%. Also, this product of the mining industry is used to obtain the thermal agent for the heating of some significant localities of the country and only a small quantity of the heat production is used for household and small scale industry consumption.

From geological point of view, the lignite deposits of Oltenia are part of the Pliocene formations (Dacian, Romanian and Pleistocene) and consist of 21 layers of coal with variable thickness and extension separated by sedimentary waste rocks.

The thickness of the layers range from several centimeters up to several meters occurring as compact formations or coal benches forming the complex of a layer.

Of the 21 lignite layers the layers V-VIII are mineable in the meadow zones and the layers V-XII in the hilly zones, that is all the layers which thickness ranges between 1.0 and 8.0 m. The lignite layers' roof and bottom include aquiferous formations with free level or pressurized water resulting in a series of difficulties and additional expenditures both during the opening and preparation and exploitation stages, due the need of dewatering works to be completed.

Of the total promulgated lignite industrial reserves more than 80% are mineable in open casts with profits while the remaining 20% are mineable in underground [1].

As a result in the five mining basins of Oltenia area, there have been delineated 20 perimeters with exploitation license for open cast operations and 21 perimeters for underground operations with license as well. Of the 41 mining perimeters delineated in the zone, after the finalization of exploitation operations and analysis of the exploitation possibilities only 14 coal pits are still in operation.

Since the year 2000 the underground operations was focused on the zones with positive geological and mining characteristics for obtaining performance to ensure the economic efficiency resulting a cost per coal ton of 15 US$. The mines with production costs higher than 15 US$ were included in a program of mine closure and preservation, the future trend being to gradually close all the underground mines so that lignite will be exclusively mined out by open cast operation in Romania.

SURFACE EXPLOITATION OF OLTENIA LIGNITE DEPOSITS

At present, in Oltenia there are only 14 open pits which operate in a unit with energy producers by coal using, named Oltenia Energy Complex. The open pits still operating in Oltenia can supply maximum 30 million tons of lignite per year depending on the market demand as presented in the table 1. The last underground mines have been closed in 2015.

Table 1. Features of open pit exploitation perimeters and annual production parameters

COAL PIT	Exploitable coal pit	Average thickness of the layer	Minimum thickness of the layer	Exploitation height	Average stripping ratio	Quality parameters			Production capacity
						P.C.	Humidity	Ash	
	(no.)	(m)	(m)	(m)	m³/t	(kcal/kg)	(%)	(%)	(mil. t/year)
Husnicioara	2	8.00	1.83	62	8.30	1700	44.0	38.7	2.2
Jilţ S.	9	21.20	1.40	100	6.30	1725	43.5	37.76	3.5
Jilţ N.	7	21.50	1.64	180	6.83	1737	42.5	38.50	2.5
Lupoaia	7	26.00	1.62	100	4.40	1709	42.0	42.00	2.3
Roşiuţa	8	30.00	1.90	170	5.50	1793	44.0	38.24	2.5
Roşia	8	21.30	1.00	130	4.50	1717	42.5	38.98	4.4
Pinoasa	8	16.20	1.00	120	6.30	1766	42.0	38.79	3.5
Rovinari	4	11.00	1.50	75	5.75	1771	40.0	40.12	1.7
Tismana I	5	17.80	1.40	40	2.50	1725	42.5	39.33	2.5
Tismana II	4	7.50	1.00	50	3.80	1628	42.5	41.21	1.5
Peşteana N.	3	10.00	1.60	80	5.40	1775	41.7	38.22	1.4
Olteţ	4	9.40	2.12	75	8.00	1777	42.5	41.12	0.5
Berbeşti	3	8.20	1.20	50	7.40	1786	42.5	40.88	0.5
Panga	3	10.40	1.00	70	7.50	1747	41.0	39.74	0.7

The underground exploitation of lignite deposit was performed in all units using the long face slope method with mechanized cutting of the coal and support of slopes with mechanized complexes. For the Romanian lignite deposit situated at shallow depth and suitable relief conditions, the open cast method was used. All the open pits have designed production capacities ranging between 0.5 and 4.4 million tons per year.

Depending on the relief conditions and vertical distance from surface from the last mineable coal layers, the open cast depth is ranging between 40 and 110 m in the meadow zones and up to 160 -180 m in the hilly zones, the stripping ratio for the total mining field range between 2.5 and 8.0 m^3/ waste/ ton of mined lignite. To reopen the open casts, in the meadow and hilly zones there were built opening trenches of 350-1500m long.

Depending on the open cast depth, the number of working benches range between 3 and 8 benches [2].

Today, all the open casts of Oltenia zone are provided with continuous flow-sheets including the following components:

-SRs – 1300. 26/3,5; SchRs – 1400. 30/7 and SRs – 2000 30/7 with theoretical efficiency ratios between 1680 and 6500 m^3/h; In the continuous flow technology (Figure 3) from the Romania's lignite coal pits, the best type which has adapted to our deposit conditions was the one made in East Germany Sch R_s1400 30/7, which has also been made in Romania with the ESRc – 1400 30/7 symbol. [4].

The symbol of these excavators after the Romanian standards is:

ESRc - q h / t (...kW)

where: ***E*** – represent excavator;
S – march system on tracks;
Rc – wheel with cutting cups;
q – capacity of one cup (l);
h – maximum hight which can be excavated (m);
t – maximum width, under the quote which can be excavated;
(...kW) – power of bucket-wheel excavator;

Figure 3. Continuous flow technology – Rosia coal pit from Oltenia [5].

- The transport of the mining bulk excavated of the working faces to the stockpiling site is carried out using belt conveyors with capacities varies from 4.400 m^3/h to 12.500 m^3/h, with separate circuits for waste to dumps and useful material to the stockpile site, and under certain circumstances of the deposit, mixed circuits are used for alternative transport of waste and coal;

- The stockpiling of the waste on the dumps using the dumpers of 4.400 up to 12.500 m^3/h and useful material stockpiling on coal stockpiles using the dumping – removing facilities or the combined ones with capacities between 1.250 and 12.500 m^3/h.

The technological flow sheets of the open pits in operation are more simple or more sophisticated depending on the ground morphology, burden material thickness, number and thickness of mineable lignite layers of the perimeter, number and thickness of waste intercalations, excavation capacities and operational sizes of the equipment.

In some open pits where the coal layers are well defined, the technological flow-sheet could be organized in a simple manner, namely each excavator works either on the coal layer or in waste, on benches forming separated technological lines.

In some other open pits the coal layers are separated by waste intercalations, in several benches and thus, the excavation process is more difficult and the selective mining with negative impacts on the productivity and quality of the mined coal.

In many open pits both excavation on separate coal benches and selective – alternative excavation of coal and waste is performed on the same bench and using the same excavator.

In the open pits where the last coal layer of the coal complex is opened, there proceeds with the use of combined exploitation method, namely the waste transport to the dumps and the second part of the waste is boomed using dumping facilities with booms lengths ranging between 120 and 170m (Figure 4).

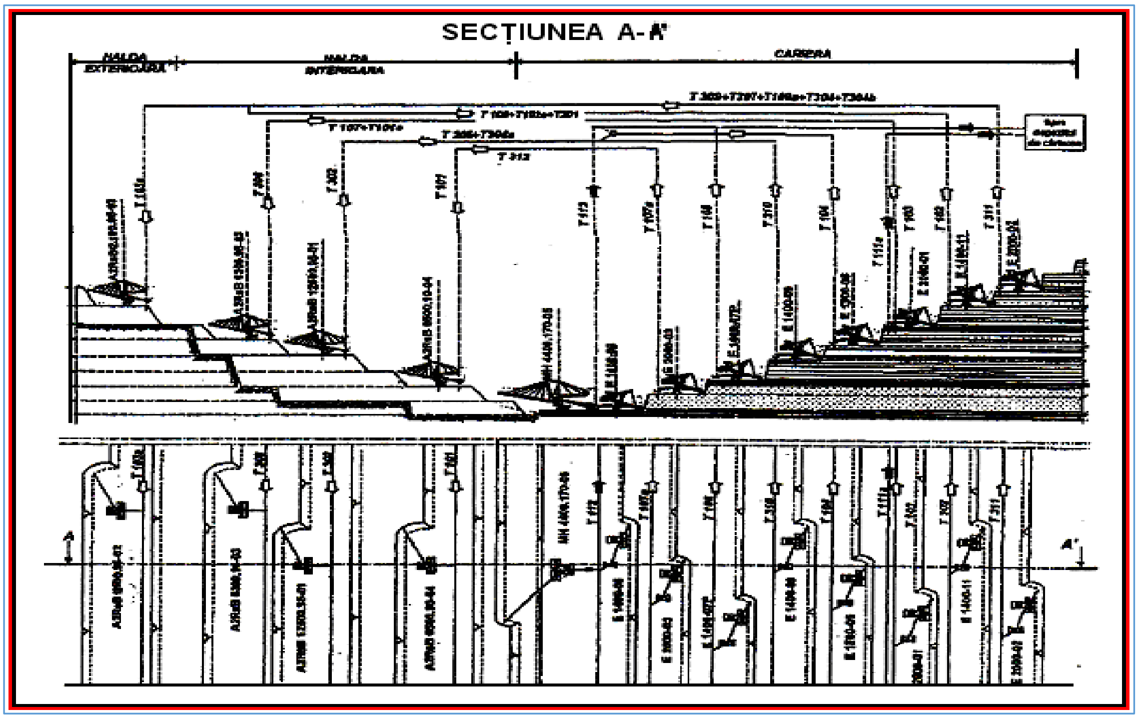

Figure 4. Combined exploitation method used at Roşia de Jiu open cast where a part of the waste is transported to external dumps, while the other part to inner dumps and partial booming of the overburden on internal dumps

The open cast working benches height is ranging between 15 and 25 m, the slope angles range between 60-65^o and are 1.000 up to 2.800 m long. The overall slope angles of the open casts range between 120 and 200 depending on the type of the rocks from the exploitation perimeter and the working technologies used.

The waste resulted at the opening trenches was transported and deposited on external waste dumps situated at variable distances from the exploitation perimeters depending on the existing relief conditions. In the meadow zones, the dumps were located near the final contour of the open cast and were built vertically with several benches, the maximum dumping height being 15-20 m.

Depending on the dumped material characteristics (humidity, consistency, loosening coefficient, particle sizes) as well as on the designed heights of the external waste dumps, their overall slope angle was established at values of 6 and 9^o.

In the hilly zones, the external waste dumps were built by filling the valleys near the open casts, the transport distance to the dump being in some cases, 10 km and even longer.

Today, the lignite open cast mining in Romania, is developed in 14 large open casts with continuous flow-sheet and a total production capacity of 30 million tons of lignite per year.

From the beginning of mining activity (1965 for underground and 1967 in coal pits) until the present day, from Oltenia have been extracted over 1.1 billion tons of coal (over 890 mil. tons of lignite extracted by surface mining exploitation and over 216 mil. tons of coal extracted by underground exploitation) and has been excavated a volume of sterile of over 5.15 billion m^3 for the mentioned production [5].

Further to the economic analysis of the 14 open casts where continuous flow-sheet technology is used there resulted a positive economic efficiency but only for those open casts where the cost per ton of mined out lignite is lower than 13 US$ per ton.

Less encouraging results have been indicated for the open casts which are still under opening stage and which have not reached the designed production capacities yet.

Table no. 2 shows the technical equipment of Oltenia open casts allowing the use of continuous technological lines.

As described in table no. 2, the most used equipment is the SchRs 1400 30/7, excavator representing 75% of the total excavators in operation and it provides 80% of the total open cast excavations.

Table 2. Technical equipment of Oltenia open pits

OPEN PIT	EXCAVATORS	DUMPERS	STOCKPILING FACILITIES	CONVEYORS Km belt
Husnicioara	5	3	6	12,8
Lupoaia	6	3	2	16,4
Roşiuţa	6	4	2	19,4
Jilț South	8	4	3	35,4
Jilț North	8	3	2	26,8
Rovinari	6	5	-	15,2
Tismana I	4	3	7	12,5
Tismana II	3	3	-	8,4
Pinoasa	5	3	2	20,2
Rosia	9	5	3	24,2
Pesteana North	5	3	4	9,4
Oltet	4	2	3	14,3
Berbesti West	3	1	-	5,6
Panga	3	2	2	6,7
TOTAL	**75**	**44**	**36**	**233,5**

Since the first rotor and bucket excavators started to operate in Oltenia - Cicani 1967 and until 1990 in Romania, there have been manufactured the SRS – 470 15/3,5 and SchRs 1400 30/7 excavators.

Totally, in Romania, there have been manufactured 28 SRS – 470 15/3.5 and 33 excavators of SchRs 1400 30/7 type.

The SRs 470 15/3,5 excavators assimilated and manufactured by the Romanian Equipment Manufacturers faced numerous failures in operations, almost all the mechanical parts failed and the experts conclusion was that the equipment was morally worn out and cannot be rehabilitated to get positive economic results and consequently, the manufacturing and use of such equipment was stopped in the lignite open casts. Almost all the excavators of this type are presently under conservation.

At the same time, it was decided that the SchRs 1400 30/7, SRs 2000 30/7 and SRs 1300 26/5 type excavators are maintained in operation until the deposit exploitation depletion of the perimeters where they operate.

MODERNIZATION OF THE TECHNOLOGICAL FLOW-SHEET OF OPEN CAST OPERATIONS

The performances obtained with the SchRs 1400 30/7 excavators throughout the years, since 1969 when the first equipments of such type were put into operation in Gârla and Tismana open pits and until now, is at average, about 2 millions m^3/ year and maximum production peaks of 5 millions m^3 / year.

The extensive use indexes calculated as a ratio between the running hours and the calendar hours and the intensive use calculated as ratio between the hourly capacity achieved and the hourly guaranteed or theoretical capacity are impacted by the geological and mining conditions of the exploitation perimeter, the rotor and cutting bucket excavators type, their technical condition and the organization of the production process. For most of the open casts of Oltenia zone, the values of the intensive and extensive use parameters are low, being much below those of the similar equipments used in advanced countries. For this reason, for obtaining the high planned mining bulk, there have been purchased many excavators and associated transport lines as well as the dumping machines which require a large number of personnel for surveillance and high costs of maintenance, running and repairs.

As a result, the rehabilitation and modernization of the sub-assemblies of the excavators, belt conveyors and dumpers became a priority.

Further to the review, throughout the years, of the running condition of the excavators, belt conveyors and dumpers considering the deposit conditions and rocks of Romania, the failures noticed and their frequency , there have been enhanced and decided the modernization solutions for each type of equipment. For instance, the modernization of the (SchRs) 1400 30/7 excavators was designed by Krupp company in collaboration with Rominex company of Timişoara, using the latest technical constructive solutions world wide. There were taken into account all the constructive improvement proposed by the designers, service suppliers and beneficiaries as a result of the expertise acquired in the execution and exploitation of the equipments both from mechanical and electrical point of view, complying with the standards, technical rules and work safety rules in force.

Also, there were made repairs and there were used efficient solution for the equipment metal framing to avoid the occurrence of unexpected events such as technical or work accidents.

The remediation and modernization depended on the type of the equipment as follows:

Excavators

The bucket rotor itself; the bucket wheel reducer; intermediate reducer, belt conveyors; rotating device of the over structure; boulders crusher; travel mechanism; metal resistance structure; lifting mechanism of the bucket wheel boom and electric installation.

There were modernized 6 SRs 1300 – 26/5 excavators; 4 SRs 2000 – 30/7 excavators and 17 SchRs 1400 – 30/7 excavators.

Belt Conveyors

Mechanical part

- The fixed and movable driving plant; shock proof wall; rakes; cleaning tape; inter-changeable travel system; driving, elongation, return and deviation drum; braking drive for the main components; elongation cable and electric cabinet.
- Route sections: sections and crossings; connection section; rollers; rollers and safety hooks.
- Fixed and movable return station; increased roller inclination angle from 30^0 to 45^0; new sealing and hang glider type plough in front of the return drum.
- Device for material take over: increased roller inclination angle from 30^0 to 45^0 and maneuvering winch for travel.

Electrical part

- Enhancement of the reliability of the starting system and improvement of the power factor.
- Command and protection circuits: diminution of starting time; simplified electric schemes, diminution of resistance number and contacts; enhancement of exploitation safety.

Dumping machinery

Modernization of the main components of the travel mechanism, discharge belt, carriage, belt conveyors installations, replacement of cables supporting the feed and discharge booms as well as electrical installation.

Conclusion

Since the start up of modernization works of the technological lines in 1995 and until today, there were modernized 27 excavators of the total 75 operating in Oltenia open casts as well as the conveyor lines and dumpers serving these excavators.

As a result of the excavator modernization the following positive results were obtained:

- by improving the intensive and extensive use of the modernized excavators , the average hourly running capacity increased by 16 - 25% and implicitly the volume of annually mined bulk of each excavator;
- diminution of production costs by reducing the consumption of buckets, teeth, electric power etc.
- elimination of risks associated to failures as a result of the running safety enhancement;
- constructive improvements allowing rapid interventions to replace the disturbed or used sub-assemblies;
- obtaining fine grain size coal resulting in a better quality of the production delivered;
- new teeth wheel buckets reducing the possibility of vibrations of the metal structure;

As a result of the belt conveyor and dumper modernization the following positive results were obtained:

- mitigation of risks associated to the failures;
- elimination of breakdowns caused by additional handling for running purpose;
- diminution of accidental stops and production increase;
- mitigation of the service amount supplied for the auxiliary equipments;
- diminution of electric power and material consumptions;
- diminution of time for moving;
- diminution of production costs.

FUTURE ACTIONS

The strategy of the medium and long term activity in Romanian open casts provides the followings:

- Development of the open cast units resulting in the increase of the performance parameters – annual production capacity, work productivity and economic efficiency. To this aim, there will be developed the open pits with deposits that can be economically viable such as: Roşia de Jiu, Pinoasa, Fărcăşeşti, Valea with Apa, Tismana I, Tismana II, Jilţ Sud, Jilţ Nord and Roşiuţa.
- Diminution of activity within mining zones and units as a result of the uneconomic efficiency;
- Continuation of the modernization programme of the rotor and cutting bucket excavators;
- Diminution of production costs below 13 US$ per ton of coal;
- Modernization of the mechanics and electrical part of the belt conveyors serving the modernized excavators;
- Rehabilitation and modernization of all dumping machines of the technological flow-sheet;
- Computer assistance and common diagram system of the excavation complex lines, transport, dumping and stockpiling operations to obtain current data referring to the running time, electric power consumption etc.

For Romania, Oltenia lignite is currently one of the main primary power suppliers.

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GENERATION AND APPLICATION OF NEW SEISMIC ATTRIBUTES FROM REPROCESSED 2D DATA TO ADAPT IT FROM OIL EXPLORATION TO POTASH SALTS EXPLORATION IN THE SERGIPE SUB-BASIN, BRAZIL

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ABSTRACT

Potassium is the seventh most abundant element of the earth's crust. However, most of minerals that contain potassium on its structure are slightly soluble or not soluble, turning it difficult to obtain the element. For that reason, the viable economic source is related to evaporites in sedimentary deposits where it is possible to obtain sylvite, sylvinite and carnallite minerals.

The best example of potassium salts extraction in Brazil is located in Taquari-Vassouras mine, located in Sergipe's onshore basin. The Ibura member's evaporites of Muribeca formation have been formed into a range of coastal environment of sabkhas, salt lagoons and tidal channels. Those evaporites have saline levels of sylvinite and carnallite, commonly characterized for being small length bodies, but with large thickness and high concentration.

Those salt levels, in many cases, are relatively thin and a lot behind the seismic resolution. On this respect, the exploration is commonly done associated to the well data analysis, and to the volumetric inferences made based on the structural and stratigraphic interpretation. The extraction of all possible information from either seismic, potential methods or electromagnetics data becomes indispensable and has high relevance in order to detect the smaller deposits and boost the small-scale mining.

Nevertheless, this study presents an exploration geophysics workflow of potassium salts, seeking to improve the identification of thinning bedding salt deposits, by using well profiles and 2D seismic network data, only. The initial procedure was the increase of the frequency band and the use of directional filters on seismic data, in order to highlight the structures, layers and faults. Hence, the development of pre-stack and post-stack sensitive attributes to the salt presence, and finally, the integrated interpretation of seismic and well data. Those methods' application results in the identification of promising zones that will permit focusing a new acquisition data necessary to accurate the resolution and take a better decision before drilling.

KEYWORDS

Potassium salts, seismic attributes, Geophysical methods in mineral exploration, Sergipe sub-Basin.

INTRODUCTION

Potassium is an abundant element in the earth's crust, it is present in various mineral rock parts, such as potassium feldspar and muscovite. Even containing between 10 – 20% K_2O equivalent of these minerals, they are not good sources of potassium, because they are sparingly soluble or insoluble and its structures are not easily broken by artificial means. Potassium does not occur in nature in its elemental form. Thus, for industrial use, the main economic sources of potassium salts are on evaporite deposits, where it is possible to obtain the sylvite mineral, which may contain up to 53% K_2O; carnallite, with may contain up to 15% K_2O, and sylvite and halite mixture, called sylvinite ($KCl + NaCl$), being the main ore of potassium (Oliveira, L. A. M. de; 2008, Nascimento & Miranda, 2015).

Other economic potassium salts sources are the kainite, langbeinite, polyhalite and schoenite. Potassium salts are commonly used for fertilizer production, and the remaining volume produced is used by the chemical industry for manufacture of special glasses, different types of soap as well as by the oil and gas industry for drilling operations. Potassium is mined and processed in 13 countries (Canada, Belarus, Russia, Germany, Brazil, Chile, Spain, China, USA, Israel, Jordan, UK, and Ukraine), being Canada the major representative (around 33% of world production) and major competitors are Russia with 19% of market share, Belarus (16%), Germany (11%), Israel (6%), USA (3%) and others (11%) (Rubiolo, 2010).

The main reserves of Potassium Salt in Brazil are located in the Amazonas and Sergipe states. In the Sergipe sub-basin (Figure 1), specifically in the region between Taquari-Vassouras and Santa Rosa de Lima localities have been reported 478 million tons proved of sylvinite, containing an average grade of 9,7% K_2O equivalent (Oliveira, 2014). The Brazilian K-salts production is lower than the large demand for industrial purposes, and it is necessary to import this mineral from largest producers. Our case study's field is located onshore, in the Sergipe-Alagoas basin, approximately 30 km northeastern Taquari-Vassouras mine (Figure 2).

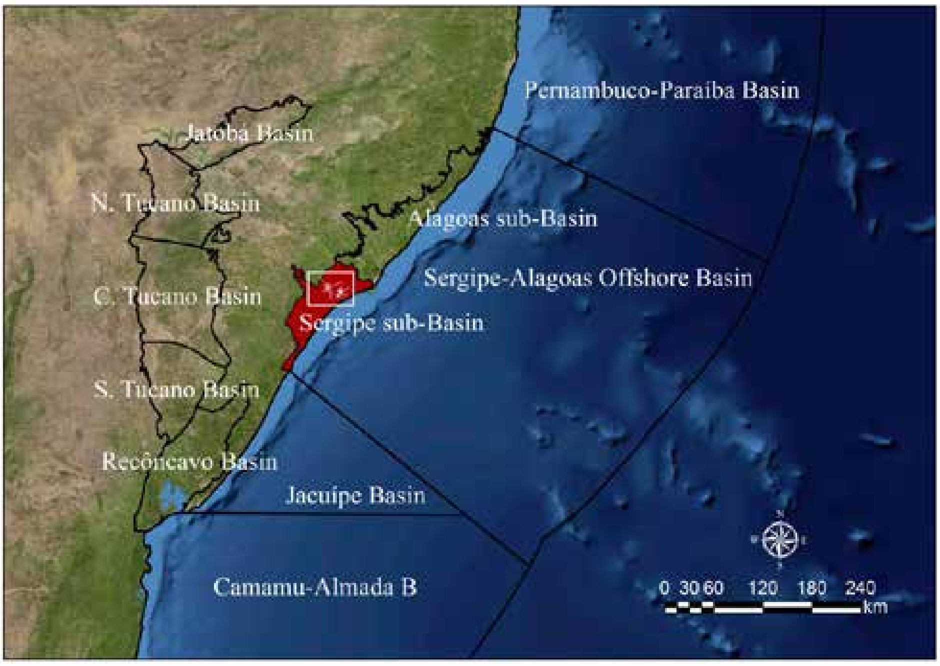

Figure 1 – The Sergipe sub-Basin (highlighted in red) location map. The main northeastern sedimentary basins appear as a reference. The white rectangle and lines inside it are the study area and seismic data.

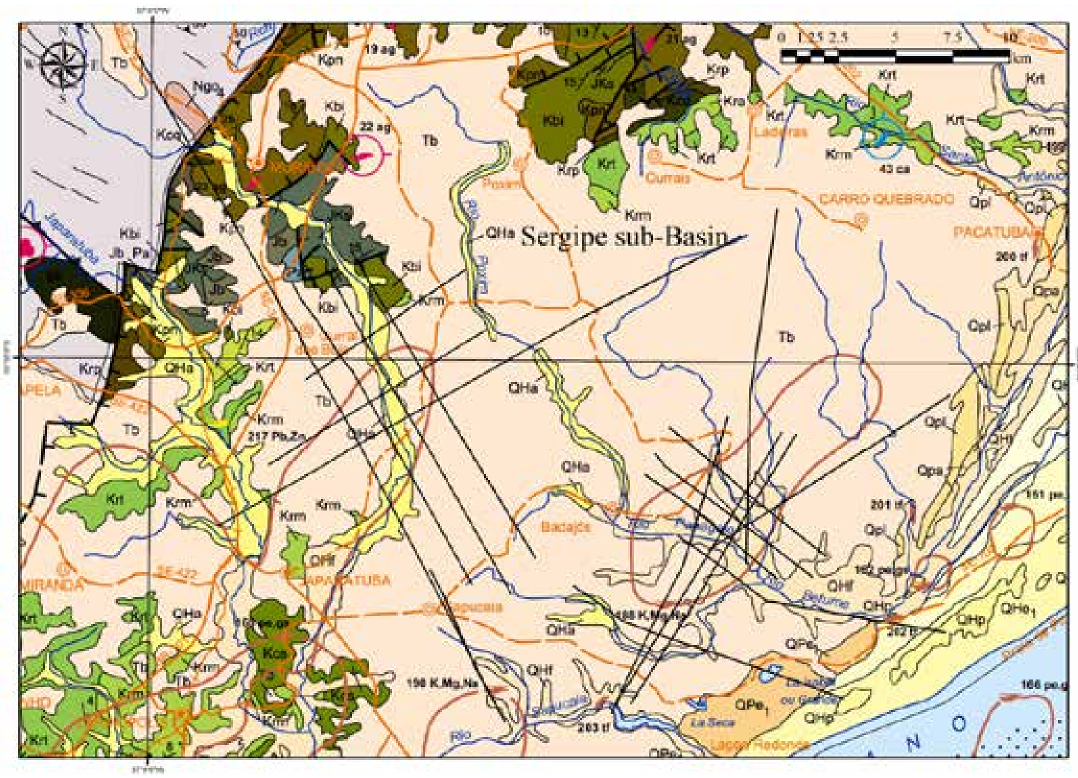

Figure 2 – Geologic surface context scratched from the figure 1's red area, where is located our seismic survey.

For a reasonable good K-salt prospection it is important to have a regional geological knowledge, including a good background about the tectonic-sedimentary basin evolution and paleogeography. All data previously acquired in the area can be relevant for contributing to a better understanding of the area, in order to characterize the potassium salt deposits both lateral and vertically.

In the world several geophysical methods are applied to the potash reserves prospection, such as airborne and ground gamma-ray spectrometry, well logging, seismic, gravity, aeromagnetic, airborne electromagnetic, remote sensing, among others. The major producing countries release its bigger and updated data bases for consulting and to be used publically.

In Brazil, most of public data bases, especially seismic and wells data, are mostly ancient and were projected to the oil and gas industry's exploration. Consequently the potash salts deposits are not well known and their detecting process is too limited. However there are different source of information that, if were well integrated, reprocessed and reinterpreted, they can be useful to generate new products and results. So we can consult both the Geological Service (CPRM, DNPM), the Brazilian Exploration Petroleum Data Bank (BDEP), provincial, local, and federal institutions and universities data bases and libraries.

Geological Aspects

According to Rancan *et al.* (2008), the Sergipe-Alagoas basin is established in geological terrains of different ages and tectonic environments. This basin was part of the Craton and the Borborema Province which are characterized by the presence of several mobile belts from the Brasiliano Cicle (Neoproterozoic). The basin is geologically represented by an asymmetrical graben, limited to the northern part of Pernambuco-Paraíba and southern Camamu-Almada basin (Souza-Lima et al., 2008 after Souza-Lima et al., 2002).

Within a regional geological context, according to Szatmari et al. (1974) cited by Araujo et al. (2009) the tectonic framework of Sergipe-Alagoas basin was shaped, mainly, during the pre-rift phase, producing the main structural features of the Aracaju High, the Riachuelo High and the Divina Pastora-Siriri Low. These large structures are bounded by normal faults, occasionally staggered preferred to NE-SW and NW-SE directions.

Over the structural highs, sediments from the Alagoas regional stage lie directly on the basement and in the lows, where the sedimentation was continuous; it was interrupted only by small gaps, permitting the presence of different deposits, from the Permian to Tertiary ages. According to Campos-Neto et al. (2007) an intense erosive phase, called Pre-Alagoas Unconformity, peneplained the pre-existing topography prior to the deposition of the Muribeca Formation. As well these authors describe, over this slightly undulating surface, the siliciclastic unit Carmópolis Member was deposited. After that, the microbialites and shales from Ibura Member interbedded thicker evaporite layers and, then, shales and calcilutites from Oiteirinhos Member (Figure 3). These three members belong to the Muribeca Formation and represent our target on this paper.

