Modeling and planning of bentonite clay mining: a case study at Bañado de Medina, Melo, Uruguay

Modelagem e planejamento de lavra de depósitos de argila bentonítica: estudo de caso: Bañado de Medina, Melo, Uruguai

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Resumo

O planejamento de lavra e seu correto sequenciamento são essenciais para viabilizar econômica e ambientalmente a explotação de bens minerais, assegurando a exequibilidade da lavra, tanto em termos operacionais, quanto econômicos. A pequena complexidade geológica ou o baixo valor agregado de um depósito mineral tendem a fazer com que as etapas de planejamentos sejam menosprezadas, iniciando-se a lavra sem o detalhamento necessário ou executando-o apenas para o curto prazo. Nesse sentido, de maneira a assegurar uma sequência de operações sustentável, bem como a previsão dos impactos ambientais provocados pelas atividades de extração, sugerindo opções que permitam o estabelecimento de medidas mitigatórias para os mesmos, avaliou-se a viabilidade do aproveitamento técnico e econômico, respeitando-se o meio ambiente local e dando ao projeto um forte caráter de sustentabilidade, de uma ocorrência de bentonita na jazida de Bañado de Medina, localizada no Departamento de Cerro Largo, Uruguai, verificando-se seu potencial para exploração comercial.

Palavras-chave: Planejamento mineiro, argila bentonítica, sustentabilidade ambiental.

Abstract

Mining planning and its correct sequencing are essential to facilitate the exploitation of minerals both economically and environmentally, thus ensuring the feasibility of the mining in operational and economic terms. The small geological complexity or the low aggregate value of a mineral deposit tends to result in the planning stages being neglected, so the mining begins without the necessary detailing or it is only scheduled for a short period of time. Thus, in order to ensure a sustainable sequence of operations, and to predict the environmental impacts caused by mining activities and suggest options that would allow the establishment of mitigation measures for these impacts, the feasibility of the technical and economic utilization was evaluated for an occurrence of bentonite in the Bañado de Medina deposit located in the Department of Cerro Largo, Uruguay, respecting the local environment in the process so as to give the project a strong character of sustainability.

Keywords: *Mine planning, bentonite clay, environmental sustainability.*

1. Introduction

In open-pit mining activities, especially those related to the exploitation of minerals with low added value, the detailed planning of extraction operations and the deposit of overburden and minerals are factors that directly influence the economic viability of projects, as in the case of tabular mineral bodies and shallow deposits of clay, limestone, or construction aggregates.

In general, the low added value of a given mineral deposit and the low geological complexity tend to result in the planning step being overlooked and the mining beginning without the necessary detailing, or only performing it over a short period of time. However, it is exactly this kind of practice that often leads to the renowned cases of predatory mining, underuse of deposits, and cases involving the greatest damage to the environment, which contradict the concept of sustainability.

The deposit in question in this study is a deposit of smectite clay located in the region of Melo, Uruguay, which, along with Boa Vista in the state of Paraiba in Brazil, Abra Del Despeñadero near the capital of Argentina, and Santa Elena in Ecuador, is one of the major deposits in South America (Luz & Oliveira, 2002; Gopinath & Lima, 2011).

Clays have been used by man since antiquity for manufacturing ceramic objects such as bricks and tiles, and more recently in many other technological applications such as adsorptive bleaching processes in the textile and food industries, in soil remediation processes, and in landfills (Barros, Melhado & Shimizu, 2002). Likewise, they are also used to adjust the rheological properties of fluids used in oil drilling, and paints, as well as for organic molecule carriers in cosmetics and pharmaceuticals, and as a support for catalysts. Interest in their use is gaining force due to the search for materials that do not harm the environment when discarded, and also due to the abundance of world reserves and their low price (Tomio, 1999). The possibility of chemically modifying clays allows the development of their use in different types of technological applications, thus adding value to this abundant natural resource (Albarnaz, 2009). Due to their particular characteristics, the clays at the Bañado de Medina deposit will be able to be used as toxin sequestrants in animal feed after passing through an improvement process (activation) that uses sodium carbonate and, therefore, changes them from calcic to sodic.

