Mine Water and the Environment (2005) 24: 58–76 © IMWA Springer-Verlag 2005

Contemporary Reviews of Mine Water Studies in Europe, Part 3

Christian Wolkersdorfer[1] **and Rob Bowell**[2] (editors)

[1]Technische Universität Bergakademie Freiberg, Lehrstuhl für Hydrogeologie, Gustav-Zeuner-Str. 12, 09596 Freiberg/Sachsen, Germany; [2]SRK Consulting, Windsor Court, 1 Windsor Place, Cardiff CF10 3BX, Wales; corresponding author's e-mail: c.wolke@IMWA.info

Abstract. Europe was once the most important mining region in the world and nearly every European country has remnants of historic and even pre-historic mining sites. Though the importance of mining activities in most European countries declines, the abandoned sites are still there and can cause environmental dangers as well as technological challenges. On the basis of selected European countries and case studies, these dangers and challenges are described and potential solutions are illustrated.

Key words: Abandoned mine; Ireland; Belgium; Czech Republic; Switzerland; Bosnia and Herzegovina

---

Ireland – How Green is The Emerald Isle? Consequences of Mining on Receiving Waters

Aisling D. O'Sullivan

[1]Civil Engineering Dept, Univ of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand; corresponding author's e-mail: Aisling.OSullivan@canterbury.ac.nz

Introduction

Ireland boasts a wealth of mining activity, possibly dating back to the Bronze Age, when copper was reputedly mined at Mount Gabriel near Schull, County Cork (Gallagher and O'Connor 1999). Over time, natural resources from Ireland such as silver, gold, iron, lead, zinc, barite, coal, and peat have supplied the materials processing and energy industries, both at home and overseas. In recent years, Ireland has played a major role in supplying lead and zinc for world markets. These deposits are primarily derived from mines located (Figure 27) at Tara (County Meath), Lisheen and Mogul (County Tipperary), and Galmoy (County Kilkenny). While resource extraction is an important driver in the national economy, mining industries cause significant environmental disturbance. Before strict legislation regarding resource extraction and associated waste management came into force in Ireland in the 1970s, many mining activities caused ecosystem devastation. Some of these sites continue, unabated, to impact neighbouring watersheds because of acid mine drainage (AMD). One notable case is that of abandoned copper mines at Avoca, County Wicklow, where adits discharge AMD directly into the Avoca River, which is classified as severely biologically impaired (Gray 1998). Historically, silver mining at Silvermines, County Tipperary, has resulted in acid discharges to the Yellow River; approximately 60% of the catchment is considered directly impacted (Aslibekian et al. 1999). Abandoned lead-zinc mine tailings at the monastic site of Glendalough, County Wicklow has resulted in moderately-acidic metal-laden runoff into the neighbouring lake. While some of this mine drainage has inadvertently been "treated" by the strategic position of a natural marsh (Beining and Otte 1996), neighbouring stockpiles of tailings remain unvegetated and thus are potential sources for metal contamination. The purpose of this paper is to present a synopsis of the major metal mining activities in Ireland, both historical and current, that have inherent mine water issues. Most of this information has already been documented in some form but has been previously disparate. It is hoped that this synopsis will aid continued rehabilitation strategies for treating abandoned mine discharges in Ireland.

Mining History of Ireland

Historically, copper mining at sites in Cork and Wicklow formed an important industry (Gallagher and O'Connor 1999). Coal mining at Arigna, County Roscommon, following initial mining for pyrite, contributed a major energy resource along with peat for Ireland and elsewhere. In later years, off shore gas harvesting on the southwest coast replaced these resources for fuel and energy supplies. More recently, most mining exploration has focussed on the carboniferous lead and zinc deposits in the Midlands region, in addition to the deposits of the Tara Mines. While current lead and zinc mining activities are constrained to operate within strict EU (and national) legislation, responsibility assumed for abandoned mine impacts is unclear. In these instances, mine water issues can be severe and their degree of impact(s) and rehabilitation strategies have only been

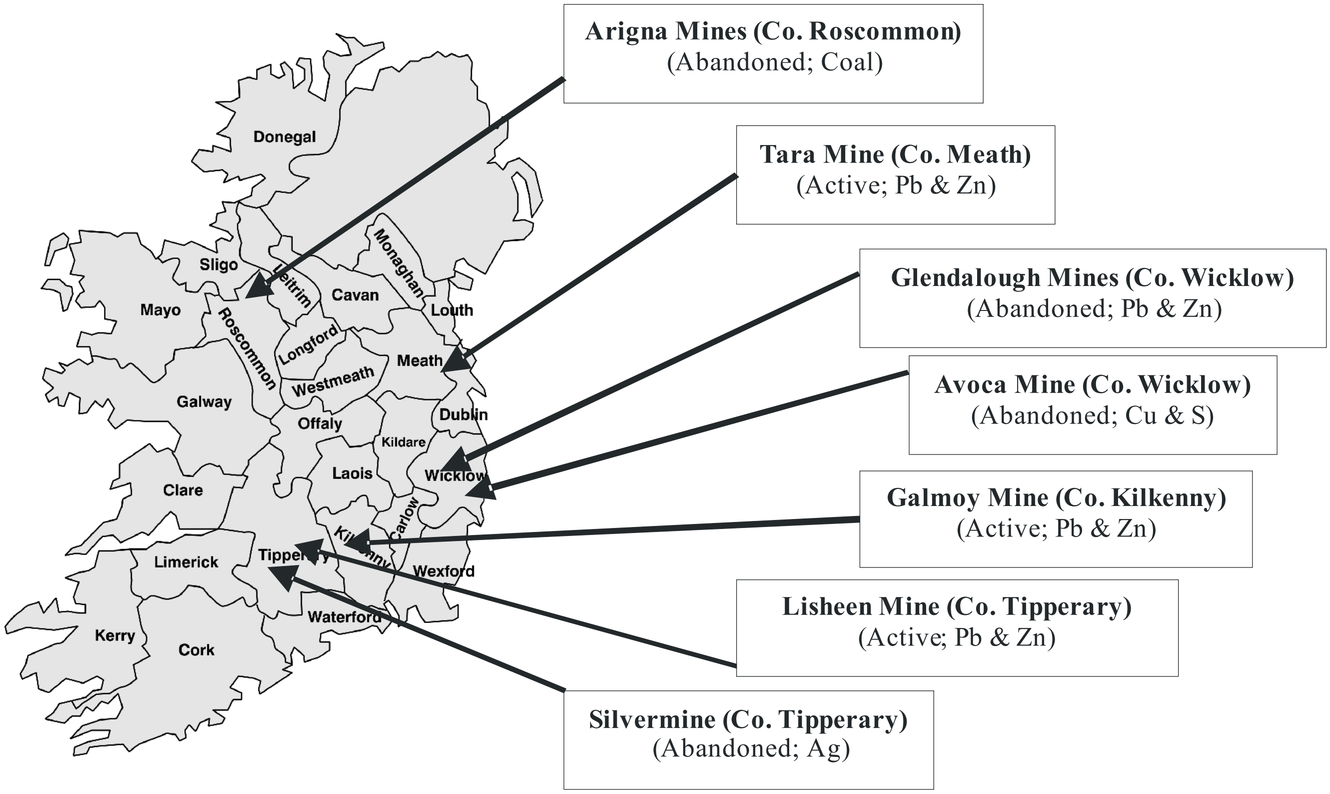

Figure 27. Map of Éire (Republic of Ireland) with counties; major mining activities are indicated

addressed relatively recently (Aslibekian et al. 1999; Beining and Otte 1996; Gray 1998). Table 17 summarises publications that have addressed mine wastewater in Ireland and provides accompanying citations where they can be examined in more detail.

The local geology of the mines in Ireland influences the associated mine wastewaters. For instance, the calcite and dolomites of the Lower Carboniferous period at Tara Mines buffer the spent water to alkaline levels (O'Leary 1996). By contrast, acidic waters emanating from the abandoned copper mines in Avoca are a consequence of the volcanic (granitic) rock formations (Bowell et al. 1999).

Table 17. Major reported wastewater issues resulting from metal mining activities in Ireland

Mine	County	Resource(s)	Wastewater Issue	Reference(s)
Avoca	Wicklow	Cu, Fe, S	AMD impacts and rehabilitation	Bowell et al. (1999)
				Gray (1998)
			Abandoned AMD impacts	Gallagher and O'Connor (1999)
			AMD Rehabilitation	Herr and Gray (1997)
			Metal contaminated soils	
Silvermine	Tipperary	Ag	Abandoned AMD sites	Aslibekian et al. (1999)
			Groundwater contamination	Aslibekian and Moles (2001)
			Mine rehabilitation	Rees et al. (2004)
Tara	Meath	Pb, Zn	Recycling of spent water	O'Leary (1996)
			Passive treatment technology	O'Sullivan et al. (1999)
Lisheen	Tipperary	Pb, Zn	Lined tailings facility	Dillon et al. (2004)
			Passive treatment technology	Treacy and Timpson (1999)
Glendalough	Wicklow	Pb, Zn	Abandoned metal runoff	Beining and Otte (1996)
Ballisodare	Sligo	Pb, Zn	Colonisation of estuary after mine tailings discharge	Tierney and Timpson (1999)
Gortdrum	Tipperary	Cu, Hg	Rehabilitation with topsoil	Dallas et al. (1999)

Future Developments

Most of the reported work addressing mine waters in Ireland is from university research (National University of Ireland at Dublin, Trinity College Dublin, University of Limerick, Sligo Institute of Technology and the University of Newcastle-Upon-Tyne in the UK). Rehabilitation of abandoned mining districts has been initiated with the assessment of Avoca, Gortdrum, and Silvermines. Continued funding is essential if sites such as these are to be adequately rehabilitated.

The successful rehabilitation of ecosystems impacted by abandoned mine drainage will also depend on applying sustainable treatment technologies, which can simulate natural processes to mitigate past activities. Passive treatment options developed and implemented overseas may serve as appropriate technologies in Ireland and are being piloted at Lisheen and in the Silvermines district. Most of these technologies have incorporated a reducing and/or oxidising strategy in their design depending on the waste being treated (Watzlaf et al. 2003). While passive treatment systems can offer many ancillary benefits, such as ecological niches, it is important to recognise that they have limitations; their space requirements may prove inhibitory. Before any passive technology is proposed, the mine waste itself must be reliably characterised and the chemistry (and biology) behind the treatment strategy clearly identified and understood.

Acknowledgements

I thank the Division of BioSciences at the National University of Ireland in Dublin (formerly UCD). David Painter (Canterbury) provided valuable feedback on the manuscript.

Received June 24, 2004; accepted May 20, 2005.

