The abandoned mine openings mapping on Santa Catarina-Brazil coal mining reclamation program

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Keywords: mapping, coal mine openings, AMD treatment.

ABSTRACT
The abandoned mine openings (AMO) mapping project has targeted to locate a number estimated of 1000 coal mine openings. Within an experimental area 173 abandoned openings were mapped, surrounding the city of Criciuma, at south portion of Santa Catarina State in Brazil. A total of 18 of these openings discharge, in average, 1,334 m³/hour of acid water (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 DTM (digital terrain model) from 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 environment. A monitoring program has been established since 2002, to quantify physical, chemical characteristics, and flow rates from discharges. A pilot water treatment is being installed near a portal (SS16), with the purpose to define treatment procedures and costs, aiming to use this treated water to supply to communities.

INTRODUCTION
For many years coal-mining activities did not take any significant measure for environment control. Due that, more than 5,500 hectares of agricultural lands were spoiled for surface mine practices and waste disposition, and 787 km of streams, and rivers were contaminated by metals and acidity. In the way of mitigate these environmental problems; a comprehensive reclamation program has been developing since the beginning of year 2000. A technical staff formed by people from universities, CPRM – Geological Survey of Brazil, and SIECESC – Santa Catarina Coal Producers Association, has conducted studies with the purpose to characterize the impact and to propose models to orientate reclamation projects. Identification and mapping of the abandoned of coal mines openings is one of the fundamental steps in the reclamation program.
The abandoned mine openings (AMO) mapping has begun on September 2002 as one project of the Santa Catarina Coal Basin Reclamation Program.
The mapping was first driven to a pilot site called Cechinel Hill, because of the nearness of urban area of Criciuma city, south portion of Santa Catarina State. The AMO mapped summed up 173 on the vicinity of Cechinel Hill, and confirmed the existence at least of 12 underground abandoned mines. The project is under progress, and at the present, 330 AMO were mapped within an area of 70 square kilometers.
The classification of AMO was done using a risk rate according to environmental and security standards created for this objective. The study of digital terrain model and the structural geology of coal bed floor enabled to locate the portals that draw surface water and the ones that discharges acid mine water (AMD).
A report about AMO was delivered to officials and coal mining companies, making available data for sealing and monitoring proceedings. An installation of a treatment station near a portal was proposed to use the treated water to supply the community. First laboratory tests show good results using lime and DAF (Dissolved Air Flotation) techniques for removal of metals and sulfate.

OBJECTIVES
The estimative is to find more than 1,000 of AMO within Santa Catarina Coal Basin that represents sources of watersheds contamination, and make those areas very dangerous for people safety and health. So, the project was headed to the following aims: a) mapping of all AMO, including portals, shafts, bore holes, 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 placed at south region of Santa Catarina State, embracing in its major extension the urban region of Criciuma city as shown at figure 01.

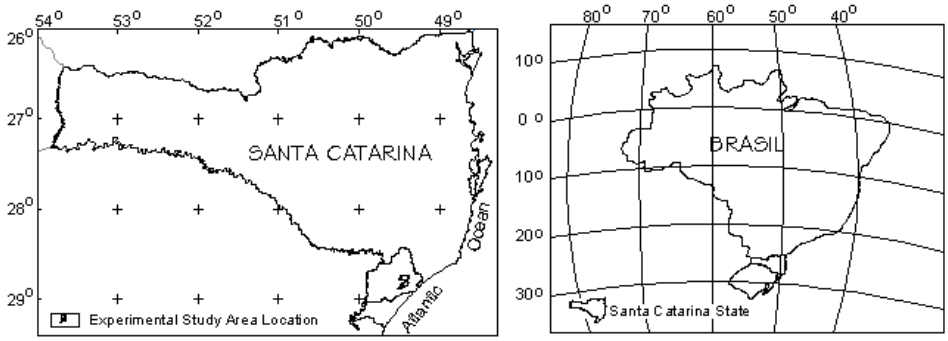

Figure 01: Location of study area within Ararangua River watershed.

The pilot area, in a total of 11 square kilometers, is defined by Barro Branco coal bed outcropping on the neighborhood of Cechinel hill. Due north, the limit overpasses Criciuma, Morro da Fumaça, Cocal do Sul, and Sideropolis borders, comprising an 34.654 meters of perimeter extension as shown at figure 2.

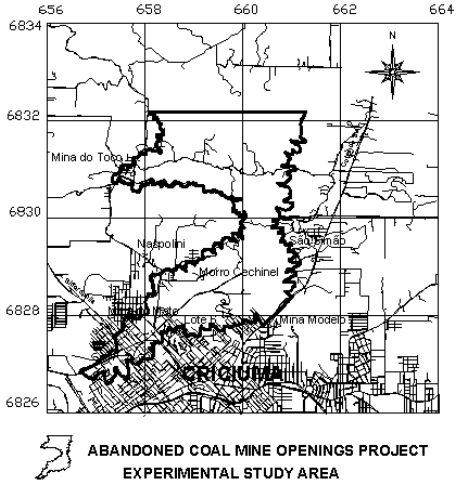

Figure 02: Location of the study area, showing urban region of Criciuma city.