Normally, the strip mining method is most frequently adopted for deposits like clay that are tabular, horizontal, and shallow (Hustrulid & Kuchta, 1995; Hartman & Mutmansky, 2002; Jenkins, Falconer & Hentz, 1979). This method makes it possible to perform environmental recuperation simultaneously, reducing the costs associated with mitigation or compensation measures that, traditionally, are performed at the end of the project. The unit operations associated with this mining method generally require detailed planning and are performed in a sequential manner that involves: separation of topsoil, removal of the cover layer of overburden, extraction of the clay, replacement of the cover layer of overburden, topsoil replacement, and topographic recuperation and revegetation.

In order for this sequence to be carried out successfully, it is essential to have planning that determines the size of the mining blocks, and appropriate sequencing in which the activities are performed in synchronization. Thus, it is evident that there are substantial financial savings to be made by avoiding long distance transport of topsoil and overburden.

In this context, our study sought to establish a method that allows the mineral body to be adequately evaluated both quantitatively and qualitatively and which provides benefits for the development of planning and sequencing of the mining, foreseeing measures that allow the subsequent recovery of the area in order to avoid the generation of environmental liabilities.

2. Case study

The Bañado de Medina deposit is located in northern Uruguay, in the Department of Cerro Largo, municipality of Melo, about 80 km from the border with Rio Grande do Sul (Figure 1) and covering an area of about 20 hectares. It is one of the first known occurrences of bentonite in the region with the potential for commercial exploitation. This deposit has been the subject of several studies aiming to facilitate its economic exploitation and, as noted earlier, the smectite of this deposit features calcium as an intercalated cation - it is necessary to activate it with sodium carbonate for the calcium to be replaced with sodium, there by increasing its technological properties (Albarnaz, 2009).

3. Geological context

The deposit, which originated from the alteration of volcanic ashes that had been deposited in a lacustrine environment and arid climate, lies within the formation of the Rastro River at the upper section of the Membro Serrinha (Yaguari formation in Uruguay) and dates to the Permian age.

Surveys done in the area enable identification of a portion within the Permian sequence of the Rastro River that is bound on its upper and lower sections by sandstones/siltstones and protected from erosion due to the faults that had kept this material in broken blocks on the terrain.

Mineralogically, the layers are composed of dioctahedral smectite, calcium, and traces of quartz and feldspar. The observations in the bentonite layer indicate a partitioning that starts in the basal part, with a layer of 30 cm directly in contact with the lower fine sandstone. Texturally compact and violet in color, it extends throughout the deposit and marks the base of the bentonite portion, known as bentonite V. Overlapping this, there is a layer of bentonite that is pinkish in color and up to 2 m thick; however, its distribution is irregular, being absent in some sections of the deposit. It appears to be homogeneous, as layering has not been observed, and it is known as bentonite A. Heading towards the top, there occur lithofacies with different characteristics, in particular the emergence of centimeter to millimeter layers that give rise to a parallel and horizontal stratification in the form of a rhythmite, with interspersed layers that are red and cream in color. This layer is called bentonite B and it typically has more

Figure 1
Location and accesses to the Bañado de Medina bentonite deposit.

silt and a more constant distribution in the deposit than the bentonite A; thicknesses of up to 1.5 m occur. Finally, at the top of the mudstone layer, in direct contact with the upper siltstone, it is possible to individualize a lithofacie, with color ranging between purple and reddish brown, often with centimeter scale intraclasts of bentonite B argillite. This layer was designated bentonite C and varies in thickness along the deposit, sometimes reaching up to 3 m. Argillite intraclasts in a matrix that is also clayey are interpreted as features related to the intrabacinal reworking associated with the reactivation of the faults, with a consequent increase in the transport energy of the medium, which promotes the erosion of the elevated faulted blocks and a remobilization and possible concentration of the sediments in degraded sections of the relief (Albarnaz, 2009). Figure 2 shows a typical profile for this sequence of bentonite layers in the study area.

