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Waste foundry sand. Environmental implication and characterization

Resíduo de areia de fundição. Caracterização e implicação ambiental

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Abstract

This paper presents the results of analyses using Scanning Electron Microscopy in field samples of waste foundry sand, as well as the results of granulometric, chemical and groundwater analyses. Field data allowed to characterize waste foundry sand and showed that there are elevated concentrations of metals in the groundwater (iron, manganese, boron and selenium), in addition to other potentially toxic elements (chromium, copper, cobalt, nickel, zinc, aluminum, iron, manganese), which are present in the waste and are considered not hazardous by current standards. Even if these elements are not considered hazardous, their concentrations above the permissible limit compromise the environmental quality of the site, posing risks to the local population, since they work in agriculture and use groundwater. Two different types of waste foundry sands were identified using granulometric analyses. Electron microscopy showed features related to morphological, chemical and mineralogical characteristics of grains that make up the waste. Quartz was the dominant mineral. Waste foundry sand is composed of two types of grains: a rounded grain with almost no incrustations formed during alloy production, and a second type of grain, which is not rounded, has incrustations, and always has several metals derived from alloys and associated with these incrustations. Chemical elements detected in groundwater with concentrations above the limits established by the regulatory bodies were found in wells located in the landfill area. Most of these elements show higher concentrations downstream, some of them with concentrations above the regulatory limit, and others show an increase in concentration upstream, indicating that the landfill may be impacting the local environment.

Keywords: Electron microscopy; Groundwater; Solid waste; Foundry sand.

Resumo

Esse trabalho apresenta resultados da análise de Microscopia Eletrônica de Varredura em amostras coletadas em campo de resíduo provindo de areias de fundição. Foram também realizadas análises granulométricas e químicas, e análise das águas de percolação do resíduo. Dados obtidos em campo permitiram caracterizar o resíduo e demonstram clara e forte concentração de metais nas águas (ferro, manganês, boro e selênio) além de elementos potencialmente tóxicos (cromo, cobre, cobalto, níquel, zinco, alumínio, ferro, manganês) presentes no resíduo, considerado pela atual normatização como não perigoso. Ainda que não seja considerado perigoso, a identificação de elementos potencialmente tóxicos nas águas em concentrações acima do permitido compromete a qualidade ambiental do local, colocando em risco a população do entorno, visto que algumas propriedades vizinhas realizam cultivo agrícola e captam água do subsolo. As análises granulométricas permitiram diagnosticar dois grupos distintos de resíduos. As determinações em microscopia eletrônica exibiram variáveis quanto às características morfológicas, químicas e mineralógicas dos grãos constituintes do resíduo. Foi possível verificar que o predomínio mineralógico residiu no quartzo. Dois tipos de grãos constituíram esse resíduo, um arredondado com quase ausência de incrustações provindas das ligas produzidas na indústria. Um segundo tipo não apresenta arredondamento, é incrustado e apresenta sempre diversos metais associados a essa incrustação, provindos das ligas produzidas. Os elementos químicos identificados nas águas acima dos limites estabelecidos pelos órgãos de controle ocorreram nos poços localizados na área do aterro, e a maioria apresenta concentrações mais elevadas à jusante, alguns acima dos limites da legislação e outros com aumento de concentração em relação a montante, indicando que a presença do aterro pode estar ocasionando impacto ambiental no local.

Palavras-chave: Microscopia eletrônica; Águas subterrâneas; Resíduos sólidos; Areias de fundição.

INTRODUCTION

Industrial waste, considering the potential danger and the serious environmental impact caused when they are not properly disposed of, should be regulated by environmental agencies. This considered, according to the current environmental legislation, supervision should be provided and proposals should be developed for minimizing the impact of this type of waste formed during metallurgical processes.

Waste disposal in soil may cause direct contamination of soil due to the presence of metals and may also contaminate the groundwater and the surrounding superficial environment. Techniques for reusing the waste foundry sand have been studied for years in Brazil, where most studies are focused on its reutilization in building industry (Deng and Tikalsky, 2006; Mariotto and Bonin, 1996; Redondo and Souza, 2003; USEPA, 2003). In other countries, based on legislation and guidelines set out by environmental agencies, waste foundry sand is already used in building industry, paving and even as an agricultural compound. The mixtures of metals and organic compounds associated with the preparation of moulds (phenolic resins) in each foundry process should be analyzed separately, in order to find viable alternatives for minimizing risks of environmental impact. Financially speaking, reutilization seems to be very attractive to foundry industry, since, if the waste is not properly disposed of, the costs with the investigation and even with the remediation of environmental damage will be higher when there is contamination of the area.

GEOLOGY OF THE STUDY AREA

The study area is located in the eastern margin of the Paraná Basin, in Sorocaba city, state of São Paulo. The Itararé Supergroup, in which the study area is inserted, is characterized by sandstones with different grain sizes and diamictites, which reflect glacial influence on its different depositional environments (Schneider et al., 1974). The textural characteristics and sedimentary structures indicate a marine or fluvial lacustrine depositional environment during a glacial cycle, since they show sedimentary structures, such as ripple marks, plane-parallel bedding, graded bedding and cross lamination. Subordinately, there are shales, siltstones, and irregular rhythmites, and, locally, regular rhythmites (varvites). In the state of São Paulo, its thickness is greater than 1,300 meters.

The Itararé Supergroup in the central part of the state of São Paulo, where the study area is located, overlays the crystalline basement, whose erosive surface locally shows evidences of reworking by ice displacement, such as, for example, the Moutonnée Rock (Almeida, 1946) and glacial valleys (Melfi and Bittencourt, 1962), as observed close to Sorocaba. The Itararé Supergroup is overlain by the Rio Bonito Formation (Schneider et al., 1974) or by the Tatuí Formation (Soares et al., 1977), both deposited in post-glacial environments.

The Sorocaba city is precisely located in the limit between the sediments of the sedimentary Paraná Basin and the rocks of the crystalline basement. The city is situated among the rocks of the Itararé Supergroup. Younger sedimentary deposits overlay this unit and are composed of alluvial deposits, sands and clays, and conglomerates in the base, occurring mainly along the main drainage channels and in the north part of the city, along the Sorocaba river. Figure 1 shows the geological map of the region and the localization of the study area.

