Some examples of Mine water problems in Tuscany

Mine Water and the Environment (2004) 23: 162–182 © IMWA Springer-Verlag 2004

Contemporary Reviews of Mine Water Studies in Europe, Part 1

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Abstract. Europe once was 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 bases of selected European countries and case studies, these dangers and challenges are described and potential solutions are illustrated.

Key words: Abandoned mine; Austria; Estonia; Europe; Hungary; Italy; mine water; Netherlands; PADRE (Partnership for Acid Drainage Remediation in Europe); policy; Slovakia; United Kingdom

European Union Policies and Mine Water Management

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Mining in European Environmental Policy

Mining is one of the oldest industrial sectors in Europe. European mining policies have been shaped by the historical importance of mining for industrial development and the relatively recent introduction of environmental concerns in public policy. As a result, the emphasis of mining policies has been on the industrial (including safety and health) and economic aspects. Within the European Commission, mining interests reside in two Directorates: DG Transport and Energy, which deals with the energy extractive industry, and DG Enterprise, which deals with the non-energy extractive industry.

Mining had been specifically excluded from much of the environmental policy developed by DG Environment. Recent reviews of relevant legislation show how the mining industry has been favourably treated compared to other industrial sectors (Hámor 2002). Mining was excluded from the Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC) and the Seveso II Directive (96/82/EC). It was included, but with greater freedom of interpretation, in the Environmental Impact Assessment Directive (97/11/EC). Whether or not it should be included in waste legislation has been a contentious issue due to the clause of the Waste Framework Directive (75/442/EEC) stating that mining waste would be excluded where it is already covered by other legislation, interpreted by the European Commission (EC) as referring exclusively to European legislation (see later the AvestaPolarit ruling). Water legislation has much less direct references to mining than waste. The Water Framework Directive (WFD) (2000/60/EC) applies to mining activities in a generic sense but there is no specific water legislation addressing the specific requirements of this sector.

In the aftermath of the Aznalcóllar (April 1998) and Baia Mare (January 2000) accidents, the EC created the Baia Mare Task Force (March 2000) to propose a plan of action. In less than one year, the EC published three communications on environmental aspects of mining emanating from two different Directorates: Enterprise, [COM (2000) 265f] and Environment, [COM (2000) 664f] and [COM (2000) 593f]. In particular, the Baia Mare Task Force recommended three key actions discussed in more detail below: amendment of the Seveso II Directive, a document on Best Available Techniques (BAT) similar to those produced under the IPPC Directive, and an initiative on the management of mining waste. Conspicuously, the Task Force with its narrow focus on tailings dam safety failed to identify the need for a water-related initiative (Kroll et al. 2001). In another independent policy initiative, mine water management will also be affected by the new Environmental Liability Directive adopted in March 2004, with national implementation three years later. This Directive will make mining operators liable for the clean up of contaminated sites.

Seveso II Directive

The Seveso II Directive (96/82/EC) has two aims: the prevention of major accident hazards involving dangerous substances and limiting the consequences of such accidents not only for man but also for the environment. The scope of the Directive is related to the presence of dangerous substances in establishments. However, article 4 (e) excluded the activities of the extractive industries. Following the recommendations of the Baia Mare Task Force, the EC [COM (2001) 624f] proposed to amend the Directive to include chemical and thermal processing of minerals and related storage operations and tailings disposal facilities if they involve dangerous substances regulated by the Directive. The European Parliament introduced new amendments calling for an extension of the scope to all mining activities. Under the final agreement, the Directive covers chemical and thermal processing operations and storage related to those operations plus operational tailings disposal facilities containing dangerous substances, when used in connection with both chemical/thermal and mechanical/physical processing of minerals. The Directive 2003/105/EC of 16 December 2003, amending Directive 96/82/EC, published in the Official Journal on 31 December 2003 requires that Member States bring into force the laws, regulations, and administrative provisions necessary to comply with this Directive before 1 July 2005.

BAT for Management of Tailings and Waste-Rock

The IPPC Bureau established a Technical Working Group (TWG) in June 2001 to develop a technical document that would contribute to the knowledge available to prevent accidents from tailings and waste-rock disposal facilities and provide technical support for legislative activities of the EC (e.g. proposed Directive on mine waste). Usually, TWGs are organised to facilitate the exchange of information between the European Union's Member States and industry under the IPPC Directive but this TWG was set up based only on the Communication of the Commission after the Baia Mare Task Force [COM (2000) 664f]. The TWG decided that the scope of its activities related to mineral processing, tailings, and the waste-rock management of ores that have the potential for a significant environmental impact or that can be considered as examples of good practice. The document covers 14 metals, 10 industrial minerals, coal only if processed (lignite is not covered), and oil shales. The issue of abandoned mines was not addressed. The final draft reference document on BAT for management of tailings and waste-rock from mining activities was published in March 2004 (http://eippcb.jrc.es).

Proposed Directive on the Management of Waste from the Extractive Industry

The most important initiative triggered by the Baia Mare report has been the development of a proposal for a new Directive on the management of waste from the extractive industry as a daughter directive from the Waste Framework Directive. The first proposal coming from the Commission relied heavily on the recent Landfill Directive (1999/31/EC). This was highly contested by interested parties. An open process of consultation helped to craft two more draft versions that were more adequate as a license-based system for the management of waste facilities in mining operations. The scope was also clarified covering now almost all mine and quarry wastes. However, the final proposal that came out of the European Commission [COM (2003) 319f] softened many provisions, excluding some waste, reducing the attention to mining voids and scrapping the duty of Member States to remediate closed waste facilities. The position of the Commission has been challenged on two fronts. First, the European Court of Justice on AvestaPolarit Chrome Oy (Case C-114-01, 11/09/2003) determined that left over rock and ore-dressing sand used directly for infilling of underground galleries would be a regarded as a by-product and not as waste. It also ruled that the "other legislation" referred to in the Waste Framework Directive can also include national legislation. Secondly, the amendments approved by the European Parliament in its first reading (A5-0177/2004) on 31 March 2004, strengthen many provisions of the proposal, in particular, the management of closed sites. The proposal follows the complicated steps of the co-decision procedure with several iterations between the European Parliament, European Council, and the EC. The Council reached a Political Agreement on a Common Position on 14 October 2004. The text approved by the Council is quite similar to the original Commission proposal. The provisions for dealing with closed sites within the Council document are less prescriptive than the European Parliament version. The final text of the Directive could be ready by the end of 2005.

Mine Water Management

The EC Framework 5 project (EVK1-CT-2000-00078) "Environmental Regulation of Mine Waters in the European Union" (ERMITE), which finished in January 2004, has produced a thorough evaluation of European legislation for mine water management (http://www.minewater.net/ermite). The ERMITE policy briefs emphasise the remediation of abandoned sites, the links between mine wastes and mine voids, and the management of so-called "inert" waste.

ERMITE has also produced guidelines for the management of mine waters at the catchment scale (ERMITE Consortium 2004). It is recommended that the EC produce similar official guidelines for the implementation of the Water Framework Directive.

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Received May 30, 2004; revised manuscript received November 18, 2004; accepted November 19, 2004

Mine Water Issues in the United Kingdom

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The UK has a rich history of both coal and metal mining. However, with a few notable exceptions, the coal- and ore-fields of the UK are now abandoned. Mine water issues are therefore a major concern across former mining areas of the UK. Problems encountered include rising mine waters (which sometimes intercept important aquifers), and surface water pollution arising from discharges of acidic and/or metalliferous mine waters from abandoned mine and spoil heaps. This summary article provides an overview of the type of problems encountered in the UK, the measures taken to address them to date, and the likely direction of future research.

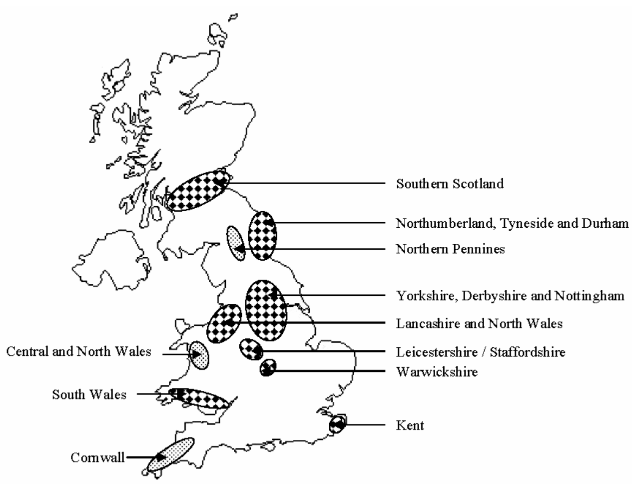

Figure 1. Main mining regions of the UK (diamonds indicate coal mining; dots indicate metal mining)

In the United Kingdom (UK), owners of mines abandoned prior to 1 January 2000 cannot be held liable for pollution from their mine unless causation of pollution can be proved. Due to the complex hydrological setting of the underground mines, it is extremely difficult to prove causation; only one successful prosecution was ever brought prior to 1 January 2000. Since most mines in the UK were abandoned prior to this date, the vast majority effectively fall outside legislative control. Further details on the legislative loophole that precipitated this situation can be found in Fry (1997).

