International Journal of Coal Geology 83 (2010) 456–466

Contents lists available at ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

Petrographic, mineralogical and geochemical characterization of the Serrinha coal waste pile (Douro Coalfield, Portugal) and the potential environmental impacts on soil, sediments and surface waters

J. Ribeiro [a,*], E. Ferreira da Silva [b], Z. Li [c], C. Ward [c], D. Flores [a,d]

[a] Centro de Geologia, Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal
[b] GeoBioTec, Geobiosciences, Geotechnologies and Geoengineering Research Center, Universidade de Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal
[c] School of Biological, Earth and Environmental Sciences, University of New South Wales. Sydney, NSW 2052, Australia
[d] Departamento de Geociências, Ambiente e Ordenamento do Território, Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal

ARTICLE INFO

Article history:
Received 27 April 2010
Received in revised form 28 June 2010
Accepted 28 June 2010
Available online 3 July 2010

Keywords:
Environmental impact
Douro Coalfield
Coal waste pile
Geochemistry
Petrology
Mineralogy

ABSTRACT

Serrinha is the largest coal waste pile resulting from mining activities in the Douro Coalfield, Portugal. The exploitation of anthracite in tens of small mines caused some environmental impacts, as is the case of the coal waste piles that exist in old mines and adjacent areas.

The Serrinha waste pile is essentially made up of 2 million tonnes of shales and carbonaceous shales, deposited in a topographical depression over about 30 years.

Despite the environmental restoration accomplished in the Serrinha waste pile, some environmental problems seem to persist. In this study a petrographic, mineralogical and geochemical characterization was done in order to recognize and understand these problems. The materials studied were coal waste, sediments and waters from the drainage system and decanting basins, soils from the surrounding areas, leachates from waste material and neoformed minerals formed at the bottom of the waste pile. The main lithologies (carbonaceous shale and lithic arenite) and coal from the Douro Coalfield were also analyzed.

Petrographic analysis shows some evidence of weathering (on organic and inorganic matter) related to the time of exposure to the weathering agents and the easy access of air within the waste pile (due to both the poor compaction and the heterogeneity of the material). Mineralogically, the composition of coal waste material has contributions from both the coal and the associated lithologies.

R-type cluster analysis of the waste pile material allows two distinct clusters to be identified. In the first cluster a sulfide fraction is represented by the association of As, Cd, Cu, Pb, Ni and Zn, while Fe clustered with Al, Co, and Ti indicates that some of the Fe and the other elements are likely associated with silicate minerals such as clays. The second cluster, represented by Cr, V, Zr, Rb, REE, Mn, Li and Ba, probably represent a silicate fraction, perhaps detrital accessory minerals.

The waste pile material, leachates, soils, sediments, neoformed minerals and water analyses indicate the existence of potential environmental impacts due to the acid mine drainage and associated leaching of heavy metals and other elements.

1. Introduction

Despite the important contribution to the economic and social development of many countries, coal mining and coal consumption have a significant impact on the natural environment. The major environmental impacts associated with coal mining include changes in land use, subsidence phenomena, increased generation of noise and waste around mining installations, soil erosion, water pollution, acid mine drainage, potential impacts on local biodiversity, and release of methane (Suárez-Ruiz and Crelling, 2008 and references therein). An overview of the environmental impacts of coal mining and associated wastes was carried out by Younger (2004). A typology of the environmental impacts related to coal mining that recognizes five major categories of hazards was presented in that work: air pollution, fire hazards, ground deformation, water pollution and water resource depletion.

Petrographic and geochemical characterization of coal may provide insights into the potential leaching of hazardous substances (Finkleman and Gross, 1999). The petrographic characterization and organic geochemistry of coal are generally not yet, considered when discussing environmental problems. However, the petrographic composition of coal may be useful in forecasting the leaching of potentially harmful compounds. The understanding of geochemical

* Corresponding author. Tel.: +351 220 402 451; fax: +351 220 402 490.
E-mail address: joanaribeiro@fc.up.pt (J. Ribeiro).

0166-5162/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.coal.2010.06.006

processes is a key to understand how the impacts occur and to develop sustainable mitigation strategies (Younger, 2004). The properties and characteristics of coal depend on its organic and inorganic constituents. Among the coal quality parameters, trace elements in coal can have great environmental, economic, technological, and human health impacts (Swaine and Goodarzi, 1995; Finkleman and Gross, 1999).

This integrative work discusses the potential environmental impacts caused by a coal waste pile that resulted from Douro Coalfield exploitation in the Serrinha area inferred from a petrographic, mineralogical and geochemical examination. The objectives of this work are: a) petrographic characterization of the waste material; b) mineralogical and geochemical characterization of waste material, sediments and waters from the associated drainage system and decanting basins, and soils from surrounding areas, in comparison with main lithologies and coal compositions from the Douro Coalfield; c) geochemical characterization of leachates from the waste material; d) mineralogical characterization of neoformed minerals at the bottom of the waste pile, and e) determination of the mobilization processes of elements in the waste pile.