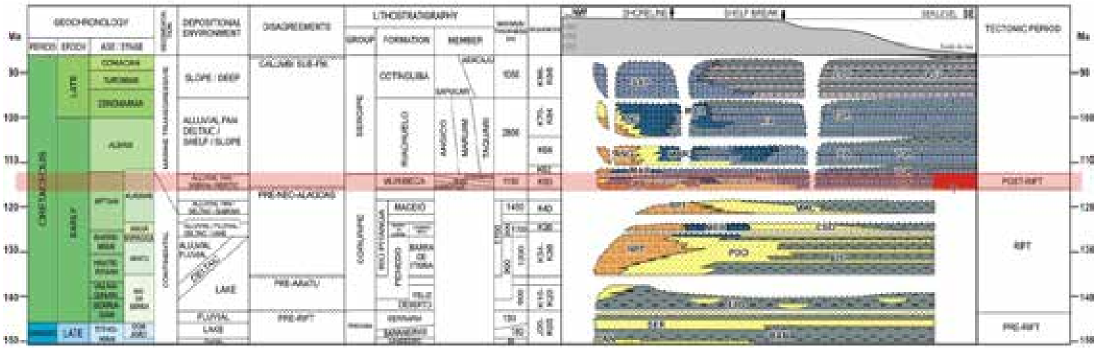

Figure 3 - Late Jurassic to Late Cretaceous portion of the Sergipe Sub-Basin`s lithostratigraphic column, illustrating the whole palaeodistribution`s Cretaceous units along the northeastern Brazilian continental margin. The reddish strip highlights the Muribeca Formation`s three members position.

At the end of Alagoas age, the sand barriers were broken as consequence of the sea level rise, opening the marine sedimentation of Riachuelo Formation (Koutsoukos, 1989). At the limit of the basin and in the lowered blocks, the deltaic fans and the thick siliciclastic rocks from Angico Member were placed. In the areas of lower sediment yield it is observed the presence of a carbonate ramp with oolite and oncolite banks from the Maruim Member which were partially dolomitized during the downgrades of the sea level. The deposition of calcilutites and shales occurred in the lagoons and slope of Taquari Member (Mendes, 1994; Falconi, 2006). The potassium salt levels of Muribeca Formation are commonly interlayered with the Riachuelo Formation`s sediments.

Objectives

1) In this work we aim to use new seismic attributes that we developed in PETREC in order to improve the quality of image seismic and turn the seismic interpretation easier and useful to mineral exploration.

2) To extract a largest amount of information from the vintage public data, seeking save economic resources of industrial mining projects.

3) Try to develop a fitted workflow in order to generate special seismic attributes which can be useful to detect thin K-salts layers and bodies.

METHODOLOGY

Partial Products generation

Initially, we developed our project with limited economic resources by using a poor public data package. Therefore, we faced significant problems listed below:

- Wells and seismic data were surveyed in 70's decade, which is why they were acquired with no controlled source;
- The survey design was projected for petroleum exploration, it means, with very different parameters;
- Some of wells were missed of log data profiles;
- All of wells were missed of check-shots;
- Any of wells did not reach the basin's basement rocks;
- Seismic data and wells did not match between them. On the opposite, wells were far away from the sections.

In order to achieve our main purpose, we applied some techniques that are commonly utilized for potential methods data processing. With it we highlight some structures, lithological contacts and the lateral continuity of the evaporitic units. In this case study, we count with 17 SEG-Y 2D data and 14 wells composite logs distributed near the line coast of Sergipe Sub-Basin (Figure 4).

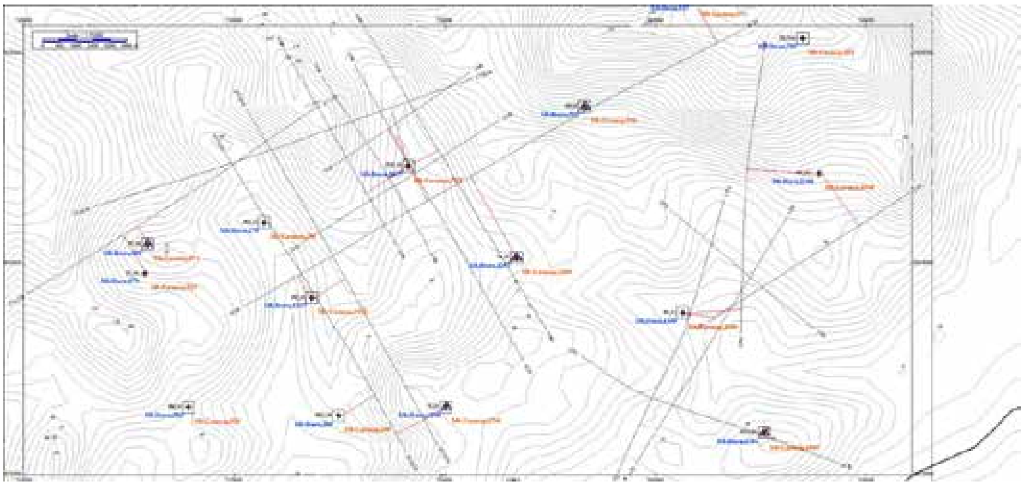

Figure 4 – Location of the whole seismic and well data project. The red lines correspond to distance measures between wells and seismic sections. The coast line is represented by a black thick line on the southeastern corner of the map.

We used the wells distribution to do a regional geologic control of the evaporitic levels presence. However, the nearest distances between wells and seismic data were of 90 to 300 meters, and others even farther are about of 500 to 2000 meters. In some cases, we made geometrical estimations when we found vertical displacements structures, considering the position of the seismic reflectors and the well horizon.

Once we imported the well data, we calculated pseudo-records by cross-plots between log wells and, thus, we obtained the Velocity and Resistivity curves, additionally to the Density and pseudo-Sonic curves. Such information were resampled and standardized to the neighbor wells, based on Density and pseudo-Density values.

Subsequently, from some Gamma-ray attribute analysis crossed by the Resistivity or Sonic/ pseudo-Sonic register, we calculated a frequency zone (GR-High and GR-Low) that highlight the Carmópolis and the Oiteirinhos Members vertical limits. Hence, it was possible to delimit the Ibura Member (Figure 5). We also calculated the pseudo-Resistivity curves and other log data profiles, following the same methodology.

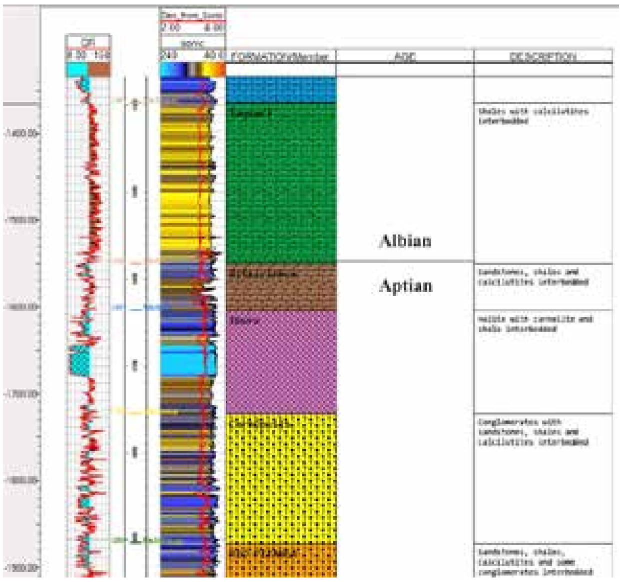

Figure 5 – One of the well logs cross-plotting (GR – Density from Sonic) used to well-tie the seismic data showing a thicker section of Ibura Member (pink rectangle). Note the clear level (Halite) interbedded by a dark blue one (carnalite) that belong to the middle part of the member. It is based by shales and finned grain sandstones, and covered by calcilutite and limestones. Vertical scale is in meters.

After that we were able to compare the well logs data where the salt levels presence was detected in different depths along the entire area (Figure 6). As a result, we have a more reliability of the seismic calibration to create a synthetic seismogram. From the cross section we infered that either the evaporatic unit (in blue color) was affected by the basement structures whose highest picks must have avoided its deposition, or some reactivation (Aptian?) deformed the Muribeca Formation.

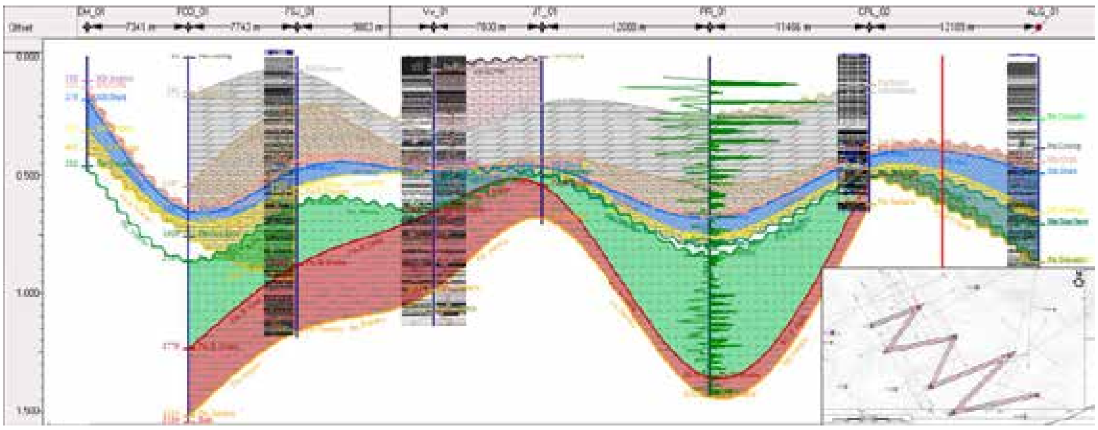

Figure 6 – Example of one of depth well correlation profiles between top formations, considering log and pseudo log curves as part of well tie workflow. The arbitrary cross section is oriented NW-SE as indicated on the location map in the lower right corner.

Looking for a good pseudo-logs cross-plotting, by calibrating them to our seismic data, we take in a count each one velocity profile of the seismic sections exported as SEG-Y files. We did calibrate the electrical logs to the seismic data by created a synthetic seismogram based on both, the deepest and shallowest well's wavelet calculation.

Thus, we got guarantee of a good statistical data analysis in order to satisfy our geological model, according to both the lowest and highest frequencies, which is useful to diminish noise in the interpretation. We can appreciate this by making a zoom in above and below the Ibura Member, which were represented in a simple hachured in the right column (Figure 7). Indeed, by the composite log we observe that the Ibura Member evaporitic levels are lying over detritic sediments (sandstone and siltstone) and are covered by calcilutites, sandstones and claystones, including some fine laminated beds of salts (Figure 7). In this same figure, the facies classification below the sonic and density header, we can observe the thinner carnalite level (purple-blue), interbedding the halite level, thicker (light blue).

The seismic color scale corresponds to same one of the facies classification, but it represents the seismic resolution, which is lower than such well logs. However, it is possible to deduce that the major formations are corresponding to those same of the wells, showing the hot colors represent, basically, detritic units and the cool colors, the evaporatic and limestone units.

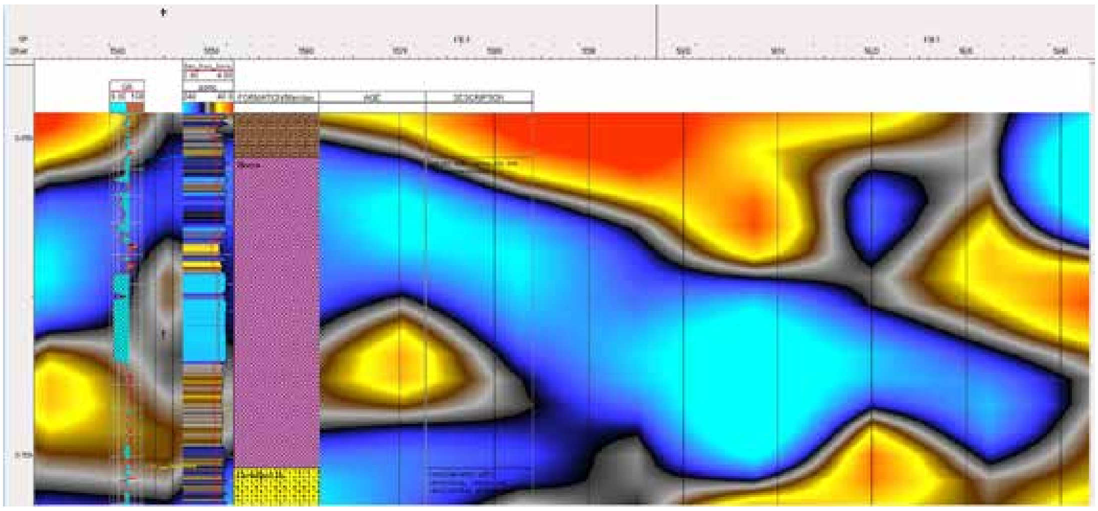

Figure 7 – Example of well tie proceedings after wavelet generation between the seismic section L-1178 and the borehole FCO-01.

After a classical seismic interpretation workflow we obtained reasonable products, showing a relative approximation of the basement structural setting and the deformation effects on the upper sedimentological units (Figure 8). In this interpreted section we can realize the structural complexity of our basin, characterizes by positive and negative flower structures, being part of a transcurrent zone that control the Brazilian northeastern rift system (Bueno, 2004).

If we plot the whole 2D seismic network as it was interpreted some years ago, it is possible to get volumetric apparent impressive partial results (Figure 9). However, we were not satisfied about such preliminary report because, for instance, there was not confidence about the lateral continuity of the interesting reflectors. Other example is the absence of sufficient resolution that would gave us the possibility to follow up the same reflector, besides it was either displaced by some fault or interrupted because of some paleotopography feature.

By using seismic attributes we highlighted features and geological structures in an alternant way for each one of sections. This was useful to define them laterally and important to enhance seismic data sub-segment which are recoverable from an entire seismic section. After that, we projected each interpreted structure or feature to its neighboring seismic section, and so on. Then, we interpolated the horizons between wells and seismic features and, thus we create surfaces to analyze their continuity along the area.

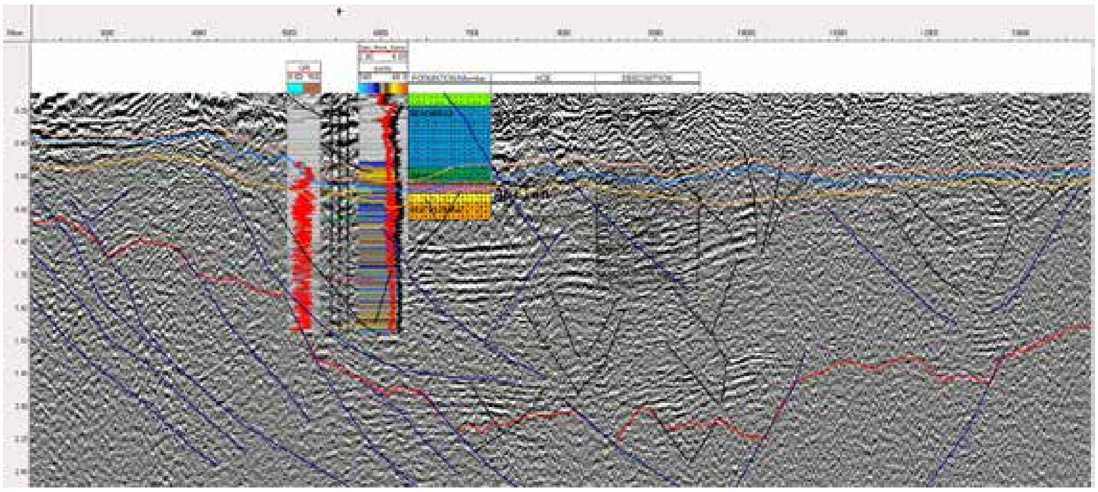

Figure 8 – 2D seismic section interpreted and fitted to the well FC0-01. Note the structural complexity and the high noise present in the section, probably due to the high velocity lithology among the strong fractured condition. The 3 main colored horizons (yellow, blue and rose) correspond to the base, top and cover of evaporates.

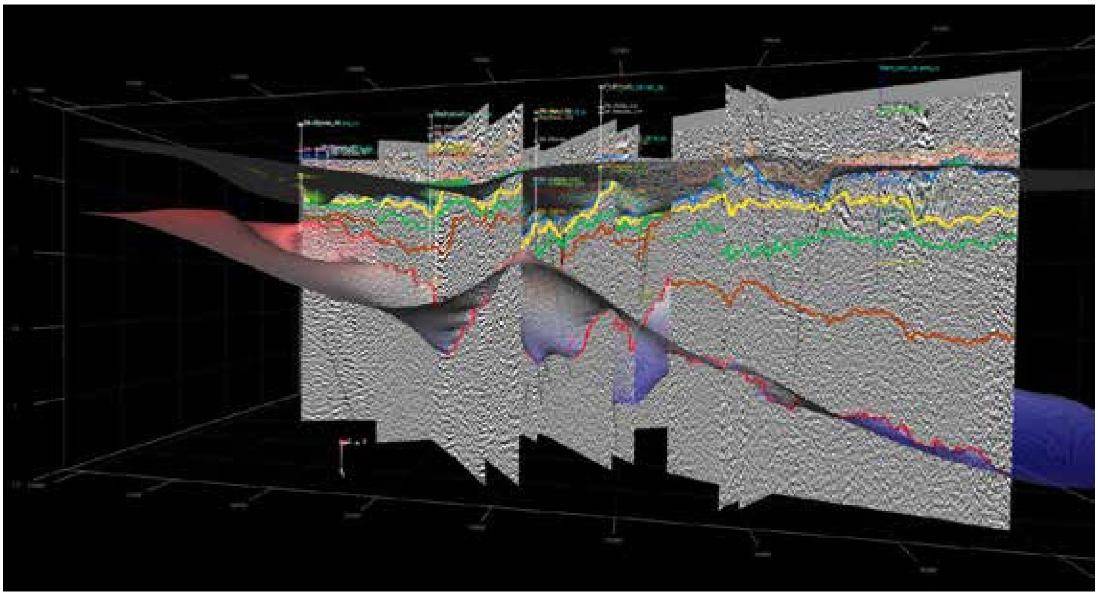

Figure 9 – Volumetric visualization of entire 2D seismic and well data set. The lower surface (red to blue transparency) corresponds to the top of basement interpolated and the upper surface (dark gray or blue) is the top of Ibura member. The yellow horizon, along the whole 2D seismic sections, is the top of Carmópolis Member.

New Attribute generation

Conveniently, we can define seismic attributes as "the quantities that are measured, computed or implied from the seismic data". Several authors introduced different kinds of attributes and their uses. The Seismic Attributes are classified basically into 2 categories: Physical attributes are defined as those attributes which are directly related to the wave propagation, lithology and other parameters. The Geometrical attributes are dip, azimuth and discontinuity.

Potential methods attributes also plays an important role in the interpretation of potential field data. There are many methods based on horizontal and vertical derivatives to delineate the edges of sources. It`s good to remain that our main aim with this case-study is to apply and adapt common attributes of potential methods for seismic interpretation. These new attributes are among the physical and geometric category and have the objective to detect edges that may be useful to highlight lithological contacts and failures seismic data. These new features enhance the signal when the data are of low quality and high signal noise.

In this order, we are pleasured to present to you our more recent seismic attributes, which were developed in-house at PETREC, in order to attend the mineral exploration industry:

a) THDPR: Total Horizontal Gradient with Phase Rotation

The spatial rate of change of seismic signal (in the X-direction) or Horizontal Derivative can help us to produce map edges, it means faults. We use Vertical Derivative (in the Z-direction) to detect vertical lithological contacts. Total Horizontal Derivative is the square root of the sum of squared x- and y- horizontal derivatives. It's commonly used as an edge-detection filter (Cooper & Cowan, 2008). We rotated the Total Derivative 90 degrees to enhance the visualization of lateral and vertical contacts in the seismic data.

b) ESR: Envelope of Seismic Reflection

Nabighian (1972) developed the notion of analytical signal, or energy envelope, of magnetic anomalies. Roest, Verhoef, & Pilkington (1992) showed that the amplitude of the analytic signal can be easily derived from the orthogonal gradients of the total magnetic fields. The vertical gradient is designed with the frequency`s gradient content in the seismic signal. These attribute easy both the faults and lithological contacts discrimination.

RESULTS

Among a best visual aspect, we obtained more precision and well-tie of our well and seismic data package. We did apply the new attributes described before, extracting higher quality of the Cretaceous levels in the seismic reflectors. As a comparative visualization we did plot the traditional Hilbert amplitudes attribute, followed down by the same seismic section (L-1541) improved it first by the ESR and secondly by the THDPR attributes and, besides each one of them, we did expose and their interpretation side by side (Figure 10Figure 11Figure 12Figure 13Figure 14Figure 15).

In the first couple of seismic profiles (Figure 10 Figure 13) we are illustrating a regional structural interpretation showing a bigger flower structure typical probably caused because the transtentional stress due to the transcurrecy

By applying the ESR attribute (Figure 11 Figure 14) some geological structures were better marked; and by applying the THDPR attribute (Figure 12 Figure 15), we observed that the seismic reflectors obtained a better lateral continuity

CONCLUSION

We developed in PETREC a couple of new seismic attributes and used them to extract the largest information possible from vintage public seismic data.

We achieved to get a better quality of image which permits the interpreter to do seismic interpretation on an easier and cheaper way, mainly for industrial mining projects.

We applied a fitted workflow and generated special seismic attributes which were useful to detect thin K-salts layers or bodies.

Thus, it was possible for us to perform the interpretation of seismic data in a more accuracy way, avoiding thinning and thickening and mistakes that could lead us to invest in drilling programs in wrong places.

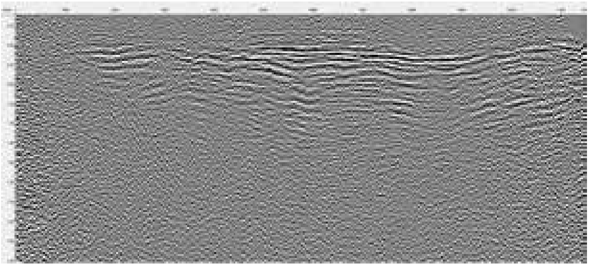

Figure 10 – L-1541 Hilbert amplitudes attribute

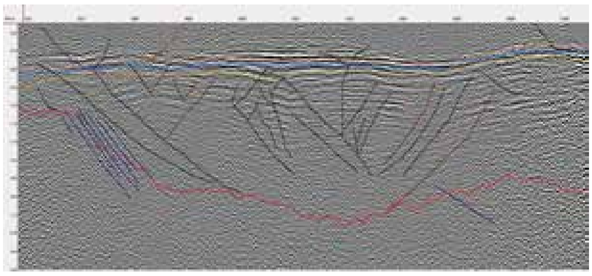

Figure 13 – L-1541 Hilbert amplitudes attribute interpreted

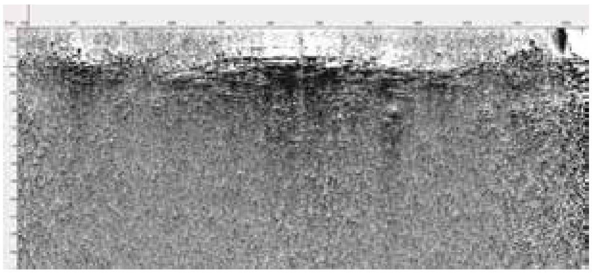

Figure 11 - L-1541 ESR attribute

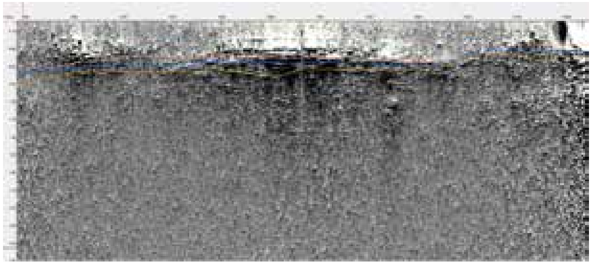

Figure 14 - L-1541 ESR attribute interpreted.

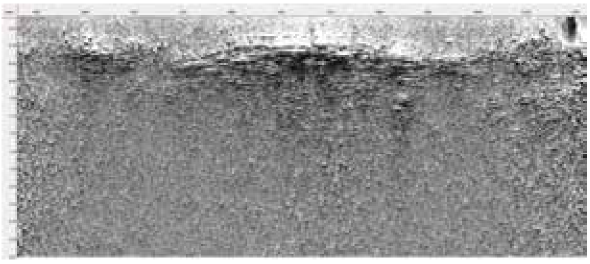

Figure 12 - L-1541 THDPR attribute.

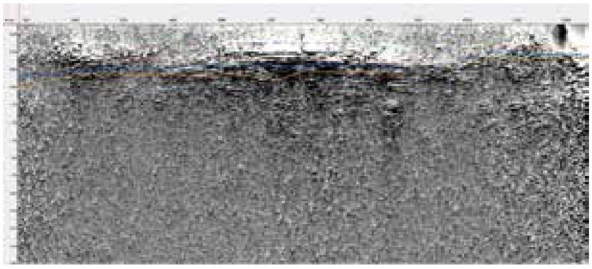

Figure 15 - L-1541 THDPR attribute interpreted.

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GEOMETALLURGICAL MODELLING TO HELP IN PREDICTING ZINC METALLURGICAL RECOVERY

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GEOMETALLURGICAL MODELLING TO HELP IN PREDICTING ZINC METALLURGICAL RECOVERY

ABSTRACT

A metal recovery at a mineral processing plant is affected by rock properties and process variables, including ore grain size liberation, head grades feeding the process, hardness among others. Additionally, metal recovery has not necessarily a linear relationship with those variables, which makes its prediction more complex. Geometallurgical tests results affect deeply the mining chain and economics and its correct modelling and prediction is of paramount importance to any mine operation. This study uses a multiple regression model to predict metallurgical recovery from geological variables, which is basically a statistical method that stablishes the relationship between a dependent variable Y, also known as response, and two or more independent variables $X(X_1,X_2,\ldots,X_n)$, called explanatories, with the constraint that there is a correlation between these and that. The methodology is illustrated through a case study in a major zinc deposit. The explanatory variables used were zinc head grade feeding the processing plant and the main ore typologies from the deposit. The independent variables were estimated via ordinary and indicator kriging at every mined block. The regression model with its associated regression error provides the means to randomly draw a value for ore metallurgical recovery at each block. The results showed that the use of geological variables for metallurgical recovery prediction provides reliable estimates as the results reconcile well against production data.

KEYWORDS

Geometallurgy, multiple regression, metallurgical recovery, indicator kriging, ordinary kriging.

INTRODUCTION

A good performance of a mineral processing plant is close linked to a proper knowledge of geology, mining, processing and metallurgy. Studying these areas simultaneously, observing relationship between them, permits to understand and quantify the variability of the ore and, in the same way, predicts the response of different rock types during mineral processing. The link between all areas involved in the ore production chain is called geometallurgy (Beniscelli, 2011). Geometallurgy aims at controlling variables which interfere directly or indirectly in the process, such as concentration of gangue minerals, ore grade, work index, reagent consumption, grain size distribution, ore liberation, hardness, grindability, humidity, concentrate quality, among others, in order to add economic value to the resource (Rossi e Deutsch, 2014; Deutsch, 2013; Beniscelli, 2011). It also enables the identification of environmental impacts and their subsequent mitigation, ore recovery increase, contaminants and by-products detection and quantification, and product quality assurance. Geometallurgy assists the selection of the size of the selective mining unit, the direction of process routes, the ore comminution stages, in addition to quantifying and determining the products used for flotation, and in metallurgy.

Geometallurgical variables modeling is complex, as it involves nonlinear variables and, usually, large number of them. Often, what is available are indirect measures of metallurgical variables. To deal with nonlinearity problem, additive variables can be estimated first and by a transfer function, as a regression model for example, the non-additive variables are estimated. As for the multiple variables issue, they should either be grouped or even eliminated. In the first case, a supersecondary variable is created. It gather secondary variables that have some similarity in a single variable. In the second case, it is eliminated variables with very low correlation with the response variable and whose sampling is too sparse, as well as variables with high correlation with another one, as these are redundant and generate bias (Deutsch, 2013; Boisvert *et al.*, 2013).

In this work ordinary kriging of zinc grade and indicator kriging of one of the geometallurgical typologies were employed to predict metallurgical recovery through a regression model. Geometallurgical typology was used during the prediction because it was noticed that each typology has a different response in mineral processing, as is showed in the scatterplot of Figure 1 between metallurgical recovery and the two main mined typologies: dolomitc breccia, BXD, and willemitic breccia, BXW. This figure shows also the scatterplot between zinc head grade feeding the process and metallurgical recovery.

Different from willemitic breccia and zinc grade, that have positive correlation with zinc recovery, dolomitic breccia has negative correlation with this variable. This occurs because this typology generates very thin material and hinders flotation process: it induces slime coating effect, which is the coating of the bigger particles by a fine layer of smaller ones.

