THE ABANDONED MINE OPENINGS MAPPING ON COAL MINING RECLAMATION PROGRAM OF THE SANTA CATARINA STATE-BRAZIL[1]

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Abstract. The abandoned mine openings (AMO) mapping project has a goal to locate a number estimated of 1000 coal mine openings. Within an experimental area 173 abandoned openings were mapped, surrounding the city of Criciuma, in southern portion of Santa Catarina State in Brazil. A total of 18 of these openings discharge, in average, 1,334 m³/hour of acid mine drainage (AMD) that flows to watersheds carrying high level of metals, acidity and sulfates. A model of underground water flow was established through structural geology, and a digital terrain model (DTM) from the surface and mine floor, aiming to identify openings that collect surface water, and openings that discharge AMD. Openings started to be closed according to risks to safety, health and the environment. A monitoring program has been established since 2002 to quantify physical and chemical characteristics, and flow rates from discharges. A pilot water treatment plant was being installed near a portal (SS16), with the purpose to define treatment procedures and costs, aiming to use this treated water to supply the nearby community.

Additional Key Words: mapping, coal mine openings, AMD treatment.

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Introduction

The abandoned mine openings (AMO) mapping began on September 2002 as one project of the Santa Catarina Coal Basin Reclamation Program.

For many years coal-mining activities in Santa Catarina State did not take any significant measures for environment control. Therefore, more than 5,500 hectares of agricultural lands were spoiled from surface mine practices and waste deposition, and 787 km of streams, and rivers were contaminated by metals and acidity. To mitigate these environmental problems; a comprehensive reclamation program has been developing since the beginning of year 2000. Technical staff including people from universities, Geological Survey of Brazil (CPRM), and Coal Producers Association of Santa Catarina State (SIECESC), has conducted studies with the purpose to characterize the impacts and to propose models to plan reclamation projects. Identification and mapping of the abandoned of coal mines openings is one of the fundamental steps in the reclamation program.

The mapping was first performed for a pilot site called Cechinel Hill, because of the proximity of the urban area of Criciuma City, in the southern portion of Santa Catarina State. The program mapped a total of 173 AMOs in the vicinity of Cechinel Hill, and confirmed the existence at least of 12 underground abandoned mines. The project is in progress, and at the present, 330 AMOs have been were mapped within an area of 70 km2.

The classification of AMO was done using a risk analysis according safety standards created by SIECESC staff for this objective. Study of a digital terrain model and the structural geology of the coal bed floor enabled location of the portals that collect surface water and discharge acid mine drainage (AMD).

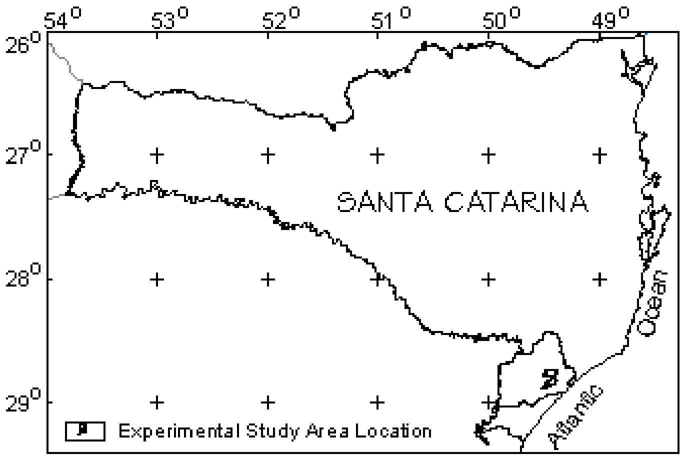
A report about AMO was delivered to officials and coal mining companies, making available data for sealing and monitoring proceedings. Installation of a treatment station near a portal was proposed to use the treated water to supply the community. Laboratory tests showed good results using lime and Dissolved Air Flotation (DAF) techniques for removal of metals and sulfate.