2. Study area: geological and environmental setting

Geologically, the Douro Coalfield is the largest outcrop of terrestrial Carboniferous (Upper Pennsylvanian [Lower Stephanian C]) coal-bearing deposits in Portugal (Lemos de Sousa and Wagner, 1983; Wagner and Lemos de Sousa, 1983; Eagar, 1983; Fernandes et al., 1987). Fig. 1 illustrates the geological and geographic setting of Douro Coalfield. Mining of anthracite A (ISO 11760, 2005) started in the Douro Coalfield in 1795 and continued until 1994. There were two main centres of exploitation, Pejão mining area and S. Pedro da Cova mining area, and tens of small mines all over the basin, scattered an area of approximately 9 km² (Custódio, 2004).

The mining activities in the Douro Coalfield had economic and technological impacts as well as a cultural significance, and contributed significantly to the economic and energy sectors of Portugal (Custódio, 2004). Between 1930 and 1990 anthracite from the Douro Coalfield was the most important national fuel used for electricity generation and the principal fuel supplied to the Tapada do Outeiro Power Plant (1959–2004).

Mining activity has caused some impacts on the environment in the Douro Coalfield area, mainly because it started in the end of 18th Century, when there was no great concern for the environment. The most significant environmental concern in the Douro Coalfield area is the large number of coal waste piles emplaced all over the old mines and adjacent areas. There are more than twenty waste piles, composed of the overburden material and discards from the washing plant. Some of these waste piles present very serious problems, as is the case of the largest one, Serrinha. A further three waste piles, namely, S. Pedro da Cova, Lomba and Midões, are also of a great environmental concern because they are self-burning (Ribeiro et al., 2010; Sant'Ovaia et al., 2010).

The development of the Serrinha waste pile resulted from the accumulation of overburden material from the Germunde underground mine (Pejão mining area), which is located 2 km NW from the waste pile (Gama and Arrais, 1996).

When Germunde mine closed in 1994, the waste material occupied 4 ha and had a volume of 1.2 million m^3. The deposition of material, continued for about 30 years, was carried out by simple discharge in a topographical depression. The waste pile is essentially made up of 2 million tonnes of shales and carbonaceous shales, heterogeneous, dark in color and with a variable particle sizes (Gama and Arrais, 1996).

An environmental restoration was carried out to address the environmental problems associated with the Serrinha waste pile, mainly the low stability of the slopes (Gama and Arrais, 1996). This recovery included: platform regularization, establishment of intermediate landings on slopes, application of calcareous gravel on slope surfaces, land covering with vegetation, installation of a collection/drainage system and decanting basins, and implementation of a forestation and landscaping plan. The platform at the top of the waste pile is currently used as a landing strip for model aircrafts.

Despite the recovery accomplished some environmental problems seem to persist in the Serrinha waste pile, specifically leaching and drainage problems (Ribeiro and Flores, 2008).

3. Sampling and analytical methodology

3.1. Sampling

A total of 17 samples (each with a mass of approximately 1 kg) were collected for petrographic, geochemical and mineralogical analysis: 9 from the waste pile material (WP4, WP8, WP13, WP14, WP15, WP16, WP18, WP20 and WP21), 5 representing sediments from the drainage system and decanting basins (SS17, SS19, SS22, SS24 and SS26) and 3 from soils of the surrounding area (SO25, SO28 and SO29). Representative samples of coal (DC-coal) and the main lithologies of the Douro Coalfield (DC-lithologies), such as lithic arenite (LA) and carbonaceous shale (CS) were also analyzed. These samples were obtained from the collection of the Department of

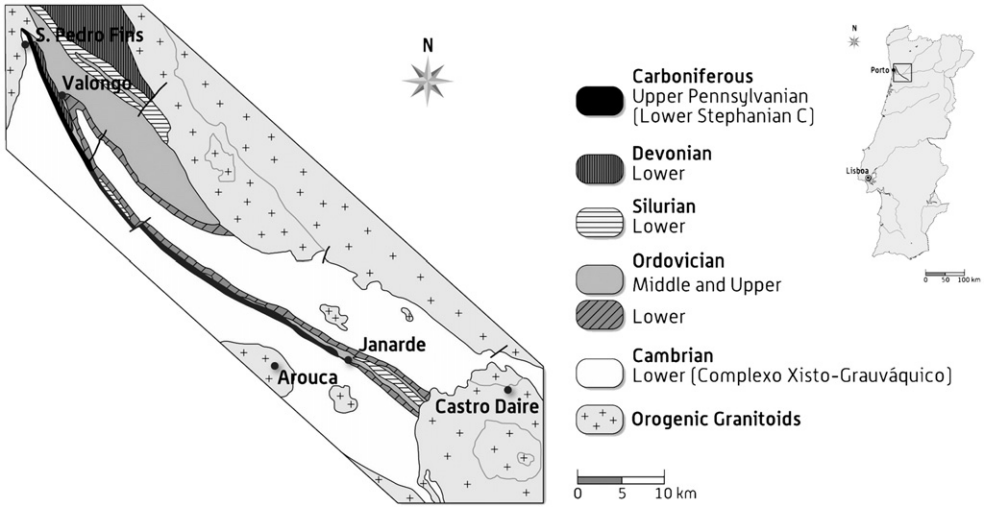

Fig. 1. Geological and geographic setting of the Douro Coalfield (modified from Pinto de Jesus, 2001).