The inability to apportion liability for mine water pollution in the UK is a serious issue given the extent of the problem and the requirements of the Water Framework Directive (WFD). Mine water pollution is currently one of the most severe and most widespread forms of aquatic pollution in the UK (NRA 1994; Younger 2001; Potter et al. 2004). The England & Wales Environment Agency has recently produced its draft pressure assessment maps, as the first stage of meeting the objectives of the European Union Water Framework Directive. The map for mining impacted waters suggests that approximately 2,500 km of streams in England and Wales, and an area of some 9,000 km^2 of groundwater bodies, are "at risk" of failure of WFD objectives due to mine water pollution.

Volumetrically, the majority of mine water issues in the UK relate to discharges from abandoned coal mines (Figure 1). Since the legal structure in the UK does not allow liability for pollution to be apportioned, the government-funded Coal Authority has adopted responsibility for addressing discharges from abandoned underground coal mines. Since its formation in 1994, the Coal Authority has implemented more than 20 full-scale treatment schemes, and oversees the monitoring of rising mine waters across the UK. The method the Coal Authority uses to prioritise and select the discharges for treatment was developed by the England & Wales

Environment Agency in the mid-1990s, based on the scale and severity of the chemical and biological impacts of mine waters on the receiving watercourses. These lists, initially produced on a regional basis, have now been combined into a national priority list. For the interested reader, Davies et al. (1997) describe the methodology, and Jarvis and Younger (2000) provide a critique of mine water impact assessment techniques in general.

The majority of these treatment systems remediate net-alkaline, ferruginous mine waters, and typically comprise aeration, settlement lagoons, and aerobic wetlands. A few include chemical dosing, either for raising pH (usually using sodium hydroxide), or for rapid oxidation of ferrous iron (usually using hydrogen peroxide). Only one Coal Authority system, at Deerplay, Lancashire, includes a reducing and alkalinity producing system (RAPS) for elevation of alkalinity (see Jarvis and England 2002). The RAPS at Deerplay treats spoil tip leachate, and is located on the same site as a larger system that treats net-alkaline deep coal mine water (settlement lagoons and aerobic wetland). Settlement lagoons and aerobic wetlands are not particularly a focus of treatment research in the UK at present. A more pressing issue at coal mine water treatment sites is the large volumes of ochreous sludge that are generated and, specifically, how to re-use or dispose of them.

With the exception of those that it owns, coal mine spoil heap discharges do not fall within the remit of the Coal Authority. Responsibility for treatment of such discharges ordinarily lies with the landowner. Novel passive treatment systems have been installed at some of these sites due to their more acidic nature (Rees et al. 2002). For example, the first compost wetland in Europe was installed at Quaking Houses, County Durham, in 1997 (see Jarvis and Younger, 1999). At Shilbottle, Northumberland, a permeable reactive barrier (PRB) is now operational, and at Bowden Close, County Durham, a RAPS unit has recently been commissioned (Younger et al. 2003). These systems are currently the main focus of passive treatment research activities in the UK. Particular areas of interest include the behaviour of sulphate reducing bacteria in aiding remediation, sulphur and carbon cycling in general, and calculating the longevity of carbon supply and its impact on the lifespan of such passive systems.

An area that has received little attention in the UK is the issue of diffuse mine water pollution. Diffuse pollution certainly arises from spoil heaps, but may also arise as seepage faces at the surface in areas of former shallow mines. Accurate quantification of diffuse sources, and designing effective approaches to remediation, is a particular area of current interest to the England & Wales Environment Agency.

There is no equivalent body to the Coal Authority that has responsibility for addressing metal mine discharges in the UK, and only one major metal mine discharge, at Wheal Jane, Cornwall, has a treatment system associated with it. There is currently no sign of any immediate resolution to this problem. Metal mine discharges affect Wales and Cornwall in particular, as well as many parts of northern England (Figure 1). Discharges can be highly acidic or circumneutral, depending on the host mineralization, and contaminants may include zinc, copper, lead, and iron. The treatment challenge is further exacerbated by typically remote locations, difficult topography, and the proximity of many discharges to the receiving watercourse. The England & Wales Environment Agency has begun assessing the severity and potential for treatment of such discharges (Environment Agency Wales 2002; Johnston 2004; Rees et al. 2004), but it remains unclear who will take responsibility for financing the construction of, and then operating, metal mine water treatment systems.

Consistent removal of metals such as zinc and copper from acidic and circumneutral mine water using passive treatment technologies is a subject of ongoing research in the UK. Efforts to date have included the removal of zinc as carbonate minerals in anoxic limestone drains (e.g., Nuttall and Younger 2000). More recently, the potential of dried and pelletised ochreous sludge from coal drainage treatment, already demonstrated as having potential for phosphorus removal (Heal et al. 2004), has been investigated as a media for metal sorption (unpublished data). Bacterially-mediated systems for zinc and copper removal are also being investigated, although there are currently no systems operating at field-scale (to the authors' knowledge).

In summary, in terms of coal mine drainage treatment, the UK has an excellent track record in both research and application. The challenges for the future will undoubtedly be in areas such as ochreous sludge management, addressing rising mine water issues, and remediating acidic and circumneutral metal mine water discharges.

Received October 15, 2004; revised manuscript received November 19, 2004; accepted November 20, 2004

Estonia

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Introduction

Estonia is a small country and generally not known for its mining, as its specific mineral resource, oil shale, is often not included in overviews and comparisons. Estonian oil shale is called kukersite. It is a light to dark brown (calcareous and terrigenous) sedimentary rock, the main components of which are organic matter of sapropel origin (kerogen, 20–60% by mass) and mineral matter (40–80%). Basically, all Estonian power generation and a large part of the chemical industry are based on burning and processing oil shale. As the calorific value of mined oil shale is low (between 10.2–11.5 MJ/kg), Estonia is Europe's leader in per capita production of solid fossil fuels (about 10 t per capita per year). Other mineral resources include phosphate (no longer mined), limestone, dolomite, clay, sand, gravel, peat, and curative mud (Figure 2). The problems related to active mine waters are almost exclusively related to oil shale mining, though from a historical perspective, water problems related to phosphate mining and uranium production are also important.

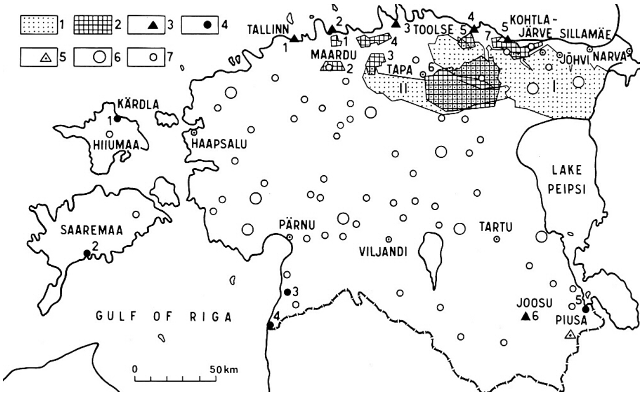

Figure 2. Mineral resources of Estonia: 1. oil shale (I – Estonia deposit, II – Tapa deposit); 2. phosphorite deposits (2.1 – Maardu, exhausted; 2.2 – Raasiku; 2.3 – Kehra; 2.4 – Tsitre; 2.5 – Toolse; 2.6 – Rakvere; 2.7 – Aseri); 3. clay deposits (3.1 – Kopli, exhausted; 3.2 – Kallavere; 3.3 – Kolgaküla; 3.4 – Kunda; 3.5 – Aseri; 3.6 – Joosu); 4. mineral water wells (4.1 – Kärdla; 4.2 – Kuressaare; 4.3 – Häädemeeste; 4.4 – Ikla; 4.5 – Värska); 5. sand for glass: Piusa deposit; 6. peat bogs with area over 100 sq km; and 7. peat bogs with area between 50 and 100 km² (Puura and Raukas 1997)

Historical situation

Oil shale

Oil shale has been extracted and used for 88 years; 900 million t have been extracted and either burnt in power plants (ca 85%) or chemically processed (ca 15%). The black areas on Figure 3 represent deposit boundaries and mined-out areas. Down to a productive layer depth of 30 m and at places covered with forests and bogs, opencast mining is preferred because it is cheaper and leads to quicker production (due to highly productive machinery), with safer and healthier working conditions than underground mining. Approximately half of the shale has been and is produced from opencast mines, while the other half is produced underground.