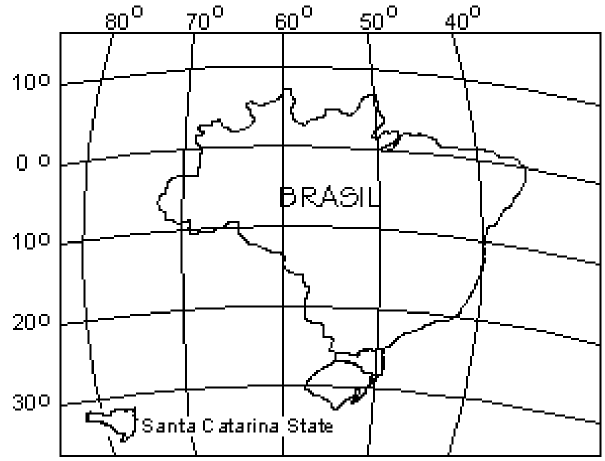
Objectives

The objective of this study is to find more than 1,000 of AMOs within the Santa Catarina Coal Basin that are sources of watersheds contamination, and increase risks to human health and safety. The project had the following aims: a) mapping of all AMO, including portals, shafts, bore holes, and subsidence induced fractures zones; b), characterizing the discharges, acidity, and metals; c) structural modeling for underground water flow establishment; d) classification of priorities for reclamation according to risks analysis and environmental standards.

Location

The experimental area of the project is in the southern region of Santa Catarina State, as shown at Fig. 1 and 2.





Figures 1 and 2. Location of the Santa Catarina State within Brazil and location of study area within the Santa Catarina State.

The pilot area with a total area of 11 km2 is defined by the Barro Branco coal seam outcropping in the neighborhood of Cechinel hill as shown at Fig. 3. The limits include Criciuma, Morro da Fumaça, Cocal do Sul, and Sideropolis borders, comprising 34.654 meters of total length.

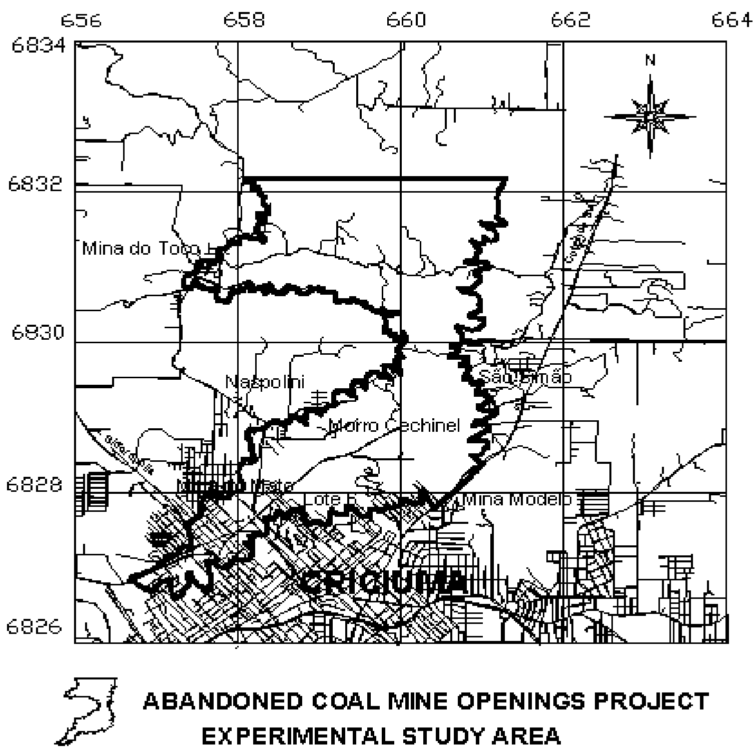


Figure 3. Location of the study area, showing the urban region of Criciuma City at bottom of the map.

Mining and Geology Context

Geology

The study site is located in the southeastern portion of the Parana intracratonic basin in which 1,200 meters of sedimentary and volcanic rocks are settled on gnaissic-granitic basement. At the southeast boundary of this basin in Santa Catarina state, there are coalfields that are 80 km long and 20 km wide. The major axis of the coalfields is oriented in a north-south direction, and its largest portion dips under the sea, whose limits are still unknown.

The sedimentary rocks in the area are formed by sandstones, siltstones, shales and coal beds that are settled on top of a marine transgressive series named Rio Bonito Formation.

Geological structures formed from vertical movements of the crust during Permian were responsible for a mosaic of down and up blocks that outlined coalfields for open pit and underground mining within the Santa Catarina Coal Basin. Under this structural framework, northeast direction faults determined not only the exposition of more than 30 km of the Barro Branco coal seam around Cechinel hill, but also the relief of the coal bed floor. As the coal bed floor dips as eastern as western directions the water through underground mines flows either towards the Ararangua or Urussanga watersheds.