Belgium – Mining and Non-Ferrous Metal Processing Activities: Environmental Impact and Remediation Measures

Ludo Diels

Flemish Institute for Technological Research (VITO), Boeretang 200, B-2400 Mol, Belgium; e-mail: Ludo.diels@vito.be

Introduction

Belgium has no operating metal or coal mines anymore. The last coal mine was closed in 1992 and the only mining operations left in Belgium are extracting clay, sand, and gravel in Flanders, and quarrying limestone, dolomite, slates, porphyries, and marble in the Walloon area. Belgium is a world leader in silica sand and flours, and Belgian marble quarrying has a tradition of more than 2000 years.

The Walloon steel industry was already famous in the 16th century. Mining of calamine, a zinc silicate, started in 1805, and formed the basis of new developments in mineral processing (patents on calamine extraction and zinc refining date back to 1809). Coal mining, which started later, delivered the energy for steel production. In addition, due to the rich Cu-Co deposits in its former colony Congo, the country continued to be an important producer of non-ferrous metals and materials. The refining and processing of non-ferrous metals currently employs some 8,900 people; in addition, the production of steel (11.1 million t in 2003) and stainless steel (900,000 t in 2003) also continues to be an important component of Belgian industry (Franceschi 2004; Newman 2000; Rombouts 1999).

Former metal and coal mines still cause environmental problems and the environmental impact of the old steel and non-ferrous industry is also significant. Impacts are both source linked (e.g. waste heaps, landfills), or non-point and diffuse (including emissions to air and water, fugitive dust, and dissolved metals from the use of slags to improve road quality). The distribution of the metal mines and the diffuse pollution by the old steel and non-ferrous metals industry led to very large areas of impact. Cleaning of these sites is technically and economically unlikely so rehabilitative measures are based on risk management, i.e., the source – path – receptor approach.

Legislation

Environmental legislation depends on the three regional environmental authorities of Wallonia, Flanders, and Brussels. Generally, environmental policy is the responsibility of the Federal Ministry of the Environment of Brussels and its comparable Flemish and Walloon ministries. Besides this, the industrial companies are responsible for environmental protection of the area influenced by their activities. Consequently, these companies are also involved in environmental investment programmes (Newman 2000).

Besides the conventional legislation related to air and water pollution, the cleaning up of contaminated sites (including the soil and groundwater) in Flanders is regulated by the Soil Remediation Decree (1995). The operator or owner of the land is responsible for the remediation of contaminated sites where the pollution entered the soil, but only if the pollution was caused by carelessness and negligence or was committed knowingly and intentionally. In the case of pollution that occurred before the Soil Remediation Decree became operational, the operator or owner is only responsible for the remediation if the contamination represents a risk to the health of people or the ecology, or has the potential to affect larger areas. In Brussels, the recently enacted Ordonnance sol à Bruxelles (RBC/05/2005) is based on risk assessment. This risk assessment can lead to a remediation plan based on control and risk management of the pollution and in some cases remediation measures. In Wallonia, the soil decree, 'Décret relatif à l'assainissement des sols pollués et aux sites d'activités économiques à réhabiliter (MB 07/06/2004),' will soon apply. It requires a preliminary site evaluation, followed by a more detailed assessment, if justified. This can finally lead to a full remediation plan, if the source represents a risk to the health of people or the ecology, or has the potential to affect larger areas.

Metal and Coal Mining

Lead and zinc mining took place in south-eastern Belgium. At the moment, we only know the location of about 3000 of the estimated 8500 mine shafts. Most of these mines were rather small, no large problems have been identified, and risks are thought to be generally limited. In most cases, the groundwater flows through limestone aquifers, which leads to immediate neutralisation and precipitation of dissolved metals. However, waste rock has been used to make road foundations and other applications, leading, in many cases, to an uncontrolled dispersion of metal contaminants. At some sites, these problems have been recognized, and waste heaps have been removed in a controlled way (e.g. some wastes of the La Plombière site were removed and landfilled).

However, coal mining was performed at rather large scales. The risks related to these mines (e.g. subsidence, movement of waste heaps, burning waste heaps, contaminated drinking water) are significant. Also, randomly located waste and large waste heaps cause environmental problems due to the leaching of metal chloride and sulphate salts and organic contaminants. Risk management measures are based on removal of contaminated soil and abatement of further leaching and erosion by isolating the waste from contact with rainwater and by revegetation of the heaps (pers. comm., B. Hendrickx). In the Kempen area, the heaps have been remodelled (shallowing of the steeper slopes) and superficially compacted by heavy trucks, decreasing both the amount of rainwater infiltration and runoff.

Non-ferrous Metals Industry

Two large regions are affected by the metal processing industry, the Kempen area in Flanders and the Liège - Charleroi area in Wallonia. The dispersion of pollutants has been caused by:

- emissions by the old thermal processes (diffuse soil contamination);
- landfill (e.g. containing goethite, slags, sludge) leaching;
- use of lead and zinc slags to stabilise roads (even to fill bomb craters);
- use of contaminated compost to improve the organic content of garden and agricultural soil;
- irrigation with contaminated surface water; and
- contaminated sediment deposited on river banks

There has been widespread pollution of soil and some infiltration of metals (especially Cd and Zn) into groundwater. Landfill leakage has also led to significant contamination of certain groundwater aquifers. In Flanders, the aquifer is a very deep sandy aquifer. Two famous epidemiological studies were performed in Flanders for 1980 – 1990, on the impact of cadmium on human health (Cadmibel and Pheecard). Current efforts are focusing on exposure routes and their relative contributions of Cd and Zn to humans. It is anticipated that:

- Cultivation of food crops will be forbidden, or limited to certain crops (with restricted metal uptake characteristics). Soils can also be treated by mixing with certain additives (e.g. based on silicates, organics, zeolites, iron shots, hydroxyapatite, lime) in order to immobilize the toxic metals and to reduce plant uptake and infiltration to the groundwater by rainwater. Large agricultural areas will have to change from food crops to industrial use.
- Use of contaminated groundwater will be forbidden.
- Large, highly contaminated areas (so called zinc deserts) are being cultivated with special Zn-

resistant grasses and soil additives; the plant cover should prevent the dispersion of metal-laden dust.

- Groundwater contamination will be reduced by removal of slags from roads. The inventory of the roads contaminated with metal slags has started.
- Contaminated sediments will need to be dredged and removed to a controlled landfill.

As the problem affects both sides of the Belgium-Holland border, the Flemish and the Dutch Ministries of Environment are cooperating, within the framework of an INTERREG III project, to make a complete inventory of the problems, to assess the related risks, and to come up with an integrated management system to manage this large risk management zone (a megasite of > 300 km²).

In Wallonia, the aquifer is sandy clay, limestone, and gravel and most of the industries are located very near to the Meuse River. The areas affected by diffuse spreading of metals (Zn and Cd) in Wallonia (originating from the non-ferrous industry) are thought to be more restricted in area. Groundwater is known to be affected near some non-ferrous industries in the alluvial zones of the Meuse and Vesdre Rivers due to the historical regular dumping of Zn- and Cd-rich slags. Other areas may also be contaminated, but the precise extent of the affected zones has not been investigated yet; preliminary studies are going on to identify the intensity of the problem and related risks. In a general way, the higher pH and loamy textures (compared to the affected zones in the Kempen region in Flanders) could prevent the contamination from infiltrating deep into the soil (Scokart and Meeus-Verdinne 1985), but the possible effects of diffuse Cd and Zn sources on groundwater quality is not known yet.

Groundwater contamination at the industrial sites will be controlled by pump and treat technology; in some cases, the effluent from this treatment will be used as industrial process water. In addition, several tests are underway on a new process of *in situ* immobilization of the metals in the groundwater aquifer, based on injecting electron donors (e.g. molasses, lactate, HRC®, MRC®) via wells to induce sulphate reducing bacteria (SRBs). Under appropriate conditions (pH between 4 and 8 and Eh lower than –200 mV), the SRBs will use the electron donors to oxidize the organics, reduce the sulphates to form sulphide, which will precipitate the metals as insoluble metal sulphides. This method has been shown to work in sand and clay aquifers and is now being tested on the clay-sand-gravel aquifers of Wallonia. Special focus is now on optimization of this method by selecting the right electron donor, injection conditions, and controlling the stability of the precipitates (Diels et al. 2002; Geets et al. 2003; Van Roy et al. 2004).

In addition, special attention is being paid to the influence of contaminated soil on surface water contamination (transport via groundwater), within the framework of the European Project AQUATERRA (505428). In this project, several groups are examining the fate of heavy metal soil contamination on surface water quality. Special attention is paid to the natural processes of transport and immobilization (retardation) of metals on their way to the surface water by looking at the influence of plants, groundwater, the interface between groundwater and surface water, and sediments.

Conclusions

Belgium has no real metal or coal mining activities anymore and the impact on the environment is rather restricted. However, the steel and non-ferrous metals industrial activities from the past still heavily affect the environment. Several risk-based measures are under study and implementation. It is anticipated that natural processes, combined with some of the remediation measures being undertaken, will lead to a reduced future exposure of the receptor (e.g. humans or surface water). All these measures are being taken within the framework of the European Integrated Management System in the framework of the Welcome project (EVK1-CT-2001-00103).

Received April 13, 2005; revised manuscript received May 18, 2005; accepted May 19, 2005.

Mine Water Issues in the Czech Republic

Arnošt Grmela and Nada Rapantova

VŠB – Technical Univ of Ostrava, Faculty of Mining and Geology, Str 17. listopadu 15, CZ-70833 Ostrava-Poruba, Czech Republic; corresponding authors e-mail: arnost.grmela@vsb.cz

Historical Introduction

From the early Middle Ages, the Czech lands have played an important role in the development of mining sciences worldwide. Deposits of gold, silver, copper, tin, tungsten, and other metals in localities such as Kutná Hora, Příbram, and Jáchymov are particularly known. In Jihlava, two of the world's first mining laws, *Jura Seu Statuta Illaviae Civitatis* and *Ius Regale Montanorum*, were issued in 1249 and 1250, respectively. The Saxonian author, Georgius Agricola (1494–1555), wrote *De Re Metallica Libri XII* in Jáchymov. That is also where the uranium ore samples used by Marie Skłodowka-Curie (1867–1934), in her research on radioactivity, originated. In the year 1875, a depth of 1000 m (i.e. the greatest depth worldwide at the time) was achieved in the Vojtěch Mine. The Annenská Shaft (1455 m) was the deepest ore mine in Europe in the year 1940; Jindřich Shaft II (1453 m) at Zbýšov u Brna was the deepest coal shaft in Central Europe. In the 17th century, the Czech lands became a significant producer of hard and brown coal; after understanding the importance of radioactive raw materials, they also became a significant European mining locality for these ores. Nowadays, all of the ore mines in the Czech Republic are closed, and this year the last underground uranium mine is to be shut down. Coal mining is also being reduced; underground coal mining only proceeds in a small part of the Upper Silesian Coal Basin and open pit mining only continues in two brown coal basins in the Podkrušnohoří area in West Bohemia. In addition to these raw materials, non-metallic raw materials, such as kaolin, perlite, raw materials for cement, brick and glass making, and aggregate is still mined in the Czech Republic.