MATERIAL AND METHODS

Body size and monitoring well installation

After the deposit was measured using a tape measure, six monitoring wells (PM) of geomechanical PVC, with a 2-inch diameter, were installed. The PM were drilled according to the standard NBR 15495-01/07 – Groundwater monitoring wells in granular aquifers: design and installation (ABNT, 2007). Four wells (PM-1 to PM-4) were drilled using auger equipment, and two wells (PM-5 and PM-6) were hand drilled.

Sampling and analyses

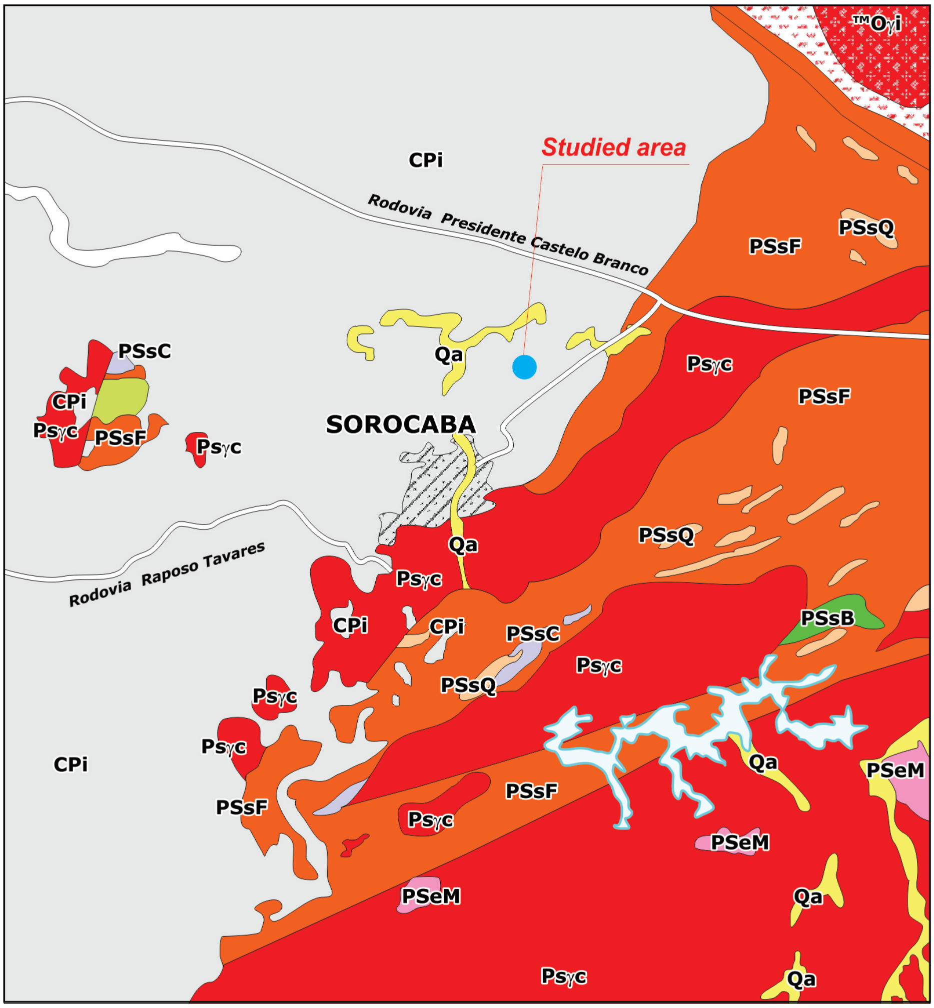
Groundwater

Araujo (2004), together with an environmental services company, carried out samplings on two different occasions (summer, from November 15th to 20th, and winter, from June 20th to 30th), and shared the data for a new interpretation. On each occasion, six samples were collected: five samples from PM-1, PM-2, PM-3, PM-4 and PM-6 wells, and one field blank from PM-5.

Groundwater sampling was conducted by low-flow purging, pumped at flow rate lower than 200 mL/min. Samples were collected after stabilization of physico-chemical parameters indicative of its quality (pH, temperature and conductivity) and transferred to sterilized polyethylene vials, which were sealed and stored at 4°C.

Water samples were analyzed by an outsourced laboratory, following strictly the preservation guidelines. The analyzed elements are:

- Metals: aluminum, antimony, barium, beryllium, boron, cadmium, lead, cobalt, copper, chromium, iron, manganese, molybdenum, nickel, silver, selenium, titanium, vanadium, zinc;



Scale: with no scale.
Source: DAEE-UNESP, 1982.

Cenozoic

Qa	Alluvial sediments - Alluvium in general, including unconsolidated sands with variable grain size, and secondarily clay and fluvial gravel bed in deposits of river beds and/or terraces.
CPi	Tubarão Group - Itararé Formation - Continental glacial, glaciomarine, fluvial, deltaic, lacustrine and marine deposits, mainly containing immature sandstones with variable grain size, passing to arkoses, conglomerates, diamictites, tillites, siltites, shales, rhythmites and rare beds of coal.
PSsC	Dolomitic and calcitic limestones and calc-silicate hornfels in thermal-metamorphic aureoles.
PSsF	Cantareira Facies - para-autochthonous and allochthonous bodies, with foliation, fine- to medium-grained, frequent porphyritic texture; partially concordant contacts and granitic composition.
Psγc	Phyllites, quartz phyllites, and graphitic phyllites in rhythmic successions, including secondarily metasiltites and quartz schists, mica-schists and quartzites.
PSsQ	Quartzites, feldspathic quartzite with subordinate meta-arkoses and metagreywackes.
PSsB	Amphibolites, metagabbros, and epidote amphibolites.
PSeM	Several homogeneous migmatites, with predominance of homophanic, ophthalmic and phacoidal migmatites.

Figure 1. Geological map of the region of Sorocaba and location of study area.

- Mercury;
- Cations and ions: chloride; nitrate; sulfate; sodium;
- Phenol;
- Others: pH; hardness.

The list of guiding values for soils and groundwater of the state of São Paulo (CETESB, 2005) was used as reference for groundwater quality. For the substances not included in the *Companhia de Tecnologia de Saneamento Ambiental* (CETESB) list, the maximum permissible values of the Ordinance nº 2,914 of the Ministry of Health (Brazil, 2011) were used as reference.