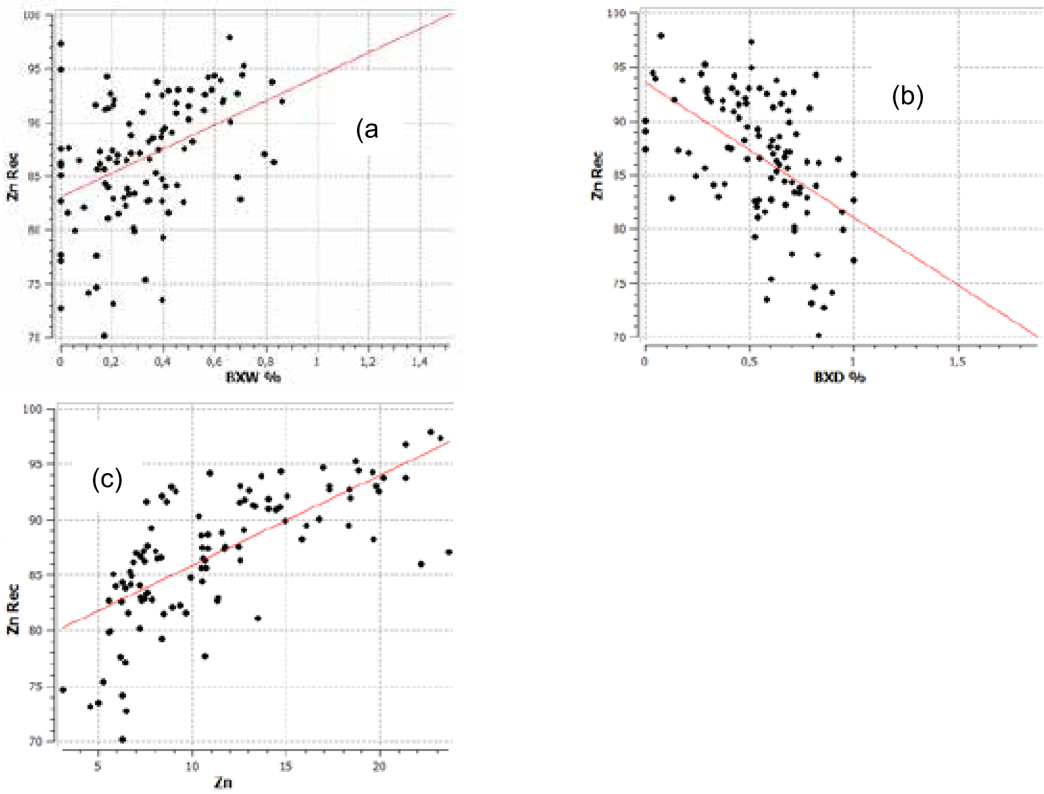


Figure 1 - Scatterplot of (a) zinc recovery versus BXW percentage, (b) zinc recovery versus BXD percentage and (c) zinc recovery versus zinc grade

The deposit being studied corresponds to the larger willemitic zinc deposit in the world, located at the northwest of Minas Gerais State, in Brazil. Mineralization is embedded in dolomitic rocks, in a hydraulic northeast-southwest breccia, and occurs in thin inclined to subvertical lenses. Zinc is present also in sphalerite (ZnS), hemimorphite ($Zn_4Si_3O(OH)_2$), smithsonite ($ZnCO_3$) and hydrozincite ($Zn_5(CO_3)_2(OH)_6$), but occurs at lower proportion in these minerals.

METHODS

Ordinary Kriging

Kriging is a generic term applied to several estimation methods that aim to minimize the estimation error variance (Sinclair e Blackwell, 2002). Through a variogram, optimal weights for nearby samples are established, thus avoiding bias and ensuring that the average error is zero. Therefore, kriging is known as the best linear unbiased estimator, BLUE (Isaaks & Srivastava, 1989).

Ordinary kriging is characterized for considering local fluctuations in average, limiting the stationarity to a local neighborhood. The estimate of a $Z^*(u_o)$ value is performed through a linear combination of near samples, as is shown in equation (1):

$$Z^*(u) = \sum_{\alpha=1}^{n(u)} \lambda_\alpha Z(u_\alpha) \quad \text{with} \quad \sum_{\alpha=1}^{n(u)} \lambda_\alpha = 1 \tag{1}$$

where $Z^*(u)$ is the point to be estimated, λ_α are the weights associate to samples and $Z(u_\alpha)$ are samples values at each point α. To minimize the error variance $\sigma_\varepsilon^2(u)$ under the unbiasedness constraint that the mathematical expectation of the error is zero, the weights are obtained from the following ordinary kriging system:

$$\begin{cases} \sum_{\beta=1}^{n(u)} \lambda_\beta \, \gamma(u_{\alpha,} u_\beta) - \mu(u) = \gamma(u_{\alpha-} u) & \alpha = 1, \dots, n \\ \sum_{\beta=1}^{n(u)} \lambda_\beta(u) = 1 \end{cases} \tag{2}$$

where $\gamma(u_\alpha, u_\beta)$ is the semivariogram between two points u_α, and u_β, $\gamma(u_i, u)$ is the semivariogram between one point u_i and the point to be estimated u, and μ is Lagrange multiplier required for minimizing the error variance (Goovaerts, 1997; Yamamoto & Landim, 2013). It is calculated $N+1$ partial derivative with respect to λ_α and μ, they are equated to zero and they lead to $N+1$ equations with $N+1$ unknown values whose solution results in N weights λ_α under the unbiasedness constraint $\sum \lambda_\alpha = 1$, thus minimizing the error variance (Soares, 2006). The minimized error variance becomes:

$$\sigma_\varepsilon^2 = C(0) - 2\sum_\alpha \lambda_\alpha \, C(u_\alpha - u) + \sum_\alpha \sum_\beta \lambda_\alpha \lambda_\beta \, C(u_{\alpha-} u_\beta) \tag{3}$$

where $C(0)$ is the covariance *a priori* of $Z(u)$.

Kriging is widely used in mining, agricultural science, environment, hydrogeology, among others, for it weights samples according to its location and clustering, which makes it the best and most accurate estimator of spatial variables .

Indicator kriging

Indicator kriging is usually employed to estimate non-linear variables and when the aim is to estimate the distribution rather than a value at some location. It offers flexibility when dealing with extreme values and with different continuity patterns, as it defines areas with greater or lesser probability of occurring a specific event. Indicator kriging can be applied to both continuous and categorical variables.

Indicators data of a random variable $I(u;z_k)$ generate a conditional probability function that is updated locally, from which is obtained a conditional cumulative distribution function, ccdf, at each unsampled location. This function depicts thus the possible values of an estimated point, being determined as

$$F(u, z_k|(n)) = \text{Prob}[Z(u) \leq z_k|(n)] = \frac{1}{n} \sum_{\alpha=1}^{n} i(u_\alpha; z_k) \qquad k = 1, \dots, K \tag{4}$$

where $F(u,z_k)$ is the proportion of z samples at u below cutoff z_k, underlain in n neighboring samples (Rossi & Deutsch, 2014; Yamamoto & Landim, 2013).

The indicator of a regionalized variable $I(u;z_k)$ has two possible values: zero, to values over a specific cutoff, or one, to values below this cutoff, according to equation (5):

$$i(u_\alpha; z_k) = \begin{cases} 1 & if \quad z(u_\alpha) \leq z_k \\ 0 & if \quad z(u_\alpha) > z_k \end{cases} \qquad k = 1, \dots, K \tag{5}$$

Indicator kriging of a random variable gives the ccdf estimation at a given cuttof z_k. Data of a continuous attribute z are discretized into k classes, and is calculated to each class the proportion of z-

data that does not exceed a given cutoff z_k. The ccdf built from the kriging of k classes represents a model of probability of uncertainty over the unsampled values $z(u)$ (Deutsch & Journel, 1998).

GEOLOGY

The zinc deposit object of this case study is located in Vazante municipality and is part of the Brasilia Belt. This belt is an orogen formed by nappes and thrusts east vergent. It extends over thousand kilometers along the western border of São Francisco craton and shows north-south direction. Vazante group is a unit of Brasilia Belt. This group was first defined by Dardenne (1979) and has a pelitic-carbonate marine sequence, being Paleoprotezoic/Neoproterozoic.

This zinc deposit is classified as Vazante Deposit type for some authors (Monteiro, 2002; Hitzman *et* al, 2003) because it is hypogenic and non-sulphide, having thus a peculiar mineralization. Hot metalliferous fluids with low sulfur in a temperature around 250 ºC and meteoric fluids along the Vazante Fault Zone generated the willemite mineralization (Lemos, 2011).

The rocks of the deposit belong to Serra do Garrote and to Serra do Poço Verde Formations – this last being the host of the mineralization. Serra do Garrote Formation has a thick package of carbonaceous slates with thin quartzite intercalated and Serra do Poço Verde, which is at the top, has mainly dolomites, besides slates and metasiltstone. The mineralization occurs in a breccia associated to the Vazante fault zone. There are three breccia types: willemitic breccia (BXW), which is the main mineralized rock type, dolomitic breccia (BXD) and hematitic breccia (BXH).

PROCEDURE

Prediction of zinc metallurgical recovery involved ordinary kriging of zinc grade and indicator kriging of dolomitic breccia. Regression model was established after factor analysis and hypotheses test based on F statistics.

First, metallurgical tests were performed at a pilot plant, in order to verify lithotypes behavior in the mineral processing route. The tests consisted of grinding, classification via wet sieving, grade analysis, froth flotation and mineralogical characterization via MLA (mineral liberation analyzer). A total of 207 boreholes were tested comprising 104 geometallurgical samples.

Besides ore grade, lithotypes samples were also used for building the geometallurgical model. For this, it was utilized 5,297 boreholes with 337,000 samples. The deposit lithotypes were grouped into six typologies, according to their behavior at processing plant:

- Typology I: willemitic breccia;
- Typology II: dolomitic breccia;
- Typology III: hematitic breccia;
- Typology IV: dolomite;
- Typology V: clay material (weathered rocks, fractures filling) and marl;
- Typology VI: slate, phyllite, shale and metabasic rock.

Multiple linear regression

To define the regression model, it was built a correlation matrix between geometallurgical typologies percentage in a stope and metallurgical recovery. Then, a regression was adjusted with the prior defined explanatories variables and, after this, an analysis of variance was conducted to test the significance of the regression. Another test was run to examine the importance of each regression coefficient and, thus, a final regression model was established. The regression model was obtained using the software *sabor.exe* from the GSLib library (Deutsch and Journel, 1998; Zagayevskiy and Deustch, 2011). *Sabor.exe* does sensitivity analyses based on linear regression and quantifies the influence of each variable in the response model.

Zinc grade ordinary kriging

It was built a zinc grade model using ordinary kriging. The distances in search ellipsoid were the same found in analysis of spatial continuity. Variograma showed maximum continuity along azimuth 55 º.

Dolomitic breccia indicator kriging

To estimate dolomitic breccia ocurrence, the lithotype information was transformed into indicators according equation 6, where BXD presence is coded as 1 and its absence, as 0:

$$i(u_\alpha ; s_l) = \begin{cases} 1 & if \;\; s(u_\alpha) = s_l \\ 0 & otherwise \end{cases} \tag{6}$$

being $i(u_\alpha{:}s_l)$ the indicator of category s_l at location u_α.

Analysis of spatial continuity showed maximum continuity along azimuth 50º. After indicator kriging estimate, data were post processed for correction of order relation deviations. Both dolomitc breccia indicator kriging and zinc grade ordinary kriging were estimated at a 12x12x3 m blocks.

RESULTS AND DISCUSSION

Linear regression

The correlation matrix (Figure 2) showed that the geometallurgical typologies that are correlated to the metallurgical recovery are dolomitc breccia and willemitic breccia. Knowing this, a prior regression was done with these typologies, and next it was processed an analysis of variance (ANOVA) to test the significance of the regression (Table 1). In ANOVA, total variance of a response variable is partioned in variance between the group average and the variance of the experimental error, i.e., variance within the group. The test checked the null hypothesis H_0 that all regression coefficients are zero ($\beta_1 = \beta_2 = \ldots = \beta_k = 0,\ k>1$) against the alternative hypothesis H_1 that at least one coefficient is nonzero. As the calculated F (16.28) is greater than the tabulated F (2.09), and the p-value is less than the stablished significance level α (0.05), the null hypothesis was rejected and the proposed model was accepted.

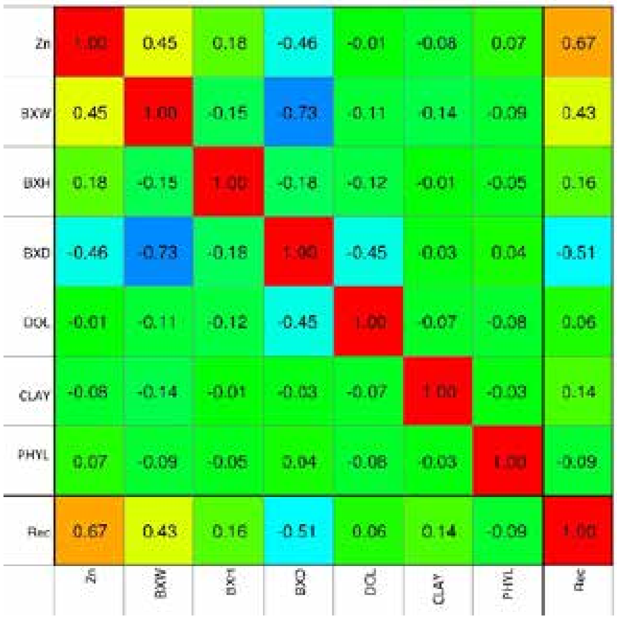


Figure 2 - Correlation matrix between geometallurgical typologies percentage, zinc grade and metallurgical recovery

Table 1– Analysis of variance to test significance of the regression (ANOVA table)

	Sum of squares	Degrees of freedom	Mean of squares	F-value	p-value	Accept in α=0.05
Regression	1774.272	7	253.467	16.277	0	yes
Residual (Error)	1762.242	97	18.167			
Total	3536.515	104				

Since the model was considered plausible, each regression coefficient were assessed to determine their individual influence in the model. In this test, the null hypothesis H_0 is that the regression coefficient is zero against the alternative hypothesis H_1 that the regression coefficient is not zero, with a significance level α of 0.05. The test results can be seen in Table 2, showing that the model can be more effective with the removal of willemitic breccia, BXW, and keeping dolomitic breccia, BXD, and zinc head grade.

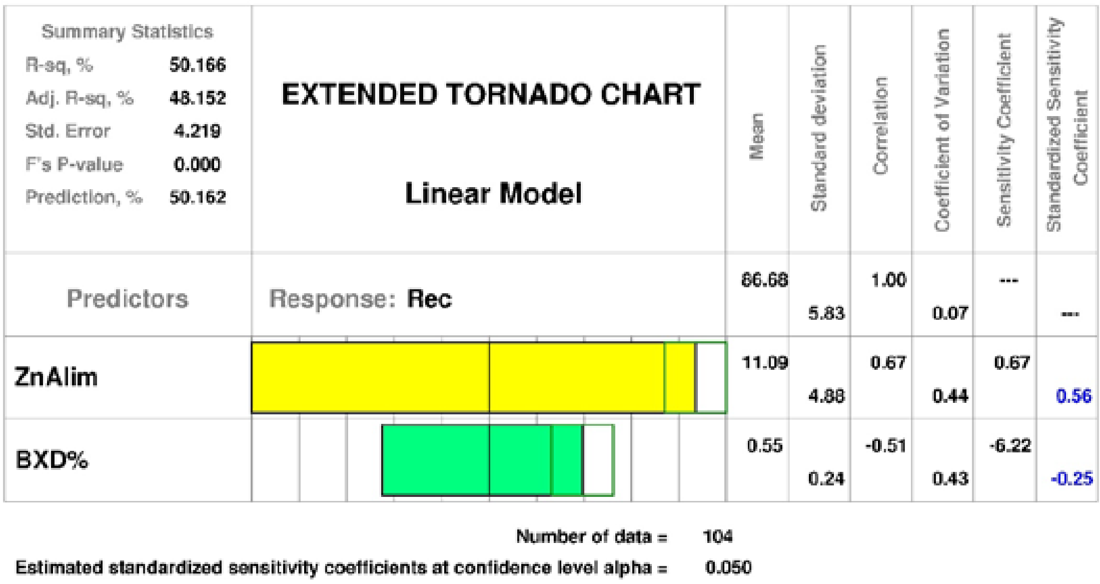
Table 2– Test for individual regression coefficients

Predictor	Coefficient	Std Coefficient	F	Accept at α = 0.05
Zn grade	0.667	0.559	46.352	yes
BXW%	-0.272	-0.010	0.008	no
BXD%	-6.377	-0.258	5.812	yes

After the regression coefficients were determined, linear regression was adjusted and an Extended Tornado Chart was plotted. This chart is a graphical plot that summarizes sensitivity analysis results. Sensitivity coefficients showed in the chart capture each predict variable influence in the response model while standardized sensitivity coefficients show the influence of uncertainty from each predict variable on model response uncertainty. The sensitivity coefficients correspond to the regression coefficients.

The chart reveals that adjusted R^2 of model is 48.15%; which is a reasonable value; the standardized error is 4.22; p-value is 0 and prediction power of the model, i.e., the percentage ratio of standard deviation of predicted and actual values, $predic = \hat{\sigma}/\sigma$, is 50.16%. More statistics can be viewed on Chart 1.

Chart 1- Extended Tornado Chart



Regression model was defined as

$$\text{Recovery} = 86.68266 + 0.66548*(\text{Zn\_grade} - 11.09231) - 6.21621*(\text{BXD\%} - 0.5493876) \quad (2)$$

Kriging

Both zinc grade ordinary kriging and BXD% indicator kriging honored the statistical summary of input data (Table 3). The decreased variance in the block model estimated is due to smoothing caused by kriging.

Table 3 – Statistics of original declustered data, estimated zinc grades and BXD percentage

Variable	Zn declustered	Zn estimated	BXD declustered	BXD% estimated
Number of samples	23,481	4,947,542	5.464.269	4.878.873
Minimum	0.05	0.59	0.00	0.00
Maximum	57.99	49.50	1.00	1.00
Mean	19.99	20.65	0.15	0.15
Variance	178.45	57.81	0.36	0.31

Recovery

Metallurgical recovery was calculated according to equation 2, using Zn grade estimated and BXD% estimated in each stope available. The recovery estimate histogram is shown in Figura 3. It shows a mean recovery of 86.78% for the stopes estimated.

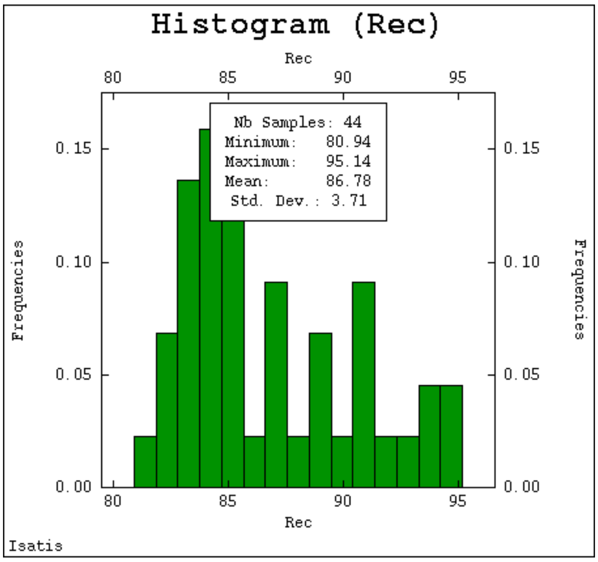


Figure 3 - Histogram of zinc metallurgical recovery estimated

Metallurgical recovery calculated values were compared against laboratorial tests of recovery for validation. The mean calculated recovery usually presented similar values when compared to the mean recovery from laboratorial test (Figure 4). The result showed an average residual close to zero, as desirable (Table 4, Figure 5). It showed, either, that 50% of the data have a residual lower than 2.47%, and 75% of the data have a residual lower than 4.66%, with a mean percentage of 3.92% of residual. Therefore, it was obtained a small residual and the regression model is suitable for estimating the metallurgical recovery.

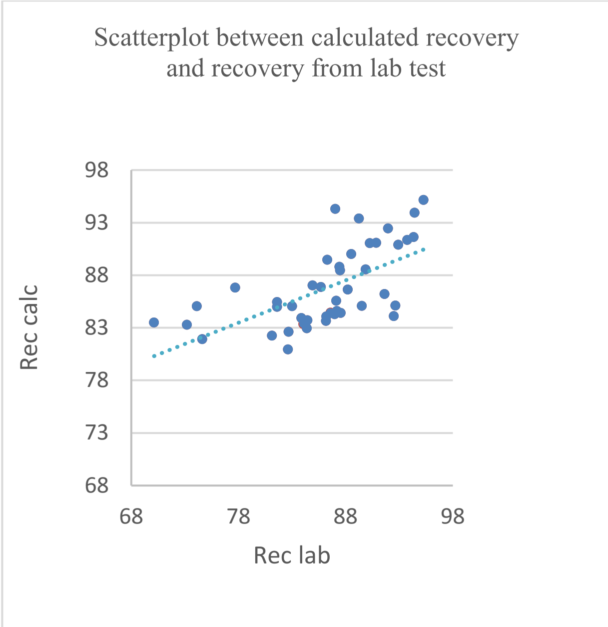


Figure 4 - Scatterplot depicting the calculated recovery *versus* recovery from laboratorial tests

Table 4 – Statistcs of Residual

	Minimum	Maximum	Mean	Q1	Median	Q3
Absolute residual	-13.36	8.39	-0.60	-2.07	0.1	2.14
% Residual	0.05%	19.05%	3.92%	1.38%	2.47%	4.66%

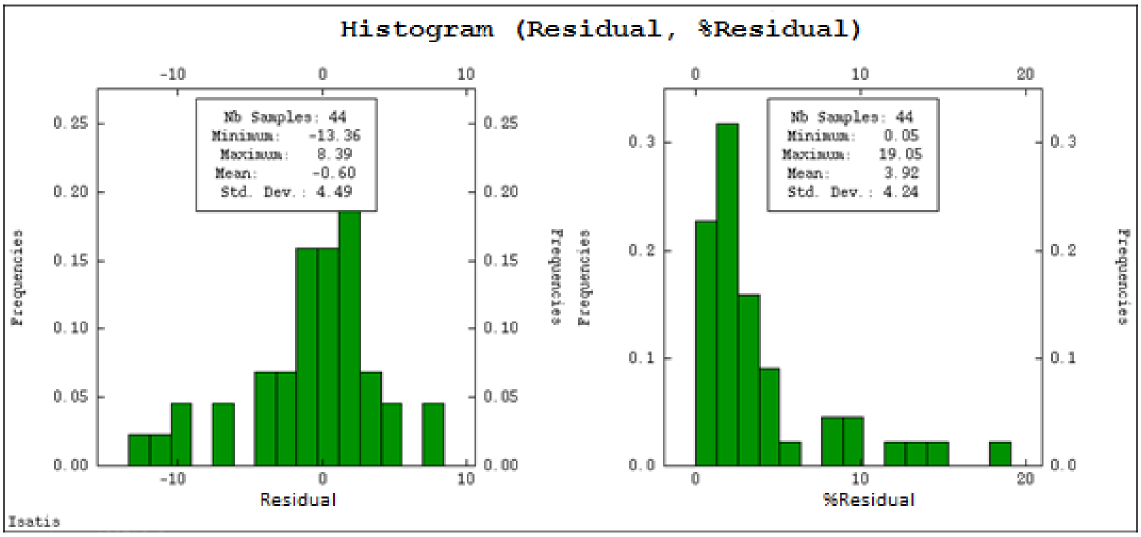


Figure 5 – Histogram of residual between calculated and lab test recovery (absolute values and percentage, respectively)

CONCLUSIONS

Geometallugy studies are highly important for defining the ore to be processed, how it should be processed and what would be the expected recovery. The use of geological variables, including the metal feeding grade provided a more adequate model to predict ore metallurgical recovery instead of considering only the metal grade, since the residual obtained showed a mean percentage of 4%, and 75% of data have residual lower than 5%. Therefore, by considering the variables that significantly affect recovery, whether in a negative or positive way, led to a more accurate and precise prognosis model for metallurgical recovery. As a result, the model can help in mine planning, beneficiation and metallurgical processes, minimizing unexpected results during mineral processing.

The estimation via kriging corroborated the concept that it provides a good unbiased estimator, as the estimated model reconcile well with original data. The indicator kriging map derived of lithotype BXD was obtained faster and at less effort compared to manual modelling through vertical sections.

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MINERAL EXPLORATION PROCEDURE(S) IN BRAZIL UNDER A NEW LEGAL SCENARIO

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MINERAL EXPLORATION PROCEDURE(S) IN BRAZIL UNDER A NEW LEGAL SCENARIO

ABSTRACT

Brazil is one of the most important mining countries of the world. Since the year of 2011, the Brazilian government intends to modify the mining legislation currently in force (mainly composed by the Decree-Law #227/1967 and Decree #62.934/1968) and, for this purpose, at least 8 legislative bills were submitted for the appreciation of the Brazilian National Congress. Even though the proposed changes comprise regulatory, tax and institutional aspects, this paper aims at analyzing the main modifications concerning the regulation of the mineral exploration phase, which, under the new legal framework, may be subject to procedural alterations. Therefore, the paper presents the current exploration phase procedure and describes the prospective modifications, not only focusing on financial matters, but also indicating the new competitive and granting criteria to be potentially implemented in Brazil. Such key subject is extremely valuable for national and international mining companies once the possible legal alterations on the mineral exploration phase procedure may impact future investments in the mining activity in Brazil. In view of this, the paper poses the current legislative scenario concerning the bills and law proposals in order to enable the mining companies to better prepare themselves for the possible regulatory changes that may arise from the New Brazilian Mining Code.

KEYWORDS

Mineral exploration, exploration phase, legislative bill, Brazilian law, Mining Code.

INTRODUCTION: BRAZIL, A COUNTRY WITH EXTENSIVE MINING POTENTIAL

According to several mining surveys, Brazil is one of the most important mining countries in the world and one of the most relevant targets for international investments in mining.

Among the many reasons that may be claimed to justify the Brazilian relevance in the international mining scenario, the natural richness of the Brazilian territory seems to represent the most obvious and plausible explanation. In fact, there is a wide range of mineral occurrences throughout the national territory, encompassing, for instance, metallic minerals, aggregates, mineral water, precious stones, noble metals, rare earths, fertilizers, etc.

Under a domestic view, the mining sector represents a vigorous and strategic area for the national economy. The importance of the sector is clearly indicated by the significant rates of job creation and tax collection that result from the entire mining productive chain.

As per the Information and Analysis on the Brazilian Mineral Economy (IBRAM, 2012, page 10), "studies conducted by the Minister of Mines and Energy's Secretariat for Geology, Mining and Mineral Processing show that the multiplier effect of job creation is 1:13 in the mining sector, i.e., for every job created in the mining sector another 13 jobs (direct jobs) are generated along the supply chain.

Therefore, in 2011 the mining sector employed about 2.2 million workers directly, not including the job posts generated in research, exploration and planning, and the manpower employed in the mines." (IBRAM, 2012, page 10).

It is important to note that, pursuant to the same study (IBRAM, 2012, page 10), "informal work arrangements in the mining industry cannot be ignored, especially when it comes to minerals of high unit value (gems, gold, diamond, etc.), and also in the extraction of mineral aggregates for the civil construction sector.

Many workers across Brazil's 5,565 municipalities fail to be covered by official statistics. Estimates, though very inaccurate, indicate somewhere between 300 thousand and 500 thousand workers" (IBRAM, 2012, page 10).

In regards with the tax income, the Financial Compensation for Mineral Production (Brazilian Portuguese acronym "CFEM") represents one of the most important mining charges in Brazil. The payment of CFEM is stipulated by the Brazilian Federal Constitution and is due once the mining titleholder conducts exploitation works.

The amount collected by the entrepreneur is distributed between federal authority (on the proportion of 12% of the total amount), the state where the mineral resource is exploited (on the proportion of 23% of the total amount) and the municipality where the mineral resource is exploited (on the proportion of 65% of the total amount). The rates are based on the net revenue and vary from 0.2% to 3% according to the mineral substance exploited.

Pursuant to Information and Analysis on the Brazilian Mineral Economy (7th Edition), "in 2012, the royalties (CFEM) reached a new record of R$1,832 billion", which demonstrates the importance of such income for the financial health of several states and municipalities that host mining enterprises (IBRAM, 2012, page 9).

Besides all the above mentioned, the importance of the mining sector for the national economy surpass its positive effects on employment and tax statistics.

Aside from that, the mineral commodities occupy a significant place on the Brazilian exports composition. The iron ore, for instance, is a traditional component of the Brazilian international sales and, thus, contributes – significantly - for the profitability of the mining activity in the country.

THE CURRENT BRAZILIAN MINING LEGISLATION

The mining activities in Brazil are mainly regulated by the Decree Law #267, enacted on February 28th, 1967 (the Brazilian Mining Code), the Decree #62,934 , enacted on July 2nd, 1968 and further rules issued by the Minister of Mines and Energy and the General Director of the National Department of Mineral Production.

The Ministry of Mines and Energy and National Department of Mineral Production are the main regulatory agencies in charge of the inspection of the mineral activities throughout the Brazilian territory.

Due to this fact, a wide range of mineral procedures are ruled by normative acts enacted on federal level by these authority instances.

Considering that the Brazilian Mining Code was enacted in 1967, many governors qualified the legislation as outdated and inadequate to rule the modern mining activity in the country.

Therefore, the Brazilian Government has been inclined to modify the Brazilian Mining Code since the year of 2011. For this purpose, many different legislative bills were submitted to the appreciation of the Brazilian National Congress.