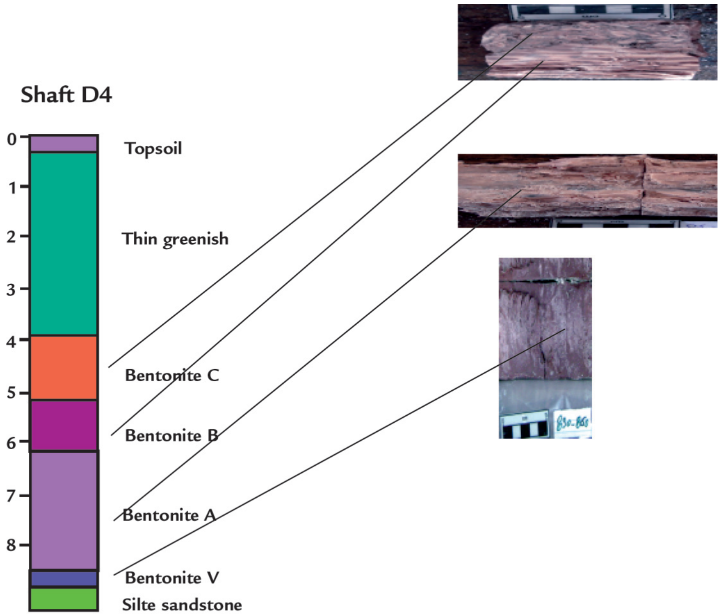

Figure 2
Typical stratigraphic profile and position of the bentonite layers of Bañado de Medina.

4. Method

Available database: analysis and interpretation

A planialtimetric survey was done with a total station using the irradiation method - 305 sample points were collected and this formed the topography database. Besides this, the limits of the lease were surveyed and the main faults observed in the area were located. Also, there were 31 boreholes distributed in a way that defined the mineral body. They were drilled with a rotary drill 2½ inches in diameter and all of them were vertical. However, only 9 of these holes show individualized information by layer, while the remaining 22 holes cluster the information, presenting descriptions only for the overburden (soil + siltstone) and the total bentonite layer. In Table 1, the information is summarized for this data set.

Table 1
Statistical summary of the database of thicknesses for the cover layers and bentonite layers.

Layer	N° of data entries	Minimum	Maximum	Average	Standard deviation	Coefficient of variation
Bentonite C	14	0.45	3.95	1.631	1.057	1.117
Bentonite B	14	0.00	3.00	1.424	0.818	0.670
Bentonite A	14	0.00	3.70	1.325	1.201	1.443
Bentonite V	14	0.10	0.70	0.344	0.183	0.034
Overburden	31	1.59	11.50	5.185	2.635	6.944
Total bentonite	31	0.00	6.45	2.273	2.241	5.020

Geological modeling

For the definition of the mineral resources, as well as for planning and sequencing of the mining, a geological model was prepared from the interpolation of the surface topographic information, the highwall, and the footwall of the bentonite layer.

As noted earlier, due to the reduced number of holes with an individualized description of the layers, we chose to model the cover layer and the total bentonite layer which consists of layers C, B, A, and V. The body was discretized into regular blocks with dimensions of 15 m by 15 m. This was basically due to the scale of planned production, the size of the existing pilot pit in the area, the sample density, and to avoid excessive smoothing of the interpolation methods. Representative surfaces were generated to the topography of the terrain, and to the the highwall and footwall of the total clay layer. By using mathematical operations between these surfaces, it was possible to obtain block models for overburden thickness and thickness of the clay layer.

In order to enable the subsequent steps of volume calculation and mining planning, a thickness value equal to zero was used as the limit of the body. This was associated with a physical limit represented by a faulting mapped in the area that is beyond the limit of the lease of the deposit (Figure 3).