Waste

Waste sample collection in the study site considered the body dimensions and depth to obtain a more representative sampling. Shovels and plastic drums were used to collect samples at nine different locations of a profile and at three other locations in trenches excavated using backhoe. Sampling was conducted according to the procedures recommended in the Manual for Management of Contaminated Areas (CETESB, 2001).

Two groups of samples were defined based on collection procedures and representativeness of the waste body in a sampling defined by its dimensions:

- Group A: Samples collected up to 20 cm deep in nine locations, 30 m apart from each other, totalizing the 270 m of width of the body (nine samples). Approximately 30 kg of samples were collected in each location. Figure 2 shows the sampling profile of Group A, and Figures 3 and 4 illustrate part of the excavation sites of this group.

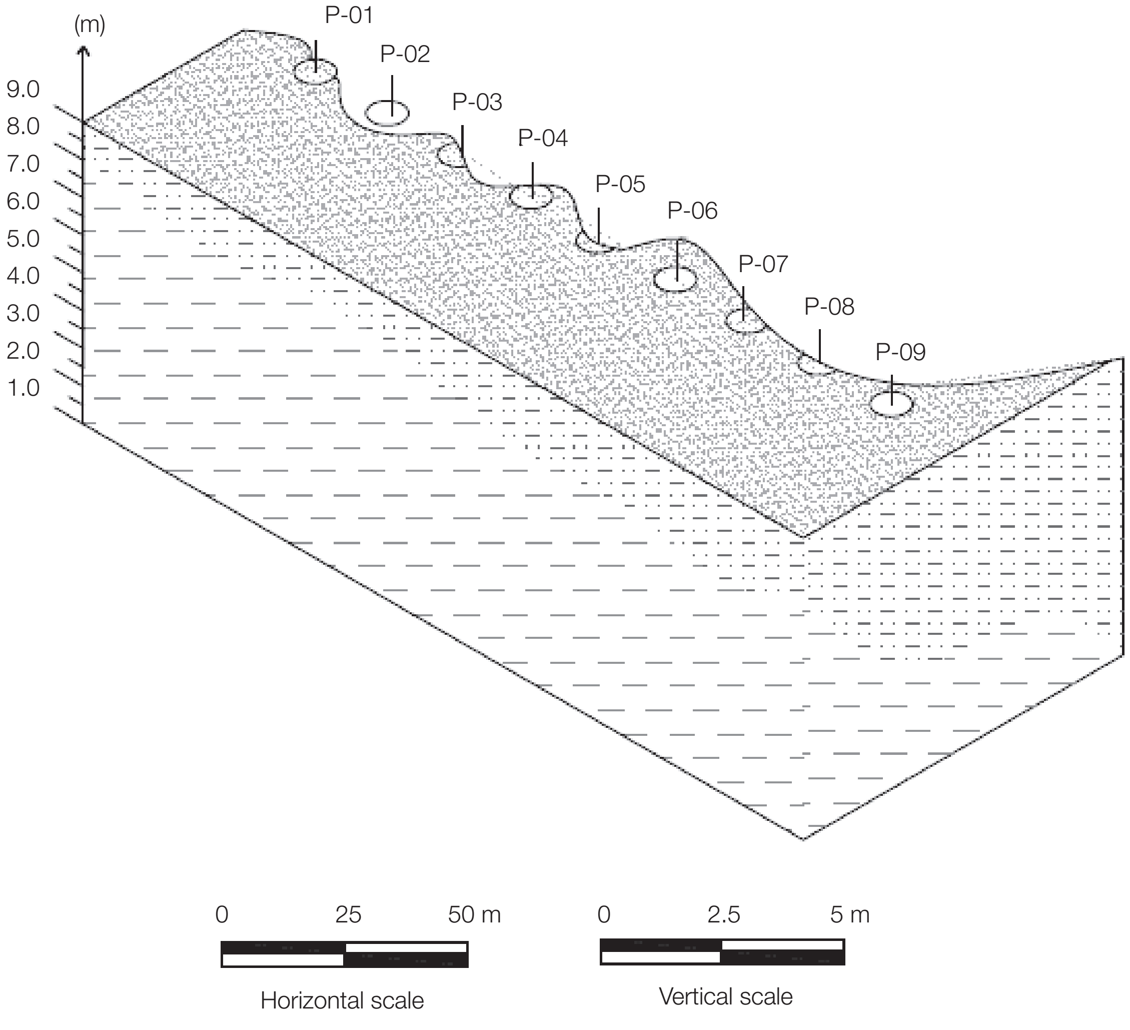


Figure 2. Profile of waste sample collection – Group A.

Figure 3. Excavation for collection of waste sample (Group A).

Figure 4. Depth of the waste collected (Group A).

- Group B: Three trenches were excavated using a backhoe in the disposal area for collecting waste samples (TR-1, TR-2 and TR-3). The size and depth of the body were considered to define the excavation sites. The approximately 6.5 m deep trenches were excavated 90 m apart from each other, and 100 kg of waste were collected in the resulting pile. Figure 5 shows the sampling profile of Group B, and Figures 6 and 7 illustrate part of trenches opened for collecting Group B samples.

After samples of each group were collected, they were mixed and homogenized, forming two major sampling groups (Group A and Group B). Two aliquots of 2.5 kg were separated from each sample for conducting the tests and laboratory analyses described below.

Determination of waste grain size

In a laboratory for grain-size analysis, the two samples were quartered, and two aliquots of 2.5 kg were extracted from each group (A and B). The samples were dried at 60°C in the oven, and after, they were weighed and sieved again. In each procedure, 200 g of sample were weighed and placed in the vibratory equipment for 20 min for ensuring a proper sieving.

Waste morphological and quantitative chemical analyses using scanning electron microscopy

For carrying out morphological analysis and quantitative and semi-quantitative chemical analyses using scanning electron microscopy (SEM), the attached energy dispersive x-ray spectrometer (EDS) system was used and, the electron backscattering diffraction technique was sometimes adopted. The sample metallization was carried out by carbon coating in the stubs. The equipment used was a LEO 440I model, Oxford, with magnification of 5 to 250,000 times. Three sections for each of the eight waste samples were made for analysis.