There are hundreds of old underground metallic and non-metallic mines in the Czech Republic that are

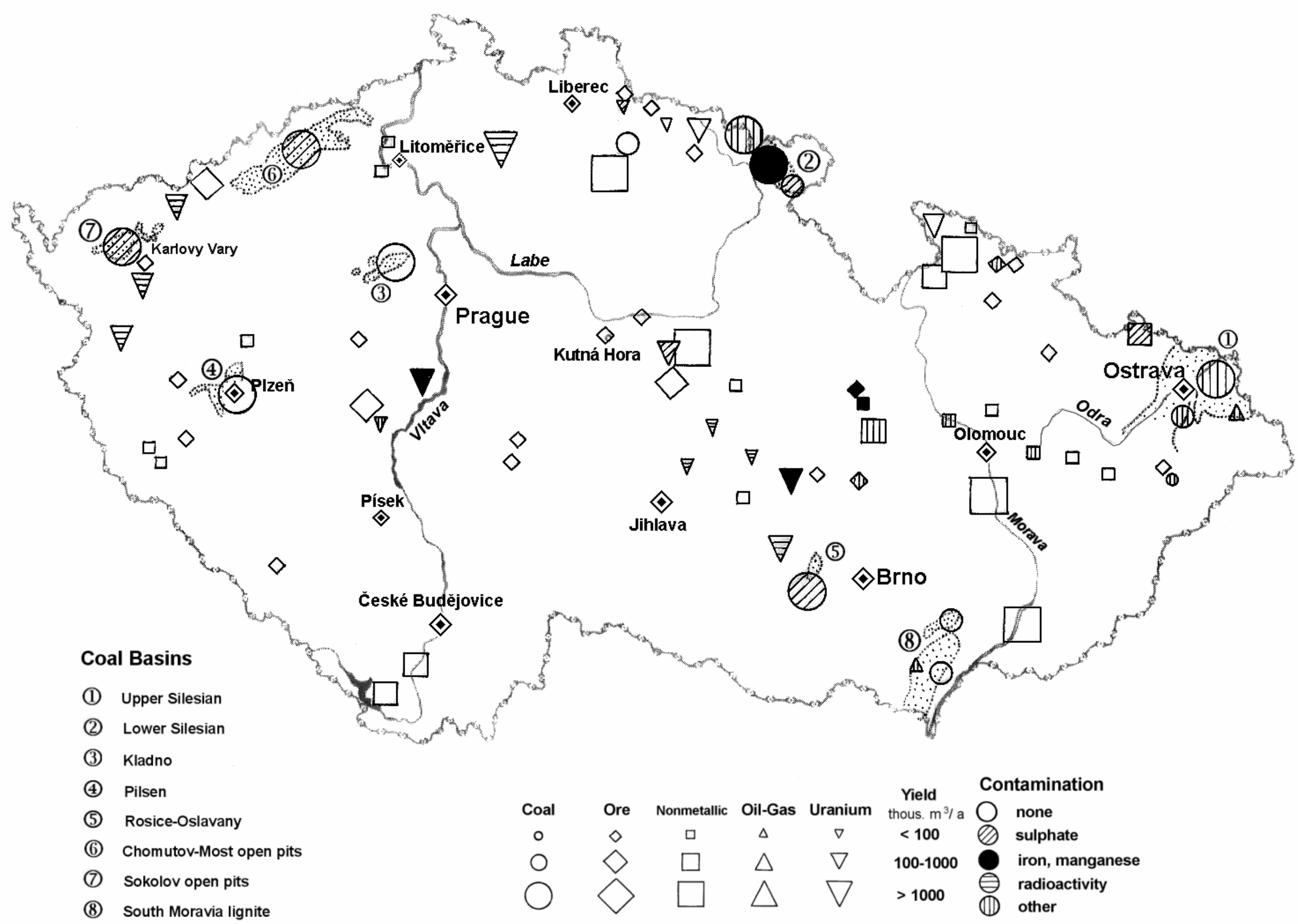

Figure 28. Mine water sources in the Czech Republic (revised from Grmela 1998)

Table 18. Legislative limits for mine water discharges (Explanatory notes: PAH – polyaromatic hydrocarbons, TDS – total dissolved solids, TPH – total petroleum hydrocarbons, Undiss. solids – undissolved solids).

Exploitation from deposit	Surface stream quality: Exception for mine water discharges	Surface stream quality: Limiting value according to 61/2003 S.B.
Coal exploitation		
pH	6 – 9	6 – 8
Undiss. solids	40 mg/L	25 mg/L
PAH	0.01 mg/L	0.0002 mg/L
Iron	3 mg/L	2.0 mg/L
Manganese	1 mg/L	0.5 mg/L
Uranium exploitation		
pH	6 – 9	6 – 8
Undiss. solids	30 mg/L	25 mg/L
Ore deposits exploitation		
pH	6 – 9	6 – 8
TDS	40 mg/L	25 mg/L
TPH	3 mg/L	0.1 mg/L
Iron	5 mg/L	2.0 mg/L
Zinc	3 mg/L	0.2 mg/L
Lead	0.05 mg/L	0.015 mg/L
Copper	1 mg/L	0.03 mg/L
Arsenic	0.5 mg/L	0.02 mg/L
Aggregate exploitation		
Undiss. solids	40 mg/L	25 mg/L

sources of mine water. Oil and gas exploitation in South Moravia is also associated with the production of mine water.

Mine Water Legislation

Legislation dealing with mine water is not uniform in the European states, which often results in non-uniform economic procedures for mine water disposal. In the Czech Republic, the Water Act No. 254/2001 Coll. classifies mine water as "special water," which is excluded from the direct effect of the Act. According to Mining Act No. 44/1988 Coll. (Section 40), the term mine water is defined as: "... all ground, surface and precipitated waters that penetrated into underground and surface mine spaces, until they are mixed with other permanent surface and ground waters". The Czech Mining Office draws the conclusion that: "… if mining activity was completed, the mining claim was cancelled, the licence for the mining company to mine was abolished … worked-out spaces cannot be taken as underground/surface mine spaces any longer, and thus any water penetrating into these spaces cannot be considered as mine water either." Mine water in the Czech Republic can be discharged into surface watercourses by permission of the water management authorities based on limited quality and quantity parameters. However, in Decree No. 61/2003 Coll., the Government of the Czech Republic imposed water quality requirements for watercourses; this imposes limits on the quality of discharged mine water by monitoring water quality in the river, after mixing has occurred. However, mine water affected streams are allowed more latitude than those affected by other sources of contamination (Table 18). Mine water cannot be legally discharged into groundwater in the Czech Republic (Grmela and Rapantová 2004).

Mine Water Management

Hydrologically, the Czech Republic affects several of Europe's watersheds, so that mine water discharged into surface watercourses affects the quality of international streams; management of mine water disposal can therefore be complicated. Mine water production for the characteristic years 1975, 1998, and 2004 is given in Table 19.

In Table 19, the effects of phasing out of mining is evident, as is the effect of legislating the exclusion of discharged groundwater from mines if the mining claim of the old mine is cancelled administratively.

Mine water sources (in a broader sense than given by the legislative definition presented above) are

Table 19. Production of mine water in the Czech Republic (in thousands of m³ annually; Grmela 1999 updated).

Production of mine water		Labe watershed	Odra watershed	Morava watershed	Total
Total Czech Republic 1975		122,000	31,000	5,000	158,000
1998	Non-metallic deposits	5,652	953	6,390	12,995
1998	Radioactive materials	19,219	185	1,906	21,310
1998	Crude oil	–	–	83	83
1998	Ores	1,740	2,838	19	4,597
1998	Coal-underground exploitation	20,739	16,849	1,932	39,520
1998	Coal-open-pit exploitation	17,750	–	–	17,750
Total Czech Republic 1998		65,100	20,825	10,330	96,255
Total Czech Republic 2004		45,024	8,891	8,379	62,294

illustrated by deposit type, yield and contamination in the map of the Czech Republic in Figure 28.

Mine Water Issues in the Czech Republic

The greatest problems associated with water related to mining in the Czech Republic are:

- The disposal of mine water from the hard coal deposit of the Upper Silesian Coal Basin (Odra watershed – pollutants: Na+, Cl-, SO_4^{2-}) and the brown coal deposits of West Bohemia (Labe watershed – pollutants: SO_4^{2-}).
- The disposal of acid solutions from chemical uranium mining by leaching in North Bohemia (Labe watershed – pollutants: U, Ra, SO_4^{2-}, and a low pH). In situ leach uranium mining was operated from 1967–1990. Uranium was extracted from Cenomanian sandstones at a depth of more than 200 m via about 9300 surface boreholes in an area of 6.3 km² at Stráž pod Ralskem. Leaching agents were H2SO4 (used $3.7 \cdot 10^6$ t), H_2NO_3 ($0.27 \cdot 10^6$ t), HCl ($0.025 \cdot 10^6$ t t), and NH_3 ($0.1 \cdot 10^6$ t t). Used acid leaching solutions is still being pumped and discharged from these mines.
- The disposal of excess water from tailing ponds and the disposal of water from water treatment plants of former ore mines (Labe watershed – pollutants: heavy metals, U, Ra, SO_4^{2-}).
- The remediation of environmental loads of old ore mining. In the Labe watershed in the Czech Republic, 3011 old environmental loads of ore (including uranium) mining have been recorded, of which in 230 cases (8%), the water outflows from old mine workings to the surface.
- In 135 cases (59%), the water downstream of these sites meets the appropriate water quality standards; in the remaining 95 (cases, the water is polluted by inorganic pollutants (Figure 29).
- The disposal of water accompanying oil reservoirs in South Moravia (Danube watershed – pollutants: total petroleum hydrocarbons).

Mine Water Issues Connected with Mine Closure

Recently, the underground uranium mines in the Czech Republic have been intentionally flooded (the last uranium mine in the deposit of Rožná will be closed in this way; the commencement of closure operations is expected in 2006). After underground mining was completed, the mines were left to be flooded naturally with controlled discharging of the mine water that exceeds a prescribed water level in the mine. This water level was determined for each deposit based on surrounding terrain morphology to avoid uncontrollable releases of polluted mine water.