Phosphate

The opencast mining of sandstone that contains phosphate was carried out in Maardu from 1964 to 1991. Altogether, an area of 10.6 km^2 was mined out and covered by waste rock plateaus with heights of 5 to 25 m. Large trenches separate plateaus from each other and from the surrounding areas.

Uranium

In 1948, a secret company was started to produce uranium in Sillamäe. Local *dictyonema* shale was mined and used for a few years, but later uranium ore was imported from Eastern Europe. In 1959, a tailings pond was established on the seashore. Incorporating pulp and wastewater from the production of tantalum and niobium, the tailings dam

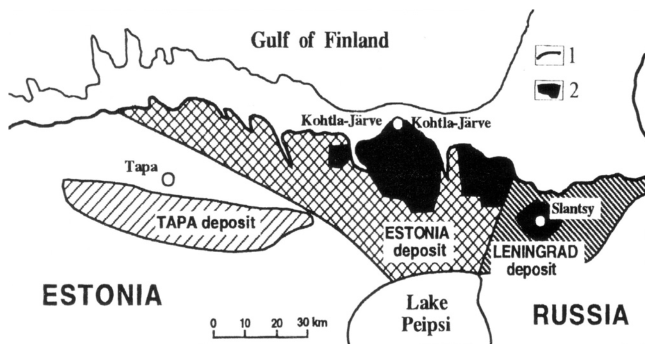

Figure 3. Location of oil shale deposits in the Baltic Oil Shale Basin: 1. Recent erosion boundary of kukersite oil shale; 2. mined out areas and fields of active mines (Raukas and Teedumäe (1997), with the permission of the Institute of Geology of Tallinn Technical University)

developed to a height of 25 m, with a tailings pond covering about 40 ha. A special remediation project is on-going and is scheduled to be completed by the end of 2006. As the share of local mine waste in the tailings pond is very small, the location is not considered as a mine waste site in Estonia.

Overview of Currently Working Mines

During the last fiscal year, which ended on 31 March 2004, the Estonian Oil Shale Co. produced 14 million t of oil shale. Narva Pitch Ltd and Aidu Pitch Ltd operate opencast mines, while Estonia Mine Ltd and Viru Mine Ltd operate underground mines. At other active mines in Estonia, 1.51 mill m^3 of limestone, 0.339 mill m^3 of dolomite, 0.168 mill m^3 clay, 0.652 mill m^3 gravel, and 1.402 mill m^3 sand was extracted in 2002, as well as 1.508 mill t of peat and 1.7 thousand t of curative mud. Relative to mine waters, however, these activities had minimal effect on the environment.

Mine Water Management and Problems

Oil Shale Mines

During the last several decades, 200–240 million m^3 of water have been pumped annually from oil shale mines and discharged into surface waters. In 2002, after several mines had been closed and flooded, 183 mill m^3 of water was pumped out, which amounts to 77% of Estonia's groundwater use (Narusk and Nittim 2003). Approximately 175 million m^3 were discharged from the operating mines. Groundwater levels surrounding the mining areas have dropped and 300 deeper wells have had to be drilled in the countryside to supply drinking water. The issue of drinking water supply in the central mining town, Kohtla-Järve, is very important at the moment. The possible alternatives are utilisation of deep groundwater (Cambrian-Vendian aquifer) that has naturally high concentrations of some elements (e.g. barium) or construction of a pipeline that would be several tens of kilometres long.

Closing of mines after decades of operation has led to other impacts. For example, towns have been established or expanded onto areas that were wetlands before mining started; with the water table rising after closure, there have been problems with flooding.

The pumped-out water is near-neutral, containing elevated concentrations of sulphate (200–500 mg/L). There are no problems with acidification, as the oil shale contains approximately 40% calcite ($CaCO_3$), buffering pyrite and acidic organic-matter oxidation products. In 2002, 86% of the waters were passed through sedimentation ponds to remove suspended solids (Narusk and Nittim 2003).

Regarding ions and complexes other than sulphate, the mine waters do not have a major impact on the chemistry of natural waters: total Fe, NH_4^+, and BHT_{20} levels are decreased, and Cl^-, HCO_3^-, K^+, and Na^+ levels somewhat increased. The concentrations of heavy metals in mining waters do not differ significantly from natural background values and are often even lower.

To avoid impacting the lakes in the Kurtna Landscape Preservation Area, the Viivikonna department of Narva Pitch Ltd use a filtration dam and infiltration pools so that they can excavate the oil-shale resources deposited on the border of the Preservation Area.

South of there, Puhatu National Park was established in 1999 to preserve the Puhatu bog and the species of the area. In the southern part of the oil-shale region of Sirgala, the mining area partly falls within the borders of this national park. It is anticiapated that the excavation will reach the problematic territory in 15 years. The impact of mining on the level of subsoil water is regularly monitored at 3 observation wells in the southern part of the Narva oil-shale region.

Maardu phosphate mine

The Maardu phosphate mine site, located in northern Estonia, 10 km east of Tallinn, is rather unique; the range of major environmental problems is not caused by the commodity itself, but by hazardous compounds in the overburden. Ordovician and Cambrian sedimentary rocks in Scandinavia and Estonia contain layers of pyritic, metalliferous and organic-rich alum shale. Exposed to the atmosphere, pyrite in the shale tends to oxidise at high rates and release acidity and sulphates. The leachate is often rich in heavy metals that were initially present as sulphides or were adsorbed/structurally contained in other solid phases of the dump. The total amount of the shale opened to oxidative weathering is 71.7 million t, with the potential to produce more than 5 million t of sulphuric acid during low-temperature oxidative weathering (assuming that each m2 of the waste rock contains, on average, 7 t of shale containing 4–6% pyrite and 9–12% of kerogen-type organic matter (Puura 1998).

Key environmental issues related to mine waters at the site are:

- Low-temperature oxidation of alum shale, leading to pollution of groundwater and surface water with sulphates (up to 1 g/L);
- A risk for breakthrough of acidity and heavy metals. At the moment, limestone still buffers all acidity formed, but especially in the north-eastern part of the site, where the limestone layer was thinnest, there is a possibility for breakthrough of contaminants; and a
- Modified surface and groundwater pattern.

Future Mining, Treatment and Remediation Activities

Oil shale remains the main mineral resource of Estonia. Present national plans have not identified any other major power generation source for Estonia for the next several decades. Because of high carbonate content, acidification and metal mobilisation are not problematic in the mining region. The main unknown factor regarding mine waters is how elevated concentrations of sulphates (200–500 mg/L) in pumped-out waters will be assessed and approached by the EU Water Framework Directive implementation, as the quantities are very large. The Estonian Oil Shale Company has been successfully demonstrating the quality of the water after purification in sedimentation ponds by trout farming.

Presently, a model for hydrological changes after mine closure in oil shale mining region is being prepared by Tallinn Technical University's Mining Institute. Maardu phosphate waste heaps continue to discharge sulphates and the risk of elevated heavy metals remains. The mixed mining waste and processing tailings pond in Sillamäe will be remediated by the end of 2006.

Received May 31, 2004; accepted November 22, 2004

The Netherlands – Rising Mine Water in the Former Dutch Coal Mines

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Introduction

Large-scale coal mining took place in the Netherlands between 1900 and 1975, when 600 million tons of coal was extracted from 12 mines. Coal extraction was primarily performed using longwall mining systems, with an average face length of 200 m and an average opening of 1 m. The extraction depth varied in the east from 0 to 500 m and in the west from 400 to almost 1000 m. Per ton of coal mined, 2 m^3 of water needed to be pumped out.