Chemical content of the waste

Since some metals (chromium, manganese, iron, zinc and aluminum) were detected by SEM, and considering that several other metals (nickel, copper, cobalt) can be released into the sands during the production of ferroalloys, waste samples were sent to an outsourced laboratory for total chemical analysis. For each sampling group (A and B), 450 grams of waste were separated and homogenized, and after, the following analyses were carried out:

- Total chromium;
- Chromium, nickel, cobalt, copper, and zinc.

The methodology used for detection of metals was the inductively coupled plasma optical emission spectrometry (ICP-OES).

RESULTS AND DISCUSSION

The results indicate that the volume of the waste body is 272,160 m^3 (270 m length, 120 m width and approximately 8.4 m height). Considering that its density is 1.8 g/cm^3, it is inferred that 490 thousand tons of waste foundry sand have been deposited during approximately 35 years of operation, as shown in Figure 8.

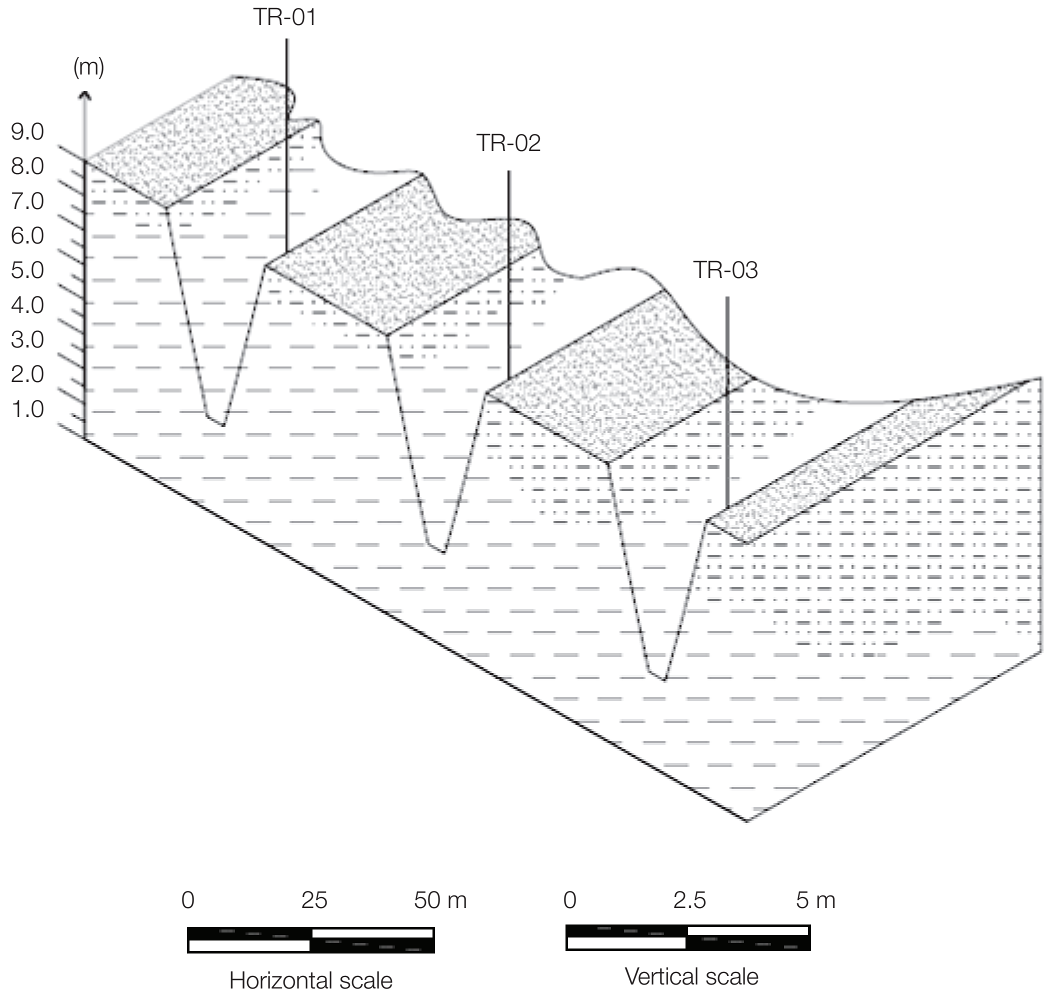


Figure 5. Profile of waste sample collection – Group B.

Figure 6. Trench 1.

Groundwater flow

The groundwater flow was determined, according to the USEPA guidelines (1994), using an electrical measurer, which measures the water level (WL) in each well after stabilization. Monitoring well location and groundwater flow are shown in Figure 9.

Groundwater chemical analysis

Among the studied inorganic compounds and elements, the following cations were detected: aluminum, barium, boron, lead, iron, sodium, manganese and selenium; as well as the following anions: chlorides, fluorides, nitrate (such as NO_3) and sulfates. Tables 1 and 2 show the comparisons between the results for these

Figure 7. Trench 2.

Source: Araujo (2004).

Figure 8. Waste disposal area.

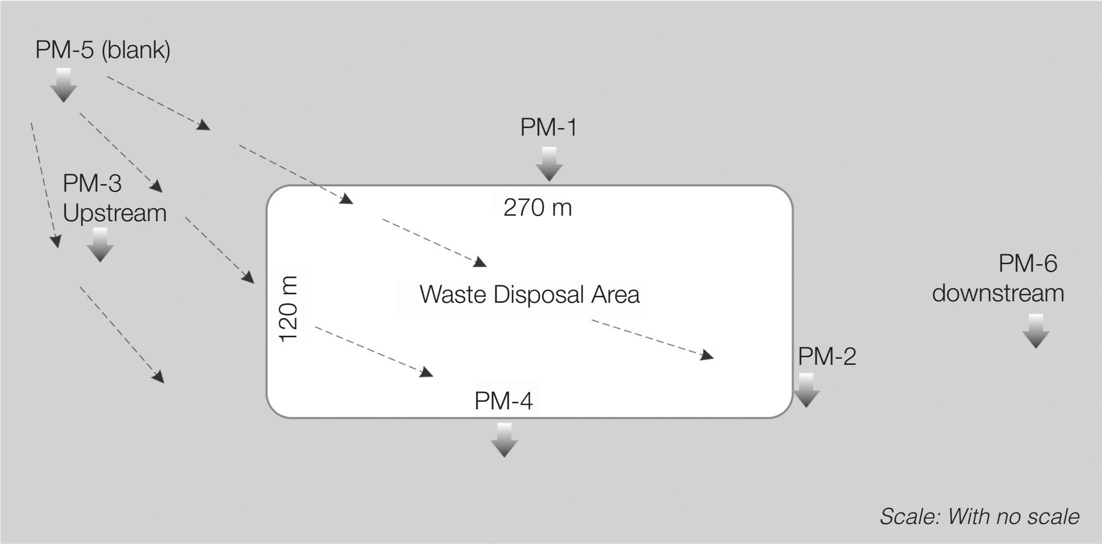


Figure 9. Location of monitoring wells and flow of groundwater.