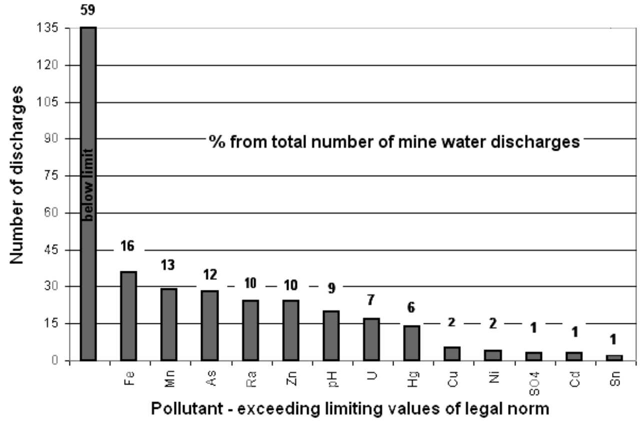

Figure 29. Discharges of gauged waters from abandoned ore mines (including uranium) in the Czech Republic – Labe watershed

Stratified mine water in the lowest levels can be a potential source of uranium in the future.

Two methods of coal mine closure were applied in the Czech Republic. Most abandoned coal mines were simply flooded. Monitoring of mine water discharges has shown growing problems associated with contamination by iron (in addition to other pollutants, such as sulphates). In the case of the former J. Šverma Mine at Žacléř, closure was performed by filling the mine workings with a self-solidifying ash mixture with an admixture of secondary raw materials in the quasi-closed hydrogeological structure of the mine. Long-term monitoring has proven that, in this case, environmental load limits have not been exceeded (Rapantová and Grmela 2002). In the Upper Silesian Coal Basin, the closure of the Ostrava part of the coalfield is complicated by continuing mining operations in the Karviná Basin, which means that the level of flooded mine workings must be kept below the level of these mining operations (Grmela and Rapantová 2002)

Conclusion

As mining activity in the Czech Republic has diminished, mine water production will be decreasing along with problems of their disposal. Furthermore, mine water discharges (quantity and quality) will be stabilised and a decreasing trend in environmental load can be presumed. Even at present, it is evident that the quality of surface streams leaving the territory of the Czech Republic is much better than it was 15 years ago. Nevertheless, mine water issues remain one of the country's primary environmental concerns.

Received March 23, 2005; revised manuscript received May 10, 2005; accepted May 17, 2005.

Switzerland

Hans-Rudolf Pfeifer and Bernhard Dold

Univ de Lausanne, Faculté de Géosciences et de l'Environnement, IMG-Centre d'Analyse Minérale, BFSH 2, CH-1015 Lausanne, Switzerland; corresponding author's e-mail: Hans-Rudolf.Pfeifer@unil.ch

Introduction

There are about 200 small ore deposits in the Swiss Alps and the Jura mountains (Figure 30, based on data of Kündig et al. 1998), most of which were mined, mostly underground, from the middle ages to 1945 (end of World War II). The last two iron mines (Gonzen and Herznach) closed around 1965 for economic reasons. A few small brown coal mines were situated in Tertiary Molasse or Quaternary gravel beds and closed down as well in 1945. Recently, the Swiss Geotechnical Commission, financed by the Swiss Academy of Science, has compiled a comprehensive data bank on Swiss ore deposits and has started to publish condensed versions on various regions (Kündig et al. 1998, Cavalli et al. 1998; Kündig et al. 1990). Between 1956 and 1984, a comprehensive survey was carried out for U, with the hope of finding enough raw material to secure Swiss needs (Gilliéron 1988). From 1980 to 1989, within the frame of a National Research project, which had the aim of inventorying natural resources, a large scale geochemical prospecting campaign was carried out in the Wallis and Graubünden areas, looking especially for W and Au (Della Valle 1991; Della Valle and Haldemann 1991; Woodtli et al. 1985, 1987). During this project, about 6,000 river sediments and soil samples were analyzed for Mo, Pb, Zn, W, Cu, Ni, Cr, Co, Ag, Th, Bi, U, As, Sb, S, Ba, Sn, and Au, but no water samples.

Environmental Data on Tailings and Mine Waters from Switzerland

The first environmental assessments of former Swiss mining activities were made starting in 1992 (Bondietti et al. 1994; Pfeifer et al. 1994, 1997; Pfeifer et al. 1999a,b). The discovery of elevated concentrations of As in surface and ground waters resulted in a new assessment of several former gold mines and their contribution to arsenic contamination (Greppin 1997; Häussermann 2000; Pfeifer et al. 2000, 2002, 2004).

The relevant environmental data is summarized in Table 20. In most cases, contamination is restricted to the immediate surroundings of the former mining site (typically, no more than 200 m away) and usually small waste rock repositories. Whereas the composition of the waste material and adjacent soils is relatively well known, there is a paucity of data on metal contents in waters and plants. The mine waters are rarely very acid (the lowest pH values measured were 3.1 [Meisser 2003], but most are between 5 and 6). In the case of U and As, the ore deposits are at the origin of an important natural dispersion extending from the headwater areas of the watersheds down to the Mediterranean, and are responsible for elevated metal concentrations in some drinking waters. In western Switzerland, dissolved and particulate U flows through the Rhone catchment, with up to 15 t

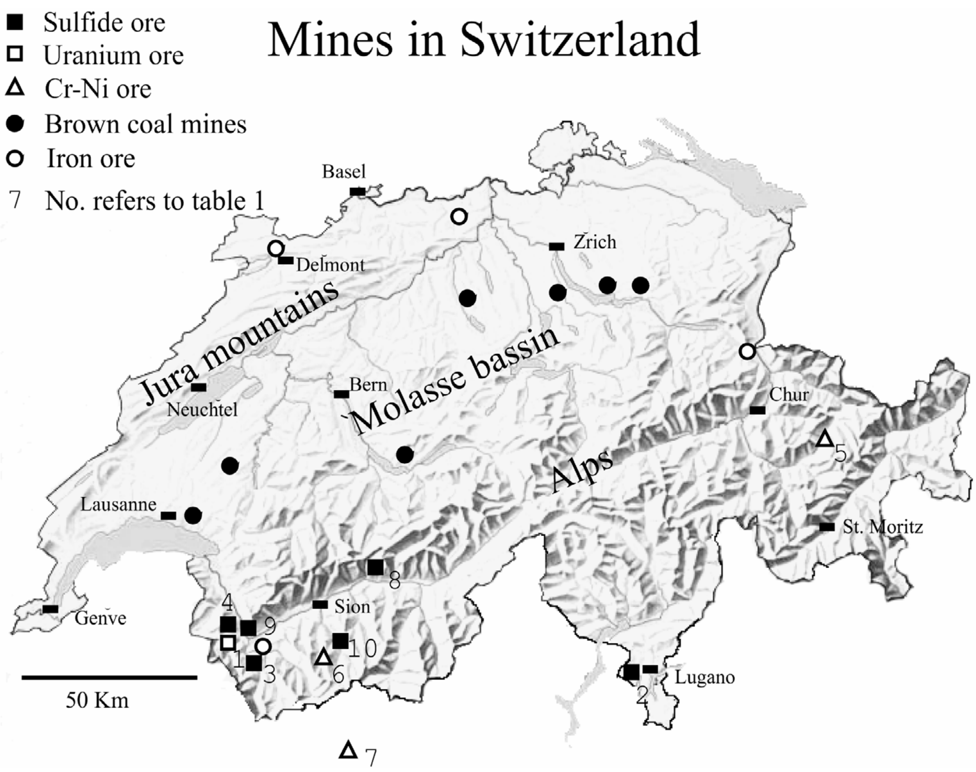

Figure 30. Selected mines in Switzerland; numbers refer to the mines mentioned in Table 20

Table 20. Overview of the available environmental studies of mining related contamination in Switzerland

Metal and locality	Environmental data available	References
U La Creusaz-Les Marécottes /VS [1]	soil (dump zone): 10–2000 ppm (3 ppm) vegetation: 51 ppm (6 ppm) water: 21 µg/L (0.5µg/L)	Dominik et al. 1992; Pfeifer et al. 1994, 2000
As Astano-Costa/TI [2]	soil (dump zone): 0.2–10% (20–100 ppm) vegetation (birch leaves): 2–10 ppm (< 0.1 ppm) water: 5–200 µg/L (<1 µg/L)	Bondietti et al. 1994; Pfeifer et al. 2000
As La Payanne-Bagnes /VS [3]	soil (natural downhill creep): 20–1250 ppm (0 ppm) water: 2–4 µg/L (<1 µg/L)	Greppin 1997
As Salanfe-Finhaut/VS [4]	soil: 10–8,400 ppm (< 3 ppm) water in mine: 750–4,000 µg/L water in local ponds: 7–750 µg/lL	Häussermann 2000
Ni Davos [5]; Val d'Hérens [6], Baldissero/It [7]	soil: 2,000–25,000 ppm (30 ppm) vegetation (birch leaves): 4.7 ppm (3,000 ppm) spring water: pH 8.5–10, 5–17µg/L (< 3 µg/L)	Juchler 1988; Pfeifer et al. 2000; Scheder and Streiff 1997
Cr Davos [5]; Val d'Hérens [6], Baldissero/It [7]	soil: 1,300–1,800 ppm (40 ppm) vegetation (birch leaves): 2.1 ppm (1.6 ppm) spring water: pH 8.5–10, 1.3–10 µg/L (< 2µg/L)	Juchler 1988; Pfeifer et al. 2000; Scheder and Streiff 1997
Pb Astano-Costa/TI [2]	soil (dump zone): 0.1–1.7% (20 ppm) vegetation (birch leaves): 1–1.6 % (0.6%) water: 0.2–9 µg/L (0.1 µg/L)	Bondietti et al. 1994; Pfeifer et al. 2000
Pb Goppenstein/VS [8]	soil (dump zone) : no data soil naturally enriched: 200–5,000 ppm (50 ppm) vegetation: no data water: no data	Woodtli et al. 1985
Pb Alesse/VS [9]	soil (dump zone): 0.05–12% soil naturally enriched: 1,000–9,000 ppm (50 ppm) vegetation: 52 ppm (*Taraxum off.*) water: 11–22 µg/L (0.1 µg/L)	Kufrin 2001
Zn Astano-Costa/TI [2]	soil (dump zone): 200–4,000 ppm (70 ppm) vegetation (birch leaves): 10–16 ppm (6 ppm) water: 20–170 µg/L (8 µg/L)	Bondietti et al. 1994; Pfeifer et al. 2000
Zn Goppenstein/VS [8]	soil (dump zone): no data soil naturally enriched: 800–2,100 ppm (300 ppm) vegetation: no data water: no data	Woodtli et al. 1985
Cu Baicolliou-Tsirouc-Biolec- Anniers/VS [10]	soil naturally enriched: 75–4,000 ppm (30 ppm) vegetation: no data water: no data	Woodtli et al. 1985

Locality number [column 1] refers to Figure 30. Legend for the cited concentrations in parentheses: 1 (…ppm): uncontaminated local reference value, 2 (…µg/L): local uncontaminated water.

of U entering Geneva lake every year (Dominik et al.1992; Pfeifer et al. 1994, 2000). In southern Switzerland and adjacent areas in northern Italy, the presence of till and river sediments stemming from the well known Permian sulfide veins in the basement of the Southern Alps is at the origin of elevated As-concentrations in surface and ground waters, which in many cases exceed legal thresholds for drinking water (Camusso et al. 2002; Pfeifer and Rey 1998, Pfeifer et al. 2000, 2002, 2004).