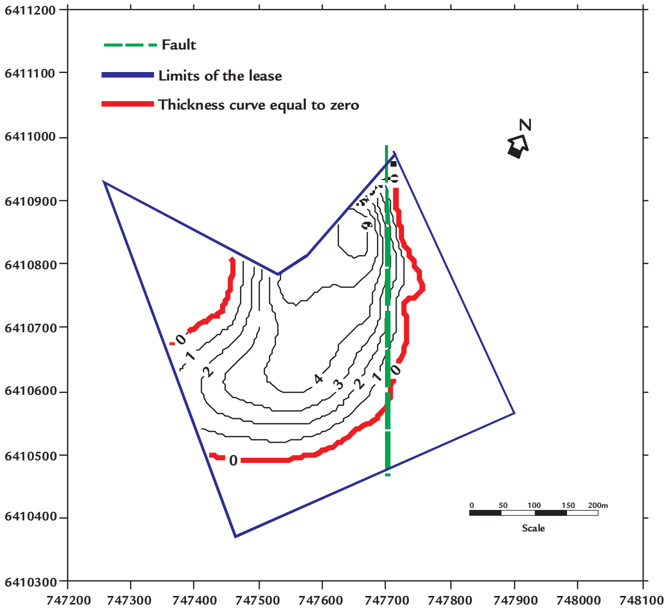

Figure 3
Map of thicknesses values of the bentonite layer and the elements that limit the mineral body.

Mining planning

From the block models of overburden thickness and thickness of the bentonite layer, constrained by the limits defined for the mineral body, it was possible to obtain the block models of the cover volume and the mineral mass (Figure 4A and 4B),which are essential for calculation of the inventory of resources available.

It should be noted that an average density value of 1.99 t/m^3 was used, which was calculated from the lengths of the drilling samples.

As noted earlier, because the mineral body is horizontally layered, not very deep, and has low variability in terms of coverage, it was decided to verify the possibility of employing a method similar to strip mining, which is widely used in coal mines, in order to utilize the previously mined cuts for disposal of the cover material from the current cuts being operated on. Thus, the transport distances are significantly reduced and the impacts on the environment are minimized, since it is not necessary to immobilize a specific area to deposit waste material, and the environmental recovery will be done in conjunction with the mining process without creating liabilities that would result in high environmental costs later on.

To this end, strips of 30 meters width were employed - equivalent to the width of two mining blocks – to ensure an adequate square size with enough room to maneuver for equipment similar to that which had already been used in a pilot pit implemented in the study area - a JCB model JS 220 LC excavator with a bucket capacity of 1 m³ and two conventional dump trucks with 8 m³ containers.

To define the orientation of the cuts and the starting point of the mining work, a block model was generated with the distribution of the stripping ratio for the study area (Figure 5A). As can be seen, the eastern portion of the deposit is the one which has the lowest stripping ratios, precisely the reason why the pilot pit had been located in that position. Likewise, it can be seen that along the edge of the fault, when compared to adjacent blocks, there is less variability between the blocks. Therefore, the blocks adjacent to the pilot pit were defined as the starting point for the mining operations and the direction for advancement of the cuts was the direction of the fault's axis (Figure 5B). Figure 5B also shows the sequence of cuts that will be mined for a period of 13 years, with each year representing production of about 7,000 tons of bentonite. Due to operational issues, areas smaller than 900 m² or 4 mining blocks should not be mined as this would result in the life of the mine being approximately 83 years.