elements and compounds, and the reference values. Only the elements with results above the detection limits were included in the analysis.

The analysis of results indicates that the following metals are present: aluminum, barium, lead, manganese and selenium in some wells, and boron and iron in most samples. Chloride, fluoride, nitrate, sodium and sulfate were also detected, but there is no CETESB reference value for comparing with these compounds. The Ministry of Health of Brazil established maximum concentration limits only for fluoride, sodium and sulfate.

Most of the elements studied is within the concentration limits established by CETESB and ANVISA (National Agency of Sanitary Surveillance) (Brazil, 2011). However, the concentration of boron was above the intervention limit at PM-2 in both samplings, with concentrations of 1.38 and 0.81 mg/L, respectively. Possibly, its high concentration is due to its increased solubility in the studied environment.

The concentrations of iron and manganese were above the intervention limits in both samplings at most wells. These metals are often found in most soils in Brazil as a result of total hydrolysis. Rocks containing these elements can release them into aqueous medium. Therefore, the soil and, certainly, the foundry sand used in the production of ferroalloys, in which manganese is also used as an alloying element, are the source for the anomalous concentrations of these elements.

Selenium was detected at PM-6 in both samplings, with concentrations of 0.02 and 0.01 mg/L, respectively, and also at PM-4 in the second sampling, with concentration of 0.01 mg/L. The CETESB intervention limit for this element is 0.01 mg/L. Selenium can be found in some types of alloys, but since elevated concentration of selenium was not observed in other wells, the above-mentioned measurements were considered isolated occurrences.

The sodium concentrations in PM-2 and PM-4 were above the limit established by ANVISA in the first (299.3 and 516.7 mg/L, respectively) and second sampling (227 and 351 mg/L, respectively). These anomalous concentrations were not caused by foundry process, and it is reasonable to think that they are related to the rocks present in the study area.

Table 1. Comparison between the results of groundwater analyses and the national reference parameters – sampling 1.

Chemical elements and compounds	PM-1	PM-2	PM-3	PM-4	PM-5	PM-6	CETESB intervention	Ordinance MS 2914
Aluminum	0.08	ND	*1.72*	0.13	ND	0.08	0.2	0.2
Barium	0.21	0,2	ND	0.21	ND	ND	0.7	0.7
Boron	0.18	*1,38*	0.18	0.18	0.18	0.18	0.5	*
Cadmium	ND	ND	ND	ND	ND	ND	0.005	0.005
Lead	ND	ND	ND	ND	ND	ND	0.01	0.01
Chloride	ND	ND	ND	ND	ND	ND	*	250
Total iron	*0.3*	0,1	*0.94*	*3.47*	*6.19*	0.11	0.3	0.3
Fluoride	0.3	**2,9**	0.1	0.2	0.2	0,8	*	1.5
Manganese	**0.35**	*1,67*	ND	*0.94*	*1.28*	ND	0.4	0.1
Nitrate (such as NO_3)	0.4	ND	0,6	0.4	ND	7.5	*	*
Selenium	ND	ND	ND	ND	ND	*0.02*	0.01	0.01
Sodium	8.84	**299,3**	3.93	**516.7**	12.4	40.9	*	200
Sulfate	11	52	ND	8	ND	14	*	250

Source: Araujo (2004).
ND: not detectable; *there is no reference parameter; value in bold: exceeded the limit of Ordinance MS 2,914; value in italics: exceeded the CETESB Intervention limit, 2005.

Table 2. Comparison between the results of groundwater analyses and the national reference parameters – sampling 2.

Chemical elements and compounds	PM-1	PM-2	PM-3	PM-4	PM-5	PM-6	CETESB intervention	Ordinance MS 2914
Aluminum	ND	ND	ND	0.08	0.05	ND	0.2	0.2
Barium	0.19	0.16	ND	0.35	0.06	0.17	0.7	0.7
Boron	ND	*0.81*	ND	0.41	ND	0.32	0.5	*
Cadmium	ND	ND	ND	ND	ND	ND	0.005	0.005
Lead	ND	ND	ND	ND	ND	ND	0.01	0.01
Chloride	5	ND	ND	47	ND	8	*	250
Total iron	*1.91*	*1.11*	ND	*3.4*	0.13	*0.32*	0.3	0.3
Fluoride	0.77	0.15	ND	**2.03**	ND	ND	*	1.5
Manganese	*0.66*	*1.62*	ND	*0.87*	ND	*0.52*	0.4	0.1
Nitrate (such as NO_3)	ND	ND	ND	10	4.26	11.2	*	*
Selenium	ND	ND	ND	*0.01*	ND	*0.01*	0.01	0.01
Sodium	60.1	**227**	0.56	**351**	3.74	88.7	*	200
Sulfate	15	1.3	7.6	112	ND	26	*	250

Source: Araujo (2004).
ND: not detectable; *there is no reference parameter; value in bold: exceeded the limit of Ordinance MS 2,914; value in italics: exceeded the CETESB Intervention limit, 2005.

Most elements, many of them above the limits established by the regulatory bodies, were detected in wells 1, 2 and 4, which are located in the foundry sand disposal area, as shown in Figure 9. Comparing the upstream well (PM-3) with the downstream well (PM-6), the results show higher concentration of elements in the well located downstream of the landfill. Even if only iron, manganese, boron and selenium are above the legal limits, the increase in the concentration of other elements indicates that the foundry sand disposal causes environmental impact in the area.