Mining

Since coal discovery in 1883, its exploitation techniques have been undertaken several developments from manual through highly mechanized. Although longwall mining has been applied in the past, today only room and pillar is the mining method used. According to Belolli (2002) there were 117 coal mines in 1942, within the Santa Catarina Coal Basin, 93 of them in Criciuma region. The majority of coal, at that time, was produced through small mines that were developed, by landowners until the limit of rudimental ventilation systems. Many of these old entrances were found during the mapping step of the project. According to Putzer (1952) there were 26 coal mines on the Cechinel hill surroundings, 14 among them abandoned in 1951. The average of thickness of the seam being mined is 2 meters, and it is formed by high sulphur and high ash coal used mainly as fuel at a power plant, which consumes nearly 2.4 Mt/year. Coal resources have been exploited through open pit and mainly through underground mines, but presently almost all use underground methods.

Underground mining around Cechinel hill was extended until coal reserves exhaustion in 1989. According to the National Department of Mineral Production (DNPM) there were 12 underground mines registered in that area, but probably exists many more probably exists whose limits have been unknown until the present.

Methodology

The work consists of collecting all information available on coal mining in the region and using the following steps:

1) Georreferencing of existing mine maps on the Criciuma area, identifying declines, shafts and drift entries.
2) Identifying evidences of waste piles near outcrops due to mining activities through aerial photo's interpretation. Aerial photos at scale of 1:20,000 and color digital orthophotos at

scale of 1:5,000 are available, and a Digital Terrain Model (DTM) was made during January to February of 2002.

3) Field surveying based on orthophotos including measuring dimensions, orientation, describing geology and geomechanics, weathering stage of rocks, roof fall, water inflow occurrence and other relating information.

4) Making a structural model of the coal seam's floor for a better understanding of the groundwater flow regime, identifying mine pools and points of inflow and outflow of water from the mine.

All mapped mine openings were photographed and their elevation determined from mine maps and drill holes. The positioning of openings was determined by GPS define surveys and orthophotos and can vary several meters (usually less than 10 meters) due to vegetation interference in the GPS signal. Survey information was compiled in a Microsoft ACCESS format database. The database and topographic maps which compose the technical collection available at the SIECESC office. That information is utilized by the Environment Branch of SIECESC and DNPM.

Main Results

Monitoring

Abandon mine openings contribute to generation of AMD, through oxidation of the pyrite content of coal seams and their enclosing rocks. Among 330 mine opening mapped until June 2005, 46 are releasing AMD into the Sangao and Ronco d'Agua watersheds and 50 others (drift entries, declines, shafts and subsidence induced fractures) are capturing surface runoff and small perennial streams and conducting water to the underground in a vicious circle capturing clean water and releasing contaminated water as AMD. With the urban growth many mine openings were leveled and AMD emerged from these locations that is collected by the city drainage system. Thus a number of old mine openings releasing AMD can be bigger than that one shown by actual mapping the workings. A preliminary evaluation of the quality and flow of water released from 13 mine openings is shown in Table 1.

Mapping of Abandoned Mine Openings

The pilot area comprises the Naspolini, Sao Simao, Mina do Toco, Vera Cruz, Cruzeiro do Sul, Santo Antonio, Operaria Nova e Mina Brasil districts of Criciuma City and a small portion of the surroundings cities of Sideropolis, Cocal do Sul and Morro da Fumaca.

The total number of mine openings mapped and registered to date is 330. The total shown in Table 2 is only mapped around Cechinel Hill.

Table 1. AMD collected from 13 mine openings (Cechinel hill, Criciuma – Santa Catarina State). Sampling in March 2003.

Points of Sampling	pH	Acidity CaCO$_3$ (mg.L^{-1})	Conductivity (uS.cm^{-1})	Al (mg.L^{-1})	Fe (mg.L^{-1})	Mn (mg.L^{-1})	Flow (m^3.h^{-1})
SS 16	3.1	234	1.064	17	0.76	1.3	303.12
SS 11A	2.7	361	1.414	30.8	7	0.89	6.48
SS 9A	2.9	322	1.339	34.8	25	2.78	259.2
SS 2D	2.7	341	1.267	25	6.2	3.8	0.36
SS 91	5.0	81	428	0.4	0.21	0.14	49.68
Modelo Mine	3.2	148	813	11	1.66	0.7	25.2
SS 40	3.4	361	1.418	14.8	61.2	4.01	257.76
SS 41	2.5	605	2.330	32	25.4	1.6	9.36
SS 49B	3.2	166	1.053	8.6	13.4	2.1	254.16
SS 51	2.6	868	2.160	31.1	152	7.6	79.2
SS 61	3.0	215	1.274	12.2	9.6	1.9	52.56
SS 27	3.1	137	827	10.8	0.5	1.5	17.28
SS 96A	2.7	497	1.668	29.7	27.8	2.8	19.44
AVERAGE (range)	**2.5 to 5.0**	**298.09**	**1,245.05**	**18.63**	**29.48**	**2.63**	**102.6**

Table 2. Abandoned mine openings mapped and classified at the pilot area.