Under a general view, the proposed modifications contemplate tax/fiscal, regulatory and institutional matters.

Nonetheless, this paper aims at analyzing the main modifications concerning the regulation of the mineral exploration phase, which, under the new legal framework, may be subject to procedural modifications.

MINERAL EXPLORATION PROCEDURE IN BRAZIL: CURRENT LEGAL SCENARIO

According to article 176 of the Brazilian Federal Constitution, the mineral resources are property of the country and may be explored/exploited by individuals and companies (who shall be Brazilian citizen or company organized under Brazilian law with headquarters and administrative body located in the country) through federal authorization.

The Brazilian mining legislation prescribes different regimes for the performance of mining activities considering, for instance, the type of the mineral substance or the stage of the mineral activity.

Nevertheless, the performance of mining activities in Brazil is usually conducted under the authorization (for mining exploration) and concession (for mining exploitation) regime.

On broad terms, under this regime, the interested party in developing mining activities in Brazil shall request the respective authorization before the National Department of Mineral Production.

The current mineral exploration in Brazil is based on the *first come first serve* criteria. Therefore, the applicant who firstly submits the respective request shall have priority over the area whether the (i) application contains all the prerequisites established by the mining legislation and (ii) the area is not covered by any prior request or title.

The Exploration Permit may be granted to individuals or companies with a period that might vary from 1 (one) year to 3 (three) years (able to be extended).

During the exploration phase, the titleholder shall comply with certain obligations prescribed in the mining legislation. Amongst such obligations, it is worth to highlight the mandatory payment of the Annual Tax per Hectare which is due to the National Department of Mineral Production (charged on the amount of R$3.06 per hectare during the original term of the Exploration Permit and R$4.63 per hectare during the extension term of the Exploration Permit).

The exploration works developed by the titleholder are essential for the definition of the technical and economic feasibility of the mineral reserve and consequent obtainment of the Exploitation Permit (or Mining Concession) that allows the extraction of the mineral substance.

It is important to note that, under the Brazilian legal framework, the surface rights are distinct from the mining rights and, thus, shall be negotiated separately. Therefore, in order to perform its exploration works, the titleholder shall pay to the surface owner indemnification and compensation costs in regards to the usage of the real estate.

MINERAL EXPLORATION PROCEDURE IN BRAZIL: PROPOSED LEGAL SCENARIO

Since the year of 2011, the intention to modify the Brazilian Mining Code currently in force has occupied the federal government agenda.

Many reasons are usually raised to justify the task and guide the purpose. Amongst the most common explanations, the governors in favor of the legal changes indicate, for instance, the need to update the Brazilian Mining Code (enacted in the year of 1967), the need to replace the National Department of Mineral Production for a regulatory agency (invested with administrative and financial autonomy) and the need to increase the public income that results from the mineral activities.

On this context, from 2011 to the current year, ten legislative bills have been submitted to the appreciation of the Brazilian National Congress concerning legal changes on the mining legal framework. They were numbered as: 37/2011; 463/2011; 3403/2012; 4679/2012; 5138/2013; 5306/2013; 5807/2013; 8065/2014; 3587/2015 and 3726/2015.

Considering the theme similarity and in order to better organize and optimize their respective appreciation, the legislative bills were attached to the bill #37/2011 which means that the examination of each individual bill shall not be conducted in disconnection with the other legal texts.

In face of the specific purpose of this paper and as the above mentioned legislative bills contemplate a wide range of mining issues, it shall be highlighted the bills that contain provisions regarding modifications on the mining exploration procedure, as follows.

Legislative Bill #37/2011: the performance of mining activities (including the exploration works) shall be preceded by a bidding process. It is important to highlight that, according to the provisions established by the original version of this specific legislative bill, only companies (not individuals) would be able to participate in the respective bidding process.

Nonetheless, under the regular legislative procedure, the congressman ahead of the initial legislative works presented to the House of Representatives a substitutive version of the bill which contemplates several suggestions of the productive sector.

This modified version prescribes the possibility of the grant of mining titles to individuals (not only to companies) and stipulates other criteria for the issuance of mining titles (not only through bidding processes). Moreover, during the mining exploration phase, the titleholder shall pay an Inspection Tax on amounts that may vary from R$2,500.00 to R$80,000.00 (depending on the size of the company).

Legislative Bill #463/2011: the *first come first serve* criteria is maintained under the exploration phase. Nevertheless, once the Final Exploration Report is approved, a bidding process is initiated for the selection of the future holder of the mining concession.

Therefore, the original titleholder of the exploration permit may not win the bidding process and, thus, may not be entitled to the mining concession. In such case, the original titleholder of the exploration will be entitled to receive a monthly payment as a financial participation in the economic results of the exploitation activities.

Legislative Bill #4679/2012: this specific legislative bill governs the exploitation of strategic mineral reserves. The proposed provisions do not stipulate the rules for the exploration phase. Nonetheless, the legislative bill prescribes that the exploitation phase shall be preceded by a bidding process.

In case the exploration permit titleholder does not win the bid, the winner shall reimburse the costs of the exploration works. Moreover, the exploration permit titleholder will be entitled to a 10% participation on the net revenue resulted from the exploitation activities.

Legislative Bill #5306/2013: the mining exploration phase shall be governed by the *first come first serve* criteria or shall be preceded by a bidding process under certain circumstances, such as on the cases that the previous titleholder resign on the exploration permit or the exploration permit is somehow revoked or extinct.

Under the exploration phase, the respective titleholders shall make an annual payment for the occupation of the area in favor of the federal authority. The amount of the payment shall be based on the extension of the area occupied by the titleholder.

Legislative Bill #5807/2013: the original version of this specific legislative bill stipulated the performance of bidding procedures as a general rule for the issuance of exploration permits. After several claims mainly raised from the mining entrepreneurs, a substitutive version was prepared by the congressman in charge of the analysis of the bill. Under this new version, the bidding process criteria is entirely replaced by the *first come first serve* criteria.

The payment of an annual amount for the occupation of the area is due by the titleholder in favor of the federal authority.

Legislative Bill #8065/2014: this specific legislative bill provides for the exploration and exploitation activities regarding the mineral substances “potassium” and “phosphate”. According to the proposed provisions, the issuance of exploration permits is based on the *first come first serve* criteria. Among the obligations applicable to the exploration phase, the titleholder shall, for instance, make the investments indicated on the Exploration Permit Plan and the annual payment regarding the occupation of the area.

CONCLUSIONS

As already indicated, the modification of the Brazilian Mining Code (and, consequently, of the mining exploration procedures) has been on the table of the National Congress since the year of 2011.

In 2013, the Brazilian Federal Government presented to the National Congress the bill #5807/2013 and centered the subject on special emphasis.

On the occasion, the president (Mrs. Dilma Rousseff) qualified the bill as a priority issue for the appreciation of the congressmen, which means that the National Congress would have 100 days to conclude the legislative procedure.

Considering the short time and the relevance of the matter, many politicians and the productive sector made a huge pressure to convince the president to revoke the priority order.

After all, the bill, on its original version, would provoke several and profound modifications on the current legislation which – according to the mining sector - could not be deeply discussed and appreciated during a so short period. To illustrate the complexity of the discussion, the original version of the bill was subject to 372 amendment proposals by the congressmen of the House of Representatives.

In view of this, the president called the bill off from the priority agenda of the National Congress in September of 2013 and, ever since, the subject seems to have been called off from the agenda of the presidency as well.

Nevertheless, the official movement of the federal government in order to modify the mining legislation, especially in the year of 2013, caused a scenario of legal and economic uncertainty which discouraged national and international investments in mining activities.

Even though the enactment of a new Brazilian Mining Code no longer occupies a central place on the federal government agenda, it is possible to identify that the future modifications in the mining legislation regarding the exploration procedures are guided by an intent to include a competition criteria for the issuance of exploration permits (such as bidding processes) and by an intent to increase rates of tax or compensation due to the regulatory authorities as a result of the performance of exploration activities (by means of an inspection fee or payment for the occupation of the mining area).

Considering the lack of certainty regarding the final term of the legislative process, the urgent modifications on procedural aspects of the mining legislation are being implemented through the enactment of administrative ordinances.

During the last year, for instance, the National Department of Mineral Production issued at least 15 administrative ordinances comprising relevant modifications of the mining legislation.

In view of this, a close monitoring of the Brazilian legal scenario is highly recommended for all those involved in the Brazilian mining sector (investors, titleholders, stakeholders etc.) in order to better prepare themselves for the legal modifications that may be implemented in a possibly near future.

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MINERAL ZONNING OF THE ALTO SERRA BRANCA PEGMATITE (NE BRAZIL): INSIGHTS FROM GEOLOGICAL MAPPING AND SURFACE PROSPECTING

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MINERAL ZONNING OF THE ALTO SERRA BRANCA PEGMATITE (NE BRAZIL): INSIGHTS FROM GEOLOGICAL MAPPING AND SURFACE PROSPECTING.

ABSTRACT

Granitic pegmatites represent igneous rocks with economic importance, once it tend to concentrate considerable contents of Be, Li, Nb-Ta, rare earth elements, besides several gemstones. In the Seridó Region, which occupies part of the Paraíba and Rio Grande do Norte states, there are several pegmatitic bodies, that represent strategic sources for non metallic minerals in Brazil. Among these, the Alto Serra Branca (ASBP) pegmatite occurs in the vicinity of the Pedra Lavrada Town. This pegmatite is part of the Borborema Pegmatitic Province, which is inserted in the Seridó Fold Belt of the Rio Grande do Norte Domain (Borborema Province). Likewise other pegmatites in the region, the ASBP pegmatite lacks of study geological studies, which motivated the development of the present work trough the cooperation between Universidade Federal de Campina Grande (UFCG) and Centro de Tecnologia Mineral (CETEM). Field studies and geological mapping has revealed that the ASBP follows a regional structural trend in the NE-SW direction, which is controlled by strike-slip foliation observed in the hosting schists. Locally, this pegmatite is cut by several fractures. On the other hand, this body is characterized by a typical mineral zoning. From its border to its core, the different zones were defined as: i) external intermediate zone, ii) internal intermediate zone and iii) core zone. The first one is composed by potassic feldspar and muscovite, besides black tourmaline and punctual occurrences of amblygonite, whereas the second one is composed by quartz + feldspar developing graphic intergrowth, besides amblygonite and schorlite in a lesser extent. At last, the core zone is mostly formed by quartz crystals with variable colors. The presence of these well defined zones allowed us to classify the ASBP as an heterogeneous type. In addition, this pegmatite hosts a potentially valuable mineralogical assemblage, including gemstones (eg. elbaite), mica, feldspars and cassiterite. These minerals occur disseminated among the different zones. These occurrences indicate that the ASBP might be an important prospective target for future specific works.

KEYWORDS

Pegmatites, Borborema Pegmatitic Province, Alto Serra Branca, Northeast, Brazil.

INTRODUCTION

In the Seridó region (NE Brazil), which covers the Paraíba (PB) and Rio Grande do Norte (RN) states, there are several pegmatitic bodies that correspond to strategic sources for industry minerals and gemstones in Brazil. In the vicinity of the Pedra Lavrada (PB) town, the main pegmatitic bodies are Alto do Feio, Capoeira, Boqueirão and Alto Serra Branca (ASBP). The latter corresponds to the main focus of this research,

This region has its economic potential know since the 1930´s, being explored form several mineral resources, including feldspars, quartz, beryl. In addition, gemstones including the famous Paraíba

Tourmaline are present in this context, being mainly extracted by small mining companies (Vasconcelos, 2006).

Over the last decade, several scientific and technology-related works has been developed in the region, between cooperation between public institutions and private companies, aiming to develop the mineral sector in the region. However, the specific geological Field aspects are still poorly known, including geological mapping of pegmatites and mapping of their main mineral zones.

The main goal of this research is to present new cartographic and basic geology data of the Alto Serra Branca pegmatite, aiming to contribute to the development of the geological knowledge of the area for future prospective worlds.

GEOLOGICAL SETTING

The ASBP is located in the southern portion of the Borborema Pegmatitic Province (Figure 1), which is part of the Rio Grande do Norte Domain of the Neoproterozoic Borborema Province (Brito Neves et al., 2000; Santos et al., 2000).

The Borborema Province was defined by Almeida et al., (1981) as a brasiliano-related geotectonic entity, which was subjected to several compressive and extensional deformation episodes that occupies the NE portion of the South-America platform.

Within the Rio Grande do Norte Domain, pegmatitic rocks are intrusive in biotite schists and garnet-biotite schists of the Seridó Formation of the Seridó Fold belt. According to Van Schmus et al., (2003), these rocks were recrystallized in a LP/HT type metamorphism, being Neoproterozoic in age and constituted by a W and rare-metals-litho-types.

In this context, the ASBP is part of several magmatic intrusions that compose the Borborema Pegmatitic Province. This geological region is located within the Seridó Fold-belt. This province was Pioneer defined by Scorza (1944), being its economic potential known since the first World War, being intensively affected by several ductile structures (Araújo et al., 2011, Beurlen et al., 2014).

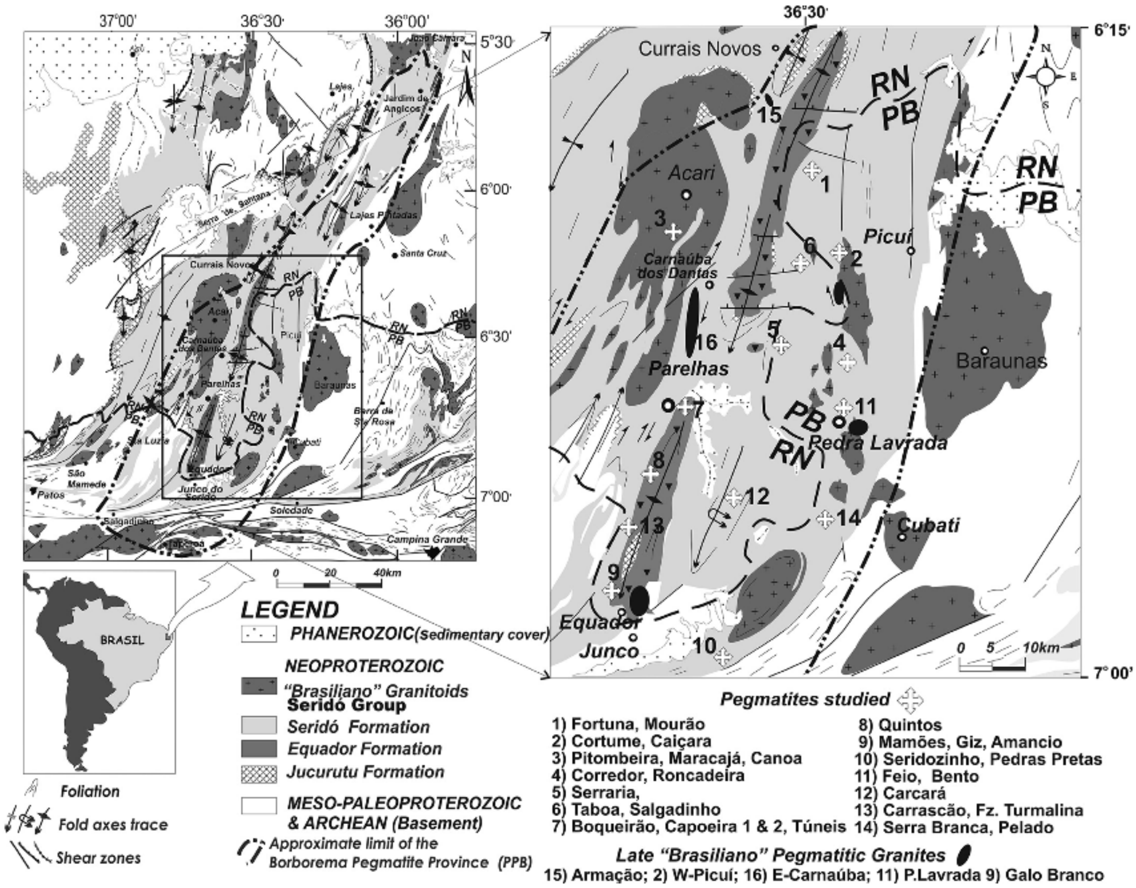

Figure 1- Geological context of the Borborema Pegmatitic Province, after Beurlen et al., (2009) and Soares et al., (2012).

METODHOLOGY

The main methodology of this work followed basic systematic on detailed geological mapping and surface qualitative surface mineral research. It involved:

- Identification and interpretation of main structures in aerial photographs and satellite images;

- Field works for collecting geological, geodesic and mesoscopic structural data using GPS and Clark compass;

- Collected samples were analyzed under petrographic microscope for mineralogical characterization;

- Treatment of the obtained data for the production of the geological map using the Arcgis software, 9.3 version.

RESULTS AND DISCUSSION

During this investigation, several transversal profiles where performed in the ASBP, in which we defined its elliptic to ovoid form oriented in the NE-SW. It is mainly interpreted by the influence of several sinistral strike-slip NE-SW shear zones which are related to the Patos Lineament. This pegmatitic is also characterized by a elevated topography compared to the wall-rocks as a response of weathering processes that affected the region. These structures are mainly ductile and associated with high-angle shear zones and sub-horizontal to horizontal stretching lineations, besides sub-vertical folds, which are frequently observed in the associated wall-rocks. On the other hand, this pegmatite is cross-cut by local fractures which can be mapped in an outcrop scale, suggesting that brittle deformation must played an important role on pegmatite emplacement in continental crust.

The main associated rocks have a typical pegmatitic texture, with large amounts of felsic minerals, being classified as leucocratic.

Field and petrographic data allowed us to the fine four main mineral zones throughout the pegmatitic body, which are: i) contact zone, ii) external intermediate zone, iii) internal intermediate zone and iv) quartz core (Figure 2). The main relationships between mineral zones and the main mapped structures can be observed on the related schematic cross-section (Figure 3).

In addition, obtained structural data allowed us to map the main family fractures that affected the ASBP. Geometric analysis revealed that this body is cross-cut by three fracture zones, which is preferentially N-S, NW-SE and NE-SW (Figure 4).

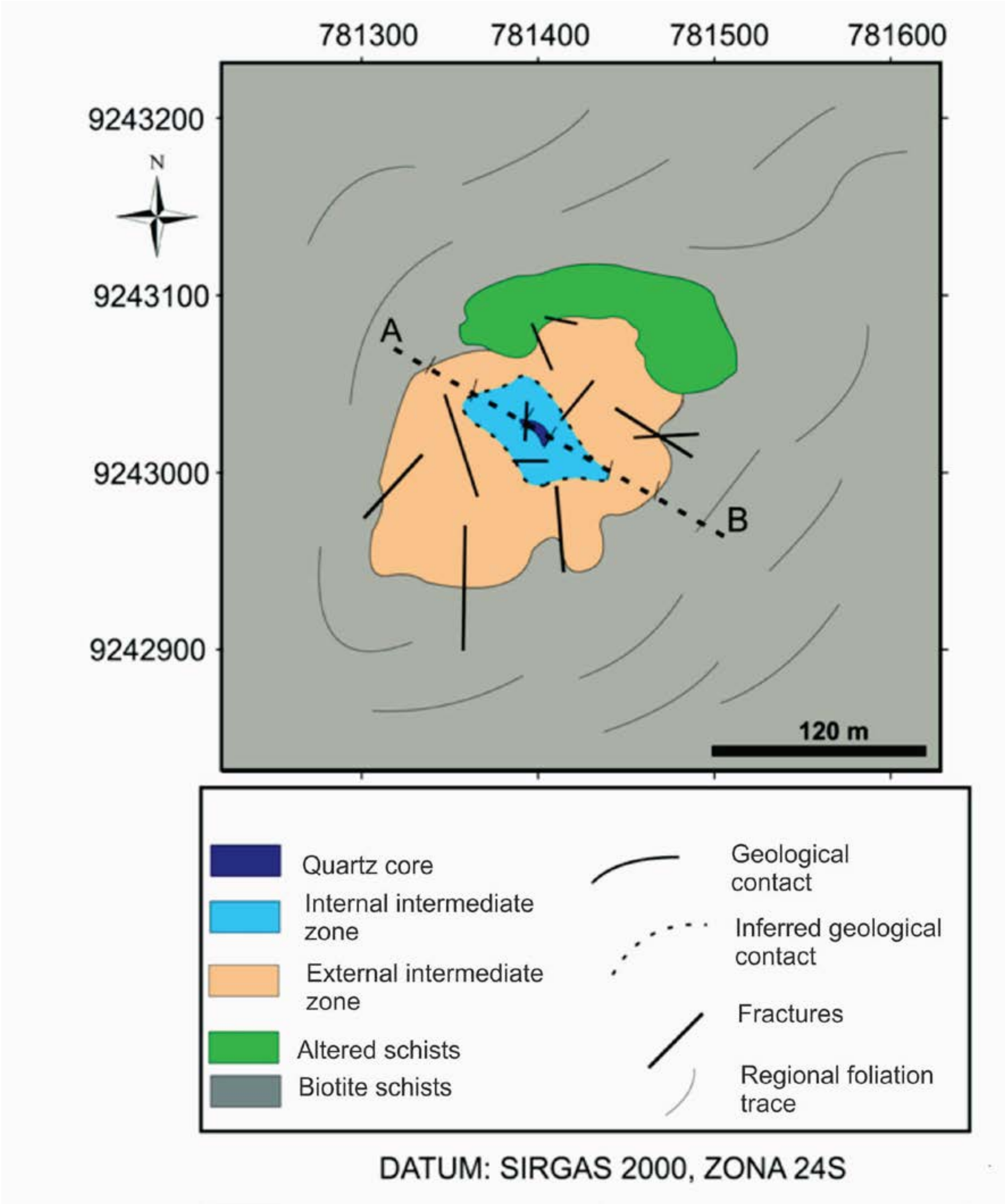

Figure 2 - Geological map of the Alto Serra Branca pegmatite.

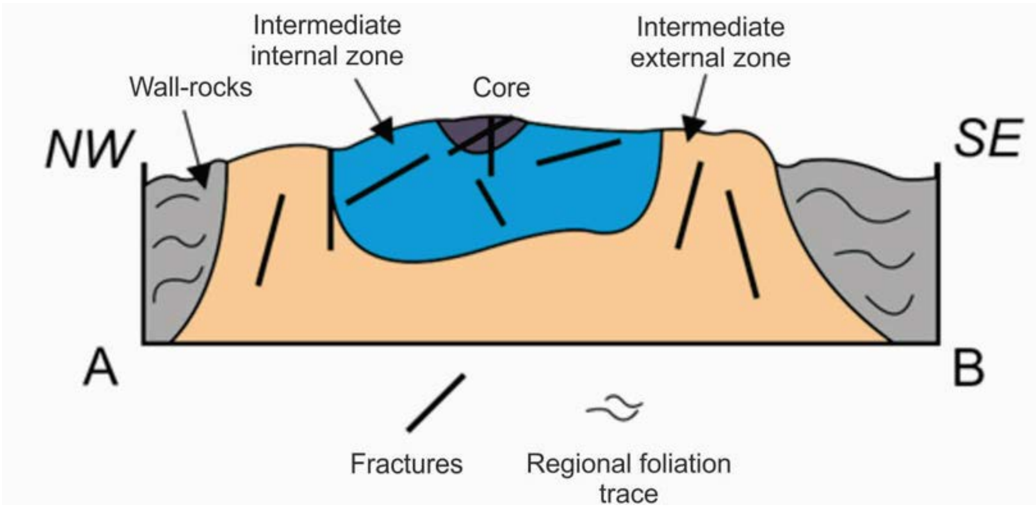

Figure 3- Geological cross-section of the ASBP.

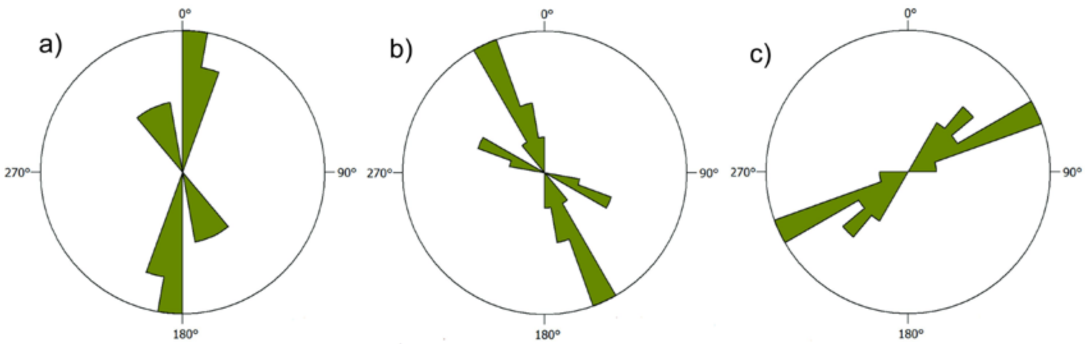

Figure 4- Rose diagrams with the main fracture families of the ASBP.

The region that corresponds to the contact zone is characterized by the border region between the wall rocks and the rims of the ASBP (Figure 5a). This zone is formed by the occurrences of ductile structures such as foliation and quartz-vein and aplitic and pegmatitic dykes rich in quartz and potassic feldspar.

The external intermediate zone is characterized by high amounts of potassic feldspar, which are associated with Black tourmaline, muscovite, phosphate minerals and albite. Apatite occurs locally, being represented by disseminated subhedric crystals, which can be partially oxidized. In addition, garnet crystals are also present and generally euhedric.

The plenty of tourmaline crystal apparently present relation to the presence of potassic feldspar and could represent an important prospective clue.

The internal intermediate zone is characterized by a simple mineralogy, being formed by the potassic feldspar + quartz association, besides a strong decrease on rock grain size. They generally exhibit graphic intergrowhs, which is typical from this zone.

Nevertheless, this zone has also pure albitized zones. In such areas, amblygonite and schorlite are present, besides bluish elbaites in a disseminated form.

At last, the central region of this pegmatite is characterized by a strong mineralogical homogeneity. It is characterized by subhedric to anhedric quartz crystals with variable colors. It is also characterized by intense fracturing forming vertical cataclastic zones. The main occurrence includes milkish and yellow quartz crystals. Other mineral occurrences are radial muscovite and cassiterite (Figures 5c and 5d).

Figure 5- Field aspects of the study area. a) Topographic unconformity between the ASBP and the wall rocks; b) Graphic intergrowth observed in external intermediate zone; b) radial muscovite observed on the core of the pegmatite; d) cassiterite crystal of the core zone of the ASBP.

CONCLUSIONS

The main obtained results can be summarized as follows:

I) The Alto da Serra Branca pegmatite follows na NE-SW trend and is intrusive in schists of the Seridó Formation of the Seridó Fold Belt;

II) This pegmatitic body is strongly influenced by high angle ductile foliation and cross-cut by fractures and joints. During geological mapping, three main families of fractures were distinguished in the main directions: N-S, NW-SE and NE-SW;

III) Detailed geological mapping has revealed that this body has a typical mineral zonning, which is marked by important economic minerals throughout its main zones. We defined contact zones between the pegmatites and wall-rocks, external intermediate zone, which is composed bt the potassic feldspar + schorlite + muscovite + amblygonite assemblage, internal intermediate zone, formed by quartz + potassic feldspar assemblage and a homogeneous quartz core, composed by punctual occurrences of radial muscovite and cassiterite.

IV) The observed zonation of the ASB is typical from heterogeneous pegmatites injected through dilatational structures in the continental crust.

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REDUCING ERROR IN SHORT TERM GRADE PREDICTION INCLUDING IMPRECISE AND INACCURATE DATA

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REDUCING ERROR IN SHORT TERM GRADE PREDICTION INCLUDING IMPRECISE AND INACCURATE DATA

ABSTRACT

Proper mining requires correct decisions on each block destination, i.e. an extracted block should go to the mill or to the waste dump. To help this decision, short term mine planning requires further sampling to reduce prediction uncertainty. Commonly the practice of estimation keeps only hard data, i.e., data considered precise and accurate verified by a quality control program. In a worst case scenario practitioners combine these hard data with soft data that are imprecise and in some circumstances biased. In this paper, direct sequential cosimulation is used to integrate secondary imprecise, biased data (soft data) into short term mine planning to update grades block model. Direct sequential cosimulation models are used to assess the uncertainty and using hard data against the model derived from using both hard and soft data, the last standardized to filter the bias. The results show the benefit of incorporating soft data after its bias correction. A case study illustrates the method.

KEY WORDS

Direct sequential cosimulation; integration data, update reserves

1- INTRODUCTION

Sampling is a continuous process along the life of the mine. Uncertainty in mine planning can be reduced by adding more samples. Frequently, sampling methods produce samples derived from distinct methods with different quality and quantity of samples. During exploration sampling is carried out by diamond drill cores (more common), which are expensive and known to produce accurate and precise results. At this stage, there are few data with high quality and they are herein referred as hard data.

Later during quasi mining more samples are available. Frequently these samples may have been collected along several campaigns, prepared using different protocols or analyzed at different laboratories. In General these informations do not have the same quality, therefore, they constitute different statistical populations. At this late stage there are many data with poor quality if compared to diamond drill cores. These samples are named soft data.

The idea here is evaluate uncertainty reduction and the benefits in enhancing resource classification of resources compared to the results using only hard data, accessing error by stochastic simulation and cosimulations. The results from different methodologies were checked considering precision for the different produced model.

2- METHODOLOGY

Three methods were chosen to evaluate the uncertainty of block grades given imprecise and biased soft data combined with hard data, namely: Direct sequential simulation (Soares, 2001) (DSS) using only hard data; Direct sequential simulation (DSS) with hard and soft data with bias and imprecision correction; Direct Sequential Cosimulation (CoDSS) with hard and soft data.