Waste analyses

Grain size variation

After samples were sieved into several fractions, grain size variation was measured for the two sample groups, as shown in Tables 3 and 4. In Group A, larger fractions (from 0.25 mm to larger than 4 mm) are present in approximately 60% of the sample, whereas, in Group B, smaller fractions (from 0.18 mm to up to 4 mm) predominate in more than 70% of the samples. Therefore, the fractions that were the most representative in weight for each group of samples were selected for morphological, mineralogical and quantitative chemical analysis, aiming to detect the possible contaminants of waste (mainly metals), which were posteriorly confirmed by qualitative chemical analysis using scan electron microscopy.

The grain size analysis of the waste indicates that it is mainly composed of fine-grained material. This characteristic indicates that this material has a large contact surface, which can favor the accumulation of chemical elements and degradation of particles by weathering and resulting leaching of its elements. Waste collection carried out in the deposit included three different segments: a superficial portion, which is intensively leached; an intermediate thick portion with material that represents the last foundry processes; and a basal portion composed of green sand, which is a result of older processes, adopted in the 1970's and 1980's.

Morphological, mineralogical and quantitative chemical analysis using scanning electron microscopy

SEM showed features related to morphological, chemical and mineralogical characteristics of the grains that make up the waste. Regarding the morphology, two types of grains constitute this waste: a rounded grain with almost no incrustations formed during alloy production, with colors ranging, in most samples, from gray to brown and yellow; and a second type of grain, which is not rounded, has incrustations, and always shows several metals derived from the alloys and associated with these incrustations. In both cases, analyses were carried out in the grains to define their qualitative chemical composition. Morphologically, bright angular grains were observed when SEM with electron backscattering diffraction technique is used: this fact indicates that there are possible incrustations of metallic elements, which were melted and casted in molds made of sands. The main elements detected are: iron, aluminum, manganese, chromium, magnesium and zinc.

SEM images and spectrograms obtained from qualitative chemical analysis of some samples of Group A are

Table 3. Grain size variation of Group A samples.

WASTE – GROUP A		
Sample	Grain size	% in weight
I-A	> 4 mm	21%
II-A	> 0.35 mm and < 4 mm	17%
III-A	> 0.25 mm and < 0.35 mm	21%
IV-A	> 0.18 mm and < 0.25 mm	14%

Table 4. Grain size variation of Group B samples.

WASTE – GROUP B		
SAMPLE	Grain size	% in weight
I-B	> 4 mm	8.06%
II-B	> 0.35 mm and < 4 mm	26.43%
III-B	> 0.25 mm and < 0.35 mm	25.42%
IV-B	> 0.18 mm and < 0.25 mm	20.43%

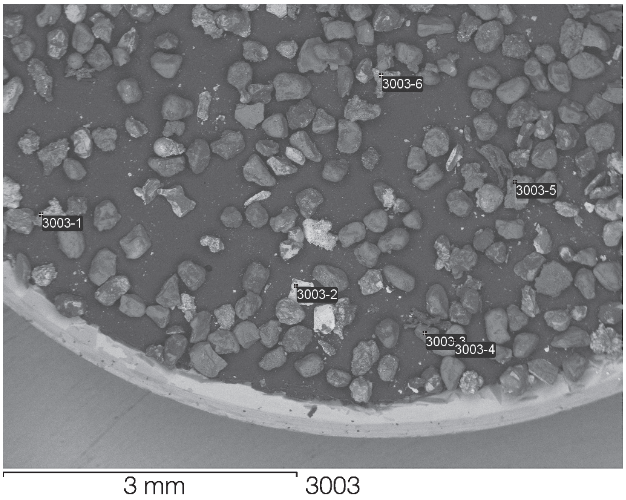


Figure 10. Scanning electron microscopy image with magnification of 50X of sample IV-A.

shown in Figures 10 to 12, and images and spectra of some samples of Group B are shown in Figures 13 to 15. Concerning the mineralogy, the presence of rounded grains with specific morphology indicate a silicatic composition, probably quartz, as shown in the spectrograms, many times with incrustations, which are formed during the production of alloys in the foundry. Metals, such as silicium, manganese, zinc, chromium, iron and magnesium, are observed in both groups, and the presence of the last four metals may indicate sand contamination by foundry processes.

Chemical content

Considering that the samples were collected from excavations, and that layers of soil have been deposited over the waste for years, the list of guiding values for soils of the state of São Paulo (CETESB, 2005) was also

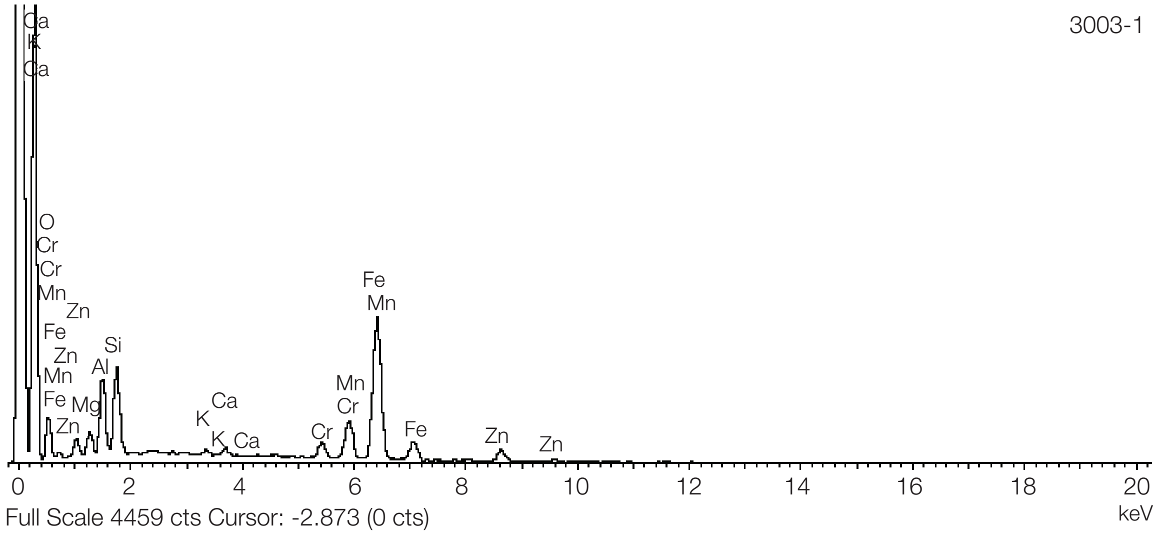


Figure 11. Energy dispersive x-ray spectrometer spectra of sample IV-A: the peak of calcium stands out, following by the iron, manganese, chromium and zinc peaks.