THE ABANDONED MINE OPENINGS ON SANTA CATARINA COAL MINING CONTEXT

An intracratonic basin in which 1,200 meters of sedimentary and volcanic rocks are settled on gnaissic-granitic basement represents the geology of the studied site. At the southeast boundary of this basin in Santa Catarina state, there are coalfields that extend for 80 km long and 20 km width. The major axis of coalfields is pointed to north-south direction, and its largest portion dips under the sea, whose limits are still unknown. Coal seams interbeded Permian marine sandstones related to the Gondwanaland geology of Parana Basin.

The average of thickness of the seam under mining is 2 meters, and it is formed by high sulphur and high ash coal used mainly as fuel at power plant complex, which consumes nearly 2.4 Mt/year. Coal resources have been exploited through open pit and mainly through underground mines, but presently almost only at underground.

The main physiographic aspect of the site is represented by the surface water divide between Ararangua and Urussanga rivers watersheds that tracks Cechinel hill crest.

The sedimentary rocks in the area are formed by sandstones, siltstones, shales and coal beds are settled on top of a marine regressive and transgressive formation (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 Santa Catarina Coal Basin. Under this structural framework, northeast direction faults determined not only the exposition of more than 30 kilometers of Barro Branco coal bed around Cechinel hill, but also the relief of coal bed floor. As coal bed floor dips as eastern as western directions the water through underground mines flow either towards Ararangua and Urussanga watersheds.

Since coal discovery in 1883, its exploitation techniques have been undertaken several developments from manual through highly mechanized. Although longwall mine have been applied in the past, today only room and pillar, in “first mining” is used as mining method.

According to Belolli there were 117 coal mines in 1942, within 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 there were 26 coal mines on Cechinel hill surroundings, 14 among them abandoned in 1951.

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

METHODOLOGY

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

1ª) Georreferencing of existents mine maps on the Criciuma area, identifying declines, shafts and drift entries.

2ª) Identifying evidences of waste piles near outcrops due mining activities through aerial photo's interpretation. There are available aerial photos at scale of 1:20,000 and color digital orthophotos at scale of 1:5,000 and DTM – Digital Terrain Model made on January to February of 2002.

3ª) Field survey based on orthophotos measuring dimensions, orientation, geology and geomechanical description, weathering stage of rocks, roof fall, water inflow occurrence and other relating information.

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

All mapped mine openings are photographed and their altitude determined from mine maps and drill holes. Positioning of openings was made by GPS survey and orthophotos and can vary several meters (usually less than 10 meters) due vegetation interference in the GPS signal.

Survey information was compiled in a Microsoft ACCESS format database and topographic maps which compose the technical collection available at Santa Catarina Coal Producers Association - SIECESC office. Those information are utilized by the Environment Branch of SIECESC and at National Department of Mineral Production - DNPM

MAIN RESULTS

Monitoring

Abandon mine openings contribute to generation of Acid Mine Drainage – AMD, through oxidation of pyrites content of coal seam and overlying strata and consequent lixiviation for surface water inflow and groundwater percolation. Among 330 mine opening mapped until June 2005, 46 are releasing AMD into Sangão and Urussanga watersheds and 50 others (drift entries, declines, shafts and subsidence induced fractures) are capturing surface runoff and small perennial streams conducting water to underground in a vicious circle capturing clean water and releasing contaminated as AMD.

With the urban growth many mine openings were leveled and being AMD deriving from these locals collected by municipal drainage system. Thus a number of old mine openings releasing AMD can be bigger than that one shown by actual mapping workings.

A preliminary evaluation of quality and flow of water release from 13 mine openings is shown in table 01 below:

Points of Sampling	pH	Acidity $CaCO_3$ ($mg.L^{-1}$)	Condutivity ($uS.cm^{-1}$)	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**	**1,333.8**

Table 01: AMD collected from 13 mine openings (Cechinel hill, Criciuma – Santa Catarina State). Sampling on March 2003.

Mapping of Abandoned Mine Openings

The pilot area comprises Naspolini, São Simão, Mina do Toco, Vera Cruz, Cruzeiro do Sul, Santo Antônio, Operária Nova e Mina Brasil districts of Criciuma city and small portion of Sideropolis, Cocal do Sul and Morro da Fumaça surroundings cities.

The total number of mine openings mapped and registered until now is 330. The total shown at table 02 is only mapped around Cechinel hill.