The coal mines in South Limburg were closed during the period of 1967 to 1974, and the pumping of mine water ceased, except at the Beerenbosch pump shaft, where it was maintained to protect the neighbouring operating German mines. The rising of these mine waters has gradually increased since then. There is concern that the rising mine water could reach into the overburden sediments. This could be a threat for existing drinking water wells in the Cretaceous limestone because of the high concentrations of salts and heavy metals in the mine water. Possible surface damage is also to be expected, on the one hand by caving as an effect of erosion of historical mineshaft fillings, and on the other hand by ground level uplift. For an overview of the Limburg Coal District, see Figure 4. The Dutch coalfield has an elongated shape and measures roughly 7 by 30 km; it is situated on the north-eastern edge of a structural high and separated from the Central Graben by a system of faults along which the Carboniferous surface sank to considerable depths. The Upper Carboniferous strata yielding the coal belong to the Westphalian A, B and the lower part of C. Important for the occurrence of mine water is the lithological alternation of shale and sandstone.

Measures Taken

During the period 1967–1974 dams have been built into the galleries to protect the neighbouring, not yet closed mines in Limburg from water influx. In this way a few underground compartments (basins) were created with water overflows on different depths (Figure 5).

To protect the then still-active mines in Germany, the Beerenbosch pump shaft near Kerkrade was installed, which kept the mine water rising level at -220 m NAP (National Ordnance Datum). This pump shaft was dismantled early in 1994 when the German mines in the Aachen mine district closed. Since then, the mine water has also risen in that part of the coalfield.

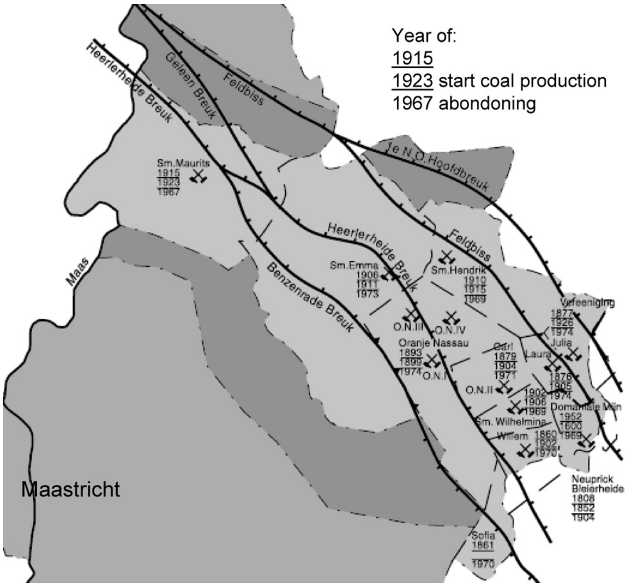

Figure 4. Limburg Coal District, tectonic faults and mining licenses

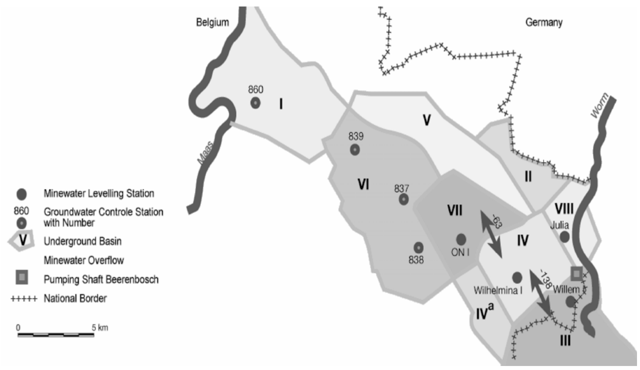

Figure 5. Mine water basins - levelling stations and groundwater

To monitor the mine water rise, water level monitoring stations were installed in four former mineshafts and, in addition, four observation wells were constructed over the mine area to monitor the water quality in the overlying limestone aquifer.

Effects of the Mine Water Rise

Water Quality

The level of the mine water is at present above the Carboniferous sediments and will continue to rise in the future. However, infiltration of rainwater maintains a groundwater level in the overburden that is above the NAP. It is anticipated that this potential difference will cause a permanent downward groundwater flow from the overburden into the Carboniferous sediments. This is being confirmed through quality measurements of the groundwater, which shows no worsening in quality. The water level in the limestone did not drop noticeably during coal extraction, which indicates that the Cretaceous limestone and the Carboniferous sediments are still poorly connected hydrologically. The implication is that the rising mine water will be stopped by the relative isolation of the strata and the downward flow of the groundwater in the overburden.

It is to be expected that eventually the original density gradient will establish itself again and that stratification of the groundwater will ultimately occur. This will not differ significantly from the original situation, where the fresher groundwater floated atop the deeper and saltier mine water. The permeability of the lower strata of the overburden is limited, and vertical permeability relative to horizontal permeability is minimal. This contributes to the effective protection of drinking water reservoirs in the overburden from the influence of rising mine water.

Ground Movements

Ground movements as a result of mine water rise can only cause damage in places where geological faults are manifested on surface and only then when uneven ground level uplift takes place on both sides of these faults. This means that on both sides the mining method must have been different. Possible caving of shallow mineshafts of before the 19th century, by erosion of the shaft fillings, can only occur on a narrow strip along the German border.

Measured Rise of the Mine Water

Currently, the water level in the eastern mining district is at about 10 m NAP, about 140 m below ground level. It continues to rise about 6 m per year. It is expected that the water table in the southeast will, at the most, increase up to the level of the river Worm. From subsidence research, it can be calculated that the level in the western mining district has increased up to -6 m NAP. The average rate of mine water rise in recent years is currently 2 to 3 cm per day in the Limburg mining district.

Measured Ground Level Uplift

Detailed levelling measurements have been carried out in the Aalbeek-Schinnen area. It turns out that the ground level uplift that occurred as a result of the rising mine water is proportional to the land subsidence that occurred as a result of the extraction of coal. The measured ground level uplift since 1974 is 23 cm. The maximum ground level uplift expected will be between 2 and 5% of the subsidence that occurred. The amount of the surface subsidence in the coal mining area of South Limburg varies between 2.5 and 10 m.

Conclusions

In the Limburg mining area, ground level uplift due to rising mine waters has, up till now, not led to new damage. It is anticipated that the rising mine water will not mix with the fresher groundwater, and does not pose a risk to the drinking water supply. Finally, there are currently no indications that mine water is being transported to the overburden.

Received June 1, 2004; revised manuscript received November 19, 2004; accepted November 20, 2004

Mine Water Issues in Slovakia

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Introduction

The complicated geology of the Slovak territory, which is part of the West Carpatians, exhibits substantial variability and hosts a high number of mineral deposits (Figure 6). Underground mining of these deposits has caused numerous environmental changes, the most important being the drainage of natural waters and the generation of contaminated mine water.

Mining in Slovakia dates back to prehistoric times and was especially significant during medieval times. Gold, silver, copper, iron, and polymetallic (Pb, Zn, Cu) ore mining was especially noteworthy. Subsequently, there was a gradual decrease in metal ore exploitation, which was accelerated by the social-economic changes that occurred in Slovakia after 1989; at present, only a single iron ore mine is operating. Coal, magnesite, and gypsum mining operations developed during the 20th century and are still going on.

Characterization of Mine Water Issues

Table 1 shows mineral deposit types that were or are exploited by underground mines in the Slovak territory, together with the type of host rock. The frequency and total average yield of mine water discharges are also shown for the individual mineral deposit types. Most of the mine discharges are of low yield, and are connected with ore veins in Paleozoic rocks. They are concentrated mainly in the Slovenské rudohorie Mts, but also occur in others mountain areas. There are also many discharges of mine water from coal deposits in Neogene sediments, ore deposits in neovolcanic rocks, and magnesite deposits. The mine water yield of approximately 460 mine discharges totals about 1.5 m^3/s. However, the presented data should be considered preliminary since not all discharges have been registered yet.

Individual ore mines in near-surface metamorphosed Paleozoic rocks, which are of low permeability, produce relatively small amounts of mine waters, rarely exceeding 1 L/s (maximum up to 20 L/s). The average mine water yield and its regime is controlled by the extent of the mine, the possibility of atmospheric water infiltration (via openings, fractures, and faults) and the climatic conditions of the locality (Bajtoš 2000). However, different hydrogeological conditions occur in Paleozoic carbonate bodies, containing metasomatic siderite, magnesite, or talc deposits, due to karst phenomena. As the extent of such carbonate bodies is not very large (maximum length of 4.5 km, in the Dúbravský masív carbonate structure), they are not regionally important and mine waters yield of individual mines do not exceed 20 L/s.