The main advantage of the proposed algorithm (DSS) is that it allows the simulaton/cosimulation without calling for any transformation of the original variables. The idea is to use the simple kriging estimated local mean and variance, not to define the local cdf but to sample from the global cdf.

2.1- Direct Sequential Simulation

Let us consider the continuous variable $Z(x)$ with a global cdf $F_z(z) = \text{prob}\{Z(x) < z\}$ and stationary variogram $\gamma(h)$.The intention is to reproduce both $F_z(z)$ and γ (h) in the final simulated maps.

The direct sequential simulation algorithm of a continuous variable follows the classical methodological sequence:

1. Define a random path over the entire grid of nodes x_u, $u = 1, N_s$, to be simulated.
2. Estimate the local mean and variance of $z(x_u)$, identified, respectively, with the simple kriging estimate $z(x_u)^*$ and estimation variance $\boldsymbol{\sigma^2_{SK}}$ (x_u) conditioned to the experimental data $z(x_i)$ and previous simulated values $z^s(x_i)$.
3. Define the interval of $F_z(z)$ to be sampled, by using the Gaussian cdf:

$$G\,(y\,(x_u)^*,\ \boldsymbol{\sigma^2_{SK}}\,(x_u)),\ \text{where}\ (\boldsymbol{\varphi_1}(z\,(x_u)^*).$$

4. Draw a value $z^s(x_u)$ from the cdf $F_z(z)$.
• Generate a value p from a uniform distribution $U(0, 1)$;
• Generate a value y^s from $G\,(y\,(x_u)^*, \sigma^2_{SK}\,(x_u))$: $y^s = G^{-1}\,(y\,(x_u)^*, \sigma^2_{SK}\,(x_u), p)$;
• Return the simulated value $z_l^s(x_u) = \varphi_1^{-1}\,(y^s)$.
5. Loop until all Ns nodes have been visited and simulated.

2.2- Direct Sequential Cosimulation

Instead of simulating N_v variables simultaneously, each variable is simulated in turn conditioned to the previously simulated variable (Gomez-Hernandez, Jaime and Journel, 1993; Goovaerts, 1997). Suppose just two variables, $Z_1(x)$ and $Z_2(x)$. Choosing the primary variable, say $Z_1(x)$, as the most important or with a more evident spatial continuity (Almeida & Journel, 1994), the joint simulation algorithm is described in detail as follows:

1. Define a random path visiting each node of a regular grid of nodes.

2. At each node x_u Simulate the value $x_l^s(x_u)$ using the DSS algorithm described in step 2 above:
• Identify the local mean and variance of $z_1(x_u)$ as the SK estimate and estimation variance $z_1(x_u)^*$ and $\sigma_{SK}^2(x_u)$; calculate $y(x_u)^* = \varphi_1(z(x_u)^*)$, φ_1 being the normal score transform of the primary variable $z_1(x)$;
• Generate a value p from a uniform distribution $U(0, 1)$;
• Generate a value y^s from $G(y(x_u)^*, \sigma_{SK}^2(x_u))$: $y^s = G^{-1}(y(x_u)^*, \sigma_{SK}^2(x_u), p)$;
• Return the simulated value $z_l^s(x_u) = \varphi_1^{-1}(y^s)$ of the primary variable.

The same DSS algorithm is applied to simulate $Z_2(x)$ assuming the previously simulated $Z_1(x)$ as the secondary variable. Colocated simple cokriging is used to calculate $z_2(x)^*$ and $\sigma_{SK}^2(x_u)$ conditioned to neighborhood data $z_2(x_\alpha)^*$ and the colocated datum $z_1(x_u)$ (Goovaerts, 1997):

$$Z_2(x_u)^*_{SCK} = \sum_{\alpha=1}^{N} \lambda_\alpha(x_u)[z_2(x_\alpha) - m_2] + \lambda_\beta(x_u)[z_1(x_u) - m_1] + m_2 \qquad \textbf{(1)}$$

• Transform $y(x_u)* = \varphi_2(z_2(x_u)^*)$. φ_2 is the normal score transform of the $Z_2(x)$ variable.
• Generate a value p from a uniform distribution $U(0, 1)$;
• Generate a value y^s from $G(y_2(x_u)*, \sigma_{SK}^2(x_u))$: $y^s = G^{-1}(y_2(x_u)^*, \sigma_{SK}^2(x_u), p)$;
• Return the simulated value $z_2^s(x_u) = \varphi_2^{-1}(y^s)$ of the secondary variable.
3. Loop until all nodes are simulated.

2.3- Standardized data: Proposal for filtering the bias and imprecision error in soft data

From geostatistical view this difference in precision and accuracy data has to be considered for integrating the two data types.

For building the model, where the hard and soft data were pooled together, it was used a correction factor to correct the mentioned bias in secondary (soft) data. This workflow can be used for situations where hard and soft data are strongly correlated. Innitally, soft data ($Z_2(u_{\alpha 2})$) are standardized (Equation 2) using the mean (m_2) and the standard deviation (σ_2) of the soft data. The transformation using Equation 2 leads to a zero mean and an unity standard deviation in the transformed data.(Minnitt & Deutsch, 2014)

$$Z_2(u_{\alpha 2})^* = \frac{[Z2(u_{\alpha 2}) - m_2]}{\sigma_2} \qquad \textbf{(2)}$$

Next, the soft standardized data $Z_2(u_{\alpha 2})^*$ are rescaled to match the hard data statistics (Equation 3) using their mean (m_1) and standard deviation (σ_1). Thus, the mean for the hard and soft data would now match.

$$Z_2(u_{\alpha 2})^*_T = Z_2(u_{\alpha 2})^{**}\sigma_1 + m_1 \qquad \textbf{(3)}$$

It is important to evaluate the data, when was created the variable “soft data with bias correction” (global correction), does not guarantee that the corrected values are within the limits "realistic"(positive values). For example, if the distribution content starts at zero, the corrected values may theoretically be negative.

3- CASE STUDY

3.1- Data Presentation

This study uses the exhaustive Walker Lake dataset (Isaaks & Srivastava, 1989) with 78 000 point support samples distributed regularly at 1 × 1 m (V_Ref_Points),. The variable V was used and the original unit was rescaled so that it resembled grades from a copper mineral deposit. To obtain the reference block grade distribution (V_Ref_blocks), the exhaustive point support dataset was averaged into 3120 blocks of size 5 × 5 m. These blocks represent the true block grades and were used for comparison.

In this case study, the data set was adapted (Araujo, 2015) from the original ones. Two types of data were considered. First, point samples were obtained regularly spaced at 20 × 20 m (V_20x20). These samples were precise and accurate and mimick diamond drillhole samples (hard data). Next soft data (secondary samples) were obtained sampling the exhaustive dataset at a of 5 × 5 m regular grid where imprecision and bias were added. Note that the direct cosimulation was performed, assuming soft data are known every node of the grid (collocated cosimulation) For this, ordinary kriging was carried out in order to obtain exhaustive soft data (V_5X5_+25%_Exhaustive). Figure 1 shows the regularly spaced samples used in this case study.

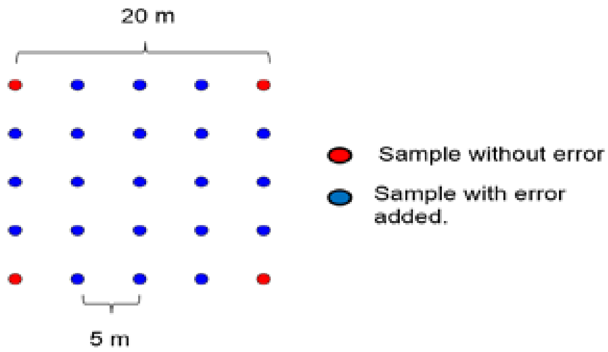


Figure 1- Data set with regular spaced samples

Table 1 shows the summary statistics for the reference point support dataset (V_Ref_points), the reference block grade distribution (V_Ref_blocks), and the sample dataset with accurate and precise data (V_20×20). The sample datasets have their mean values very close to the true mean, which indicates that there were no biases or imprecision. The data with bias and imprecision (V_5×5_+25% and V_5X5_+25%_Exhaustive) has a mean and standard deviation 25% greater than those of the reference point distribution (V_Real_points) to mimic the situation in which poor-quality data induce biases that are subsequently transferred to the grade estimation process.

Table 1- Summary statistics for the original reference and for the biased and imprecise soft data

Data	Nº of samples	Mean	Standard Deviation	CV	Minimum	Maximum
V_Ref_points	78000	2.78	2.50	0.90	0.00	16.31
V_Ref_blocks	3120	2.78	2.49	0.89	0.00	15.68
V_20X20	195	2.73	2.43	0.89	0.00	10.13
V_5X5_+25%	2925	3.44	3.12	0.90	0.00	18.30
V_5X5_+25%_Exhaustive	78000	3.44	3.12	0.90	0.00	18.30

Figure 2 shows the cross correlogram between hard data and soft data. The samples present moderated correlation (0.60). This moderate correlation can be caused by different sampling techniques or by distinct preparation protocols, which lead to possible measurement errors formed by laboratory analytical error plus the sum of all other sampling preparation errors.

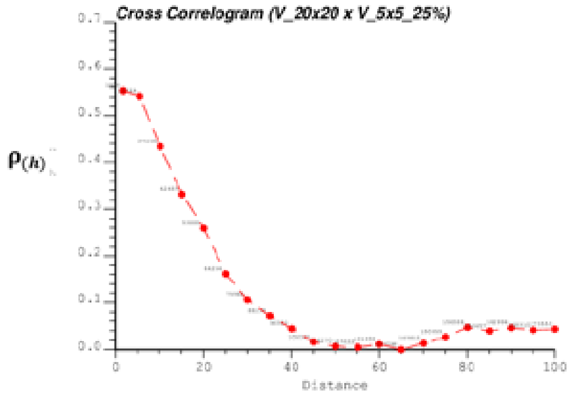


Figure 2- Omnidirectional cross correlogram for hard data and soft data

Equation 4 shows the variogram used for simulating using the different methodologies: Direct sequential simulation and Direct sequential cosimulation. In the cosimulation, for simplicity, the collocated cokriging was applied with the Markov-type approximation (Goovaerts, 1997), i.e., only the hard data variogram and the correlation coefficient between hard and soft data is needed. For the spatial continuity, the major direction was defined as 157.5º, the minor direction as 67.5º and a spherical (Sph) variogram model. For each methodology, 50 realizations were simulated.

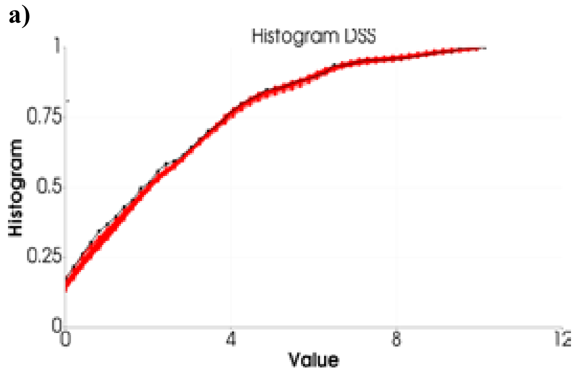
$$\gamma_V(\mathbf{h}) = \mathbf{1.0} + \mathbf{2.0} \cdot \mathbf{Sph}(\mathbf{1}) \cdot \left(\frac{\mathbf{N157.5E}}{\mathbf{36\ m}}, \frac{\mathbf{N67.5E}}{\mathbf{16\ m}}\right) + \mathbf{2.92} \cdot \mathbf{Sph}(\mathbf{2}) \cdot \left(\frac{\mathbf{N157.5E}}{\mathbf{84\ m}}, \frac{\mathbf{N67.5E}}{\mathbf{40m}}\right) \quad \mathbf{(4)}$$

4- RESULTS AND DISCUSSION

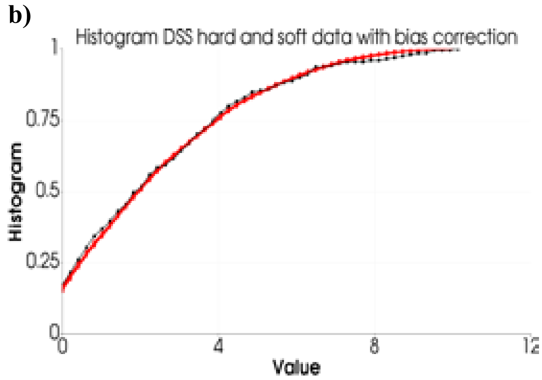
4.1 Validation

In Figure 3 the black line represents the declustered hard data (V_20X20) cumulative histogram and the red lines are the realization histograms. Figure 3a shows the histograms of Direct sequential simulation with only hard data whilst figure 3b the histograms of Direct sequential simulation with hard and soft data with bias correction. The plots show good statistics reproduction. Figure 3c shows histogram reproduction for Direct sequential cosimulation with hard and soft data. The results depart from the hard data statistics when soft data was used with their error embedded. The difference is more evident around the upper quartile (Q3), where cumulative probabilities are overestimated when compared against situations a and b. In this last case, the bias and imprecision were transferred to realizations.

a)



b)



c)

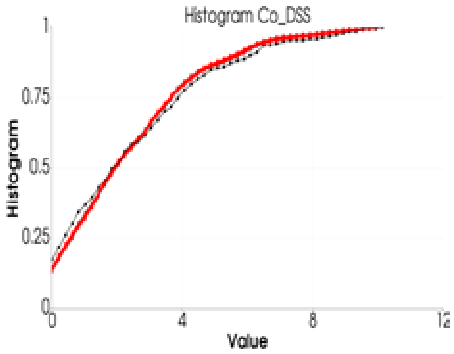
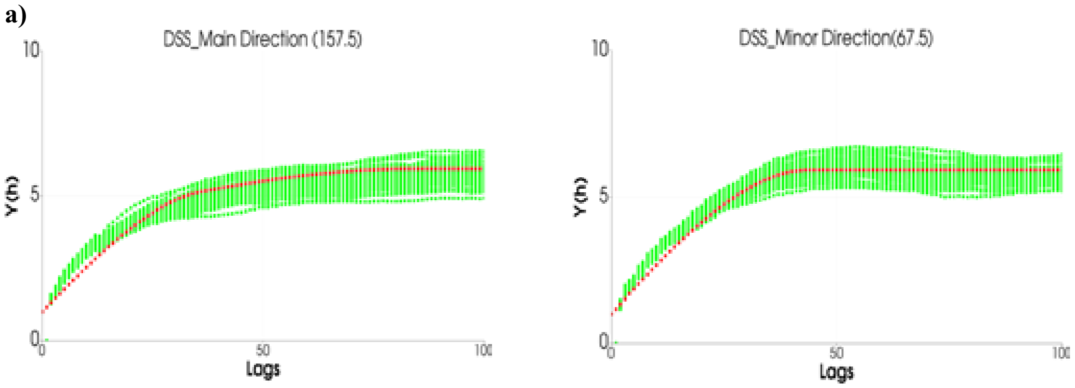


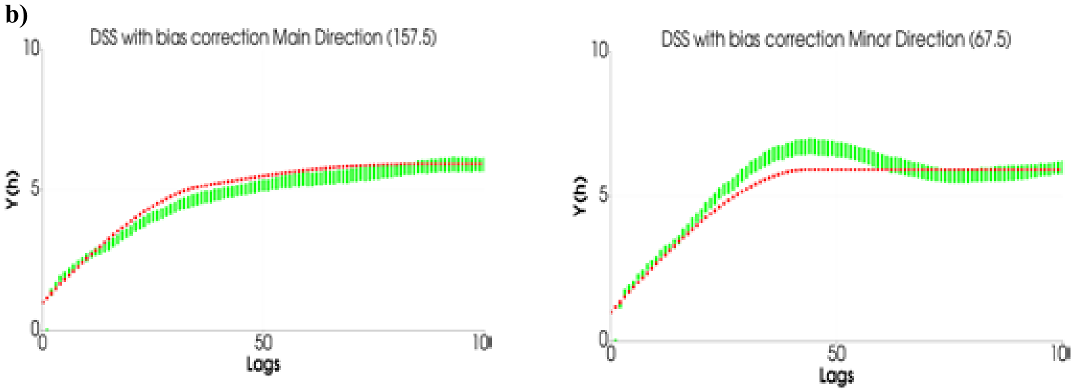
Figure 3- Histogram of simulated models compared against the hard data histogram a) Direct Sequential Simulation with only hard data b) Direct Sequential Simulation with hard and soft data with bias correction c) Direct Sequential Cosimulation with hard and soft data

Figure 4 shows the variograms reproduction by the models. Red line represent the input variogram model (V_20X20) and green lines the ones derived from the realizations at the major and minor directions.

a)



b)



c)

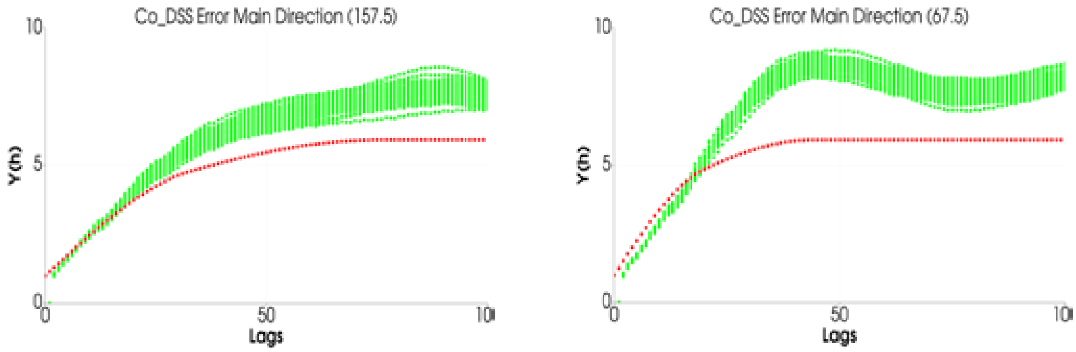


Figure 4- Variograms reproduction by the various models) Direct Sequential Simulation with only hard data b) Direct Sequential Simulation with hard and soft data with bias correction c) Direct Sequential Cosimulation with hard and soft data

For evaluating the correlation reproduction between hard and soft data by cosimulated models figure 5 shows the scatterplot between realization_4 and realization_20 obtained by direct cosimulation using both hard and soft data versus the reference block model, the correlation coefficient is 0.58, which is close to correlation between hard and soft data.

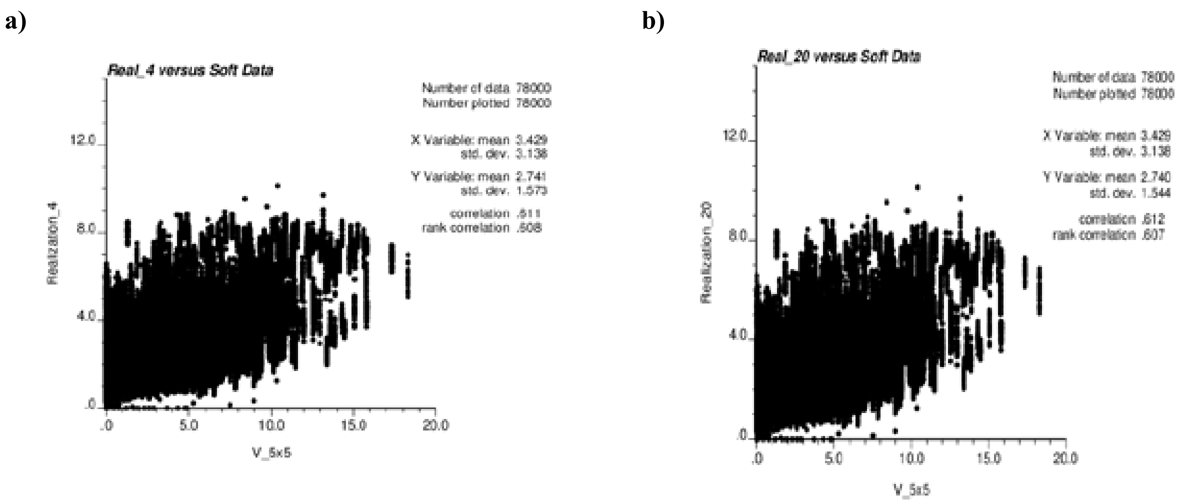


Figure 5-Scatterplot of the point simulated grid in Direct sequential cosimulation with hard and soft data a) Realization_4 and b) Realization_20 versus point references of soft data (ρ = 0.60). This is plotted point simulated grid versus point references

. 4.2-Reducing block misclassification

The simulations and reference model were reblocked into 5x5 m blocks (Table 1). To calculate the real error (equation 5) it was used the E-type model and the reference block model [V_ (Ref_blocks)] which represents the true block values.

$$Error_{Real} = \frac{[E\_type - V_{\text{Ref\_blocks}}]}{E - type} \quad (5)$$

Figure 6 shows real error when the methodologies are compared. For Direct cosimulation with hard and soft data (brow line) the error is lower, it means,more precise when compared against Direct simulation using only hard data (blue line). Direct sequential simulation model with hard and soft data with bias correction (yellow line), has more blocks with less error and it is more precise. In this methodology, when the soft data was corrected using the bias and imprecise error, , more data was used to conditioning the realizations and the results tend to be closer to the reference block model, increasing influence of the soft data in the realizations.

Figure 6- Real error in block using the reference block model for comparison between the methodologies a) Direct Sequential Simulation with only hard data b) Direct Sequential Simulation with hard and soft data with bias correction c) Direct Sequential Cosimulation with hard and soft data

Equation 6 shows how error was obtained using the interquartile range and E-type from the simulations at blocks 5x5 meters (other approach of the error in Li, Dimitrakopoulos, Scott, & Dunn, 2004, for instance):

$$Error_{Calculated} = \frac{(Q_{95} - Q_5)/2}{E - type} \quad (6)$$

where the interquartile range $Q_R = (Q_{95} - Q_5)/2$, measures spread of the block values and E-type approximates the estimated value for the block.

Figure 7 shows the calculated block error used as a criterion to classify the blocks with uncertainty within 10% to 90% interval. In the Direct Sequential Simulation considering only hard data, all the blocks had uncertainty larger than 30%, due to the few and sparse data. In the Cosimulation, the results were better if compared to Direct Sequential Simulation using only hard data, as the correlation between hard and soft data is moderate. Using Direct sequential simulation with hard and soft data with bias correction, and considered as hard data afterwards, improved the results and decreased the uncertainty at every block.

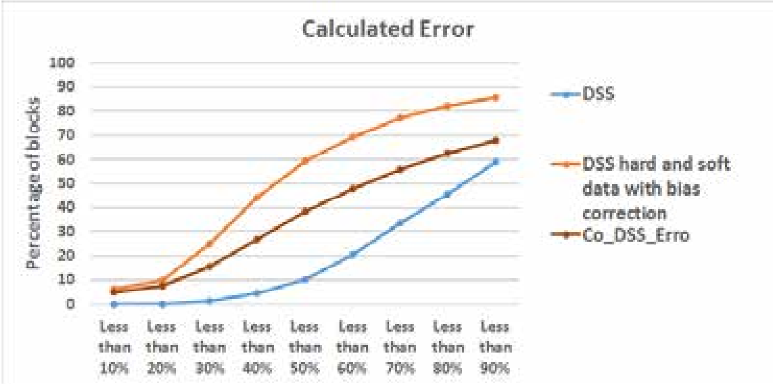


Figure 7- Calculated error of block using the reference block model for comparison between the methodologies a) Direct Sequential Simulation with only hard data b) Direct Sequential Simulation with hard and soft data with bias correction c) Direct Sequential Cosimulation with hard and soft data

5- CONCLUSION

Direct sequential simulation and Cosimulation presented in this case study use the original variable without requiring any priory or posterior transformation. In general, these algorithms showed a good reproduction of univariate and bivariate statistics and spatial continuity model of the data.

In the case of using few hard data (precise and accurate) withr Direct sequential simulation there is a clear loss of precision in the derived model.

For using soft (imprecise and inaccurate) data integrated with hard data it was proposed two methodologies: Direct sequential collocated cosimulation combining either hard and soft data. Hard and Soft data exhibit moderate correlation which means no significant weights will be assigned to the second ones when estimating/simulating the primary variable. An alternative chosen used using Direct Sequential Simulation with hard and soft data after bias correction. This led to the best results showing that the soft data may improve short term geological modelling whether an appropriate methodology is used to include these data (after correction). Thus, when the bias and imprecise error was filtered from the soft data, more data was used in the simulations and realizations were closer to the reference block model. Consequently, the real error and calculated error in the block values were lower.Therefore, it is advantageous to incorporate imprecise measurements for stochastic simulations using the adequate methodology.

6- ACKNOWLEDGMENTS

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RULES OF MONITORING AND COMBATING METHANE AND FIRE HAZARDS IN GOB OF LONGWALLS MINED WITH CAVING IN HARD COAL MINES

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RULES OF MONITORING AND COMBATING METHANE AND FIRE HAZARDS IN GOB OF LONGWALLS MINED WITH CAVING IN HARD COAL MINES

ABSTRACT

Statistics disasters that have occurred in recent years in Polish hard coal mines show that most of the events took place, or were initiated in the gob of longwalls mined with caving. The up-to-date solutions of monitoring the space of the gob focused on distribution of gases and fire hazard developing in the gobs show that the research methodology, based on the results of periodic measurements with hand held instruments and air, sampling for laboratory tests to assess methane and fire hazards in the gob is imprecise and the phenomena taking place in the gob are beyond the control or are poorly controlled. Therefore a new method for continuous monitoring of gases distribution in the gob within the system of automatic gasometry system has been proposed. The knowledge of changes of gob gases concentration, particularly methane, oxygen, carbon monoxide and carbon dioxide allows for the hazard assessment and can be the basis of his fighting.

Mining by longwalls with caving under the conditions of methane and spontaneous fire hazards occurrence requires the selection of prevention measures to reduce the hazard. The most effective measure consists in the use of ash and slag produced by power plants mixed with process water from the mines or flotation tailings. The economic management of wastes from power generation in the prevention measures against fire hazard at longwalls positively influences the reduction of spontaneous fire hazard in the gob and, in the case of mining of seams in the surrounding of deposits with high methane contents, significantly reduces the inflow of methane into the gob. Administration of inert gases, i.e. nitrogen or carbon dioxide into the gob is also an important means of combating this hazard in the gob.

The article shows how the proposed innovative method of monitoring gob gases, assisted by computer simulation methods, allows for current investigation of the effectiveness of the undertaken measures focused on combating methane and fire hazard in gob of longwalls mined with caving.

KEYWORDS

Monitoring air in gob of longwalls, combating methane and fire hazards in gob of longwalls mined

INTRODUCTION

In recent years the explosion hazard in the gob of longwalls mined with caving constitutes the most serious gas hazard which has often been the source of the latest mining disasters, what is confirmed by the statistics of the disasters in the Polish mining industry that have recently occurred. It is recognized in practice that cavity fires, spontaneous heating sources, displacing of sparking compact roof rocks, forming a rock debris, can be a source of ignition or an explosion within the space of the gob.

Supervising and monitoring of gas concentration in the gob of longwalls mined with caving are of crucial importance in the conditions of conducted mining operations both for current assessment of methane – fire hazard and for the course of conductance of fire fighting preventive measures. This issue is one of the main tasks of ventilation services of hard coal mines. Despite the widely developed hazards fighting methods, including sealing of the gob with ash-water mixtures, or administration of inert gases (nitrogen or carbon dioxide) the occurrence of inflammations or even explosions in the gob has not been avoided recently.

While monitoring of the atmosphere condition in the mine workings with circulating air flow conducted by monitoring systems is now at a high technical level, the state of the atmosphere in inaccessible places, i.e. gob and sealed off spaces is poorly recognized, and often remains even out of control. Currently used measurement methods, based on chemical laboratory analyzes of samples of gases, taken for the early detection of endogenous fires do not guarantee a direct and continuous monitoring of processes taking place in the gob with the view of the hazard assessment. The result is such that one does not have a certainty on current basis whether the scope of the applied preventive measures for the elimination of the origination of the hazard in the gob had been properly selected.

Experimental studies in this respect were carried out in Czech mines (Adamus, 2011) by periodically taking a sample of air followed by its subjection to a gas chromatographic analysis in a laboratory. Solutions are known worldwide with regard of monitoring and control of gob gases (Brady, Harrison & Bell, 2009) with a view of fire hazard based on the so-called “tube system” (tube bundle system), which are efficiently applied in mines in Australia, the USA, India and China. These systems consist in gas chromatographic analysis on surface of air samples taken from the gob and the sealed off area with the use of a central pump and tube bundle systems. However, bearing in mind the vastness and structure of the Polish ventilation network, the transfer of the aforementioned solution to the conditions of Polish mines is impossible due to technical reasons

In recent years, the works have been undertaken in the country (Wasilewski & Cimr, 2011, Wasilewski., Cimr & Wach, 2010, Wasilewski, Łaskuda & Wach, 2011, Final Report of Development Project R09 0004 04 (N524), 2011) on a new approach to the issue of the assessment of the hazard in the gob by the development of automated air sampling system together with the measurement of gob gases concentration CH_4, O_2, CO, CO_2 and its recording in the system of automatic gasometry. Monitoring of gases within the space of the gob of a longwall mined with caving by measuring of the oxygen, methane, carbon monoxide and carbon dioxide, along with the registration of parameters in mine automatic gasometry system has provided a lot of data of a cognitive character. Computer simulations (Dziurzyński, Krach, Pałka & Wasilewski, 2008, Dziurzyński & Wasilewski, 2009, Dziurzyński, 2010) using a numerical model of the flow of a mixture of methane and air in the gob are also an important element of this new methodology of exploration and assessment of the condition of methane – fire hazard in the gob.