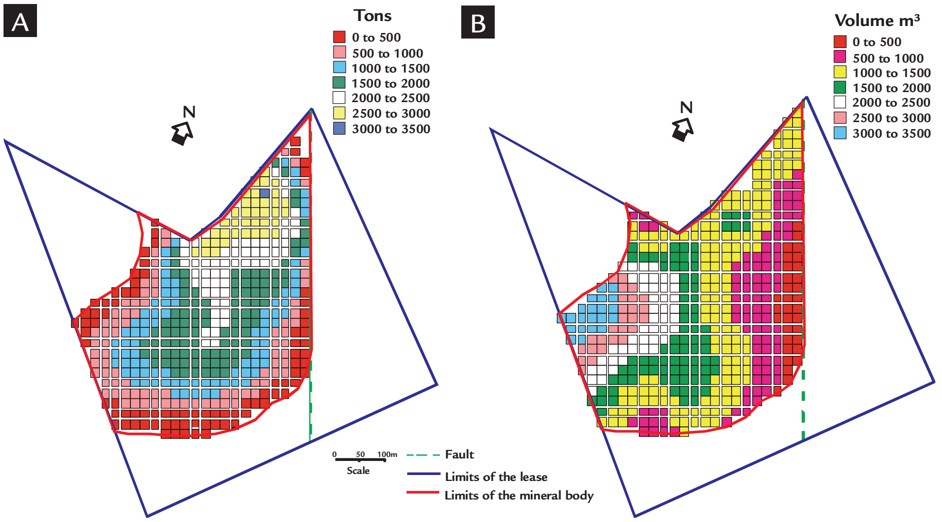

Figure 4
Block models of (A) in situ volume of the overburden layer; and (B) the bentonite mass.

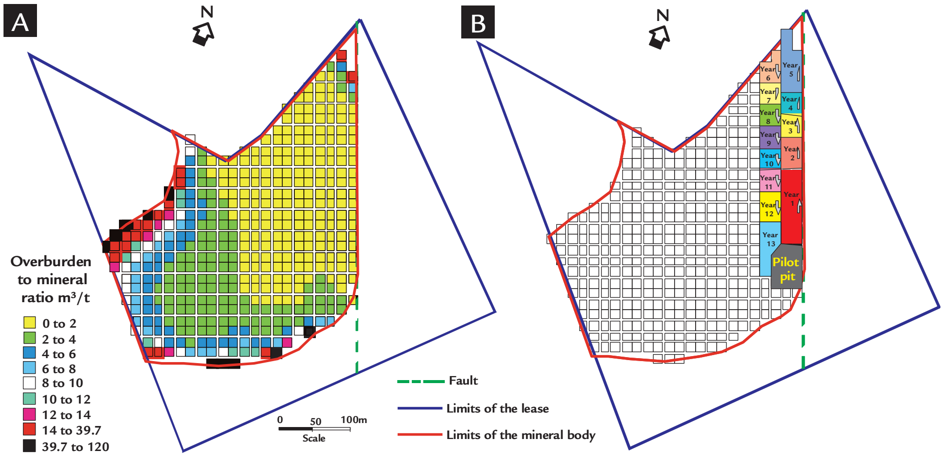

Figure 5
(A) Block models of the overburden-mineral ratio of the study area.
(B) sequencing of mining for a 13 year period of operation.

Fleet and equipment

During the evaluation of the economic viability of the project, material was extracted from a pilot pit in order to perform technological tests. At this phase of the operation, a hydraulic excavator and two trucks were used, which demonstrated sufficient capacity to achieve the level of planned production for this deposit.

To verify the economic viability of the equipment in the mining operations, their contracted costs were used. Charges are based on the handling of material, whether overburden or mineral, for up to 400 meters distance. Given the low rates of production necessary and because they have already proven to be effective, it was assumed that similar equipment with the same size would continue to be used in the mining, which ensures that the required production is achieved in a period of around 15 days worked.

Using a value of US$ 28.00 per ton (FOB mine) for bentonite; after stripping, loading, transport, and deposition, and a swelling rate of 57% for the overburden and the mineral, it was possible to obtain the value of the stripping ratio limit which represents the maximum amount of overburden to be removed without financial loss. It was equal to 4.21:1 (Figure 6).

As the amount of overburden represents the significantly larger portion in relation to the total material handled, alternatives were sought in terms of equipment that would allow operation at higher stripping ratios, thus increasing the utilization of the deposit and the financial return, while at the same time enabling more efficient operation and environmental sustainability. To this end, from the description of the clay mining done by Geremias (2000) in the southern state of Santa Catarina, where a bulldozer was used to perform the removal of topsoil, stripping of the overburden, and topographic reconstruction of the cuts already mined, the viability of also inserting this equipment into the mining operation of this case study came to be analyzed. Figure 7 shows a simplified schematic of the mining cycle with the inclusion of the bulldozer in the mining operations, and Figure 8 presents the fluctuation of production costs, taking into consideration the alternatives for the equipment used.