The chemical composition of mine waters in the Paleozoic rock environment is controlled mainly by the sulphide: carbonate mineral ratio and by the extent of the mine and the mineral deposit. The chemical composition of mine water from ore deposits without sulphides and carbonates (quartzite veins) is hydrogeochemically like background water. Dispersed sulphidic mineralization generates slightly acidic mine waters of low TDS content, enhanced SO_4 concentrations, and elevated levels of some

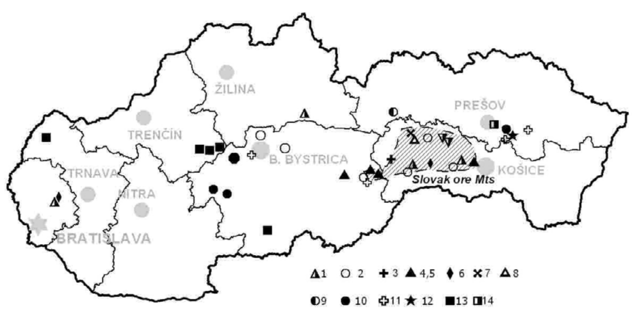

Figure 6. Regional distribution of mine water issues in Slovakia; symbols represent mineral deposit types, numbered to correlate with Tables 1 and 2

Table 1. Quantity and frequency of mine water discharges in Slovakia, classified by mineral deposit types; *Q* = total yield, *n*: number of issues, PM: Paleozoic metamorphities, MS: Mesozoic sediments, PS: Paleogene sediments, NR: neovolcanic rocks, NS: Neogene sediments

Deposit type	Raw minerals	Host rocks	Main mine districts/deposits	*Q* L/s	*n*
1. hydrothermal quartz-sulphidic veins	antimonite, gold	PM	Pezinok deposit (Malé Karpaty Mts.) Dúbrava deposit (Nízke Tatry Mts.), Betliar, Čučma, Zlatá Idka, Popoč ore districts (Slovenské rudohorie Mts.)	30	37
2. hydrothermal siderite-sulphidic veins	siderite (chalkopyrite, cinnabar, barite)	PM	Rudňany ore field, Slovinky- Gelnica ore field , Rožňava ore field, (Slovenské rudohorie Mts.)	450	36 0
3. metasomatic siderite	siderite	PM	Nižná Slaná - Kobeliarovo mine, Železník deposit (Slovenské rudohorie mts.)	27	4
4. metasomatic magnesite deposits	magnesite	PM	Dúbravský massif deposit, Bankov deposit (Slovenské rudohorie Mts.)	91	5
5. metasomatic talc deposits	talc	PM	Mútnik, Samo deposits (Veporské vrchy Mts.)	8.4	7
6. stratiform sulphidic deposits	pyrite, chalkopyrite	PM	Smolník deposit (Slovenské rudohorie Mts.)	6	1
7. stratiform uranium deposits	uranite, molybdenite	PM	Novoveská Huta deposit (Slovenské rudohorie Mts.)	10	5
8. gypsum and anhydrite sedimentary deposits	gypsum and anhydrite	MS	Novoveská Huta – Tollstein deposit (Slovenské rudohorie Mts.)	12	1
9. sedimentary Mn deposits	pyrolusite, manganocalcite	PS	Švábovce-Kišovce mine (Hornád basin)	5	1
10. polymetalic ore veins, Au and Ag stockworks	galenite, sphalerite, gold, silver	NR	Štiavnica-Hodruša mining district, Kremnica (Central-Slovakia neovolcanites Mts.), Zlatá Baňa deposit (Slanské vrchy Mts.)	400	30
11. veinlet-disseminated hydrothermal mineralization	cinnabar	NR	Dubník Hg deposit, Merník deposit (Slanské vrchy Mts.), Malachov deposit (Central-Slovakia neovolcanites Mts.)	2	3
12. veinlet-disseminated hydrothermal mineralization	noble opal	NR	Dubník opal mine (Slanské vrchy Mts.)	0.5	1
13. coal deposits	brown coal, lignite	NS	Nováky, Cígeľ, Handlová (Horná Nitra basin), Modrý Kameň coal mines	450	5
14. salt deposits	rock salt	NS	Prešov-Solivary mine (Košice basin)	0.5	1

metals (Table 2) when carbonate minerals are absent (quartz-sulphidic veins), or $Mg\text{-}Ca\text{-}SO_4\text{-}HCO_3$ type waters when carbonate minerals are present (carbonate-sulphidic veins). If only carbonate minerals are present (metasomatic siderite, magnesite and talc deposits, carbonate veins) and sulphide content is equivalent to the geochemical background, alkaline $Ca\text{-}Mg\text{-}HCO_3$ or $Mg\text{-}Ca\text{-}HCO_3$ type mine waters are produced. Stratiform sulphide deposits produce metal-sulfate type acid mine waters with a high total dissolved solids (TDS) content.

Higher mine water yields occur in ore mines in neovolcanic rocks due to the high permeability of the area due to regional faults. Large faults drain phreatic waters over large areas, but also enable ascent of geothermal waters from underlying aquifers (mainly Triassic carbonates). Mine water yields of main drainage galleries can exceed 100 L/s (Table 2). In shallow galleries, $Ca\text{-}Mg\text{-}HCO_3$ type mine waters (hydrogeochemical background) prevail, but in larger mines, the water is dominantly of the $Ca\text{-}SO_4$ type, due to the influence of sulphide oxidation. Coal mines drain large amounts of groundwater from neogene aquifers (Tables 1, 2). Complex hydrogeological conditions results from the location of the deposits under an erosion basin and the presence of both overburden and footwall aquifers. Groundwater sometimes bursts into the mines; the sand and andesite layers are particularly dangerous (Kováč 1999). The natural chemical composition of the groundwater changes with depth from a $Ca\text{-}Mg\text{-}HCO_3$ to $Na\text{-}HCO_3$ type, with a TDS content up to 0.6 g/L, but is then altered by the oxidation of pyrite, realgar, arsenopyrite, and auripigment in the coal workings to $Ca\text{-}SO_4$ type water; the TDS increases to 4 g/L, the SO_4 content increases to 2.4 g/L, and metal concentrations increase (Fe to 25 mg/L, As to 1.2 mg/L) in the abandoned mines. However, these high concentrations are decreased by dilution by the natural groundwater. Mine waters of the Modrý Kameň coal region contain gaseous carbon dioxide.

Table 2. Hydrological and hydrochemical parameters of chosen mine water discharges. Asterisk indicate data linked to mines operation, others data represent abandoned mines.