Under the conditions of combined hazards development of a comprehensive methodology for actions within the framework of methane-fire prevention measures acquires particular significance. The use of ash and slag generated in power plants and mixed with mine process water or flotation tailings (Dziurzyński, 2010) is the most effective measure. The methods of prevention and combating of methane-fire hazard in the gob also consist in sealing off the gob and injection of inert gases, as well as supplying of foamy antipyrogens. In very gassy seams methane is also used for inertisation of the space of the gob (Nawrat, 1999), often using methane drainage systems for this purpose.

The aim of the administration of these means is to reduce the oxygen content in the gob gases, cooling of a heated up coal and reducing or eliminating of coal oxidation. Efficiency of application of various methods as preventing measures against methane-fire hazard in the gob requires supervision and monitoring in order to assess the state of spontaneous fire hazard.

Research observations and experiments (Wasilewski et all., 2011) showed how the monitoring of gases in the space of the gob of a longwall minded with caving in the system of automatic gasometry also allowed to monitor the concentration of gases in the gob of the longwall after its sealing off, because of the fire in the gob. This way one can follow, on current basis, the effect of administering of ash and water mixture into a sealed off zone as a means of extinguishing a fire in the gob. This process was observed for several months until the unsealing of the longwall in order to ventilate it after the firefighting operations were terminated.

Long-term observation of gas concentrations in the gob provided an extensive material input to perform detailed analysis and determining the distributions of gas concentrations in the gob, taking the account of the of execution of prevention measures in the form of administration of ash and water mixture into the gob.

Computer simulations methods are becoming increasingly useful in the analyses and assessment of the of methane-fire hazard in the Polish mining industry. A numerical model of flow of the mixture of methane and air in the gob (Dziurzyński et all., 2008, Szlązak, 1999, Szlązak, 2000) is the basis of the simulation. Developed system VentZroby (VentGob) (Dziurzyński et all., 2008) allowed for the determination of the distribution of gases concentration and propagation of gob gases within the area of the gob.

AN INTEGRATED GOB SENSOR

Recognizing that an important element to identify a hazard in the gob is the ongoing supervision and monitoring of atmosphere parameters of the gob an integrated gob sensor has been developed (Wasilewski & Cimr, 2011, Wasilewski et all., 2010) which had a form of a tube-probe (Fig. 1) with pre-drilled holes for the free migration of gob gas. The sensors (CH_4, CO, O_2, CO_2) were placed inside the probe for automatic measurement of parameters characterizing the state of the atmosphere in the gob and automatic recording in the monitoring system.

A pipeline (Wasilewski & Cimr, 2011) made of perforated pipes, laid on the floor of the supervised gob in which an integrated gob sensor was placed, was monitor the condition of the atmosphere and the gas parameters in the gob of longwalls mined with caving. With the advance of the face of the longwall the probe, with an integrated gob sensor, remained ever deeper and deeper in the gob.

The scope of observation in gob included monitoring of the following parameters:

- concentration of methane in the range of 0÷100% CH_4,
- oxygen concentration 0÷25% O_2,
- concentration of carbon monoxide 0÷1000 ppm,
- carbon dioxide concentration 0÷5% CO_2,
- air temperature, in the range of: up to +70°C.

Figure 1 – An integrated gob sensor with the set of probes

In the course of the study with the use of sensors placed in the gob many valuable records were obtained for identification of hazards in the gob but also many difficulties were observed regarding the maintenance of the continuity of the measurement line in the gob, failure of gas sensors due to watering of the measurement line and electronic systems, and lack of access to sensors needed for their calibration.

Therefore, it was considered that this solution could be useful in the conditions of an experiment, however, it could not be used in routine operation conditions. Taking the advantage of the experience gained a new solution was proposed (Final report from research task No 3, 2013) based on automatic air sampling via suction hoses from the gob instead of placing of the integrated gob sensor within the space of the gob. For this purpose an integrated gob sensor ZCZ-MP (Fig. 2) was developed for automatic air sampling together with the measurement of concentration of gob gases CH_4, O_2, CO, CO_2 and recording of the date in the automatic gasometry system.

The metrological parameters of this solution are the same as in the previous one, but the significant difference is that the air sampling from the gob is by automatic suction into the measuring chamber and the measuring systems (sensors) for measuring of the concentration of gob gases are located outside the gob. An important element of the new approach is also the possibility of air sampling r from several points in the gob.

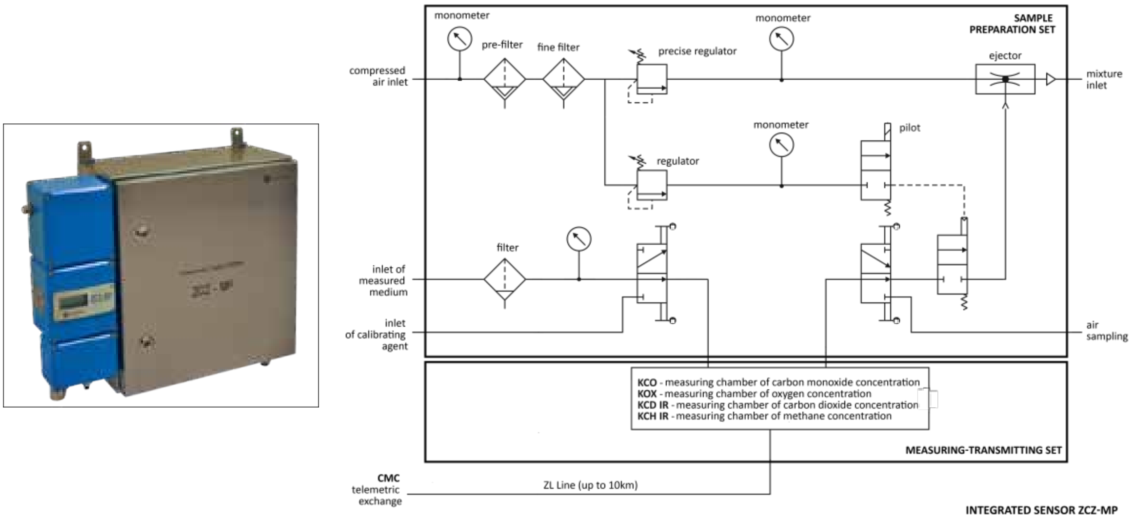
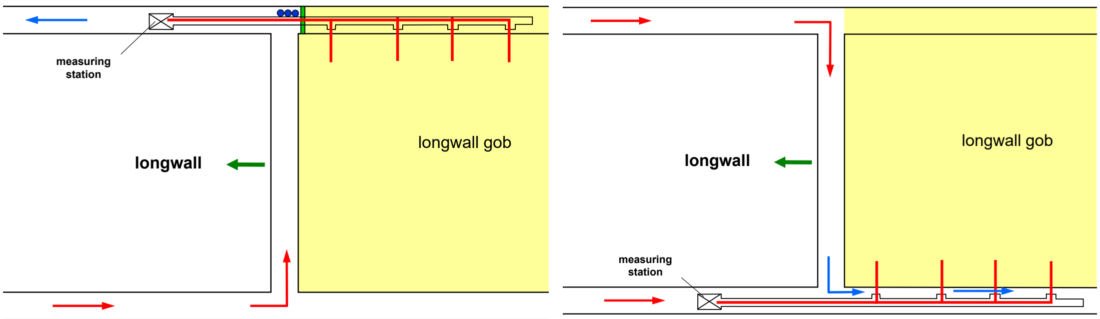


Figure 2 – An integrated gob sensor ZCZ-MP, with the system of automatic air sampling from the gob

Examples of installation of a measurement line in the system of air sampling from the gob to the integrated sensor ZCZ-MP (Final report from research task No 3, (2013)



Longwall ventilated by U system   Longwall ventilated by Y system

Figure 3 – Diagram of installation of measuring Line for continuous monitoring of gob gases in longwalls ventilated by U and Y systems.

ACTIVE METHANE-FIRE HAZARD FIGHTING IN THE GOB

Studies on mechanisms of formation of voids after mined out coal seams and their nature have been carried out for many years (Mazurkiewicz, Popiolek, Niedojadło, Sopata & Stoch, 2015). Considerations in this respect were conducted together with a discussion on the stresses occurring in the rocks surrounding mine workings. With regard to the mechanism of formation of voids it is assumed that the height of the full cave-in exceeds 1 to 2 times the average thickness of the mined-out seam. All scientists, dealing with the problems of the formation of voids, also pay attention to the occurrence of some "zones" in those voids (Fig. 4). From the viewpoint of absorption capacity of the sealing means based on a mixture of ash and slag from power plants with the process water or tailings, the most significant are void spaces between the blocks. Complex methods of prevention and combating methane-fire hazards in the gob, used in Polish hard coal mining also consist in injection of inert gases, as well as foamy antipyrogens into the mine-out spaces.

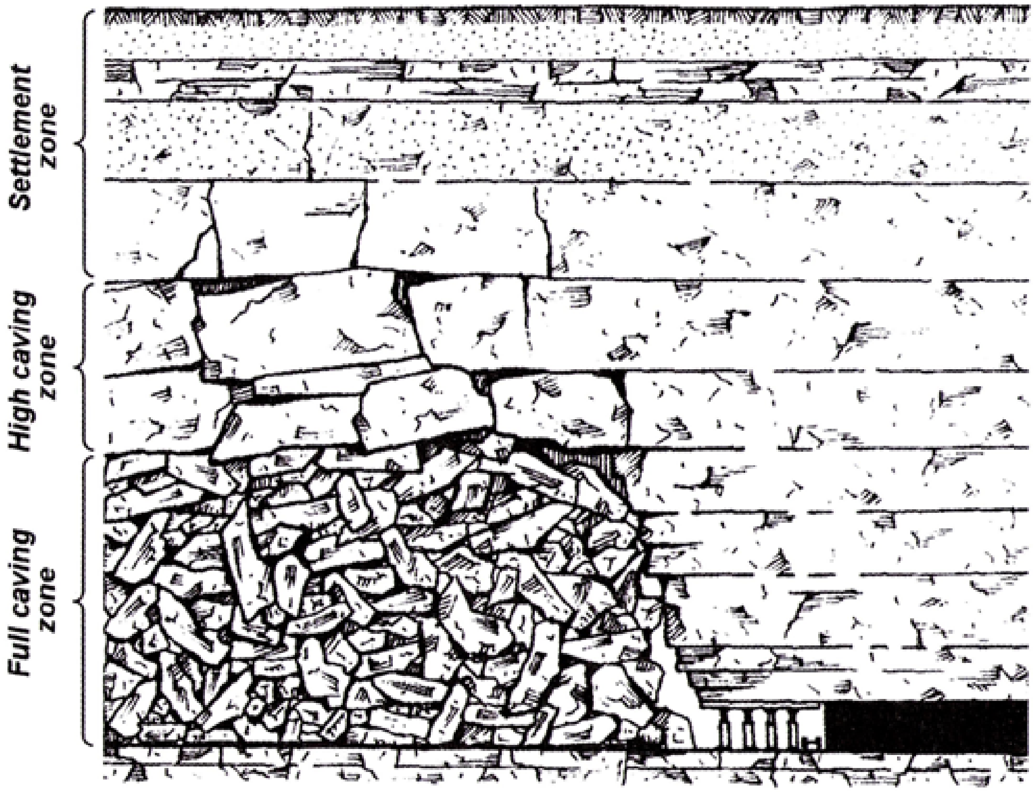


Figure 4 – Diagram of the formation of voids in conditions of the carboniferous strata (Mazurkiewicz et all., 2015)

The presence of the so-called zone of full rockfall (Fig. 4), in the gob, constitutes the basic site for discharging of liquid mixtures. Those are the void spaces to which liquids and mixtures containing sealing agents can inflow (penetrate). Direction of the slope of the mined-out seam or spreading potential of the mixture are also essential features for filling up of voids with liquid mixtures.

So far, the effects of filling up of void spaces of the gob with wastes from power plants mixed with water were beyond the control with regard of the impact of this technology on changes in the distribution of gob gases, and thus on the effectiveness of fighting of methane-fire hazard in the gob. The proposed (Final Report of Development Project R09 0004 04 (N524), 2011) method of sealing and filling of gobs simultaneously with continuous monitoring of gases concentrations in the gob, allows, on current basis, to follow the effectiveness of preventive measures and firefighting in the gob.

OBSERVATION OF REGION – LONGWALL 565, SEAM 510 IN PANEL A EAST AT THE HORIZON OF 665M

Exploitation of longwall 565 in seam 510 A East at 665m horizon Mysłowice-Wesoła mine, Wesola mining area in Myslowice, with the length of 230 m and width of 915 m was conducted by longwall along the strike system with roof caving at the height of 3m, at an inclination of 6°, with a local leaving of about 1.0m coal shelf in the roof (Wasilewski et all., 2011).

The longwall 565 in seam 510 A East, horizon 665 m, was supplied, including a boost fan, with air stream's volume of about 1460 m^3 / min, wherein along the longwall ventilated with "U" ventilation system about 1100 m^3 / min of air was flowing.

The longwall 565 in seam 510, panel A East, as required by regulations, was entirely covered by methanometric protection system within the mine's automatic gasometry system. The location of the system's sensors is shown in Figure 5.

On 16. 05. 2010, on the shift beginning at 22.00hrs in the area of longwall 565 the works were carried out related to the preparation of the longwall for mining operations. At about 23:44 hrs a local inflammation of methane occurred in the gate I East (ventilation), at the junction with the longwall 565, which affected with its range two employees, who suffered burns (minor accidents).

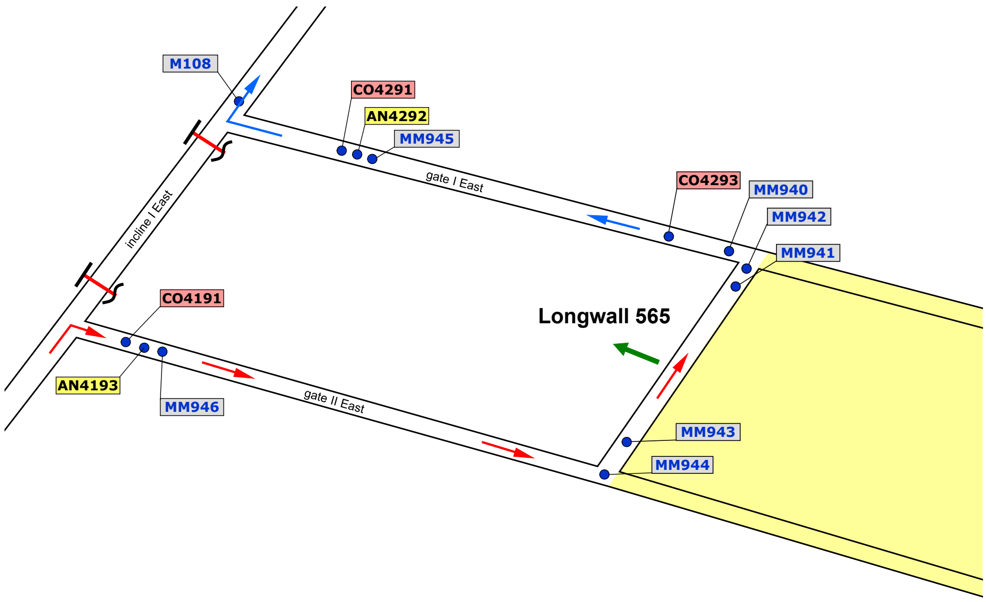


Figure 5 – Location of sensors in longwall 565,seam 510A east.
(from its start-up, before the fire – May 2010)

After termination of the fire fighting operations, the area of the longwall 565 in the seam 510A was sealed off from the remaining mine workings by the explosion-proof stopping in gate I East and a water seal in the gate II East ahead of the longwall and at the face of the longwall 565 (Fig. 6). Access to a water seal was ventilated by means of a separate ventilation with the use of air-duct with the booster fan installed in the fresh air current in incline I East below the gate II East. During that time the area of the longwall 565 seam 510A, being sealed off, was monitored in the automatic gasometry system (Wasilewski et all., 2011) by means of sensors, the location of which is shown in Figure 6. These sensors were used for a 4-month observation (December-March) of air parameters in the region of the sealed off longwall 565 seam 510A.

Active firefighting in the gob of longwall 565

At the beginning of 2011 active fire lighting operations were commenced in the gob of longwall 565 (Final Report of Development Project R09 0004 04 (N524), 2011).

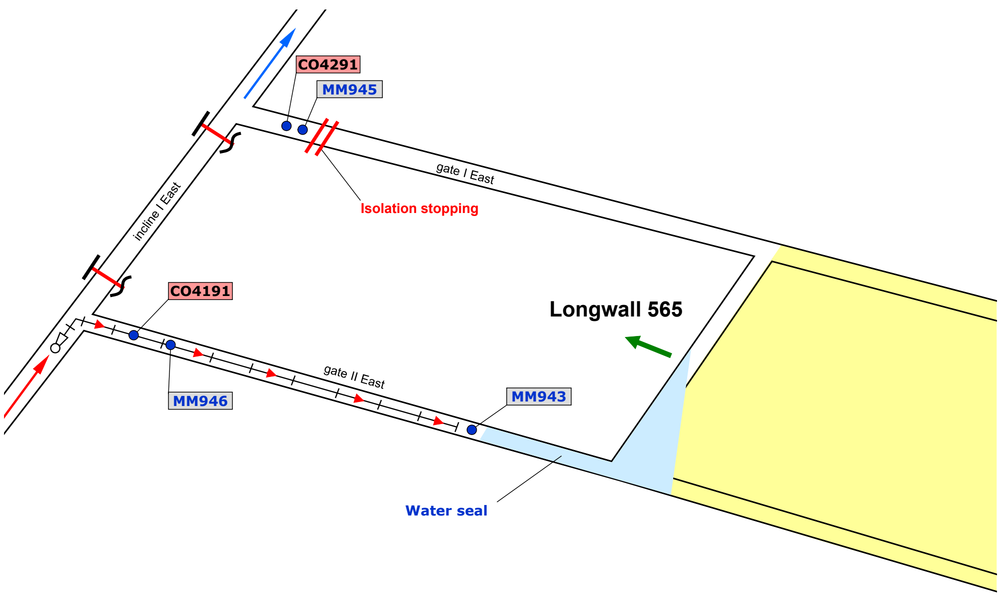


Figure 6 – Diagram of sealing off of the longwall 565 seam 510A East and location of the sensors
(during rescue operations – December 2010 – March 2011)

Administration of fly ashes from haulage cross-cut into section D_1, horizon 665 m

In January active fire fighting operations were commenced by administration of fly ashes in the form of ash-water mixture via holes from haulage cross-cut into the D_1 section at horizon 665 m, running about 130 meters above the gob of longwall 565 (fig 7) (Final Report of Development Project R09 0004 04 (N524), 2011).

The administration of fly ashes started on 11.01.2011 at 7^{00}, and lasted with the output of 1.5 m^3 / min, periodically on individual shifts. The schedule is shown in the table 1.

Table 1 – The sealed off gob of the longwall 565 in January 2011

date	Time of fly ashes administration
11.01.2011	shift I to IV
14.01.2011	shift IV
17.01.2011	shift I and III
18.01.2011	shift I to IV
19.01.2011	shift I to IV
20.01.2011	shift II and III
27.01.2011	shift I to IV

Table 2 – The administration of ashes to sealed off gob of the longwall 565 through the holes in February 2011

date	Quantity of ashes	Hole- sight
01.02.2011	399 t	R-5 on sight 527
02.02.2011	473 t	R-5 on sight 527
07.02.2011	492 t	R-6 on sight 557
08.02.2011	201 t	R-8 on sight 597
10.02.2011	250 t	R-8 on sight 597
16.02.2011	253 t	R-8 on sight 597
17.02.2011	264 t	R-8 on sight 597
13.04.2011	672 t	R-7 on sight 594

Altogether 19 425 tons of fly ashes were supplied to a sealed off longwall 565, while in the period February – April 2011, 6 433 tons of fly ashes were delivered, while 2 782 tons of ash-water mixture was injected into section D_1 into the gob of longwall 565 through the holes drilled from the haulage cross-cut (Table 2).

Monitoring of gases concentration in gobs of longwall 565 from haulage gate D-1, horizon 665

Observations of gases concentrations in the area of longwall 565 seam, 510A eastern that was on fire (Final Report of Development Project R09 0004 04 (N524), 2011) was conducted several months from December 2010 to April 2011, registering gases concentration in the gob through a hole drilled from haulage cross-cut D-1 and circulating air parameters at stoppings sealing off the longwall 565, after unsealing also at the longwall 565 itself The gob probe was located in the hole of above the sealed off gob of longwall 565 (fig. 6) from the side of haulage gate D-1. The individual probes (CH_4, O_2, CO_2, CO) of the integrated gob sensor (gob probe) connected with automatic gasometry system provided a very large amount of data (registration by several sensors in the cycle every 2 seconds), for further detailed analysis and interpretation. During several months of observation the study was carried out on, among others, the effect of applied fire extinguishing means, including backfilling with mixture of flotation tailings in the gob of the sealed off longwall on the change of gases concentrations in the gob of the longwall and adjacent workings.

The collected data are of cognitive character, but also provided a wealth of input data for modeling research in computer simulations.

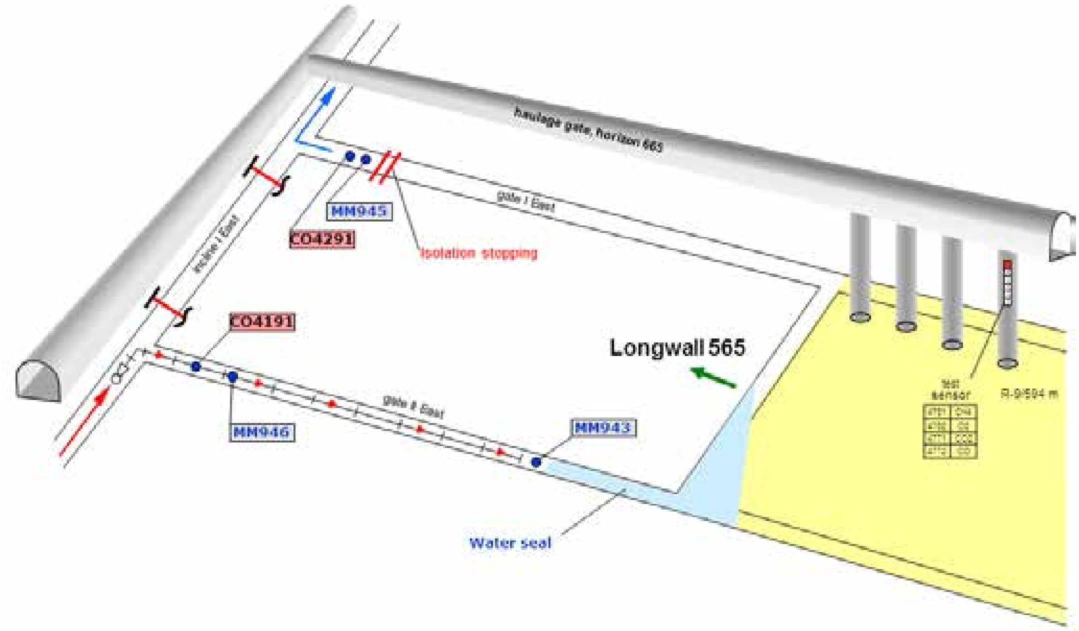


Figure 7 – Manner of monitoring of gases concentration in the gob of sealed off longwall 565, seam. 510A East through holes from cross-cut D-1 (during firefighting operations – December 2010 – March 2011)

Methane concentration recorded in the area of the sealed off longwall 565 in February 2011 (Fig. 8) were at a low level, i.e. below 1% CH_4 on all sensors in the region. Temporary increases were probably the result of feeding of standard mixture during periodical, once a week, calibration of the sensors. Changes in methane concentration, especially in the first half of February, were the effects of pushing out of methane from gobs of longwall 565 as a result of administration of ash-water mixture into the gob during the firefighting rescue operations.

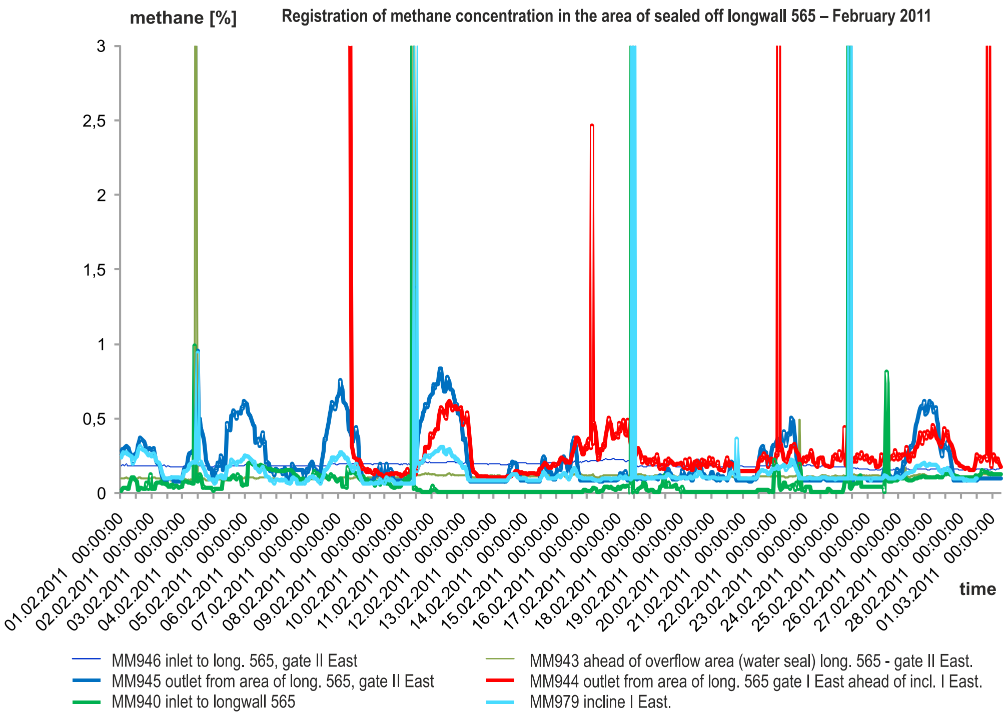


Figure 8 – Graph of air parameters in the longwall 565 in seam 510A eastern. (February 2011)

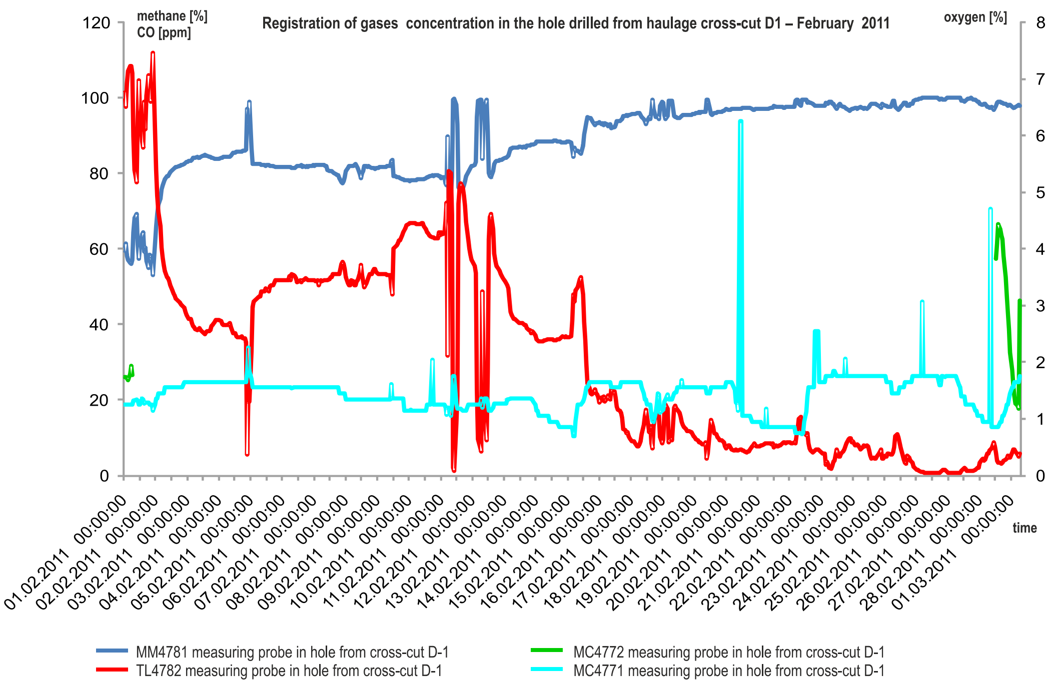


Figure 9 – Graph of air parameters in the hole drilled into the gob of longwall 565 from cross-cut D-1 (February 2011)

Interesting changes in gases concentrations were registered in the month of February (Fig. 9) with the use of gas probes of the integrated gob sensor (ZCZ) located in the hole from cross-cut D-1 to the gob of longwall 565 (Fig. 7). This applies, in particular, to the concentration of methane and oxygen in the gob of longwall 565. Concentration of methane increased from 60% CH_4 in early February to 90% CH_4 in the second half of the month. At the same time the oxygen concentration decreased respectively from about 7% O_2 to about 1% in the second half of month. Such changes were, most likely, the result of administration of significant amount of the mixture of ash and water during firefighting rescue operations in the gob of the longwall. The nature of changes in the concentration of these gases in the gob (fig. 8 and 9) was, undoubtedly, associated with the periods of delivery of ash-water mixture into the gob through the hole from the haulage cross-cut D-1.