Mine Water Related Initiatives

The Mine-Water Interdisciplinary Network Europe (M-WINE) was initiated by a European workshop (70 participants) in May 2002 at the University of Lausanne to bring together European scientists to improve the knowledge and exchange experiences on mining related contamination. The second one (60 participants) was organized in June–July 2003 in Lisbon by the Geological Survey of Portugal (IGM). The 3rd meeting took place in August 20th 2004 in Florence (Italy) during the 32nd International Geological Congress (IGC). The network groups currently include about 250 European researchers.

Received May 18, 2004; revised manuscript received May 15, 2005; accepted May 17, 2005.

Bosnia and Herzegovina

Sanda Midžić and Irem Silajdžić

Hydro-Engineering Institute Sarajevo, Stjepana Tomića 1, BIH-33000 Sarajevo, corresponding author's e-mail: smidzic@utic.net.ba

This section is based on the European Union's R&D ERMITE project (Kupusović et al. 2001).

Historical Background

In 1844, an expedition of French geologists visited Bosnia and Herzegovina, which at that time was a European component of the Ottoman Empire. With their work and geological maps, they located various mineral deposits. The area is richly endowed with natural resources, including extensive and varied mineralization, some of which can generate acid rock drainage (ARD), causing contamination of nearby vegetation, soil and water.

There are 110 sites where coal is deposited in the territory of Bosnia and Herzegovina. Bauxite mines are located at four different locations: in the Herzegovina region, in the North-Bosanska Krajina region, in the Central-Jajce-Banja Luka region, and in eastern Bosnia-Milići-Zvornik. In northeast Bosnia, from Srebrenica to Maglaj, Zavidovici, and Teslić, there are breakthroughs of tertiary igneous rocks that

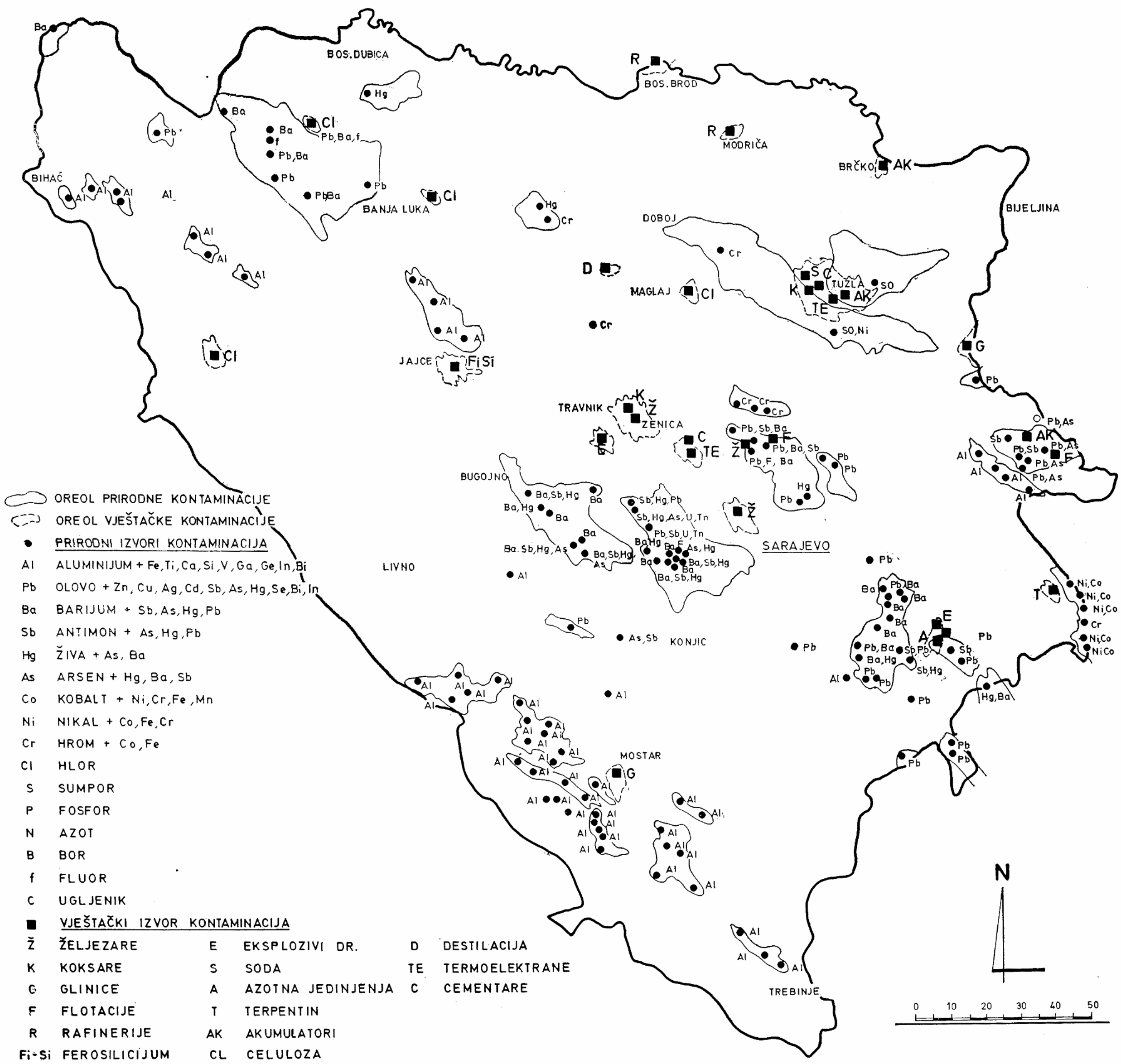

Figure 31. Areas of natural or industrial contamination in Bosnia and Herzegovina (after Kubat 1987)

are associated with occurrences of Zn, Pb, Sb, Ag Bi, As, Fe, and other minerals. This area, rich with iron ore, zinc, sulphide minerals, and non-metal minerals has attracted geologists for many years. Iron ore production was concentrated in Jablanica and Vares, while production of manganese ore took place in Bosanska Krupa. The Vares iron ore mine in central Bosnia is one of the oldest mines in Bosnia and Herzegovina, and dates back to at least 1692. Among the non-metal mines, the largest and most important for the Bosnia and Herzegovina economy are salt deposits, which are located in the Tuzla region.

Although most of the mining areas are associated with sulphide minerals that have the potential to generate ARD, little attention has been given to contaminated or acidic mine water in Bosnia and Herzegovina. The environmental aspects of mine water have been neglected relative to the attention paid to mine safety.

Overview of Currently Working Mines

A poor post-war economy and the complex political situation in the Balkan region have affected the mining industry in Bosnia and Herzegovina, causing it to operate at minimal capacity. Mines in Bosnia and Herzegovina cannot expect to be competitive on the foreign markets due to outdated technology and an inadequate transportation infrastructure. At present, and for the near future, ore utilization will be dependent on the domestic market.

Generation of electrical energy in thermal power plants consumes about 80% of the coal produced and thus drives the industry. Mining is needed to support the state energy system, and therefore the state itself, but the state invests little in the development of the mining sector.

Nearly all metal mines (e.g. iron, copper, lead, zinc, silver) have been closed, but the majority of industrial-mineral mines (e.g. sand, gravel, stone, calcium carbonate, slate, clays, gypsum, salt, barite, shale) are still active. Only the Srebrenica lead and zinc mine and Posušje and Milići bauxite mines remain in production, and they are being operated at approximately 10% of their capacities. None of the closed sites have been rehabilitated. Some of the abandoned bauxite sites are now used as uncontrolled landfill sites for disposal of communal wastes. A naturally formed lake at the Vares abandoned open pit iron mine is now used for fish farming and recreational purposes. It is the same with the abandoned bauxite mine at Mrkonjic.

Figure 32. The Srebrenica Spring, Veliki Guber, and the Kisjelica River (Midžić 2002)

Mine Water Management and Problems

Environmental problems related to active and abandoned mines and their mine waters are serious threats to the aquatic environment and require special attention. Figure 31 indicates areas of natural (acid rock drainage) and industrial (e.g. heavy metal factories, thermal-power plants, mineral processing) contamination in Bosnia and Herzegovina contaminated with lead, mercury, arsenic, antimony, barium, aluminium, and compounds such as sulphuric acid.

The following areas of sulphide mineralization are associated with ARD:

- Mrkonjić Grad – Jajce-Prozor – Konjic: Fe, Mn, Ba, Cu, As, Hg
- V. Kladuša – Sanski Most: Mn-Pb, Ba
- Borovica-Vareš – Čevljanovići – Srednje: Pb, Zn, Ba, Cu, Au, Ag, Hg

- Olovo – Kaljina – Podromanija: Pb, Mn
- Jugoistična Bosna (Foča-Prača): Sb, Cu, Pb, Zn, Ba, Mn
- Šekovići – Drinjača – Kravica: Fe, Mn, Cu, Pb
- Srebrenica: Pb, Zn, Cu, Ag, Au, Sn, V, Bi, In, Hg, Sb, Mn

One of the most interesting is the Srebrenica lead and zinc mine, which is located in permeable porous media; part of the deposit lies above and part below the piezometric ground water level. In an area of 100 km^2, there are 120 mineral springs, of which 50 are highly mineralised (Fig. 32). Most of these springs are near old mine shafts. The high precipitation, high porosity of the watershed, and number of old mine shafts that accumulate precipitation constantly recharge the capacity of these mineral springs.

Unfortunately, few studies have been done to assess the impact of the mining industry on water resources in Bosnia and Herzegovina. Due to this lack of systematic monitoring of mine water quality and quantity, the exact type and degree of mine water pollution is unknown. There has been very little research on the effect of mine drainage on the environment or potential pollution abatement measures.

The nation's legal framework mainly addresses wastewaters generated during ore beneficiation, including leachate from tailings (Midžić 2001). There are no laws, strategies, or activities addressing the environmental problems of abandoned mine sites. In very few cases, legal obligations related to land recultivation are being implemented. There are no other legal obligations on the mining companies concerning mine water pollution control or decontamination of closed mine sites, and no institution responsible for control of the environmental impact of abandoned mines. The dispersion of responsibilities in the field of water and environment in different ministries and sectors is an additional problem when attempting to address issues of mine waters and their impact on the environment.

Future Mining, Treatment or Remediation Activities

Current market conditions only favour coal extraction for thermal power plants. Since private investors have not shown interest in metal mining, it is evident that the state, as the owner of the abandoned mines, should take care of mine water pollution control and treatment.