	Q **(L/s)**	**Measured period**	T_{water} **(°C)**	**Chemical type of mine water**	**TDS (g/L)**	**Contaminants**
1. Quartz-sulphidic ore veins in Paleozoic rocks						
Zlatá Idka Hauser adit	1.6–2	1997	8.4–9.6	Ca-Mg-HCO_3	1.9–2.2	As, Fe, Mn
Čučma, Gabriela adit	0.5–38	1991–1992	7–10	Ca-Mg-HCO_3	0.3–1	As, Sb
2. Carbonate-sulphidic ore veins in Paleozoic rocks						
Rudňany, Mier shaft*	16–25	1988–1997	8–17	Mg-Ca-HCO_3-SO_4	1.4	Sb,As,SO_4
Bindt, František adit	3.4–18	1985–1997	6.6–8	Mg-Ca-HCO_3	0.4–0.8	–
Slovinky,Alžbeta adit*	13–20	2000	8–9	Mg-Ca-SO_4-HCO_3	1.4–1.9	Fe, Mn, SO_4, As, Sb
Rožňava *	8.7–10	1991–1999	9–16	Ca-Mg-Na-HCO_3-SO_4	0.9–1.2	Fe, Mn
3. Metasomatic siderite deposits in Paleozoic rocks						
Nižná Slaná mine*	19	2000	9	Mg-Ca-SO_4-HCO_3	0.5–8	Fe,Mn,SO_4
4. Metasomatic magnesite deposit in Paleozoic rocks						
Dúbravský masív deposit*	35–45	1989–1990	15	Mg-Ca-HCO_3	0.4–0.5	–
Bankov*	12–25	1981–1988	18.5–21	Mg-Ca-HCO_3		–
Podrečany*	18–20	1980	12–14	Ca-Mg-HCO_3	0.2–0.4	–
Burda*	12–13	1959	12.5–13	Ca-Mg-HCO_3	0.9–1	–
5. Metasomatic talc deposit in Paleozoic rocks						
Mútnik*	3.3–9.4	1995		Ca-Mg-HCO_3		–
6. Stratiform sulphidic (pyrite) deposits in Paleozoic rocks						
Smolník, Pech shacht	6	1999	15	Mg-Fe-SO_4	4.9	pH, SO_4, Al, Cu, Zn
7. Stratiform uranium deposits in Paleozoic rocks						
Novoveská Huta, Vodná adit	2.5–10	1994–1998	9–10	Ca-Mg-HCO_3-SO_4	0.7	Ra, U, Rn, SO_4, Fe, Mn
8. Gypsum and anhydrite sedimentary deposits						
Novoveská Huta Tollstein	10–15	1987–1993	8–9	Ca-SO_4	1.9–2.2	SO_4
9. Sedimentary Mn deposits in Paleogene sediments						
Kišovce-Švábovce	4–20	1973–1995	13–16	Na-Ca-HCO_3 +CO_2	2.5–4.1	Fe, Mn, As
10. Au-Ag and polymetalic ore veins in neovolcanic rocks						
B. Štiavnica-Hodruša district VDŠ adit	100–130	1993	16–18	Ca-SO_4	1.2–1.3	SO_4, Fe, Mn, Zn,
Kremnica district, KDŠ adit	70–100	1987–1988	19–20	Ca-SO_4	1.5	SO_4
11. Hg mineralization in neovolcanic rocks						
Dubník Hg	1.2–2.5	2002	9–9.7	Al-Ca-Fe-SO_4	0.9–1.2	pH, Al, Fe, Mn, Zn, Co
12. Noble opal mineralisation in neovolcanic rocks						
Dubník opal	0.5–1	2002	7	Al-SO_4	0.8	pH, Al, Fe, Mn, Zn, Co
13. Coal deposits in neogene sediments						
Nováky*	112–156	1992–1998	15–25	Na-HCO_3	0.3–0.8	SO_4
Handlová*	116–156	1992–1998	15–28	Ca-Mg-HCO_3	0.5–1	SO_4, Fe, Mn, As
Cígeľ*	128–160	1992–1998	10–19	Ca-Mg-HCO_3	0.4–1.3	SO_4
Modrý Kameň* (mine / boreholes)	48–77 97–164	1979–1983	18	Ca-Mg-HCO_3	2–4	SO_4
Gbely* (mine / boreholes)	16–24 2.6–10.1	1990–1996	15–22	Ca-Mg-HCO_3	0.75	Fe, Mn, NH_4
14. Salt deposits in neogene sediments						
Prešov-Solivary*	0.5–0.6	1800–1979		Na-Cl	310	Na, Cl, SO_4

Mine Water Exploitation

In the past, mine waters were mainly used in mining technology, but nowadays, many abandoned mine water discharges are used for drinking purposes, mainly in the Slovenské rudohorie Mts. and Central Slovakia neovolcanities region (Cicmanová et al. 1999). Utilisation of other mine water discharges is limited mainly by elevated metal concentrations (most often Fe, Mn, Sb, and As), or SO_4, and TDS.

The thermal energy potential (TEP) of the largest mine water discharges reaches values of some MW, so exploitation of their geothermal energy is possible using heat pumps (Bajtoš 2001). A specific problem is the need to isolate the most concentrated TEP resources; this can be done by pumping the groundwater to the surface through the mine workings or a borehole. The Kremnica thermal swimming baths, which are supplied through an underground borehole outflow (Q = 39 L/s, t_{water} = 56.8 °C) from the Ľudovít shaft, is an example.

Mine Waters and Environment

From an ecological point of view, the most important problems are the long-term effects of mining on groundwater circulation and the contamination of surface waters. Groundwater levels in Paloeozoic rocks have been lowered, affecting nearby domestic wells. Similarly, the irreversible drying up of the exploited "Markus" spring (the Spišská Nová Ves town water supply) by gypsum mine drainage in Lower Triassic sediments has been well documented. The "Teplá voda" spring yield (the Jelšava town water supply) has being gradually decreased by the "Dúbravský masív" magnesite mine dewatering but it is anticipated that after future mine flooding, it will probably be renewed. The dewatering of the Kišovce-Švábovce Mn mine depressed groundwater levels in the surrounding paleogene sediments and the level of the mineral waters in the underlying Triassic carbonate structure. The exploited "Tatra" mineral spring was irreversibly destroyed during the mining; the mineral water now flows out of the mine.

Mine water issues can contaminate surface water bodies. An extreme example is the contamination of the Smolník stream by acidic metal-sulphate mine waters from the Smolník pyrite deposit (Slovenské rudohorie Mts.), with concentrations of 0.4–1 g/L Fe, 0.03–0.14 mg/L Mn, 0.1–1.3 g/L Al, 3–90 mg/L Cu, 5–140 mg/L Zn, and 2.7–4.2 g/L SO_4. Acid metal-sulfate mine waters also contaminate streams in the Dubník district (the Slanské vrchy Mts.). Mine waters of quartz-antimony veins have high Sb and As content (tens of mg/L). Mine waters of U-Mo mineralisation in the Novoveská Huta, occuring together with carbonate-sulphidic veins, introduce a special type of contamination (tenths of Bq/L ^{226}Ra, hundreds of Bq/L ^{222}Rn).

Received June 26, 2004; revised manuscript received November 18, 2004; accepted November 19, 2004

Austria

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Historical Situation

Austria has a long tradition in mining. The first underground mining (for chert) commenced about 4000 B.C., and salt was mined from approximately 1000 B.C. From the 11th to the 15th centuries, mining played an important role in Austria's economy.

Water can be of benefit in mining, for example, in the solution mining of salt. However, it can also cause problems. In the 16th century, the Röhrerbühel copper mine was amongst the world's deepest underground operations (with an 800 m deep vertical shaft), and suffered significant problems with water ingress. The Schwaz copper-silver mine also had problems with water ingress and developed an elaborate water haulage system to deal with it. In 1361, a terrible water inrush stopped operation of the Oberzeiring silver mine (Weber 1997).

Current Mining

Today, mining contributes only 0.5% to the Austrian Gross Domestic Product. However, the remaining 99.5% of the GDP would not be possible without the availability of those mining products. Indeed, despite the fact that some metals (iron ore, tungsten), industrial minerals (graphite, gypsum, kaolin, magnesite, salt, sulphur, talc, oilshale) and energy fuels (lignite, natural gas, oil) are mined in Austria, most of the minerals and metal commodities (such as ferro-alloy metals) have to be imported.

The exploration, exploitation and (underground) storage of mineral raw materials, as well as their beneficiation, are governed by the Mineral Act (MinroG), which was enacted 1 January 1999 (Mineralrohstoffgesetz 1999). Key articles regulate miner safety, protection of the environment, protection of mineral deposits during production, and usability of the surface after the mine closure. The utilisation of mine water is regulated in § 106 of MinroG.

Mine Water Management and Risk Assessment

There is a strong need for mine water risk assessment. As a matter of fact, controlled drainage of mine waters is of crucial importance for the entire mining period as well as post-closure. A careful observation of changes in the inflow of water into mine voids allows the timely recognition of risks and the development of methods to minimize their impact. The chemical composition of mine waters can also greatly impact the environment. In addition, geotechnical problems can result from water in alpine areas. Most problems arise at old, abandoned mines, as most of those mines were not closed "*lege artis*".

The Austrian mining authorities require quantitative and qualitative mine water balances for underground operations. A mine water balance may be defined as the difference between the total of inflowing water into the mine openings and the total amount of natural drained or pumped water at the main mine entrance.

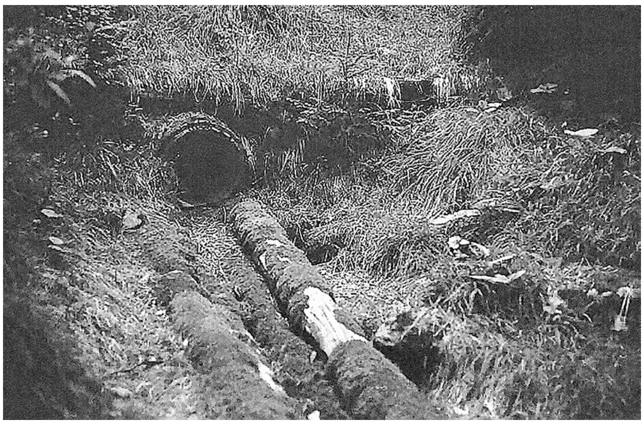

Figure 7. Water outlet before water outburst in 1998

Figure 8. Same water outlet after water outburst

Quantitative Balances

Sufficient knowledge of the hydrogeological situation is essential to define necessary safety measures during or after mining. Such information includes: where the main water inflows occur; the (maximum) variation of the inflow with respect to precipitation; the amount of mine water that can be freely drained; and the amount to be pumped. Insufficient knowledge about the hydrogeological situation can result in incorrect conclusions and cause serious problems.