ABANDONED MINE OPENINGS AT PILOT AREA	Quantity
Open drift gallery dry	25
Open drift gallery with AMD	11
Closed drift gallery with AMD	7
Open drift gallery collecting surface water	20
Decline	1
Opening filled up with earth	56
Opening due to subsidence	7
Ventilation shaft closed	5
Ventilation shaft open	7
Service shaft closed	1
Registered based on other mapping or mine information	33
TOTAL	**173**

Structural Model

The structural model of the coal seam floor was built based on elevation information from underground workings. As the whole area is situated above the water table, water just flows through the mine forming locally small mine pools. Flow direction within these local flow systems are estimated by assuming it approximates the coal floor topography.

Besides the structural information and flow direction assumptions, mine information was collected identifying places where pillar were retreated and general mining development took place, considering some locations were underground workings from different mines that were interconnected constituting a huge mine complex. All of this information was considered together, trying to better understanding of the water dynamics inside the mine complex.

The model shows that the probable main directions of water flow inside the mine is toward the south-southeast and west-southwest from an underground water divide (Fig. 3).

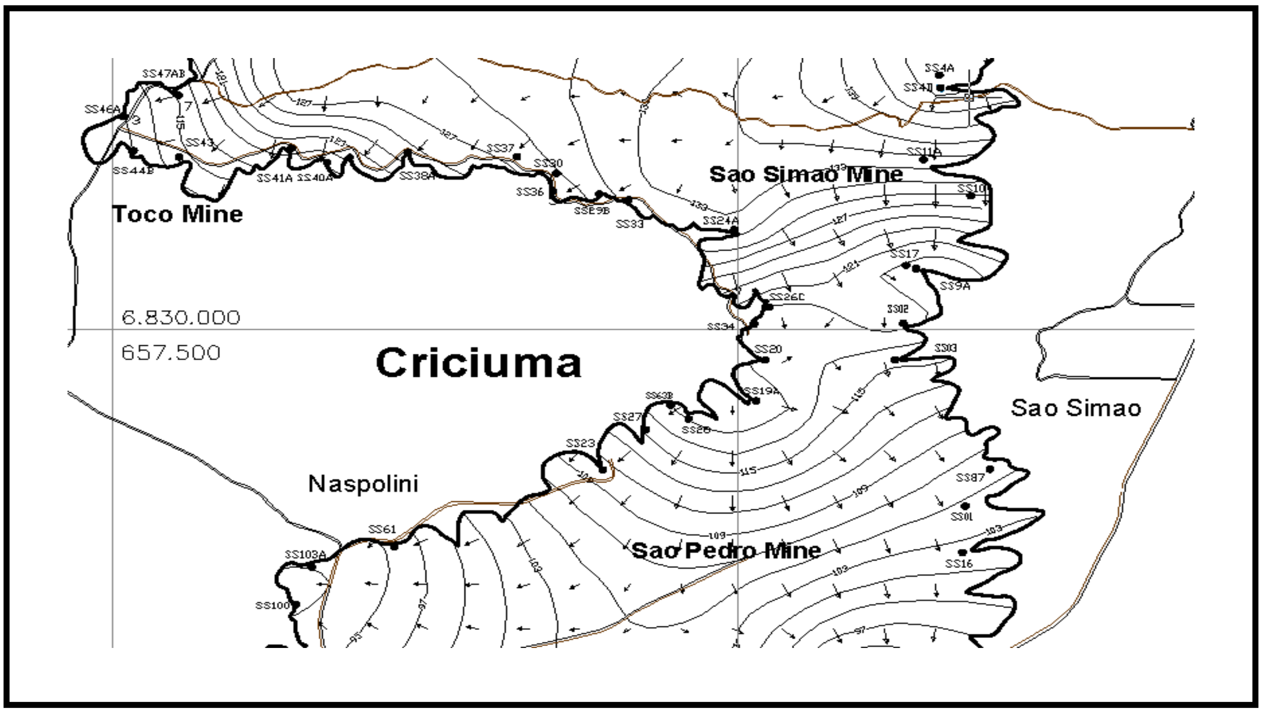


Figure 4. Map showing structural model of the coal seam floor and flow directions inside the mines.