Scientists and experts in Bosnia and Herzegovina have been developing an increased environmental awareness and a regulatory framework. Research has primarily been focused on treatment of mineral processing waste waters. There is a significant lack of expertise on prevention and minimization of mine water impacts and therefore, the scientific community, government, and civil society must be trained. There is a need to establish a regional scientific network to intensify R&D activities, including organization of regional conferences, workshops and training, and publishing activities. There is also a need for transfer of expertise through joint environmental projects. Finally, in order to address these needs over the long term, new environmentally-oriented curricula must be taught in the high schools and universities. Bosnia and Herzegovina cannot do this on its own; the support of worldwide education institutions will be needed.

Received April 4, 2004; revised manuscript received Feb 9, 2005; accepted Feb 27, 2005.

Portugal

Marina M. S. Cabral Pinto and Maria Manuela Vinha G. Silva

Dept of Earth Sciences, University of Coimbra, Largo Marquês de Pombal, PL-300-272 Coimbra, Portugal; corresponding author's e-mail: marinacp@ci.uc.pt

Overview of Mining in Portugal

In Portugal, there is evidence of mining from pre-Roman times, especially for Cu-Au-Ag and Fe-Cu-Sn. The Roman epoch exploited mainly Au in the north of the country, and Cu, Au, and Ag in the Iberian sulphide province. But most mining occured in the 20th century, exploiting deposits of Fe and Mn, Sn and W, radioactive ores for Ra and U, as well as deposits of Ag and Au (Nero 2004a). In addition, in the Iberian sulphide province, deposits of Cu and Sn, Cu, Zn and Pb, and pyrite for S were mined. Nowadays, only two metal ore mines are active: Neves-Corvo (Cu, Sn) and Panasqueira (W, Sn). Both have been developed following the enactment of environmental regulation, and are subject to environmental controls, monitoring requirements, closure procedures, and remediation requirements

(Rodrigues 1998; Sá 1994). Neves Corvo anticipates activity till 2029, with exploitation of Zn beginning in 2006 as its Sn reserve has diminished.

Abandoned/Inactive Mines and their Environmental Impact

Despite the fact that Portugal is a country with a remarkable mining history, not until the previous decade did the Portuguese become aware that the exercise of this activity has brought about significant environmental consequences. In the past, the concerns about the impacts focused on those which affected productivity, such as the stability of the excavations and of the waste dump, and only on the mine's life time.

Portugal has about 175 old abandoned mine sites, some of which are seriously degraded and contaminated (Figure 33), and large volumes of old mining residues (Table 21), some of which have significant environmental impact. Of 85 abandoned mines (not including the uranium mines nor the most problematic ones), studied by Oliveira et al. (2002), 14% were found to generate acid mine drainage (AMD) and/or to pose a high degree of environmental risk.

Tailings and waste dumps can have a chemical and radiological impact on a local or regional scale. The fact that much of Portugal's mineralization is associated with sulphide minerals, along with in situ acid leaching of uranium, provides great potential for the production of AMD. Examples include polymetallic sulphides mines in the Iberian sulphide province (e.g. S. Domingos, Aljustrel, Caveira, Lousal), uranium mines (e.g. Urgeiriça, Cunha Baixa, Quinta Bispo, Vale de Abrutiga), W and/or Sn mines (e.g. Covas, Montesinho, Vale das Gatas, Tuela, Murços, etc), Au and/or Ag mines (e.g. Castromil, Jales, Penedono, Freixedo, Terramonte), and Cu mines (e.g. Miguel Vacas). The drainage of waste piles and fine grained tailings can be particularly problematic (e.g. Montesinho, Jales, Argoselo, Vale das Gatas, Terramonte, Adoria, Lousal, Caveira).

The main geochemical signatures with environmental importance are: W ores: As-Cu-Mo-Pb; Sn ores: As-Be-(Cu); W-Sn ores: As-Zn-Cd; Au-Ag ores: Pb-As-Zn-Cd-(Ag); Pb-Zn ores: Pb-Zn-Cd-(As)-(Ag); Fe ores: Fe-(P)-(V)-(Mn); coal: (As)-(Fe); sulphide ores: Cu-Pb-Zn-Fe-As-Sb; Mn ores: Mn-Ba-Fe; and U ores: U, ^{226}Ra, Cl, F, SO_4^{2-}, Ca, Mn, Fe (Oliveira et al. 1999).

In terms of environmental risk, the mines are ordered as follows: uranium, massive sulphides (Iberian sulphide province), tin and/or wolfram and/or gold (often accompanied by non-dominant sulphides), and coal (Costa and Leite 2000). Mines that had used chemical methods for ore treatment were more likely to have extensive (in terms of impact or duration) pollution problems (Oliveira et al. 1999; Costa and Leite 2000).

Portugal was particularly rich in uranium mines (Table 21). The U-mineralization was generally associated with sulphide minerals. Up to 2000, approximately 4370 t of U_3O_8 were produced, in addition to the production of radium salts, resulting in about $13 \cdot 10^6$ t of mining residues (Nero et al. 2003). At many old mining sites, low grade ores, waste rock, tailings dams, leaching pads, and sludge from effluent treatment still exist. In the Vale de Abrutiga U-mine, located close to the Aguieira dam reservoir, a lake was formed in the open pit. Acid water from the low grade ore, waste rock, and pit lake flows directly to the reservoir. Surface waters draining the mine site have a pH ≈ 2.6, high conductivity (up to 6000 μS cm^{-1}), high concentrations of U, SO_4^{2-}, Zn, Fe, Mn, Ra, Cu, Th, and Pb; the contaminant concentrations are higher in winter than in summer (Pinto et al. 2004). The surface water from the reservoir, close to the confluence of the contaminated streams, and the groundwater cannot be used for human consumption or irrigation. Stream sediments have high geoacumulation indices for U, Fe, Ag, Zn, Cr, Co, and Pb (Pinto et al. 2004). The Urgeiriça U-mine was mined by in situ acid leaching to recover U from the low grade ore. This greatly increased the level of U and Ra contamination, especially of groundwater (Pereira et al. 2004). Surface and ground water have Ra contents above maximum permitted values, according to Portuguese law. Mine drainage water has high levels of U, ^{226}Ra, SO_4^{2-}, Al, Mn, Ni, Zn, Be, Co, Cu, and Cr. The soils and stream sediments from the main watercourse show high average radionuclide activity (Pereira et al. 2004). However, the uranium mining complex of Urgeiriça does not greatly affect radon concentrations (Neves et al. 2003). In the Cunha Baixa U-mine, acid leaching was also used. Surface water has high levels of U, Mn, Zn, Al, and Sr. Elevated levels of U were found in alluvium and stream sediments up to 10 km downstream (Oliveira et al. 2002).

The Caveira and Lousal mines are located in the Iberian sulphide province. The mineralization consists of pyrite, chalcopyrite, galena, sphalerite, and other sulphides, with Au as one of the secondary minerals. In the Caveira mine, the tailings, waste dump, and an acid lake continue to pollute an area extending 15 km downstream from the mine site. Surface water has high concentrations of Cu, Pb, Zn,

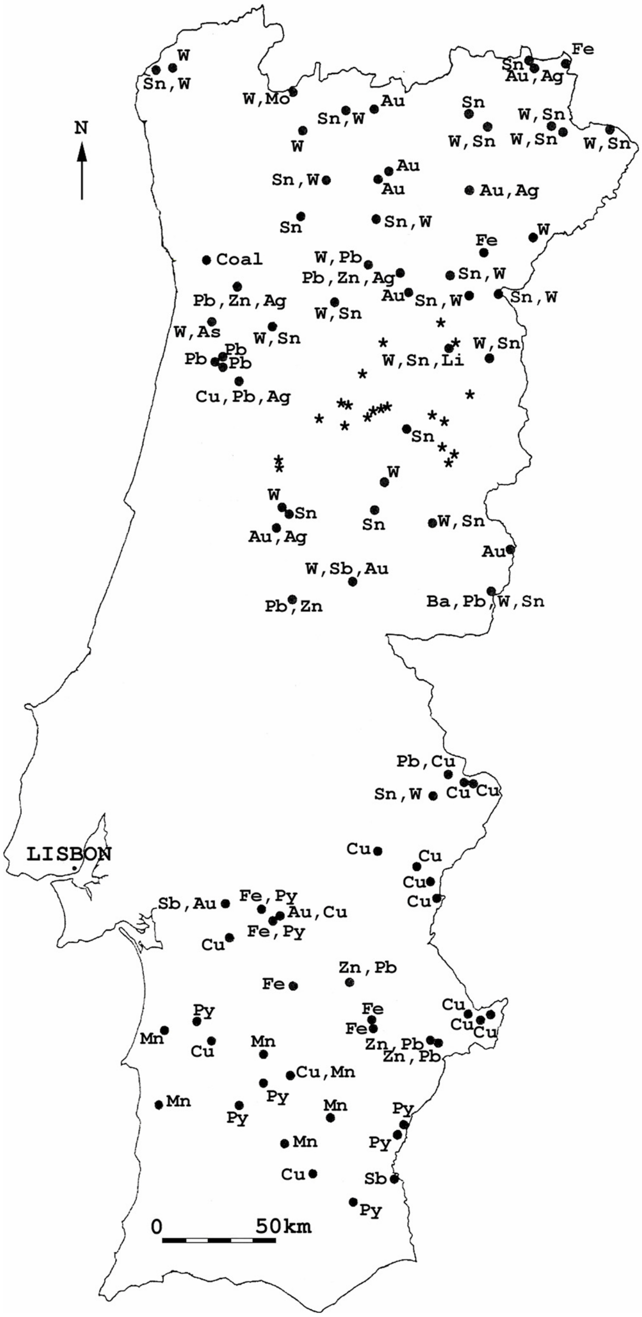

Figure 33. Major abandoned mines in Portugal (adapted from Oliveira et al. 2002). ★: uranium mines.

As, Mo, Se, Cd, and Fe; stream sediments show anomalies of Pb, As, Sb, Hg, Cu, and Zn; soils are contaminated with Mo, Pb, Ag, As, Hg, Cd, Sb, Bi, and S (Silva et al. 2003a). The S. Domingos pyrite mine, inactive since 1966, exploited Cu, Pb, Zn, S, Fe, Ag, and Au. The open pit is flooded with acidic water (pH ≈ 1.7). The interaction of meteoric water with the tailings and permeable slag material also generates AMD (Quental 2001). Water, sediments, and soils samples from this mine site should be considered as hazardous materials (Macalady 2003).