In this way, the effects of conductance of fire fighting operations in the gob were continuously monitored in the system of automatic gasometry which fully confirmed the innovative nature of the solution of controlling the atmosphere in the gob. On the basis of the course of gases concentration in the gob one can state that the conducted fire fighting operations in the gob effectively led to the suppression of the fire in the oxygen-free atmosphere and the atmosphere being inerted with methane.

Model research on distribution of methane concentration in the gob of longwall 565 after its sealing off

Based on the available data (mining and geological maps, design of longwall 565, ventilation data, registrations from the monitoring of the area) a numerical model was developed (Final report from research task No 3, 2013) for the longwall 565 in seam 510. The balance of air and methane in the mine workings and the gob of the ventilation region during mining operations was made on the basis of the obtained results of simulation calculations mine and gob the area of the ventilation during the operation, which was considered as the initial - boundary conditions for numerical simulations of the state of ventilation in the area of the longwall 565 and the distribution of gases in the space of the gob of this longwall after its sealing off.

In accordance with the plan of liquidation of fire hazard in the longwall 565, the mine sealed off the region and set up a fire area. On the inlet into the longwall in the gate II eastern an explosion proof water seal was formed, taking advantage of significant water inflow and favorable inclination of this working (Fig. 6).On the side of gate I eastern (outlet from the longwall) an explosion proof stopping TP-5 was erected. The above mentioned information was used in the computer simulation system to reconstruct the conditions occurring within the sealed off area and in the gob of the longwall 565, roads withdrawing the air from the longwall 565.

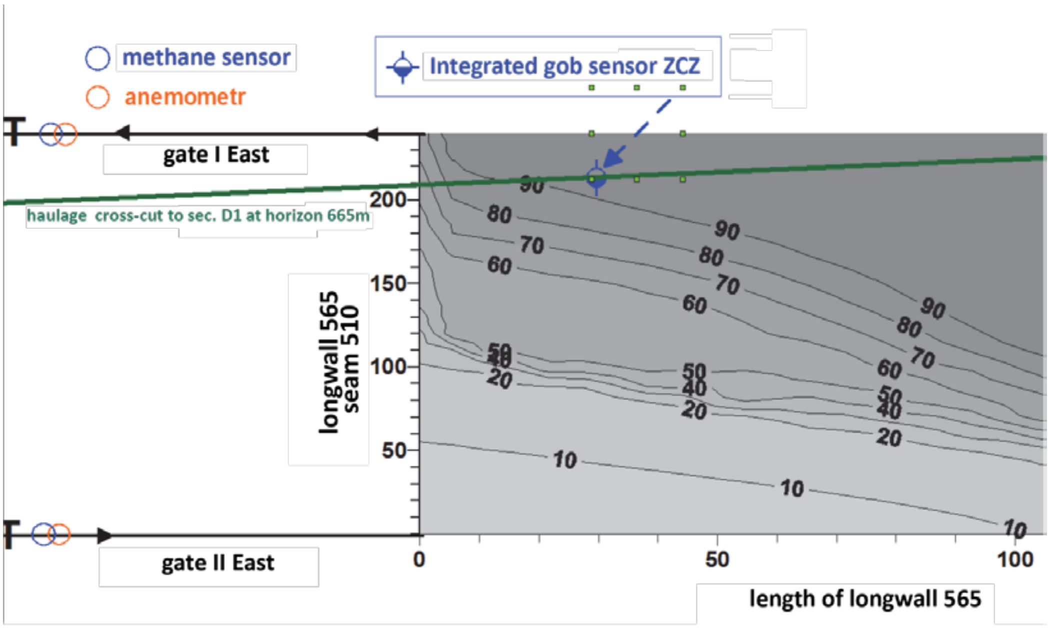


Figure 10 – Isolines of distribution of methane concentration in the gob of longwall 565, in the sealed off area (Final report from research task No 3, 2013)

Presented distribution of methane concentration (Fig. 10) in the gob reconstructed well the concentration of methane in the gob of longwall 565 on the site of location of the gob sensor ZCZ.

SUMMARY

The research experiment consisting in long-term observation of air parameters in the area of the longwall 565 seam 510A and gases concentration in the gob of this longwall during a fire in the gob, and conducted fire fighting rescue operations by the administration of ash-water mixture into the gob was successfully completed in early April 2011.

Air parameters, including changes in gases concentration in the gob of longwall 565 recorded with the use of gas sensors (ZCZ) of gas measuring probe in the hole from the cross-cut D-1 drilled to the gob of longwall 565, showed an increase in methane concentration in gob by up to 90% CH_4 in the second half of February and a simultaneous decrease in oxygen in the gob to about 1% O_2. Such changes in gas concentration in gob, during the fire and during active fire fighting rescue operations, testified about obtaining of an inert atmosphere in the gob, which was, no doubt, also the result of administration of the significant amount of the ash-water mixture into the gob during the fire fighting rescue operations in the gob of the longwall.

This way the possibility of ongoing monitoring of gases concentration in the gob in the system of automatic gasometry was demonstrated and following the effects of conducting fire fighting rescue operation in the gob what constitutes a completely innovative solution to control the atmosphere in the gob. At the same time based on changes in gases concentration in the gob one can consider that the conducted fire fighting operations in the gob led to the suppression of the fire in the oxygen free atmosphere and the atmosphere being inerted with methane.

During the experiment, a lot of data was acquired about the concentration of gases in the gob, including data from continuous monitoring of gases concentrations and observation of the impact of the applied hazard prevention by administration of ash-water mixture to the gob on fire. The obtained data were used as input data for a computer simulation of gases distribution in the gob during a fire, taking into account the applied fire fighting method and the administration of fire extinguishing agents. Distribution of methane concentration in gob obtained in the model appropriately reproduced the measured methane concentration in gob of the longwall 565, on site of the gob sensor ZCZ.

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STRUCTURAL CONDITIONING AND SUMMARY OF MAIN GEOLOGICAL EVENTS IN MINERAL PEGMATITES, SERIDÓ (PB-RN)

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STRUCTURAL GEOLOGICAL CONDITIONING AND SUMMARY OF MAIN EVENTS IN MINERAL PEGMATITES SERIDÓ (PB-RN)

ABSTRACT

The Seridó region covers an abundance of mineral resources that make up the majority of industrial minerals in Brazil. Geologically, this region is composed of rocks of the Seridó Pegmatític Province, which is located in the Rio Grande do Norte Domain of the Borborema Province. Its structure is strongly controlled by the E-W Patos Lineament and other NE-SW and N-S shear zones. This regional fabric controls extensional sites. Recent works have interpreted geological controls on the mineralization along most of pegmatitic bodies. The Pedra Lavrada and Junco do Seridó region in the Paraíba State and the vicinity of Carnauba dos Dantas in Rio Grande do Norte can be highlighted, once they concentrate several mineral occurrences explored by mining companies. On the vicinity of these towns, five similar pegmatitic bodies were mapped in a 1:2.500 scale and the mineral occurrences were recorded. They are: i) Taboa (tourmaline, garnet and rose quartz, ii) Alto do Feio (rose quartz, tourmaline, apatite and garnet), Alto do Boqueirão (tormaline and garnet), iv) Alto Serra Branca (elbaite and phosphates and v) Galo Branco (feldspars and kaolin). Apparently, most of these rocks correspond to heterogeneous pegmatites with well-defined mineral zoning from the rim to the core. However, some features suggest the evidence of homogeneous pegmatitic sites.

KEYWORDS

Pegmatites, Seridó PegmatiticProvince, NE Brazil

INTRODUCTION

The Seridó Pegmatitic Province corresponds to an important mining district in northeastern Brazil between the states of Paraíba and Rio Grande do Norte (Santos et al., 2014). This province is characterized by important mineral occurrences, including various minerals with industrial application such as mica, quartz, feldspar and kaolin, as well as extensive gemmological content which is known worldwide, such as aquamarines and elbaite tourmalines, including the famous Paraíba tourmaline of São José da Batalha region (Paraíba state).

Recent studies and detailed geological mapping have given importance to mineral zoning of pegmatite bodies in this region, especially in pegmatites that occur in the vicinity of Pedra Lavrada Town (PB). Mineralization control is usually defined in regions strongly affected by deformation or by petrology affinities with pegmatites, which are often described as heterogeneous in the international literature (London, 2008 and references therein).

The main objective of this paper is to describe some of the most important mineral occurrences in the context of Pegmatitic Seridó Province, NE Brazil, as well as the main regional structures that affect the region.

Seridó Pegmatitic Province

The Seridó Pegmatitic Province is inserted in the Seridó Belt of the Rio Grande do Norte Domain (Figure 1), which is located in the northern portion of the Borborema Province. The latter was defined by Almeida et al. (1981) as a Neoproterozoic tectonic entity that occupies the eastern portion of northeastern Brazil and was consolidated by the convergence of the São Francisco-Congo and São Luis-West Africa cratons during the Brasiliano-Pan-African orogenic cycle.

Regionally, the Rio Grande do Norte Domain consists of several sequences of orthogneiss and migmatites, which are Archean and paleoproterozoic in age, including the Jaguaribeano, Rio Pirangas and São José do Campestre domains. In addition, these rocks are intruded by several Ediacaran granites related to the Brasiliano orogenic cycle (Brito Neves et al. 2000). This area is limited by the Ceará Central areas on north and on south by the Senador Pompeu transverse shear zone and the Patos lineament.

Throughout this mining region, several occurrences of mineralized pegmatite bodies are known, including Fortuna, Mourão, Costume, Serra Branca, the Alto do Feio, among others.

The pegmatites contain well defined mineral zoning areas with sterile edges and homogeneous mineralization, disseminated in pockets in its interior. They were described by Johnston Jr (1945) as heterogeneous pegmatites.

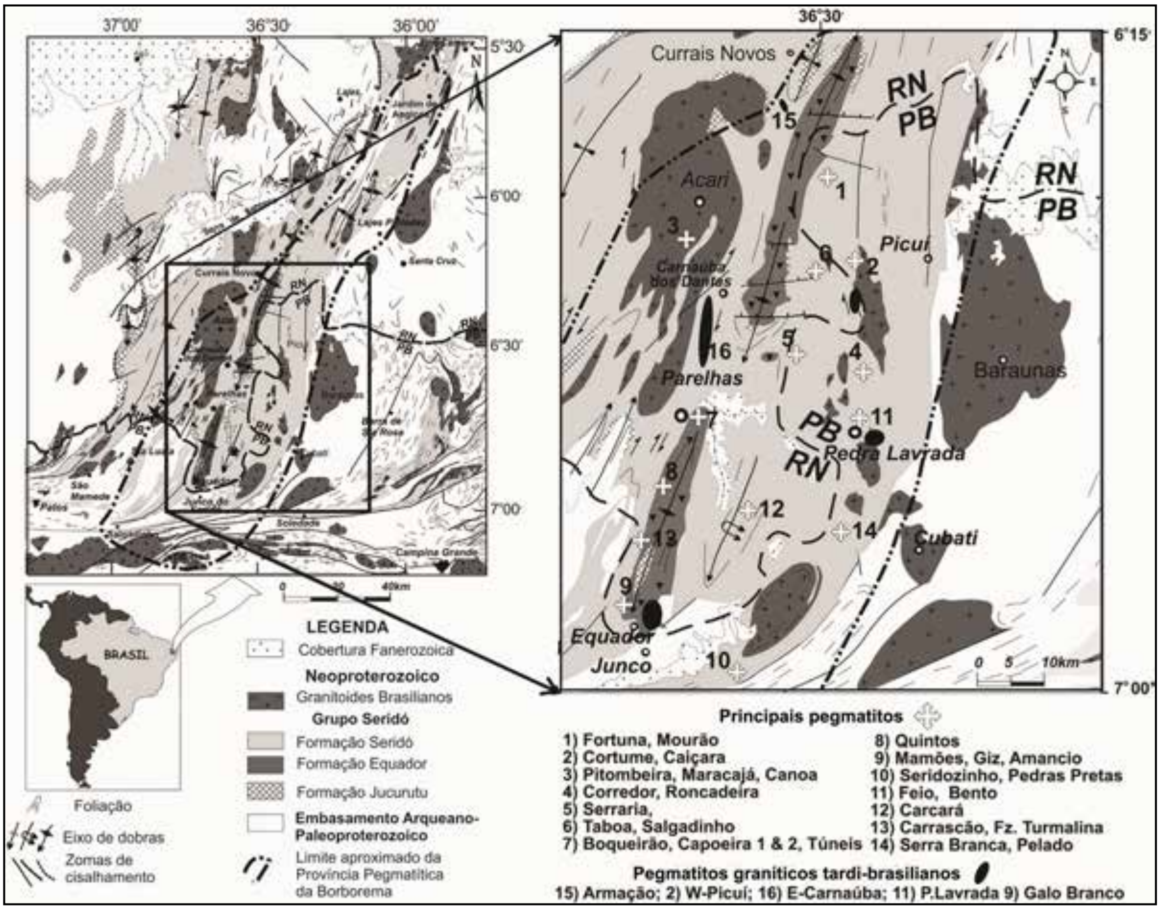

Figure 1 - Geological map of the PPS area with the location of the main mineralized pegmatites, modified from Buerlen et al., (2014).

Main regional structures

The Seridó Pegmatitic Province is strongly affected by ductile shear zones. The most important of them corresponds to the Patos lineament, which has a regional extent and is considered by several authors as a terrane boundary (Brito Neves et al., 2000). This structure is E-W oriented and corresponds to a dextral strike-slip shear zone which strongly deforms the rocks of the Seridó Fold Belt and affects the borders of the mineralized pegmatites.

In addition, this region is also affected by NE-SW and N-S transcurrent shear zones, which can present up to 30 km extent. These are particularly important, because they are responsible by the ovoid and elongated shape of the pegmatites. Some examples of these structures include the Nova Palmeira, Pedra Lavrada and Picuí-João Câmara shear zones.

In specific regions, this ductile deformation migrates to a brittle regime. forming transtensional sites, which are usually related to the main mechanism of emplacement of mineralized pegmatites in the region as it was refered by several authors, including Santos et al (2014 and references therein). This brittle tectonics also control the injection of mineralized veins and dykes that cross-cut pegmatitic bodies, being mostly mineralized in elbaite tourmaline, garnet and other important minerals.

Pegmatitic zoning and mineral occurrence

Well-known pegmatitic provinces can be described in terms of its heterogeneous distribution of mineralization as described by London (2008). The zonation observed in most of the pegmatites of the Seridó Pegmatitic Province can provide an insight of the mineral distribution in the region.

So far, most of studied pegmatites can be grouped in three main zones of mineral distribution. They are: i) border areas, ii) intermediate zones and iii) homogeneous core.

The edge region is also known as contact zones. It is marked by the interaction of pegmatites and host rocks. The latter is usually represented by biotite schist and garnet-biotite schist of the Seridó (Figure 2A). These rocks are strongly influenced by the aforementioned shear zones. In addition, it is pretty common in this region the presence of supracrustal in the pegmatitic matrix, as an evidence of forced intrusion. This region is also characterized by extremely thick textures, which concentrate occurrences of centimetric to metric albitic feldspar, quartz and muscovite. Kaolinitic levels resulting from secondary feldspar alteration is also common, but spatially restricted (Figure 2b). Additionally, some gemologic minerals with economic importance tend to be concentrated in this region including *água-marinha* beryl variety (Figure 2c) and elbaite tourmaline, besides widespread garnet crystals.

The intermediate zones, which are also known as wall zones are characterized by systematic decrease of rock grain size, forming a thiner phaneritic texture. From an economic point of view, these region tend to be sterile. It concentrates mostly quartz and potassic feldspar with graphic intergrowth that is commonly interpreted as a result of chemical instability events in the last stages of fractional crystallization (Fenn, 1986).

Finally, the core areas are mainly characterized by milky quartz, occurring citrus and Murion variations. Eventually, radial muscovite crystals (Figure 2d) are frequently observed, in addition to minor black tourmaline occurrences.

However, it is important to note that some of these bodies are homogeneous or mixed with one or more pockets core of quartz or scarce in relation to the core. The understanding of the mineral distribution in this bodies is more complex and represents a further research target.

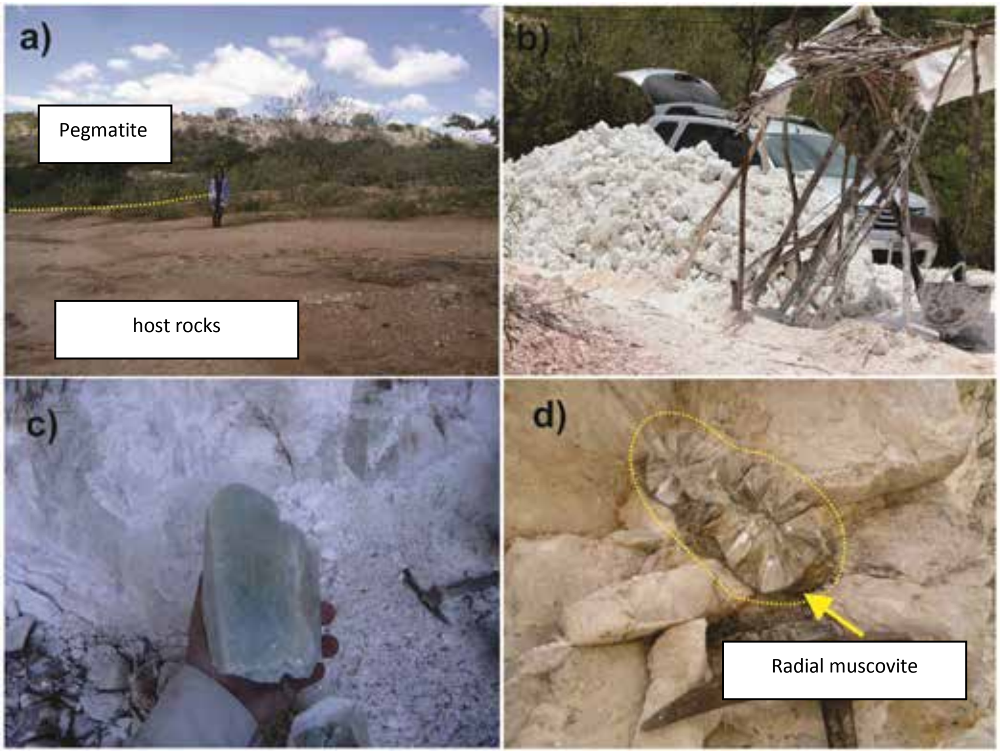

Figure 2 - Field Aspects of the studied pegmatites. a) Relationship between the enclosing schists and pegmatite, b) kaolin extraction, c) green beryl d) radial muscovite in homogeneous core quartz zone.

Conclusions

The findings of this study can be summarized as follows:

- The Seridó Pegmatitic Province hosts several mineralized pegmatites that are strongly affected by transcurrent shear zones, including the E-W Patos Lineament and the NE-SW Pedra Lavrada, Nova Palmeira and Picuí-João Câmara shear zones. Transtentional sites can be regarded as the main mechanism of pegmatitic emplacement in the region.

- Most of the heterogeneous pegmatites of the region have similar characteristic mineral zoning, as in several well-known pegmatitic districts worldwide.

- Based on the main mineral occurrences, these areas are divided into: i) border areas, ii) intermediate zones and iii) contact zones;

- The mineralogy varies from the edge to the center, concentrating a major mineral heterogeneity in the contact zones with the host rocks which includes feldspar, quartz, and gemmological minerals such as beryl and tourmaline. On the other hand, the inner regions are characterized by homogeneous patterns with varied quartz crystals. In addition, it can also contain other disseminated minerals;

- The identification of mineralized zones in the various pegmatite bodies represents a geological prospective tool that is essential for the extraction of these ore deposits.

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THE ROLE OF BRITTLE STRUCTURES ON THE EMPLACEMENT OF MINERALIZED PEGMATITES IN THE PEDRA LAVRADA DISTRICT, NE BRAZIL

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ABSTRACT

Brittle structures and dilatation surfaces can eventually be filled by later magmas or residual fluid injections, resulting in veins and dykes. The Pedra Lavrada city in Paraíba state, NE Brazil is characterized by several occurrences of granitic pegmatites that are explored nowadays for potassic feldspar, white micas, quartz and eventually gemstones. It has been recently argued the importance of the structural geology of the region in the genesis of mineralization of these pegmatites. In spite of the complex structural pattern that affects the region, the ductile-brittle and essentially brittle tectonics are extremely important, once they control most of pegmatitic injections, including mineralized ones. The first regime controls the shape and orientation of most of the pegmatitic rocks, such as the Alto do Feio and Alto Serra Branca pegmatites. This deformation is related to a transtensive event that also injected Ediacaran granitic suites, which are sterile in economic minerals. On the other hand, brittle tectonics, which is represented by fractures, joints and other dilatational structures, has a singular orientation pattern. They are usually sub-vertical and horizontal, and can be oriented in NE-SW, NW-SE directions, but are mainly E-W and N-S. In addition this latter can form veins and dykes which are generally pegmatitic and aplitic in composition and usually host important ore minerals such as cassiterite, amblygonite, garnet and elbaite tourmaline, which are usually not explored in the area. The identification of such structures crosscutting the major pegmatites and granites, may represent a strategic geological source for these ore minerals in the Pedra Lavrada region, that must be better investigated in future prospecting works.

KEYWORDS

Brittle structures, mineralized pegmatites, northeast Brazil.

INTRODUCTION

Brittle tectonics can usually plas an important role on the transport and concentration of mineral deposits on the continental crust, including pegmatitic rocks (London, 2008). The Pedra Lavrada mining district is inserted on the Borborema Pegmatitic Province (Figure 1). This province comprises an area of 75 x 150 km of several occurrences of granitic pegmatites that are intrusive in supracrustal rocks of the Seridó Fold Belt (Beurlen et al. 2009).

Since the 1940´s, systematic geological mapping and field works demonstrated the economic importance of pegmatitic bodies of this region. Johnston Jr. (1945) was pioneer in determining the importance of mineral zoning on these rocks, defining the main pegmatitic groups as: i) homogeneous and ii) heterogeneous, based on mineralization styles.

On a stratigraphic point of view, the Seridó FoldB is composed by the Jucurutú, Equador and Seridó formations (Van Schmus, 2003). Most of pegmatitic bodies are intrusive in biotite schists and garnet-biotite schists of the Seridó formation, with minor amounts on the quartzites of the Equador Formation.

This mining district is located in the boundary between the Paraiba and Rio Grande do Norte states, covering the Cubati, Pedra Lavrada and Picuí towns. This region is characterized by large occurrences of supracrustal rocks of the Seridó Fold Belt, Paleoproterozoic dioritic to granodioritic orthogneisses of the Serrinha Pedro Velho Complex and Ediacaran granitic intrusions which are related to the Brasiliano orogenesis at ca. 600 Ma (Santos et al., 2000).

These rocks, including the studied pegmatites follow a regional structural trend on the NE-SW directions, due the strong influence of shear zones that affect the region, including the E-W Patos Lineament and the NE-SW Pedra Lavrada and Picuí João Câmara strike-slip shear zones. However, on specific pegmatitic bodies, such as the Alto do Feio and Alto da Serra Branca, several brittle structures seems to have been very important on the emplacement of these rocks, besides the transportation and concentration of some important ore minerals. In this paper, we present field relationships and mesoscopic structures aiming to demonstrate the importance of brittle structures on the emplacement of these pegmatites.

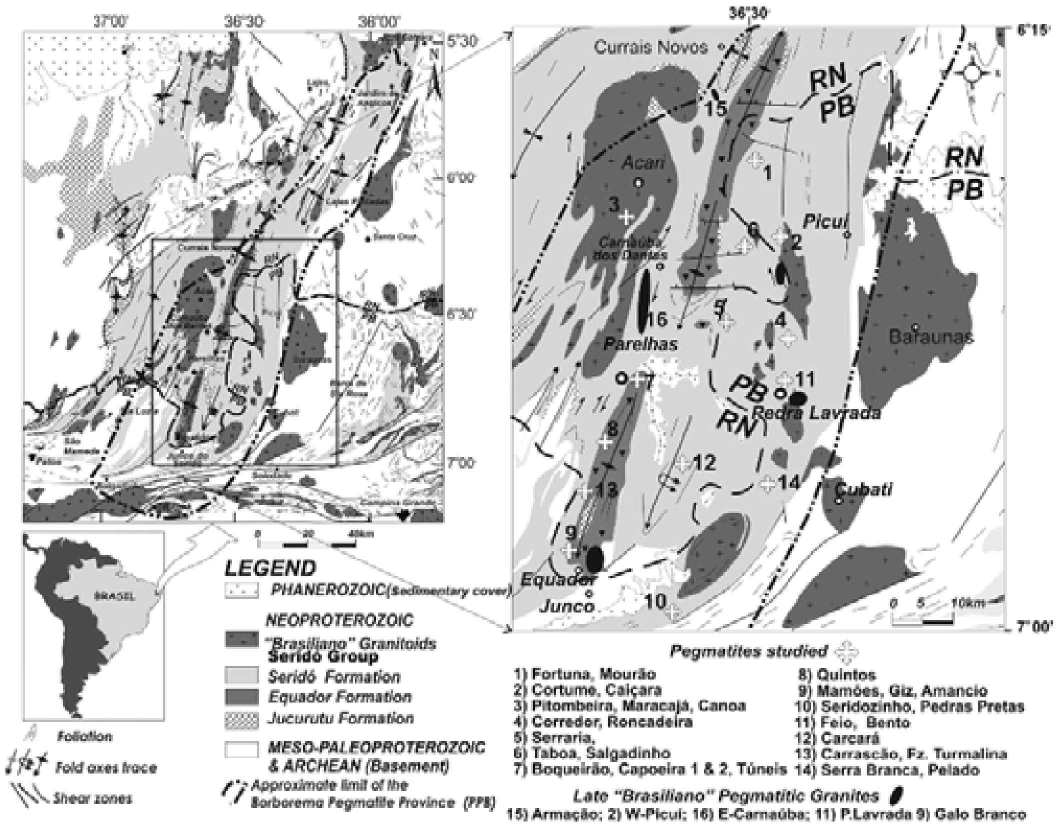

Figure 1 – Regional geological map of the Borborema Pegmatitic Province and the location of the main pegmatitic bodies, after Beurlen et al., (2014).

GEOLOGY OF THE STUDY AREA

The Alto do Feio and Alto da Serra Branca pegmatites present circular to ellipsoidal forms. They are intrusive in mica-schists and paragneisses of the Seridó Formation, developing sharp and irregular contacts. Their main structural trend is controlled by the combination of NE-SW local ductile shear zones and fractures that are mainly E-W and N-S, which strongly affect supracrustal host rocks. In addition, nowadays, these rocks are particularly important for the region, once they are sources of industrial minerals, such as quartz, muscovite and feldspar that are extracted by small mining companies. Minor fractures also occurs in the area, being injected by aplitic and pegmatitic rocks, that cross-cut the regional trend. This tectonics is also associated with several quartz-veins with a major E-W related-trending.

Equigranular monzogranites, diorites and porphyritic mesocratic granites are closely associated with the pegmatitic bodies, and may be the main source for the fluids that originated pegmatitic rocks in the region. Like most heterogeneous pegmatites of the Borborema Pegmatitice province, these rocks are characterized by a clear mineral zoning with mineral homogeneity increase towards the central zones. On both pegmatites, zonation and mineral assemblage are very similar between them, usually with disseminated economic minerals on the external zones and quartz nuclei on the inner zones.

In general, these rocks are leucocratic, inequigranular and present typical pegmatitic texture. The external zones are usually referred as rim, border and contact zones. These regions are characterized by contact relationships with the wall rock and are extremely heterogeneous (Figure 2a). However, regarding these specific pegmatites, a typical mineral assemblage can be easily recognized. It includes up to 5 cm of quartz + potassic feldspar + lamellae muscovite ± albite association. On the other hand, xenoliths of schists are usually observed in these zones. Moreover, tourmaline, including subhedric to anhedric schorlite, prismatic elbaite crystals and euhedric brownish garnet are disseminated in pegmatitic matrix.

Intermediate and wall zones are present in both pegmatitic bodies, being characterized by a considerable granulometric decrease. This zone is mostly homogeneous with the predominance of the quartz + potassic feldspar paragenesis (Figure 2b). A typical characteristic of this zone is the plenty of graphic textures throughout all associated outcrops. The presence of this irregular intergrowth is usually related to chemical disequilibrium episodes in later stages of magma fractional crystallization (Fenn, 1986). In spite of this, subhedric to angedric prismatic tournalime crystals and radial muscovite lamellae can be commonly present and are generally associated to fracture zones.

At last, the core zone in both pegmatites is mostly formed by large amounts of huge (up to 1,5 meters) of massif crystals of quartz. Depending on the pegmatite region, this mineral can vary from anhedric to euhedric, with different colors including yellow and hyaline variations. However, whitish quartz is by far the most common phase, especially in the innermost areas. In addition, uncommon minerals of the Borborema Pegmatitic Province are also present in these rocks, including pyrolusite and iron-oxides (mainly hematite) with dentritic habit, besides pure albite, including anhedric cleavelandite variety (Figure 2c) and euhedric cassiterite crystals (Figure 2d), that can be present in a disseminated form, but in a lesser extent.