Discussion

Water Dynamics into Abandon Mine Underground Workings

The flow direction showed at map (Fig. 4) can be explained by structural modeling since that the follow assumptions based onto old mine workings maps are reasonably accurate: a) The Sao Simao and Sao Pedro, as well as Antonio de Luca A and B mines are interconnected; b) The Sao Simao and Antonio de Luca mines are not interconnected; c) The Sao Pedro mine is interconnected with the Modelo mine; and d) the full extraction areas are reasonably well represented.

According to monitoring program, the areas of full extraction correspond to larger surface water inflows, which was proven by the corresponding proximity to higher outflow openings with greater outflow and close connection of discharge with the hydrologic regime.

The principal springs are located on the east side of Cechinel hill and are identified as SS-09 and SS-16, discharging up to 562 m^3/h of AMD to the Barbosa and Ronco d'Agua streams, respectively.

The SS-09 opening drains water from collapsed areas of the Sao Simao mine. As the called SS-11 opening is the nearest downstream point nearest to the extracted pillar area of Sao Simao mine, probably some roof fall material is blocking a flow path diverging AMD from the SS-09 spring. The SS-16 spring drains the biggest mined pillar area from the Sao Simao and Sao Pedro mines. A reasonable portion of the total inflow from those mines comes through SS-87 opening which that cannot be quantified as this water is collected by the municipal drainage system. The rest of the water flows south and reaches the surface through the Modelo mine which drains 25 m^3/h (average flow rate).

The main springs of AMD on the west side of Cechinel hill are at SS-40A, SS-49B and SS-51 adits that belong to the Antonio de Luca mine and discharges altogether 596 m^3/h to the Sangao River.

Although the SS-40A and SS-49B openings are farther from collapsed areas of the Antonio de Luca mine, they drain most the water because of higher slope of those adits. The density of geological structures on the west side of the hill could explain why the greatest water inflow on this side compared to the east side as the collapsed areas are equivalent in size. The pillared areas are intercepted by faults which increase the hydraulic conductivity and water inflow.

Dynamics of Surface Water

In many places (SS18, SS19, SS20, SS24, SS26, SS38, SS47, SS55, and SS60) surface water is contaminated before it enters to mines through percolation under exposed solid wastes, mine waste piles or in contact with untreated sewage. Once it enters that mines, the water is in contact with oxidation products and becomes acidic.

The mapping of mine openings has shown that, a large number of galleries collect water from the surface, both from shallow aquifers and runoff.

The surface water inflow is, in the most of cases, conditioned by the opening positions in relation with natural streams. In these cases those points are important elements of mine inflow only surpassed by collapsed areas due pillar extraction. The mine complex itself constitute a system of collection, contamination and discharge of AMD.

The ventilation shafts and declines also collect surface water, but are secondary in relation with other openings due to much smaller number of points. The number of openings with water inflow is larger on the west side than on the east side. Water is conditioned by wastes deposition in front of portals that dam rain water, diverting it into the mines.

Conclusions

Most of the existing abandoned mine openings at Cechinel Hill have been located as part of this project. This does not means that all AMOs have been mapped, but others are mainly in heavily populated areas or where there are dense vegetation covering.

In most cases it is very easy to access these mine openings, which constitutes, besides environmental risk, a danger to human safety and health. There are 64 abandoned places that are still open, which represents 37% of a total of 173 mapped. Shafts and declines constitute the biggest risk to human safety.

The reclamation projects, now in progress consist in closing of partially or totally closing openings with clay or concrete seals which will result in elimination of safety risks, and will reduce air and water inflow to underground mines, reducing AMD generation and avoiding underground diversion of streams. Uncontaminated streams can provide an extra source of water for local inhabitants in the communities of the Naspolini, Sao Simao and Mina do Toco districts. These projects will help to improve water quality and reduce environmental impacts on water resources due to mining activities.

Monitoring of SS-16 point, at the Sao Simao district, has lower concentrations of metals (Al, Fe and Mn), sulfates and acidity in the discharge that varies from 30 to 300 m^3/h. These low concentrations of pollutants compared to other springs induce us to construct a treatment plant there designed to neutralize water, remove metals through high performance dissolved air flotation system coupled with sulfate removal techniques allowing water reuse.

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