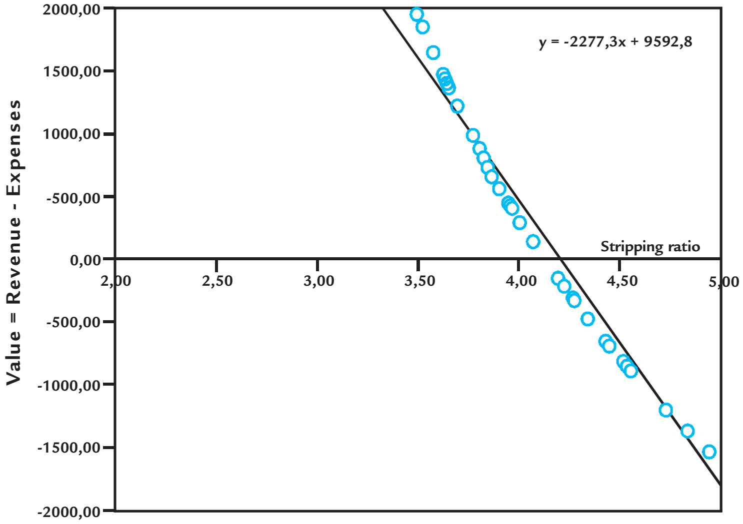

Figure 6
Correlation between the stripping ratio and economic value.

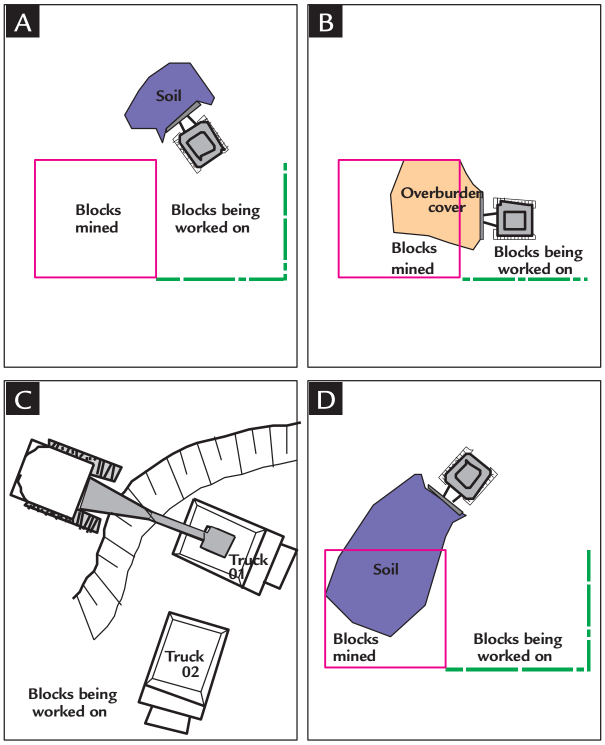

Figure 7
Simplified diagram of the proposed mining cycle, considering the inclusion of a bulldozer in the operation. (A) Removal of the topsoil to a position which does not interfere with subsequent work. (B) The bulldozer removes the overburden cover to the pit previously mined - in the first year it should be removed to the pilot pit. (C) The excavator performs the excavation and loading of the bentonite clay onto trucks that will transport it to the depot near the exit of the area. (D) The bulldozer replaces the topsoil cover in the pit that has already been filled with overburden. In this way, a pit will always remain open until the beginning of a new cycle.

