Journal of Geochemical Exploration 144 (2014) 456–467

Contents lists available at ScienceDirect

Journal of Geochemical Exploration

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

Hydrogeochemical behavior around the abandoned Kettara mine site, Morocco

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ARTICLE INFO

Article history:
Received 22 June 2013
Accepted 8 December 2013
Available online 18 December 2013

Keywords:
Kettara abandoned mine site
Acid mine drainage
Hydrochemistry
Groundwater contamination

ABSTRACT

One of the most serious environmental issues related to the mining industry in Morocco and elsewhere, is the pollution from abandoned mine sites. The production of Acid mine drainage (AMD) causes obvious sources of groundwater contamination. With the objective to investigate the impact of the AMD produced at the abandoned Kettara mine site (Morocco), groundwater sampling campaigns were performed during dry and wet seasons at this site. Water samples were analyzed to determine the hydrochemistry composition. The obtained results were analyzed using different research methods such as multivariate statistical analysis and geochemical modeling techniques.
Investigation results show that the hydrochemistry of water samples is characterized by the relatively significant enrichment in Ca^{2+}, Mg^{2+} and SO_4^{2-}. The typical mine waters belongs to the $(Ca^{2+} + Mg^{2+})$-SO_4^{2-} type. Seasonal variations in major ion concentrations were partly attributed to dissolution/precipitation processes. The saturation index (SI) for representative minerals in waters shows that groundwater samples are undersaturated with respect to most potential sulfated secondary minerals.
The results of the study will serve to identify pollutants from the abandoned mine drainage and assess the degree of groundwater pollution. They can also be used to prepare a rehabilitation scenario and prevent further environmental pollution.

1. Introduction

Acid Mine Drainage (AMD) produced from mine wastes is one of the most challenging environmental problems currently facing the mining industry. Mining operations produce large amounts of wastes such as waste rock and tailings; these wastes must be properly managed to protect the environment. In this regard, more attention is required when these wastes contain sulfidic minerals such as pyrite and pyrrhotite. The oxidation of sulfides exposed to atmospheric conditions tends to acidify waters that are then more prone to mobilization of metals contained in the rock; these phenomena generate an acidic leachate called Acid Mine Drainage (AMD; also called ARD for Acid Rock Drainage) (e.g. Aubertin et al., 2002; Ritcey, 1989; SRK, 1989). The drainage water quality from tailings impoundments is influenced by: 1) precipitation and sedimentation of secondary minerals, 2) mineral adsorption by suspended materials (clays, organic matter) and 3) water dilution by adding surface water along the flow path (Nordstrom and Alpers, 1999).

When mine wastes have the potential to produce AMD, waste management and mine site rehabilitation should be performed to inhibit the AMD generation, the effluents produced should also be managed properly to meet existing regulations on water quality (Maqsoud et al., 2012). If not managed properly AMD production occurs and can affect the surrounding mine site area. For example when the AMD have high levels of sulfate and heavy metals at low pH, the biodiversity of water-ecosystems decreases (Sydnor and Redente, 2002; Tordoff et al., 2000) and soils can be contaminated (Khalil et al., 2013). Also groundwater can be affected by this contamination and its impact is more important when water resources are limited particularly in arid and semi-arid regions (Dhakate et al., 2008).

Increased knowledge of groundwater geochemical evolution in arid and semi-arid regions could lead to improved understanding of hydrochemical systems in such areas, leading to sustainable development of water resources and effective management of groundwater resource (Jalali, 2009). Most research groups have focused on the environmental impact of AMD especially soil and plant contamination (Khalil et al., 2013; Liu et al., 2009; Zhou et al., 2007), the impact on the surface and groundwater (Bhattacharya et al., 2012; Cidu et al., 2009, 2011; Delgado et al., 2009; Denimal et al., 2002; El Adnani et al., 2007; Equeenuddin et al., 2010; Gemici, 2004; Olías et al., 2012; Sadek, 2012), toxicity to aquatic life (Chen et al., 2007; Lin et al., 2005), and human health assessment of the residents (Bao et al., 2009).

The abandoned Kettara mine site is one of the most problematic mine site around Marrakech city (Morocco) where population is directly exposed to problems related to the AMD and its rehabilitation became necessary. Thus, the rehabilitation scenario being investigated at the Kettara mine site involves using fine alkaline phosphate waste

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http://dx.doi.org/10.1016/j.gexplo.2013.12.003

(APW) as both an amendment and a 'store and release' (SR) cover (Hakkou et al., 2009). This process requires that all of the Kettara coarse tailings will be collected and placed over the old tailings pond. The coarse tailings would be amended with approximately 20 cm of APW; then, an APW capillary barrier would be placed over the Kettara mine waste. In the semi-arid climate, this cover will act as water infiltration barrier and will limit infiltration and water percolation to the reactive mine wastes; consequently AMD production will be inhibited (Hakkou et al., 2009).

Based on these investigations, instrumented column tests were performed to evaluate the feasibility of using phosphate limestone wastes as moisture retention layer in a SR cover with capillary barrier effects to control water infiltration and consequently AMD generation at the Kettara mine site will be inhibited. Results of these experimental tests show that the SR cover can limit deepwater infiltration (Bossé et al., 2013); so, the SR cover could be used efficiently to control AMD at the Kettara mine and rehabilitation work can go ahead once the financial problems will be overcome.