An example of this is the blockage and collapse of some old lead-zinc mine adits that had operated in the 19th century and were closed about 50 years ago (Figures 7 and 8). The main host rock for the mineralization is a karstic limestone. At most times, there was no significant water inflow, but in wet periods (such as after snowmelt), water drained out of

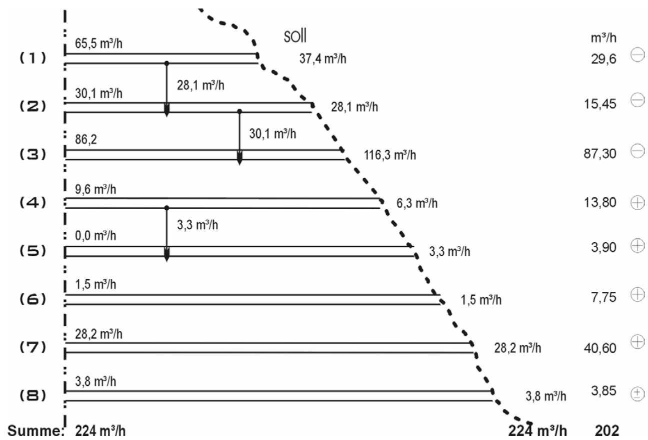

Figure 9. Quantitative water balance

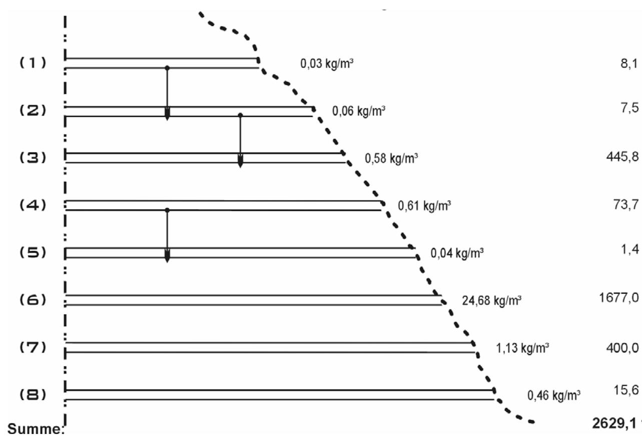

Figure 10. Qualitative water balance: mass balance of total dissolved solids.

the deepest adit, which was about 100 m above the bottom of a valley. As the deepest adit was water-bearing only periodically, concrete tubes had been inserted to drain the mine when necessary. No-one noticed when some tens of meters of the part of the adit near the surface became completely blocked with fine-grained material. There was no evidence of any malfunction of the drainage system until 1999, when due to a very wet autumn, lots of snow that winter, and an extreme wet spring, the inner adit became completely flooded. At midnight, 26 June 1999, a huge explosive water outburst occurred, producing a mudflow that flooded the valley. Fortunately, nobody was hurt, but this example shows clearly that sufficient knowledge of the hydrogeological regime is essential. Additionally, underground mines should be drained properly. In particular, adits in water-bearing carbonate rocks should remain open to allow water to freely drain.

Qualitative Water Balance

Knowledge of the chemistry of mine waters is of crucial importance for exploration and for the utilization of mine waters. However, changes in the chemistry of mine waters, especially those draining evaporite deposits, may indicate possible problems in the stability of mining openings.

Solution mining makes use of the natural solubility of salt by controlled solutions. However, uncontrolled dissolution can adversely influence the stability of pillars between the mining voids. If uncontrolled water contacts underground workings, then parts of the underground system may destabilize. The resultant subsidence can induce more unplanned infiltration and increased instability. Due to this, any water inflow into an evaporite mine has to be drained properly, so that contact between water and soluble materials is avoided.

A detailed quantitative water balance (Figure 9), comparing ingress water into the mine system and drained water at the portals, should be done at least twice a year (during dry and wet periods). In evaporite mines, either operating or not, there is also a need for qualitative balances (Figure 10), to check whether salinity of the water is stable or not. An increase in total dissolved or suspended solids may indicate uncontrolled dissolution. For example, the quantitative balance in Figure 9 clearly shows negative balances in the upper levels and positive balances in the lower levels, due to malfunctions in the drainage system.

Though most Austrian mine waters are known to be of good environmental quality, there are some localized areas where abandoned mines cause affect the receiving streams. One example is the above-mentioned abandoned medieval silver mines near Schwaz in Tyrol, where elevated antimony concentrations have been found recently (e.g. Wolkersdorfer and Wackwitz 2004). Another source of antimony, as well as some other heavy metals, is the former Brunnalm mining area in Tyrol, where elevated concentrations were found close to the old mine workings (Schaffer at al. 2001).

Conclusion

Quantitative and qualitative mine water balances, which should be tailored to the specific type of operation, are a simple but effective tool for an early diagnosis of risks during operation of mines. They are also an important prerequisite for mine closure. Therefore, this method of risk assessment is essential for any mining operation and is part of the approval procedure for exploitation permits.

Received May 18, 2004; revised manuscript received November 16, 2004; accepted November 16, 2004

Hungary

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Mining History

Mining that occurred in Hungary during prehistoric times (flint) through the medieval ages (e.g. precious metals, salt) did not significantly impact ground water. Mine water pumping only became significant at the beginning of the 20th century.

Classic Issues

Sizable mineral reserves such as brown coal, manganese, and bauxite are located in basin areas of a karstic massif called the Transdanubian Mountain Range. As these reserves are situated near or beneath the water-table, security of mining operations required continuous mine dewatering.

After World War II, three different methods (passive, preventive, and active) of mine dewatering were applied in Hungary, depending on the risk to mining. In the passive case, only the amount of water that flowed spontaneously into the galleries was pumped out. The preventive case was enforced when there was a pending danger of an unexpected water in-rush from the surrounding network of large underground cavities; this required that controllable pathways be opened by horizontal or oblique fore-drilling to direct the water into pre-arranged dewatering facilities. When considerable depression of the water table was required, active dewatering was implemented prior to shaft-sinking; this required the drilling of large diameter (up to 5 m) pumping wells.

Between the mid-1970's and mid-1980's, approximately 860,000 m³ per day (600 m³/min) of karst water was discharged from the mining operations of the Transdanubian Range (Figure 11).

Adding in the water supply needs of the region (200 m³/min) meant that about 800 m³ were being removed every minute. However, the long-term mean groundwater recharge for the region is only about 600 m³/min. As a result, a significant depression in the karst water table occurred over a total aquifer region of 8,000 km². The average depression was 30 – 50 m, but near mines, depressions of 100 – 150 m were observed. By the end of this period, previously existing water supplies had been drained. Moreover, the famous thermal water springs, which had been used for centuries as health spas and then as important tourist attractions, were significantly affected.

To replace the damaged local provisions, new, large-scale water supply projects were installed using the existing mine dewatering structures (Figure 12). Unfortunately, 5 to 10 years after this was done, the extraction of underwater mineral deposits became less profitable. Combined with political considerations, the authorities and the mining companies mutually agreed to close the mines.

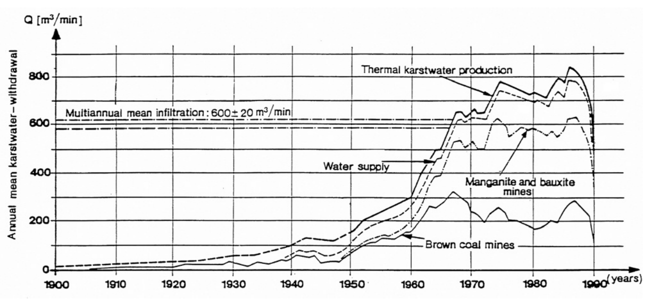

Figure 11. Annual mean karstwater withdrawals from the main karst of the Trandanubian Central Mountains Range from 1900 to 1991

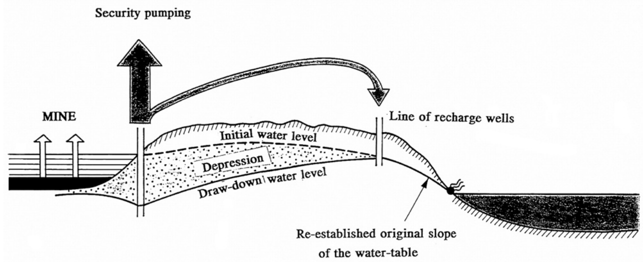

Figure 12. Artificial recharge to restore the initial gradient of the water table and the discharge of the damaged thermal springs