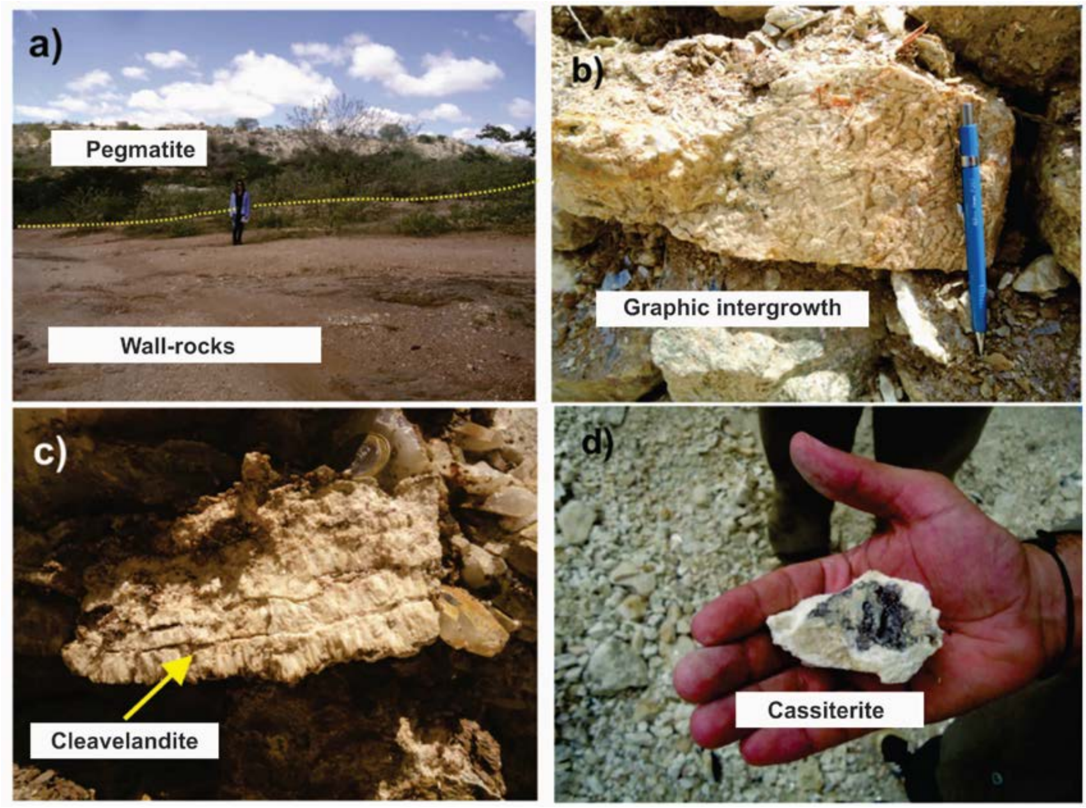

Figure 2 – Field aspects of the studied pegmatites including rare mineral occurrences for the Borborema Pegmatitic Province.

THE ROLE OF BRITTLE TECTONICS

The studied pegmatites have a strong structural control, which is related to distinct tectonic regimes. The ductile rheology is responsible by the formation of several strike-slip shear zones in the area that form tear-drop shapes on supracrustal rocks in regional maps. However, brittle tectonics is also particularly important. This regime is recorded in fractures and joints that are related to the last deformation stage of the region.

Geological mapping has reviewed the presence of four main families of brittle structures that follows main directions: i) NW-SE, ii) NE-SW, iii) E-W and N-S (Figure 3). These latter are the most common structures on these rocks. On the other hand, random fracture directions are responsible for aplitic and sterile pegmatites along the whole area and seem to be not spatially and temporal associated with the mineralized rocks so far.

Most of the mapped fractures are concentrated in the border zones of pegmatites and occur in the contact regions between them and the supracustal rocks. In general, they cross-cut the regional foliation and trends, tending to develop several slicken-side surfaces and fracture zones with cataclasitic regions or eventually forming local gouge lines. On the Alto do Feio pegmatite, these fractures are considered as an important structural control of mineralization. For instance, several quartz-rich veins with vertical character are formed by silex + white to yellow quartz and radial muscovite, besides greenish elbaite tourmaline in the border zones, suggesting that SiO_2-rich fluids were crystallized on dilatational sites. The most probable sources for these fluids are the adjacent granites. Most of it has an NW-SE strike.

Moreover, in the core zone, amorphous silica is also present, but generally concentrating schorllite tourmaline and cassiterite crystals in the E-W direction, which suggest the rotation of the main fracture trending.

In addition, a similar mineralogy and structural trending is observed in most fractures of the Alto Serra Branca pegmatite; however there is an increase of medium angle fracture families, especially in the border zones. In the quartz core, there is also a tendency to form NE-SW fractures, which are fairly concordant with the regional ductile deformation. An important aspect of these structures is the presence of minor disseminated phosphate minerals including anhedral amblygonite, which is considerably rare in pegmatites of the Borborema Province, whereas N-S fractures tend to crystallize high amounts of hyaline quartz.

On the other hand, NW-SE fractures and joints that are usually NW-SE, usually cross-cut the N-S and NE-SW family, being normally characterized by quartz-rich fine aplites and milkish quartz-veins, which are very often sterile, but dislocate horizontally previous fractures and related-structures. However, we suggest that the influence of these structures was particularly important in a post-pegmatitic emplacement scenario.

At last, most of mapped fractures follow regional mylonitic sites, including similar directions and kinematics, which can be interpreted as coeval with the late stages of ductile deformation. They must plaid an important role for crust fragmentation and ascent of pegmatitic bodies. Additionally, the presence of quartz and feldspar sigmoids, S-C structures and other structural markers also demonstrate that strike-slip ductile structures were active during the injection of these silica-rich magmas.

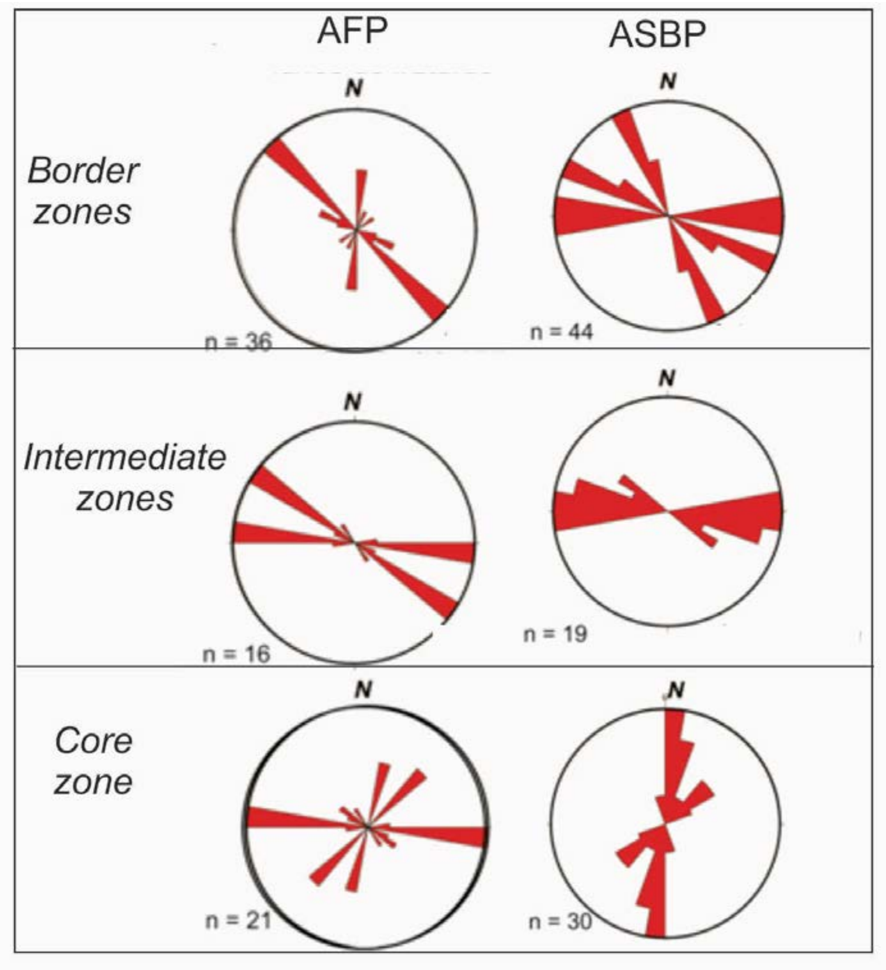

Figure 3 – Main structural trends of mapped fractures in the pegmatitic rocks. AFP = Alto do Feio pegmatite, ASBP = Alto Serra branca pegmatite.

DISCUSSIONS AND CONCLUSIONS

Our study aims to demonstrate the importance of brittle structures on the emplacement, development and concentration of important economic minerals in pegmatites of the Borborema pegmatitic Province. In our study case, we focused on the Alto do Feio and Alto da Serra Branca pegmatites, which are part of the Pedra Lavrada mining district, an important area of industry mineral production in northeast Brazil.

Brittle structures are mainly concentrated in for main structural trends, which are: i) NW-SE, ii) NE-SW, iii) E-W and N-S. Some of it is related to the pegmatite shape, developing several fracture and cataclastic zones, besides the formation of local gouge-rich lines. The main importance of these structures lies on the structural control of important economic minerals, such as elbaite tourmalines, cassiterite, amblygonite and feldspars. Other important minerals include muscovite and quartz crystals of variable colors.

The importance of brittle structures and additional structural controls on pegmatites of the Borborema pegmatitic province was firstly pointed out by Agrawal (1992) that described several deformation events related with regional folding. On the other hand, Jardim de Sá (1994) has determined sequential deformation events that strongly affected the Seridó Fold Belt and its consequences for pegatitic intrusions.

In addition, Araújo et al., (2001) focuses on geometric and kinematic analysis of shear zones and faults that were closed related to pegmatitic injections in the region. This authors, grouped the main according to the structural style as: i) homogeneous pegmatites injected along structural unconformities, such as previous foliation and schistosity planes and ii) heterogeneous pegmatites injected through dilatational stages on a late-kinematic regime.

Based on the present data, we suggest that the alto do Feio and Alto Serra Branca bodies has similar characteristic to heterogeneous pegmatites that are strongly controlled by brittle structures, such as faults and joints. However, the presence of ductile markers also indicates that a ductile regime was acting during that time. Thus, we suggest that these rocks were emplaced in the continental crust during its fragmentation and coeval to late stages of transcurrent episodes in the area.

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USING GEOLOGICAL MAPPING AND SURFACE PROFILES TO UNDERSTAND THE MINERAL DISTRIBUTION ON THE ALTO DO FEIO PEGMATITE, PEDRA LAVRADA REGION, NE BRAZIL

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ABSTRACT

The Alto do Feio pegmatite occurs in the vicinity of the Pedra Lavrada city (Paraíba State), with an elongated form on the NE-SW direction. Regionally, this body belongs to the Borborema Pegmatite Province, occurring in the south portion of the Rio Grande do Norte Domain. Field studies and detailed geological mapping (1:2.500) revealed that this pegmatite is hosted by ductile deformed schists and paragneisses of the Seridó Formation. Transverse schematic geological sections along the main trend of the pegmatite indicated a clear mineral zonation, defined in three main regions from border to the centre: i) border zone (composed by feldspar and, in a minor concentration, tourmaline, apatite, garnet and mica), ii) core marginal zone (presenting quartz crystals and feldspar forming a graphic texture and concentrations of apatite and garnet) and iii) homogeneous core (composed mainly by quartz). This body is also cut by many fractures with vertical to sub-vertical attitude that are responsible for injections of quartz veins. The presence of border zones and a homogeneous quartz core allowed us to categorize Alto do Feio Pegmatite as heterogenic. Despite the increasingly quartz and feldspar exploration in this region, this pegmatite hosts other economically important minerals, such as micas (mainly muscovite), tourmalines and garnet.

KEYWORDS

Mineralized pegmatites, Borborema Pegmatitic Province, Alto do Feio Pegmatite, NE Brazil.

INTRODUCTION

The studied area is located near the city of Pedra Lavrada (Paraíba State), which is located 232 km from the state capital João Pessoa. This region and its adjacencies concentrate a large number of pegmatitic bodies that are potentially mineralized in various mineral species, including: feldspar, quartz, graphic granite, also locally known as prego, tantalite, beryl, mica (muscovite and biotite) and gems (Vasconcelos, 2006). As an example, we highlight the Manoel Paulo, Tanquinho, Pendanga, Sino, Serra Branca and Alto do Feio (focus of this research) pegmatites, which are exploited since the 1930s.

Objectives

Perform a superficial mineral prospection in the Alto do Feio pegmatite to better understand its geological controls and mineral distribution, given the importance of the pegmatites from the geological and economic point of view, especially in the study region. For this work, we propose a scheme of mineral zonation throughout this body, which is constrained by geological mapping and schematic geological profiles, as well as present geological characteristics of the country rocks.

Pegmatites

Pegmatites are igneous rocks formed by crystallization of residual enriched on fluids in granitic magmas (Johnston 1945; Jahns, 1955). Commonly, they present holocrystalline, inequigranular and phaneritic texture. Its main feature is the coarse texture evidenced crystals centimetric to metric, result of a slow cooling of magma.

Johnston (1945) classified pegmatites by their mineral distribution. This author divided granitic pegmatites into two main types: a) homogeneous and b) heterogeneous. Homogeneous pegmatites present quartz, feldspar and mica as essential minerals that are regularly distributed throughout the rock. They have tabular form with a mineral grain size ranging from centimetres to decimetre. In general, homogeneous pegmatites are usually extracted in block form for purposes of ornamental rocks. On the other hand, heterogeneous pegmatites have lenticular, rounded-shaped or flat disc shapes arranged irregularly forming structures in zones. They are characterized by a greater mineralogical variety.

There are also the mixed pegmatites, which have intermediate characteristics with respect to homogeneous and heterogeneous ones. A distinctive feature of this type of pegmatite is the presence of two or more quartz-rich regions throughout the mineralized body. These, as well as heterogeneous pegmatites are the main sources of quartz, feldspar and mica for use in industry, due to its zoned occurrence.

Borborema Pegmatitic Province

Located along the states of Paraíba and Rio Grande do Norte, this province was originally denominated Borborema Pegmatitic Province by Scorza (1944) to designate an important area of occurrence of mineralized pegmatites in the central portion of northeast of Brazil.

The pegmatites of this Province are concentrated in an area of 75km x 150 km, in the east-southeast of Seridó range, Rio Grande do Norte Subprovince of Borborema Province. The stratigraphic distribution of this area include Neoproterozoic granites and supracrustal rocks. Supracrustaal rocks present from the bottom to the top the Jucurutu, Ecuador and Seridó formations, inclusing metagraywackes, metaconglomerates, quartzites, paragneisses and schists of the Neoproterozoic aged Seridó Group (Van Schmus et al. 2003).

RESULTS AND DISCUSSION

The Alto do Feio pegmatite present an elongated shape in the NE-SW direction due the influence of regional deformation, forming a major topographic high in the study area. It is mostly hosted by supracrustal rocks, which are mainly represented by schsists (Figure 1).

During this study, geological mapping was carried out on a scale of detail (1:2.500). The geological map of the work area can be seen in Figure 2.

Its border areas can be deformed by regional ductile shear zones that are widespread in the region, being most controlled by the strike-slip Patos Shear zone. On the other hand, brittle structures such as fractures are widespread in the inner portions of the pegmatitic body. Most of them follows the N-S, NE-SW and NW-SE directions, being interpreted by later deformation, once they cross-cut the Alto do Feio pegmatite and the supracrustal rocks as well (Figure 2).

Structural analysis allowed us to define the main structures which are inserted throughout the mineralized zones of the pegmatite. The main obtained results are measured foliation, lineation and additional structural markers, as well as a NW-SE schematic geological section can be observed in Figure 3.

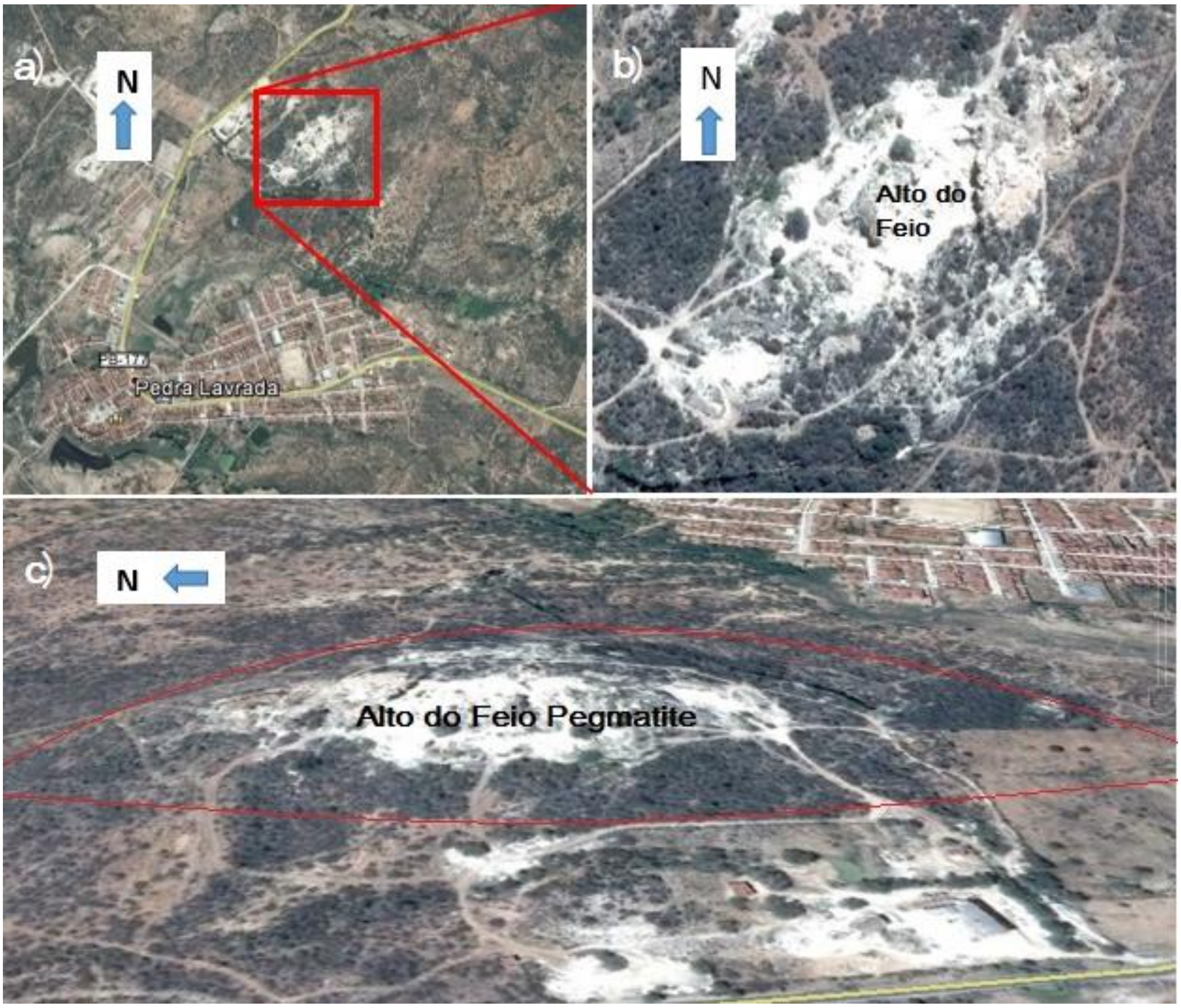

Figure1 - Satellite image showing the location of the Alto do Feio Pegmatite and its country rocks.

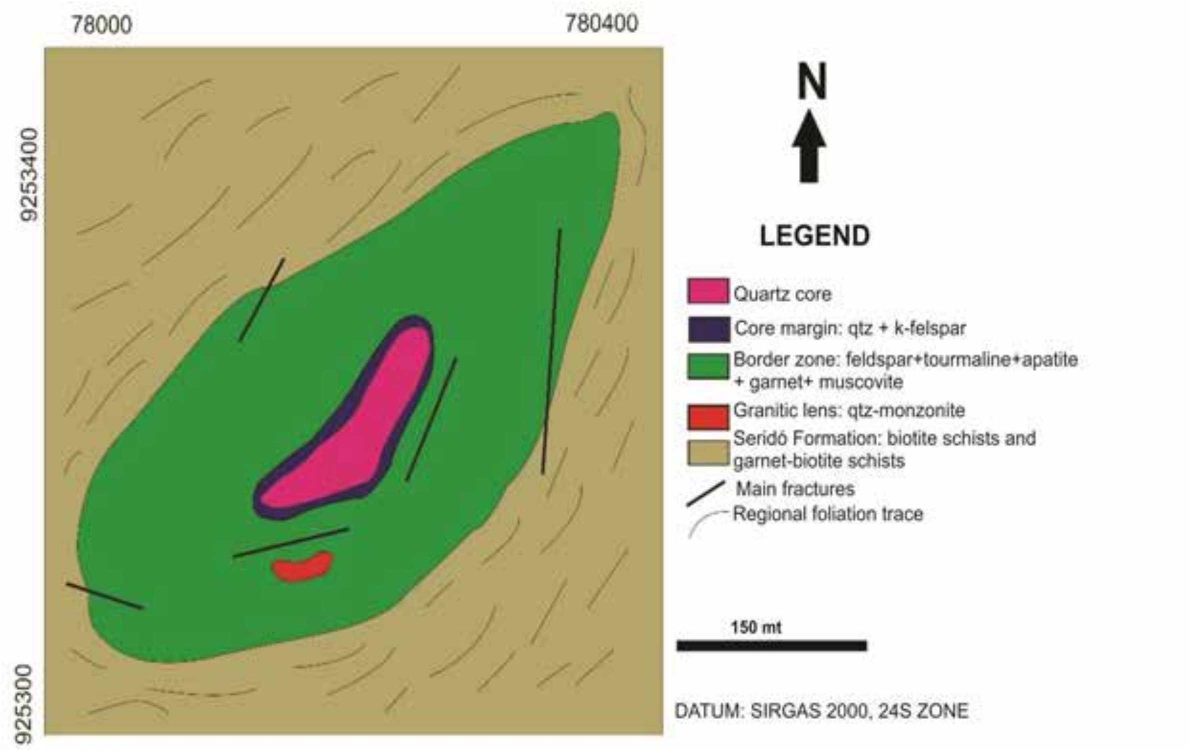

Figure 2 – Detailed Geologic Map of the Alto do Feio pegmatite and country rocks.

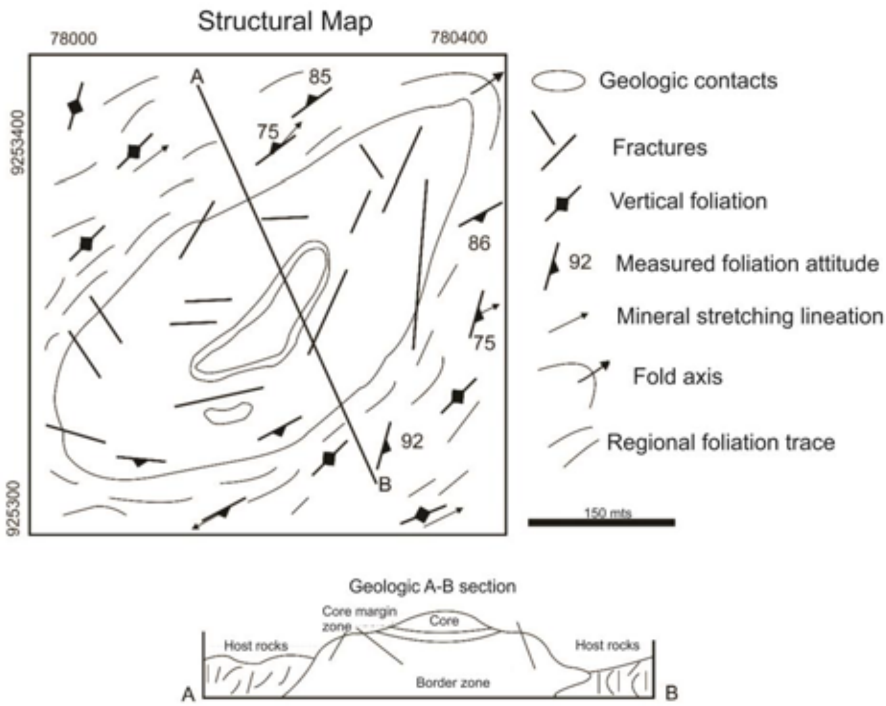

Figure 3 - Structural map of Alto do Feio pegmatite and adjacencies and schematic A-B geological section (NW-SE).

Country Rocks

In the studied area, metasedimentary rocks of the Seridó Formation of the Homonymous Group are widespread. These rocks have lepidoblastic texture with biotite lamellae accompanying the main directions of the regional foliation and lineation (Figures 4 (a) and (b)), being the main country rocks of the Alto do Feio Pegmatite.

The main observed rock types correspond to feldspathic mica schists, occurring as biotite schist and garnet-biotite-schist with punctual occurrences of aluminosilicate phases (probably andaluzite). On the other hand, other litholotypes described in the literature, such as as calk-silicates, paragneiss and metavolcanic rocks were not observed in the study area. Major mica crystals (mainly biotite) throughout the pegmatitic body are partially folded, which contribute to the formation of schistosity texture that may occur as a crenulation style. These rocks outcrop across the edge of the pegmatite Alto do Feio, being interpreted in this work as its enclosing portion.

Figure 4 (a) and (b) – Field aspects of country rocks (biotite-schist) of the Alto do Feio pegmatite. Such rocks are strongly deformed due the influence of regional deformation.

Alto do Feio Pegmatite

Based on geological mapping and transverse cross-sections, that this pegmatite present a typical zoned structure, which can be constrained by three major mineralized areas, which are: i) border zone, ii) core marginal zone and iii) core zone; which enable us to classify it as a heterogeneous pegmatite.

Border zone

This region is characterized by a coarse-grained distribution of minerals and well-developed crystals ranging from centimetric to metric in size, which reflects the main pegmatitic texture. The mineralogy of this zone consists of feldspar, with a predominance of plagioclase, quartz and minor concentrations of tourmaline, apatite, garnet, muscovite and potassic feldspar (Figure 5).

Figure 5 - Border area with presence of a matrix rich in feldspar, tourmaline, apatite, garnet and muscovite.

Core Marginal Zone

This region was defined as an intermediate region of contact between the core and the edge of the pegmatite. The main outstanding feature of this region is the presence of a decrease in crystal sizes and the presence of the graphic texture. This aspect can be evidenced by the occurrence of quartz and feldspar crystals in "worm-like" habits (Figure 7), which are typical from disequilibrium conditions in the magmatic chamber. In this region, apatite and garnet crystals are very common. Kaolin occurs locally as a result of secondary alteration of potash feldspar. In addition, in regions where the rock is fractured, silexite crystals occur (amorphous silica).

In most of pegmatites of the Borborema Pegmatitic Province, this described this region as wall-zones (Beurlen et al., 2009 and references therein), which present similar mineralogy and texture as well as a strong relationship which minerals formed in more internal regions of the pegmatitic rocks.

At last, a lens of light-gray granitoid was mapped. It is a rock with medium texture, predominantly phaneritic and inequigranular.

Petrographycally, the main mineralogy consists of quartz, potassium feldspar (orthoclase), plagioclase, biotite, amphibole (hornblende) and tiny muscovite crystals. As the rock has only 10% of mafic minerals, it was also classified as leucocratic. Macroscopic modal analysis on samples collected in the field revealed that its petrographic composition is quartz-monzonitic (Figure 8). Such occurrence can be correlated with several Neoproterozoic granites that are widespread in the region. In general, this rocks are interpreted to have a strong relationship with the pegmatites, however, its geological meaning is out of the scope of our research.

Figure 7 – Sample collected from the core marginal zone, exhibiting a typical graphic texture as a result of disequilibrium of the original magma.

Figure 8 - Granitoid with a typical quartz-monzonitic composition, that occurs as a lens within the Alto do Feio pegmatite.

Quartz Core

Located in the central part of the pegmatitic body, this region comprises a solid mass of quartz with variations of rosy to milky colour. There are a predominance of rose quartz in the centre and milky quartz occupying the outermost portion. It is possible to observe on a smaller scale the presence of disseminated crystals of plagioclase, dendritic crystals of pyrolusite dendrite crystals), cleavelandite (rare variety of sodic plagioclase, Figure 6) and geodes with amorphous silica. This region is intensively explored for quartz and muscovite extraction for small mining companies in the region.

Figure 6 - Quartz Core exhibiting contact between cleavelandite and milkish quartz crystals.

CONCLUSIONS

This study allowed us to obtain additional information geology, mineralogy, and economic potential of Alto do Feio pegmatite, located in the vicinities of the Pedra Lavrada city.

Geologically inserted in the Borborema Pegmatitic Province, this pegmatite has elongated shape in the NE-SW direction, with biotite-schist and garnet-biotite-schist of the Seridó Formation interpreted as its main country rocks, being s controlled by regional ductile deformation and strongly affected by local brittle structures.

This pegmatite has minerals irregularly arranged forming structures strongly zoned with systematic variations in texture, besides being affected by local fractures of various directions. It displays border zone, margin core zone and quartz core, as well as a lens of dark quartz-monzonite;

The observed mineral zonation, allowed us to classify this rock as a heterogeneous pegmatite. Important minerals are distributed throughout these zones, such as micas, garnet, pyrolusite and others. This work contribute for the geological knowledge of the study area as well for future prospecting works on pegmatites of the Borborema Pegmatitic Province.

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