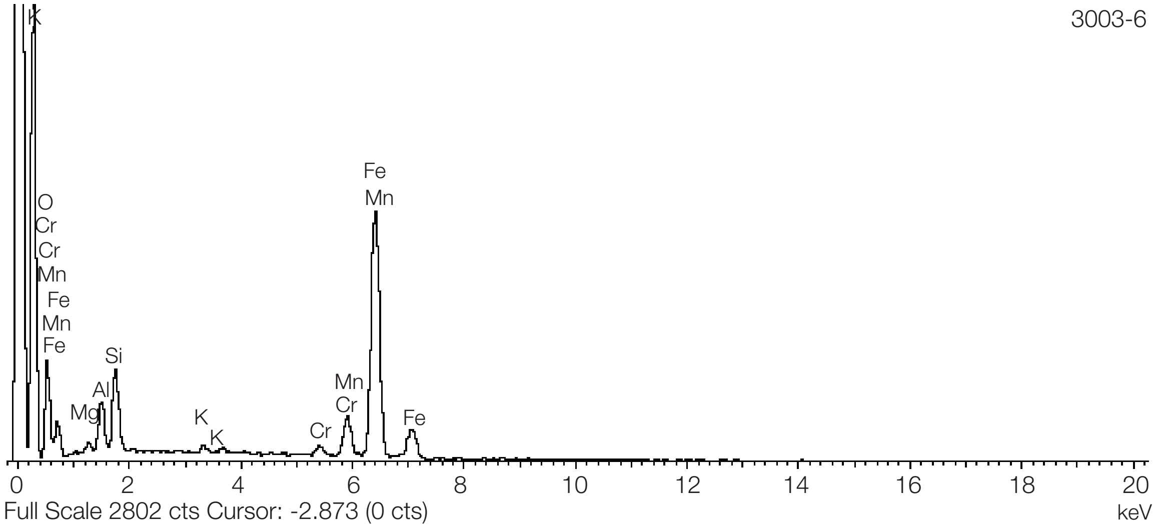


Figure 12. Energy dispersive x-ray spectrometer spectra of sample IV-A: the peak of K stands out, following by the iron, manganese, silicon and chromium peaks.

used as reference. This classification, which is used to determine if a waste is hazardous or not, was developed based on the standard ABNT NBR 10,004/2004 (Solid Waste: Classification) (ABNT, 2004a). According to this standard, waste is considered toxic when the extract obtained from the sample, according to the procedures of the standard ABNT NBR 10,005 (ABNT, 2004b), contains any of the contaminants in concentrations above the values listed in Annex F of standard 10,004. Among the metals detected using SEM, chromium is the only element with a corresponding reference value in this standard.

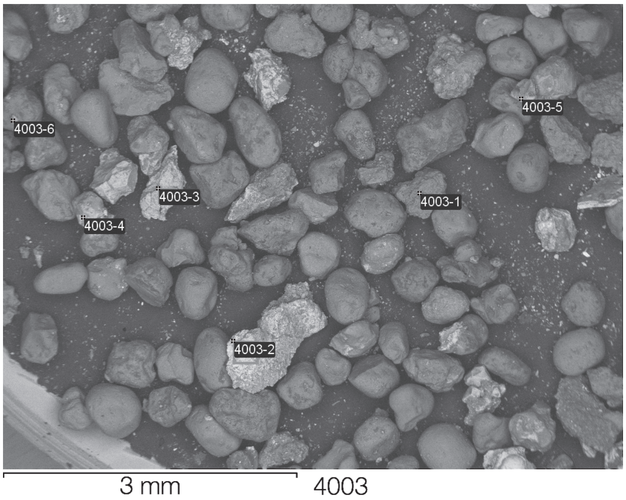


Figure 13. Energy dispersive x-ray spectrometer image with magnification of 50X of sample II-B.

Table 5 shows the comparisons between soil results for the waste studied and prevention and intervention values in São Paulo, Holland and United States (USEPA, 1996a, 1996b; Vrom, 2000).

Based on the analytical methods used in this study, the comparisons between the concentrations of potentially toxic elements present in the waste and the reference values showed that no element was found in a concentration above the limit established, as shown in Table 5.

The concentration of these elements was also measured in the groundwater, but they are not mentioned in this paper, since they are below the detection limit. Table 6 shows the comparison between the chromium concentration and the reference value of the standard NBR 10,004.

As shown in Table 6, chromium concentration in the waste is not hazardous and belongs to class II. However, analyses carried out for this study did not determine whether this element is inert or not (a refinement of the standard), since this was not an objective of this study.

Even if the waste is not classified as hazardous, the presence of these elements in the groundwater may compromise not only the waste disposal area, but also its surroundings. Next to the disposal area, there is a superficial stream (brook), whose water is used by some neighboring farms — one of them is a corn field. The risk to the environment is even greater since residents in those areas use wells to collect groundwater to meet their needs.