Table 21. Portugal's abandoned mines: numbers (№) and notable examples of each type and volume of resultant residues (extracted from Nero 2004a with some modifications)

Type	№ of mines	More important examples	Wastes ($1\cdot 10^6$ m³)
Radioactive Ore	61	Urgeiriça, Quinta Bispo, Cunha Baixa, Vale de Abrutiga, Castelejo, Bica	8.52
Polymetallic	10	São Domingos, Aljustrel, Lousal, Caveira	6.57
Sn and W	40	Argozelo, Covas, Montesinho	1.44
Basic metals	28	Terramonte, Coval da Mó, Miguel Vacas	0.99
Fe and Mn	16	Orada, Cercal/ Rosalgar, Ferragudo	0.61
Coal	3	São Pedro da Cova, Pejão	2.2
Au	12	Jales, Castromil, Penedono, Freixeda	1.27
Other	5	Gouveia de Baixo, Cortes Pereira	0.67
Totals	175		≈ 22

Castromil is an abandoned gold mine in NW Portugal that left a large amount of tailings and sulphide-containing (mainly pyrite and arsenopyrite) wastes. The soils have high Pb and As content (Reis et al. 2003; Silva et al 2003b), and a pH of about 4 was found in a well in the vicinity of the mine (Pinto 2001). The Penedono Au-mine occurs in a similar situation to that of Castromil. The waste rock, ≈ 1 million tons (Matias et al. 2003), has high levels of As, Pb, Zn, Cu, Mn, and Bi; the mine waters are acid; the surface waters have high contents of As, Cu, Zn, Cd, Mn, Al, and sulphate, but the groundwater is not polluted (Matias et al. 2003).

Argoselo was mined for Sn-W in the north of Portugal. The mine tailings (≈ 1 million tons) have significant levels of As, Cu, Zn, W, Fe, and Cd, and primary sulphides (arsenopyrite, pyrite, chalcopyrite, sphalerite), and supergenic minerals (arsenates, sulphates, and oxides; Oliveira and Ávila 2003). The mine waters are acidic (pH ≈ 3.7) and rich in Mn, Al, Cu, Pb, Zn, Cd, Ni, Co, and Be. Stream sediments and soils near the old mine site are contaminated with As, Cu, and Zn (Oliveira and Ávila 2003). At the Segura mining area (44 small mines), Sn, W, Ba, and Pb were exploited until 1953. No significant AMD was associated with the old mine workings, but the waters associated with mineralized veins have high levels of As, Fe, and Mn and should not be used for human consumption or agriculture activities. Soils must not be used for agriculture or residences due to their Sn, B, As, and Ba concentrations, while stream sediments show Sn, W, B, As, Cu, Ba, Pb, and Zn anomalies (Antunes et al. 2002).

The Pejão mine site is a recently abandoned coal mine, with many waste dumps dispersed nearby. Mine water and waste drainage is acidic, with higher levels of water contamination in winter than in summer. However, the contamination is not strong and is localized, because the wastes are poor in heavy metals and coarse-grained, which prevents the acid leaching of metals. Only Fe occurs at truly anomalous levels (Oliveira et al. 1999).

Remediation Legislation and Activities

Decree-Law 198-A/2001 establishes the most important principles and objectives concerning the remediation and monitoring of old degraded mine sites. Its fundamental purpose is the environmental rehabilitation of mining areas and its specific objectives are the following:

- To eliminate the risk factors that constitute a threat to public health and safety, and which result from water pollution, soil contamination and possible existence of unstable waste dumps or unprotected cavities;
- To rehabilitate the landscape environment and the natural development conditions of the local fauna and flora, with reference to the respective habitats previous to the explorations;
- Identify the patrimony abandoned by the old explorations, whenever this represents a significant economic relevance or a testimony of industrial archaeology;
- To create conditions for the economic valuation of the recovered areas based on their specific potential in each particular case, namely for agricultural and forestal use, promotion of tourism and culture, besides other kinds of uses found adequate and convenient;
- To ensure a good application of the financial resources to use in the Programme, through the maximization of the binomial social benefits/costs, namely in terms of the economy and efficiency of the solutions to adopt.

This Decree-Law also assigns the responsibility for the reclamation of abandoned mine sites for a period of ten years to the EXMIN – Industrial Co. of Environmental and Mining Services, S.A. Priority has been given to the radioactive and sulphide mines. Some old mines (Jales, Au and Argoselo, Sn-W) are already remediated and many others (e.g. Vale de Abrutiga, U, Urgeiriça, U, Cunha Baixa, U) are now being reclaimed, using methods and techniques such us slope stabilisation, confinements, agronomic restitution, compaction of residues, surface impermeabilization, inertization or inhibition using natural or biochemical materials and removal and storing in open pits or underground cavities (under aerobic or anaerobic conditions; Nero et al. 2003; Nero 2004 a, b). Tailings and sludge from several U mines are being removed and confined to a few existent open pits, reducing the contaminated areas to about 50%, and their acid waters are treated with strong bases. Post remediation monitoring is being carried out on slopes stability and subsidence levels, waters, soils, and air in the neighbourhood of the mining areas.

Impact evaluation of water is done according to Decree-Law № 236/98. The limits for radioactive waste exposures are described in Regulamentar Decree № 34/92. In Portugal, there is no legislation to evaluate environmental impacts on soils and stream sediments; it is therefore common to estimate the impacts on soils by using the Canadian Norms (Canadian Council of Ministers of the Environment 1991) or Dutch Norms (Swartjes 1999).

Acknowledgements

We thank Prof. G. Nero, EXMIN administer, and Dr. Matos Dias, EXMIN consultant, for valuable information, and Professor A. Neiva for the revision of this manuscript.

Received April 13, 2005; revised manuscript received May 20, 2005; accepted May 21, 2005.

References

Antunes IMHR, Neiva AMR, Silva MMVG (2002) The mineralized veins and the impact of old mine working on the environment at Segura, central Portugal. Chem Geol 190: 417–431

Aslibekian O, Childs P, Moles R (1999) Metal concentrations in surface water in the vicinity of the silvermines abandoned mine site. Environmental Geochemistry and Health 21 (4): 347–352

Aslibekian O, Moles R (1999) An investigation of environmental contamination at the Silversmines abandoned mines site in Ireland based on the preliminary delimitation of pollution hot spots. Mine Water and the Environment 20:73–80

Beining B, Otte M (1996) Retention of metals originating from an abandoned lead-zinc mine by a wetland at Glendalough, Co. Wicklow, Ireland. Biology and Environment 96 (B2): 117–126

Bondietti G, Gex P, Gini G, Hansen J, Hunziker J, Pfeifer H-R (1994): Heavy metal contamination around the Au-Mine of Astano (Ticino, Switzerland). Eclogae geol Helv 87: 487–490

Bowell RJ, Dey M, Griffiths L, Rees SB, Williams KP (1999) Geochemical assessment of Waste Rock: Implications for disposal and treatment. In: IMWA 20th Mine Water Conf, Seville, Sept 1999, 519–524

Camusso M, Galassi S, Vignati D (2002) Assessment of river Po sediment quality by micropollutant analysis. Water Res 36: 2491–2504

Canadian Council of Ministers of the Environment (1991) Interim Canadian environmental quality criteria for contaminated sites. Manitoba, CCME EPC – CS34, 1–20

Cavalli D, Haldemann E, Jaffé F, Rouiller J-D (1998) Karte der Vorkommen mineralischer Rohstoffe der Schweiz, 1.200’000, Blatt 2:Wallis-Berner Oberland, mit Erläuterungen. Schweiz Geotechn Komm (Eds), Zürich

Costa LR, Leite MM (2000) A Recuperação Ambiental de Áreas Mineiras Degradadas nas Políticas de Integração da Indústria e Ambiente do Ministério da Economia. Boletim de Minas 37 (3): 167–171

Dallas W, Good J, Timpson JP (1999) Overview of 25 years of metalliferous mine rehabilitation in Ireland. Biology and Environment 99 (B1): 77

Della Valle G (1991) Métallogénie de l’or en Suisse. Proj FN 2000-5.628, rapport final: Valais Ed Dépt Min, Univ Genève

Della Valle G, Haldemann EG (1991) Métallogénie de l’or en Suisse. Proj FN 2000-5.628, rapport final: Disentis, Grisons, Ed Dépt Min, Univ Genève

Diels L, van der Lelie N, Bastiaens L (2002) New developments in treatment of heavy metal contaminated soils. Re/Views in Environmental Science and Technology 1: 75–82

Dillon M, White R, Power D (2004) Tailings storage at Lisheen Mine, Ireland. Minerals Engineering 17 (2):123–130

Dominik J, Cuccodoro S, Gourcy L, Santiago S (1992) Uranium enrichment in the surface and ground waters of the Alpine Rhone watershed. In: Vernet JP (Ed), Impact of Heavy Metals on the Environment. Elsevier, Amsterdam, pp 397–416

Franceschi G (2004) Belgium, Mining Annual Review. Mining Communications Ltd. London, UK, 3 pp

Gallagher V, O’Connor P (1999) The Avoca Mine Site. Biology and Environment 99(B1): 43–57

Geets J, Diels L, Van Geert K, Ten Brummeler E, van de Broek P, Ghyoot W, Feyaerts K, Gevaerts W (2003) In situ metal bioprecipitation from lab scale pilot tests. Proc, Consoil 2003 – CD-ROM, 1641–1648

Gillieron F (1988) Zur Geologie der Uranmineralisation in den Schweizer Alpen. Beitr Geol Schweiz, Geotechn Serie 77, Kümmerly and Frey, Bern

Gray N (1998) Acid mine drainage composition and the implications for its impact on lotic systems. Water Research 32 (7): 2122–2134

Greppin R (1997) Géologie régionale et contamination environmental par arsenic de l’indice d’arsenopyrite de La Payanne, Bruson, Val de Bagnes, VS. Diploma thesis, Sciences de la Terre, Univ of Lausanne

Grmela A (1998) Důlní vody. In: Štamberová, M, Michalová M, Mikšovský J, Prchalová H: Vodní zdroje v České republice. VÚV T.G.M. Brno, 76–84

Grmela A, Rapantová N (2002) Protection of groundwater resources quality and quantity in mining areas. In: Fabbri AG, Gaal G, McCammon RB [Ed], Deposit and Geoenvironmental Models for Resources Exploitation and Environmental Security, Part 5, Kluwer, Amsterdam, p 385–397

Grmela A (1999) Mine water and its present utilization in the Czech Republic. In: Proc, XXIX IAH Congress on Hydrogeology and Land Use Management, Bratislava, Slovak Republic, p 745–750

Grmela A, Rapantová N (2004): Experience with Coal Mine Closure in the Czech Republic – Mine Water Problems. Invited lecture, University Newcastle, Great Britain

Häusermann A (2000) L’arsenic dans les eaux et les sols de l’ancien site minier de Salanfe (Valais). Trav de diplôme, Sciences de la Terre, Univ Lausanne

Herr C, Gray N (1997) Metal contamination of riverine sediments below the Avoca mines, south east Ireland. Environmental Geochemistry and Health 19 (2): 73–82