The performance of the future rehabilitation could be evaluated using groundwater quality around the Kettara abandoned mine site. This assessment requires a fairly accurate knowledge of the initial groundwater quality before rehabilitation works. For that, this work is performed with emphasis on the impact of acid mine drainage on groundwater quality.

This paper provides a conceptual assessment in order to better understand the dominant hydro-geochemical processes controlling spatial variation in chemical composition of the groundwater. The hydrogeochemical processes governing water quality were determined by examining the groundwater types based on major ion data and principal components analysis (PCA).

2. Materials and methods

In this section we present a description of the studied area, followed by geological and hydrogeological condition configuration then sampling and analytical procedure is presented.

2.1. Study area

The abandoned Kettara pyrrhotite ore mine is located approximately 30 km north–north-west of Marrakech city in the core of the central Jebilet Mountains (Fig. 1a). The mining village of Kettara and the mining infrastructure are located downstream from the tailings pond area (Fig. 1d). According to the latest statistics (2004), the population of Kettara is approximately 2000 (Hakkou et al., 2008a). The climate is classified as semi-arid with a mean annual rainfall of approximately 250 mm. Rainfall can occur over short periods and with high intensity. The annual potential evaporation typically exceeds 2500 mm.

From 1964 to 1981, the mine produced more than 5.2 million metric tonnes (Mt) of pyrrhotite concentrate containing an average of 29 wt.% of sulfide. The pyrrhotite extraction generated tailings with a wide range of particle size distribution. Although ore reserves were still abundant, the mine was closed in June 1982 due to difficulties encountered during pyrrhotite concentrate production.

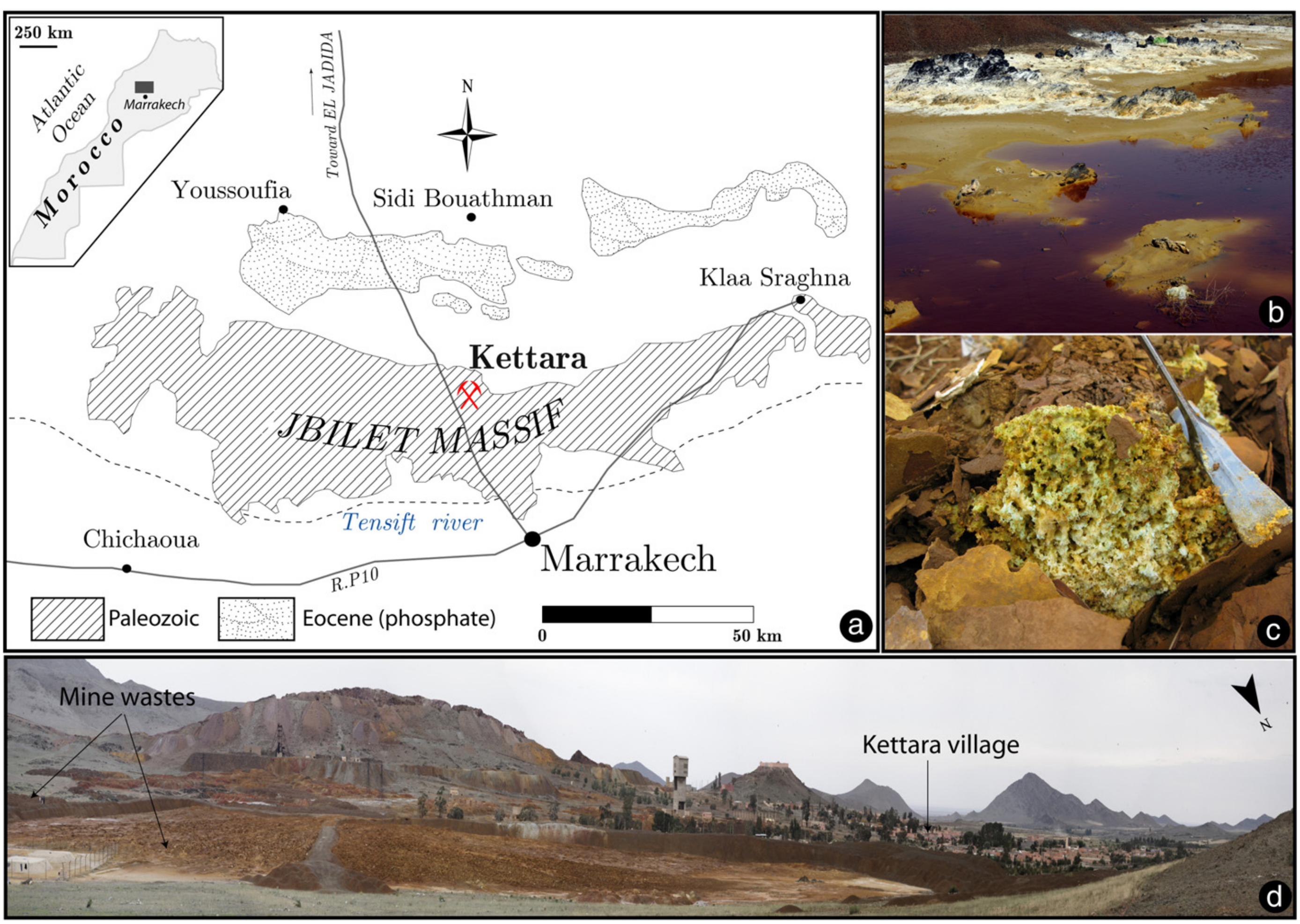

Fig. 1. The study area: (a) location, (b) AMD effluent, and (c) secondary minerals, (d) panoramic view.