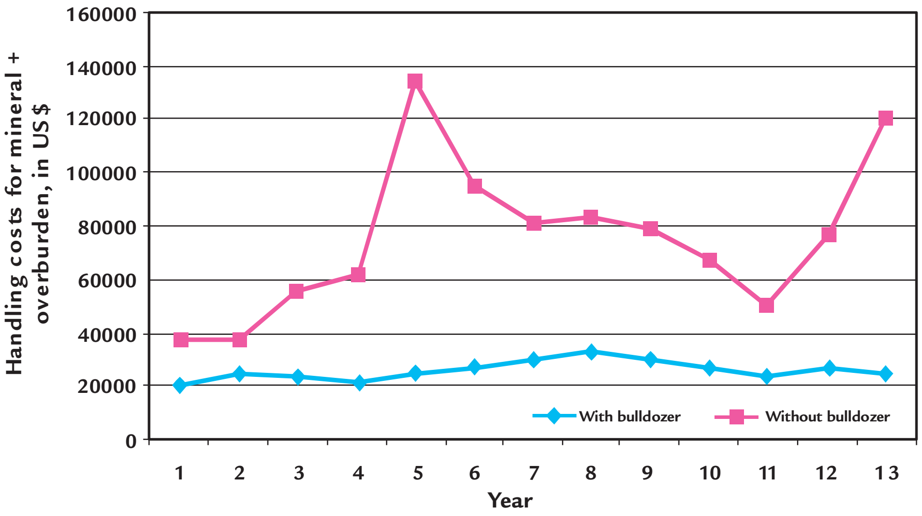

Figure 8
Fluctuation of production costs, taking into consideration the alternatives for the equipment used.

Environmental diagnosis

The area has many environmental features favorable to mining activities: (i) vegetation cover is composed only of grasses; (ii) gentle undulating topography; (iii) drainage to a specific point, with the most significant waterways also being distant from the area; (iii) favorable location - it borders on a paved road; (iv) considerably distant from populous areas, since the town of Bañado de Medina is about 1,800 meters from the mining area; and (v) water table depth below the bottom level of the pit.

No matter how small the size of a project, mining activities are characterized as having significant environmental impact in areas where they are located. Thus, nowadays there is consensus that any mining activity should contemplate proposed mitigation and remediation of environmental impacts, starting from the early stages and even during the design stages, in order to avoid the liabilities which greatly affect the operating costs of mining companies. With this in mind, Table 2 presents an environmental correlation matrix of the project which shows the main impacts related to the mining, as well as their respective mitigation measures.

Impact	Measure
Removal of vegetation coverage	Revegetation with grasses
Removal of fertile soil	Stocking and replenishment in the pit
Generation of dust and noise	Curtaining
Visual impact	Curtaining
Aggradation drains	Drainage and sedimentation

Table 2
Correlation between the environmental impacts and the corresponding mitigation measure.

5. Results and discussion

Since only about 50% of the total drillholes available had a description individualizing the layers of bentonite, it was not possible to use the more sophisticated modeling methods or interpolation which would allow, for example, a model to be obtained with a view to possible selective mining. As the layers were grouped into a single package, it was also not possible to fully investigate the extent to which mineralogical and textural differences would influence in the density and moisture content of the material - features which are extremely relevant both in relation to volume calculations of the resources and in relation to the costs for drying or transportation of the material.

Studies and geological mapping prior to this work allowed faults to be used as the physical limits and the body could be compartmentalized in certain positions of the deposit. Also, geological models could be created by obtaining the other limits of the body and then the shape of this body could be discretized in mining blocks. From the block model with information about layer thickness, volumes and tonnages were calculated, both for the coverage and the minerals, thus enabling the development of distribution models for the stripping ratio and the scheduling of the block extraction sequence in the deposit.

The strip mining method adopted, which was already being used during extraction from the pilot pit, proved to be efficient; however, the introduction of a bulldozer to remove the overburden would reduce the time required to reach the desired production, as well as significantly reduce costs. It can be observed that the insertion of the bulldozer enables blocks to be mined with a much higher stripping ratio, which ensures an increase in the reserves and great savings in the mining, thus avoiding predatory mining and giving the project a character of sustainability. There would be an increase in mineral reserves, while the material handling costs would drop significantly (Figure 8).