Juchler SJ (1988) Die Böden auf Serpentinit in der subalpinen Stufe bei Davos. PhD Diss no 8716, ETH-Zurich

Kubat L (1987) Geohemijski aspekt apsorpcije i prirodne i vjestacke kontaminacije terena i Vegetacije u Bosni i Hercegovini [Geochemical aspect of absorption and natural and artificial contamination of the soil and vegetation of Bosnia-Herzegovina]. Geoloski Glasnik [Geological Herald] 30 (1), 223–230

Kufrin P (2001) Contamination en plomb dans l’environnement: cas dun ancien site minier près d’Alesse (VS) et de l’autoroute à Lausanne-Dorigny. Diploma thesis, Sc nat env Univ Lausanne and Geneva

Kündig R, Mumenthaler T, Eckhardt P, Keusen HR, Schindler C, Hofmann F, Vogler R, Guntli P (1998) Die mineralischen Rohstoffe der Schweiz. Ed. Geotechn Komm, Zurich, 522 pp

Kündig R, Wenger C, Steiger R, Bianconi F (1990) Karte der Vorkommen mineralischer Rohstoffe der Schweiz, 1.200'000, Blatt 1: Tessin-Uri, mit Erläuterungen. Schweiz Geotechn Komm [Eds], Zürich

Kupusović T, Midžić S, Sijajdzic I, Bjelavac J (2001) ERMITE Report D1 – National Case Studies, No 6, Bosnia and Herzegovina, 1–30

Macalady DL (2003) Arsenic and other trace metals at abandoned mine sites in the Baixo Alentejo, Portugal. IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 250–251

Matias MJ, Abreu MM, Oliveira JMO, Magalhães MC, Basto MJ, Ávila PF, Joaquim CA (2003) Mina de ouro de Santo António-Penedono. Consequências ambientais da exploração mineira e seu abandono. IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 337–339

Meisser N (2003) La minéralogie de l'uranium dans le massif des Aiguilles Rouges (Alpes occidentales). PhD thesis, Univ of Lausanne, Lausanne, 501 pp

Midžić S (2002) Impact of Mine Water on the Environment, unpublished Master Thesis, Univ of Tuzla, 146 pp

Midžić S, Kroll A, Amezaga J (2001) Mine Water Pollution Control – The Legal Situation at Bosnia and Herzegovina and EU Levels. Proc, Regional Conf on Water Law, Teslic, 1–15

Nero JMG (2004a) A situação portuguesa relativamente à reabilitação ambiental de minas abandonadas recuperação ambiental de áreas mineiras abandonadas. Workshop "Reabilitação Ambiental das Áreas Mineiras Abandonadas" 38 pp

Nero JMG (2004b) A recuperação ambiental de áreas mineiras abandonadas; Uma nova e importante actividade em Portugal. Comunicado de Imprensa 19 pp

Nero JMG, Dias JMM, Pereira AJSC, Godinho MM, Neves LJPF, Barbosa SVT (2003) Metodologia integrada para caracterização do cenário ambiental em minas de urânio desactivadas. III Seminário sobre Recursos Geológicos, Ambiente e Ordenamento do Território, UTAD, Vila Real, 91–100

Neves LJPF, Rodrigues ACSL, Pereira AJSC (2003) Concentrações do gás radão em habitações da região uranífera de Canas de Senhorim-Nelas (Portugal Central). IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 267–269

Newman HR (2000) Minerals Yearbook – Area Reports International: The Mineral Industry of Belgium and Luxembourg, Reston (USGS), 5.1–5.2

O'Leary W (1996) Wastewater recycling and environmental constraints at a base metal mine and process facilities. Water, Science and Technology 33 (10–11): 371–379

O'Sullivan A, Murray D, McCabe O, Otte, M (1999) Wetlands for rehabilitation of metal mine wastes. Biology and Environment 99 (B1): 11–17

Oliveira JMS, Ávila PF (2003) Dispersão geoquímica de metais na área mineira degradada de Argozelo (Vimioso). IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 243–246

Oliveira JMS, Farinha J, Matos JX, Ávila PF, Rosa C, Machado MJC, Daniel FS, Martins L, Leite MRM (2002) Diagonóstico Ambiental das Principais Áreas Mineiras Degradadas do País. Bol Minas 39: 67–85

Oliveira JMS, Machado MJC, Pedrosa MY, Ávila PF, Leite MRM (1999) Programa de Investigação e Controlo Ambientais em Áreas do País com Minas Abandonadas: Compilação de Resultados. Estudos, Notas e Trabalhos, Instituto Geológico e Mineiro 41: 3–25

Pereira AJSC, Neves LJPF, Dias JMM, Campos ABA, Barbosa SVT (2004) Evaluation of the radiological hazards from uranium mining and milling wastes (Urgeiriça-central Portugal). XI International Congress of the International Radiation Protection Association 10 pp

Pfeifer H-R, Beatrizotti G, Berthoud J, De Rossa M, Girardet A, Jäggli M, Lavanchy J-C, Reymond D, Righetti G, Schlegel C, Schmit V, Temgoua E (2002) Natural arsenic-contamination of surface and ground waters in Southern Switzerland. Bulletin appl Geol 7: 83–105

Pfeifer H-R (1999a) Environmental risks related to natural and mineral ore deposits of the Central and Western Alps. Schweiz Mineral Petrogr Mitt 79: 339–340

Pfeifer H-R (1999b) Contamination of soils, sediments, plants and waters by natural or mined ore deposits in Switzerland. In: Wenzel W et al. [Eds], Proc 5th Internat Conf Biochem Trace Elements, Vienna, July 1999, p 972–973

Pfeifer H-R, Derron M-H, Rey D, Schlegel C, Dalla Piazza R, Dubois JD, Mandia Y (2000) Natural trace element input to the soil-water-plant system, examples of background and contaminated situations in Switzerland, Eastern France and Northern Italy. In: Markert B, Friese K [Eds], Trace metals – their distribution and effects in the environment. Elsevier, Amsterdam, p 33–86

Pfeifer H-R, Gueye-Girardet A, Reymond D, Schlegel C, Temgoua E, Hesterberg D, Chou J (2004) Dispersion of natural arsenic in the Malcantone watershed, Southern Switzerland: Field evidence for repeated sorption-desorption and oxidation-reduction processes. Geoderma 122, 205–234

Pfeifer H-R, Hansen J, Hunziker J, Rey D, Schafer M, Serneels V (1997) Arsenic in Swiss soils and waters and their relation to rock composition and mining activity. In: Prost R [Ed], Contaminated soils: 3rd Internat Conf Biogeochemistry of Trace Elements, Paris, May 15–19, Colloque 85, INRA ed., Paris

Pfeifer H-R,Vust M, Meisser N, Doppenberg R, Croci Torti R, Domergue FL, Keller C, Hunziker J (1994) Uranium contamination of soils and plants in the vicinity of a pechblende vein at La Creusaz/Les marécottes (Wallis). Eclogae Geol Helv 87: 491–501

Pinto LFSS (2001) Caracterização ambiental da zona envolvente à mineralização de Castromil – Paredes. MSc thesis, Univ Aveiro Portugal 143 pp

Pinto MMSC, Silva MMVG, Neiva AMR (2004) Pollution of water and stream sediments associated with the Vale de Abrutiga Uranium Mine, Central Portugal. Mine Water and the Environment 23: 66–75

Quental L (2001) Results from the Southern European test site S. Domingos, Portugal. 1st Mineo Workshop, Vienna 32 pp

Rapantová N, Grmela A (2002) Environmental impact of mine liquidation on groundwater and surface water. In: Fabbri AG, Gaal G, McCammon RB [Ed], Deposit and Geoenvironmental Models for Resources Exploitation and Environmental Security, Part 5, Kluwer, Amsterdam, p 365–384

Rees SB, Bowell RJ, Farrell L, Brackley I, Connelly RJ (2004) Rehabilitation of the Silvermines mining district, Ireland. Mining Environmental Management

Reis AP, Silva EAF, Pinto LS, Patinha CAF, Sousa AJ, Fonseca (2003) Krigagem da Indicatriz na avaliação de risco de contaminação numa área mineira abandonada (Castromil-Serra da Quinta). IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 240–242

Rodrigues CM (1998) Legislação Ambiental Aplicável à Indústria Extractiva. Divisão de Minas e Pedreiras do Instituto Geológico e Mineiro. Comunicações do 1º Seminário de Auditorias Ambientais Internas: 13–24

Rombouts L (1999) Belgium. Mining Annual Review – The Mining Journal: 49; London

Sá AC (1994) Reabertura das Minas da Panasqueira. Portugal Mineral, ano IV 38

Scheder M, Streiff A (1997) Etude biogéochimique du bassin versant de la Borgne (Val d'Hérens, Valais, Suisse), Diploma thesis, Sciences de l'Environnement, Univ of Lausanne and Univ of Geneva

Scokart P, Meeus-Verdinne K (1985) Speciation and mobility of heavy metals in polluted soils. Proc, Conf on "Metal cycling in the environment"? Brussels, SCOPE Belgium, 245–252

Silva EAF, Patinha CAF, Reis P, Fonseca EC (2003a) Definição do grau de contaminação na área da mina abandonada da Caveira. IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 334–336

Silva EAF, Pinto LS, Patinha CAF, Reis P, Fonseca EC (2003b) Distribuição do As e Pb na envolvente da mina abandonada de Castromil: implicações ambientais. IV Congr Ibérico de Geoquímica, XII Semana de Geoquímica, Resumos: 236–239

Swartjes F (1999) Risk-Based Assessment of Soil and Groundwater Quality in the Netherlands: Standards and Remediation Urgency, Risk Analysis 19 (6): 1235–1249

Tierney P, Timpson P (1999) Natural colonisation by plants of old mine tailings at Abbeytown, Ballisodare, Co. Sligo. Biology and Environment 99 (B1): 77

Treacy P, Timpson P (1999) The use of wetlands to prevent environmental pollution from acid mine drainage. Biology and Environment 99 (B1): 59–62

Van Roy S, Vanbroekhoven K, Diel L, Dejonghe W (2004) Immobilization of heavy metals in the saturated zone by sorption and in situ bioprecipitation processes. Proc, Mine Water 2004 –Process, Policy and Progress, Univ Newcastle upon Tyne, UK, 53–60

Watzlaf G, Schroeder K, Kleinmann R, Kairies C, Nairn R (2003) The passive treatment of coal mine drainage. NETL, US Dept of Energy, 72 pp

Woodtli R (1985) Projet UROMINE, recherches minières exécutées au Valais par les universités de Lausanne, Fribourg et Genève. Swiss Nat Sc Foundation, National Project no 7, Rapport final, Arch Géol Suisse, Berne

Woodtli R, Jaffe F, Von Raumer J (1987) Prospection minière en Valais: le projet UROMINE. Mat Géol Suisse, Série géotechn, vol 72