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 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**

Table 02: Abandoned mine openings mapped and classified at Pilot Area

Structural Model

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

Besides the structural information and flow direction assumptions, mine information was collected identifying places where retreating mining took place and general mining development was made, considering some locations were underground works from different mines was interconnected constituting a huge mine complex. All those information was considered together, trying to better understanding of water dynamics inside the mine complex. The model shows that the probable main directions of water pathways inside the mine runs towards South-Southeast and West-Southwest from underground water divide. See figure 03

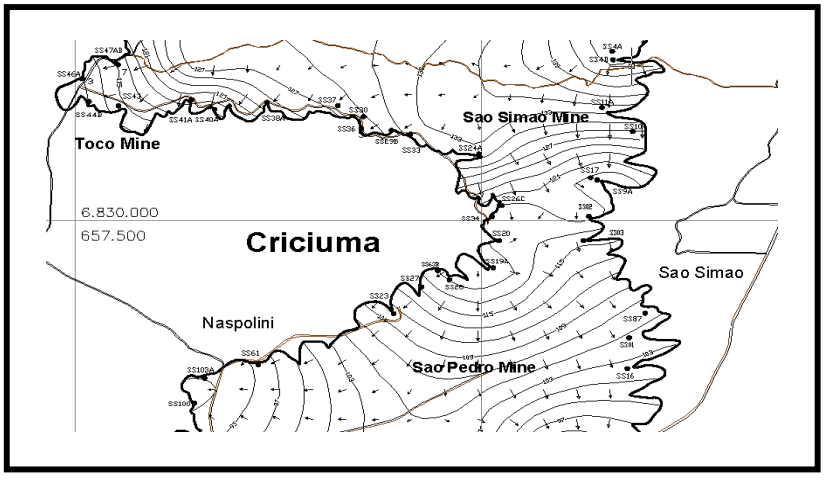

Figure 03: Map showing structural model of Barro Branco coal seam floor and flow directions inside the mines.

DISCUSSION

Water dynamics into Abandon Mine underground workings

The dynamics of water can be explained by structural modeling assuming that the follow assumptions based onto old mine workings maps are reasonably accurate: a) São Simão and São Pedro mines as well as Antônio de Luca "A" and "B" mines are interconnected; b) São Simão and Antonio de Luca mines are not interconnected; c) São Pedro mine are interconnected with Modelo mine; and d) the full extraction areas reasonably well represented.

The areas of full extraction correspond to bigger surface water inflow, which was proved by correspondent proximity to higher outflow openings and close connection of discharge with hydrologic regime.

The principal springs are located at east side of Cechinel hill and are identified as SS-09 and SS-16, discharging up to 562 m³/h of AMD at Barbosa and Ronco D'água streams respectively.

The SS-09 opening drains water from collapsed areas of São Simão mine.
As the called SS-11 opening is the nearest downstream point from pulled pillar area of São Simão mine, probably some roof fall material are blocking a flow path diverging AMD for SS-09 spring. The SS-16 spring drains the biggest dismantled area from São Simão and São Pedro mines. A reasonable portion of the total inflow from those mines comes through SS-87 opening which is impossible to quantify as this water is collected by municipal drainage system. The rest of water flows south and reach surface through Modelo mine which drains 25 m³/h (average flow rate).
The main springs of AMD at west side of Cechinel hill are situated at points called SS-40A, SS-49B and SS-51 which belongs to Antonio de Luca mine complex and drains altogether 596 m³/h to Sangão river.
Although SS-40A and SS-49B openings are more distant than SS-51 from collapsed areas of Antonio de Luca mine, they drain the most part of water inflow a cause of higher declivity towards those points. The pillared areas are intercepted by faults and diabase dikes at Northeast direction which amplify hydraulic conductivity increasing water inflow in that portion of mine.
The denser presence of these geological structures in the west side of the hill could explain why there is a biggest water inflow in this side in comparison to east side as the collapsed areas are equivalent in size.

Dinamics of Surface water

The mapping of mine openings has shown that, a large number of galleries collect water from surface, both from shallow aquifers and runoff.
In many places (SS18, SS19, SS20, SS24, SS26, SS38, SS47, SS55 e SS60) surface water are contaminated before ingress to mines through percolation under exposed solid wastes, mine waste piles or in contact with untreated sewage. Once into the mines, the water in contact with oxidation products became acid.
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 acid mine drainage.
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 bigger at west side than at east side. This is conditioned by wastes deposition in front of portals that dam rain water, driving it into the mines.

CONCLUSIONS

The most of existent abandoned mine openings at Cechinel hill are located. This does not means that do not exist others that could be mapped, manly in heavily populated areas or where there are dense vegetation covering.
The most of cases is very easy to access these mine openings constituting, besides environmental risks a danger to people safety and health. There are 64 abandoned places that still open, which represents 37% of total 173 mapped. Shafts and declines constitute the biggest risk of people safety.
The reclamation projects, now under development, following modeling phase consists in closing partially or totally with clay or concrete seals of mine openings will results in reduction of elimination of safety risks, will reduce air and water inflow to underground mines reducing acid mine generation and avoiding underground diversion of streams. These uncontaminated streams can provide an extra source of water for local inhabitants at communities of Naspolini, São Simão and Mina do Toco districts. Also these projects will help to improve water quality and reduce environmental impact on water resources due mine activities.
The monitoring of SS-16 point, at São Simão disctrict, has shown that water have lower concentration of metals (Al, Fe and Mn), sulfates and acidity in a discharge varying from 30 to 300 m³/h according hydrologic cycles. This low concentration of pollutants comparing with other springs encourage us to implement there a treatment plant designed to neutralize water, remove metals through high tax dissolved air flotation system coupled with sulfate removal techniques allowing water reuse.

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