Furthermore, because optimizing the process for utilizing the deposit translates into concern for sustainable development, this creates a positive image before the agency responsible for mining, the agency responsible for environmental control, and society in general.

The mining method suggested would enable the overburden from the section being worked on and the topsoil cover that had been kept to the side to be immediately placed on the previous section. Furthermore, with the implementation of the planned mitigation measures, damage to the environment could be significantly minimized, thereby recuperating the area and even offering counter measures through forest curtaining and revegetation.

6. Conclusions

The analysis sequence used in this work, involving the mining planning and the proposed environmental recuperation, is traditionally employed for mineral deposits with similar characteristics. Unfortunately, however, there are still very few examples of studies done with a minimum level of detailing, for deposits similar to this one, that is, with little geological complexity or low added value.

By the analyses carried out in this study, the extraction method suggested proved to be efficient; however, the introduction of a bulldozer for overburden removal would reduce the time required to achieve the desired production and significantly reduce costs, in addition to allowing mining in situations in which the stripping ratio is higher, thus increasing the utilization of the deposit and the financial return.

In order to allow the detailing of the economic utilization or alternative destinations for the Bañado de Medina bentonite, it would be advisable to individually describe the layers that make up this deposit or other similar deposits in the region. The calculation of volumes for each layer would enable mining planning that contemplates their selective utilization, especially on the basis of the studies of technological features that are already being conducted by the Rio Deserto company.

Additionally, future studies of alternative sequencing or of unit operations that allow reduction in moisture content could justify the installation of specific equipment for drying the product, which would significantly reduce transportation costs.

Regarding environmental issues, the hierarchy of the impacts indicates how important it is to collect water samples downstream from the deposit and have them analyzed by a laboratory or a reputable certified institution before the commencement of activities, as this can serve as a parameter for implementation of monitoring the risk of water contamination during the life of the mine.

7. References

ALBARNAZ, L. D. TT., DANI, N., FORMOSO, M., MEXIAS, A., LISBOA, N. A. A jazida de Bentonita de Bañado de Medina, Melo Uruguai. ***Pesquisas em Geociências*** (UFRGS. Impresso), v. 36, p. 263-281, 2009.

BARROS, M. M. S. B., MELHADO, S. B., SHIMIZU, J. Y. ***Serviços preliminares de construção e locação de obras***. São Paulo: Escola Politécnica da Universidade de São Paulo – Departamento de Engenharia de Construção Civil. 2002.

LUZ, A. B., OLIVEIRA, C. H. ***Bentonita – União Brasileira de Mineração – UBM***. Rio de Janeiro: CETEM, Centro de Tecnologia Mineral – Ministério da Ciência e Tecnologia, 2002.

GEREMIAS, M. L. Lavra e recuperação ambiental simultânea em minas de argila no sul de Santa Catarina. ***Revista Tecnol. Ambiente***, Criciúma, v. 6, n. 2, p. 55-74, jul./dez. 2000.

GOPINATH, T. R., LIMA, A. A. ***Modelagem e lavra de depósitos de bentonita da região de Boavista, Paraíba***. Disponível em: http://www.brasilminingsite.com.br/anexos/artigos/12_0.pdf. Acesso em junho 2011.

HARTMAN, H. L., MUTMANSKY, J. M. ***Introductory mining engineering***. (2 ed.), John Wiley & Sons, Inc. ISBN 0-471-34851-1, 2002. 570 p.

HUSTRULID, W., KUCHTA, M. ***Open pit mine planning and design***. Rotterdam: A. A. Balkema, 1995. 636p.

JENKINS, J. D., FALCONER, R. A., HENTZ, D. A. ***Method for the segmented mining and drying of bentonite***. Assignee: International Minerals & Chemical Corp. Appl. Nº.: 92,600. Filed: Nov. 8, 1979.

TOMIO, A. ***Mineração no Mercosul e mercado de bentonita***. Campinas. UNICAMP – Universidade Estadual de campinas, Instituto de Geociências, 1999.

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