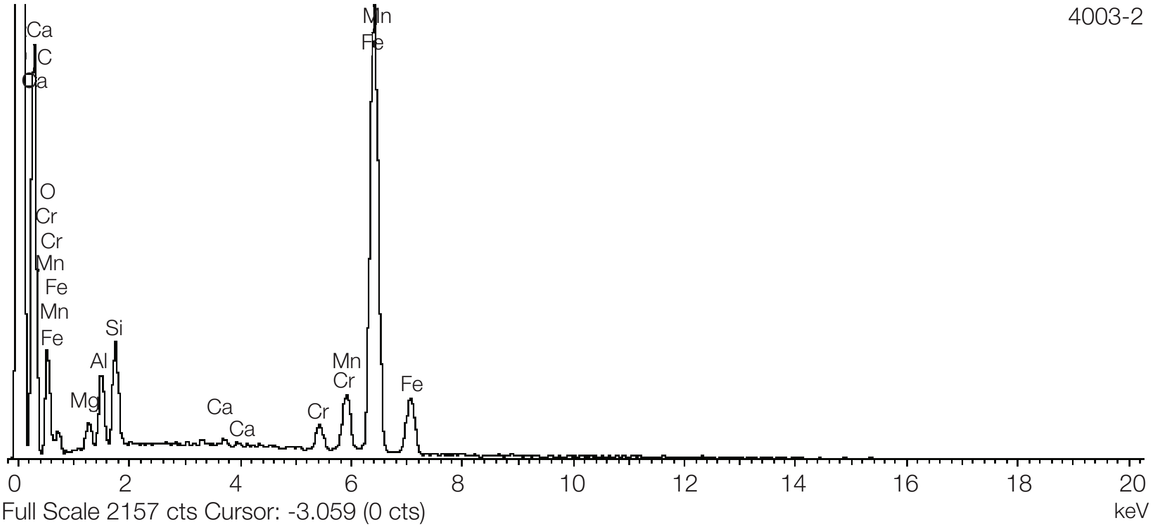


Figure 14. Energy dispersive x-ray spectrometer spectra of sample II-B: the peak of calcium stands out, followed by the iron, manganese and chromium peaks.

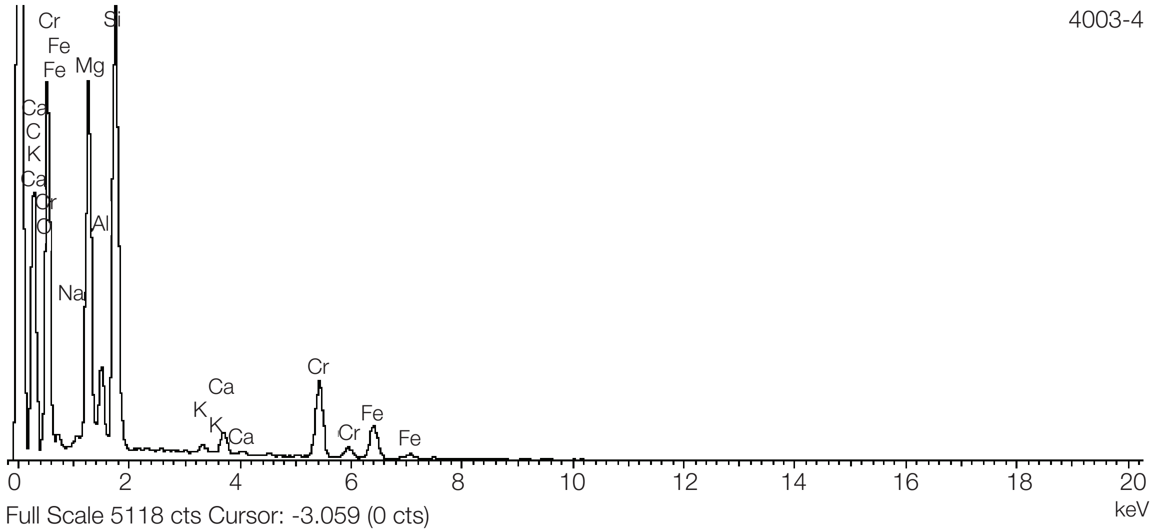


Figure 15. Energy dispersive x-ray spectrometerspectra of sample II-B: the peak of silicon stands out, followed by the iron, chromium, calcium, aluminum and potassium peaks.

Table 5. Reference values for cobalt, copper, chromium, nickel and zinc, compared with the concentrations measured in the area.

ANALYTICAL RESULTS OF WASTE SAMPLES (mg/kg)								
Parameter	Group A	Group B	CETESB			Holland standard	USEPA	
			Agricultural	Residential	Industrial		Residential	Industrial
Cobalt	2.4	2.3	35	65	90	240	23	300
Copper	18	13	200	400	600	190	*	*
Chromium	75	50	150	300	400	380	*	*
Nickel	36	36	70	100	130	210	*	*
Zinc	156	43	450	1000	2000	720	*	*

*Value not established

Table 6. Chromium concentration compared with the reference values of NBR 10,004.

Analytical Results for chromium (mg/L)			
Parameter	Group A	Group B	NBR 10,004 - Annex F
Chromium	0.068	0.051	5

CONCLUSIONS

Based on the data obtained, the following conclusions can be drawn about the waste:

Waste disposal procedures did not consider a careful analysis of its hazardousness and, consequently, did not acknowledge the presence of some metals in the grains, which, if in high concentrations, may be harmful to the environment when under the effect of supergene processes of degradation caused by weathering, during the time the waste is exposed to the weather.

The elements detected in the groundwater (most metals) with concentrations above the limits established by the regulatory bodies were found in wells located in the landfill. Most of these elements show higher concentrations downstream, some of them with concentrations above the regulatory limits, and other elements show a increase in concentration upstream, indicating that the landfill may be impacting the local environment.

The results obtained using SEM were not conclusive for analysis of environmental risk to the study area, although several metals have been chemically and morphologically detected in a few sites. Some of these metals are present in concentrations above the limits permitted by current legislation on the management of contaminated areas.

The possible contamination of the groundwater that permeates the waste body is a demonstration that even if the contamination was not evident when the waste was initially disposed, the surface conditions — rainfall, presence of organic acids (fulvic acid) and inorganic acids (mainly carbonic acid, result of the reaction of carbon dioxide with rainfall water) — favor the degradation and leaching of chemical elements, which, if in significant quantities, compromise environmentally the water table.

The current methodology for classifying the waste takes into consideration the concentration of "potentially polluting" constituents, according to the tests conducted in laboratory, simulating physicochemical changes, such as leaching and solubilization. Once the waste is disposed in the environment and exposed to weathering processes, physicochemical changes will certainly occur, since, posterior to processes, such as hydrolysis, solubilization and others, the waste constituents, in addition to undergo changes, will react with the elements present in the area where it was disposed. Owing to the "simplification of the standard", the waste was not properly managed, mainly in the past, and the environmental agency is not even aware of the liabilities owed by many foundries. Few studies investigate the environmental impact of this type of waste.

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