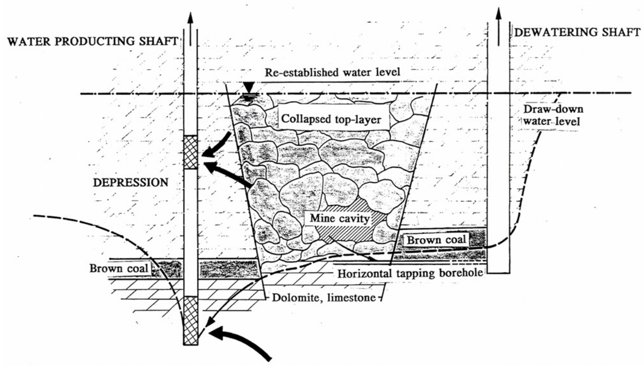

Figure 13. Closed brown coal mine as underground pollution source

Current Status

Prior to the decommissioning of the mines, the state authorities required the relevant companies to perform a clean-up operation. This operation involved bringing to the surface those substances which would have harmful effects when mixed with groundwater (Figure 13). However, only partial clean-up was accomplished before the companies declared bankruptcy. The security-equipment (i.e. roof supports, ventilation, light, pumps, transport facilities and related electrical network) had to be left in place as they could not be retrieved safely (collapse and water intrusion). Consequently, several thousand tonnes of iron structures, 10–20,000 m³ of wooden structures, hundreds of tonnes of hydraulic oil, and considerable amount of various chemical substances (fire extinguisher material, plastics used for sealing, etc.) remained there.

Analysis of water samples taken from the subsequent pumpings, which were intended to purify the affected areas, revealed that the rock-material itself was the source of a number of contaminants. The most prominent natural pollutant was pyrite, which was dispersed throughout the host-rock. During the mining operation, pyrite in the fractured rock was oxidized as a result of the forced ventilation. Once inundated by the recovering water table, the acid salts dissolved; the acid solution in turn dissolved other materials left in the mines.

Pollutants originating from the altered host-rock are relatively inexhaustible. Their overall contribution was found to be at least 1,000 times that of the man-made pollutants in the pumped water during the control period, which lasted several months. This has serious implications on the potential use of groundwater for water-supply purposes.

Several techniques were applied to protect the water-supply facilities against these underground pollution sources: Artificial barriers (injected concrete screens) were created to seal up various mine cavities in order to reduce circulation, creating dead areas of water. Pumping the water to the surface, treating it and then injecting it was also tried but was found to be of limited success. Initial results were promising but later it was shown that the pumping only created "short circuits" in the tunnels, allowing uncontaminated water to arrive at the surface. Once the pumping ceased, pollution resumed. The most successful method was a hydraulic defence. This involved continuous long-term pumping to create small-scale local depressions in order to keep the contaminated water in place (i.e. away from the water-supply area).

The costs of these remedial pumping operations, which commenced in 1991, had to be paid by the state (the tax-payers). The mining companies responsible for causing these environmental problems could not be held liable as they had dissolved without any legal successor. The environmental impact from the mining and particularly from the mine decommissioning is significant and will continue for at least several decades.

Focus for Future Research

The lesson to be learned from this experience is that adequate planning for mine decommissioning (which is a complicated procedure) must be formulated in detail prior to licensing mining projects. On-going reviews of the decommissioning procedures should be carried out during the life of the mine, as new problems and information arise. Furthermore, a budget for the mine decommissioning must be retained in the care of the licensing authority, and the mining company must be required to contribute to it on a regular basis.

Received April 22, 2004; accepted November 20, 2004

Italy – Some Examples of Mine Water Problems in Tuscany

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Historical Situation

The mining history in the Tuscany region (Central Italy) is representative of mining activities in Italy, including the stone sector. Tin, copper, lead, zinc, and iron deposits are present in central and southwestern Tuscany in the Metalliferous Hills and on Elba Island (Figure 14). Today, almost all of the mines are closed because of mineral exhaustion or because of unfavourable economic and environmental conditions; the exceptions are the numerous marble and sandstones quarries of Carrara and the rock salt mines of Volterra.

Many sites were exploited from at least 1000 B.C. up to the 1970s and 1980s. Evidence attests to exploitation during the Etruscan, medieval and modern periods (in particular, the historical literature

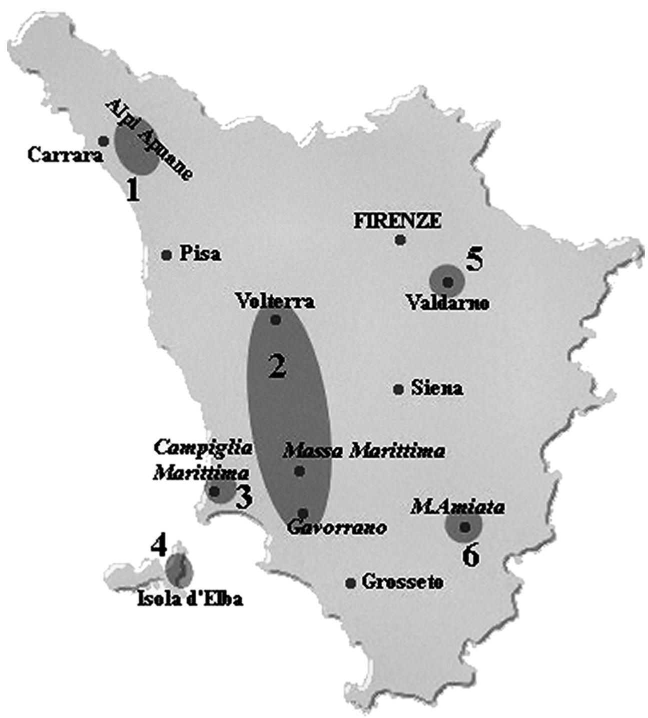

Figure 14. Location of the principal mining areas in Tuscany: 1) mines of the southwestern Apuan Alps; 2) Metalliferous Hills; 3) Campiglia mines; 4) Elba mines; 5) Santa Barbara Upper Valdarno lignite; 6) Mt. Amiata (the most important mine is in Abbadia S. Salvatore village)

by Vannoccio Biringuccio, 1480–1538). Some historical mines in northwestern Tuscany (Apuan Alps) exhibited great mineralogical variety, but ore quantities were limited (with the exception of barite and possibly silver). More recently, mining since the end of the 19th century up to the 1980s was based on pyrite, iron, barite, cinnabar, and lignite deposits (Tanelli 1983). The cinnabar mines were situated around Mt. Amiata. In this ancient volcanic area and in the northern area of the Metalliferous Hills, geothermal resources are very important. Lignite was exploited from a large open mine in Saint Barbara, closed some years ago (Upper Valdarno, near Florence), and from Ribolla underground mines, near Grosseto, closed down after a serious accident which resulted in 45 fatalities (4 May 1954). Pyrite mining mainly supplied the chemical industry, and subordinate iron production, together with Elba mines (limonite and hematite). The pyrite mines are concentrated in a restricted area in the northern Grosseto district; of these, Gavorrano, Fenice Capanne, Niccioleta, and Campiano were the principal mines. The Gavorrano was one of the largest pyrite mines in Europe and is famous because it represented the historical evolution of mining techniques in small drifts. In contrast, Campiano represents modern mining based on wide rooms.

The main geological context of the Tuscan mines, in particular in the Colline Metallifere area, is represented by the contact between the carbonate units and the granite, granodiorite, and quartz-monzonite intrusions. The area is characterized by NNW–SSE elongated post-orogenic basins developed over an antecedent extensional horst and graben structure consequent to the Thyrrenian sea opening. Typical of this tectonic province are intrusive bodies, with decreasing age from west (7–8 My) to east (4 My), the emplacement of which was followed by more extension. The activity of the province is attested by important geothermal fields (Larderello, Amiata) located within a major mining district (Campiglia, Elba Island, Amiata, Abbadia, in Figure 14).

Figure 15. Water pumping system at the Gavorrano underground mine (at present, about 80 L/s)

Mine Water Management and Problems

At present, except for rock quarries, the only working mines are for rock salt (near Volterra, by Solvay S.P.A.). Large quantities of fresh water from the Cecina river and from wells are utilized (10^6 m^3/year) to extract, by dissolution, about 2.10^6 ton/year of salts, for soda and chlorine producing. This activity results in hydrologic and hydrogeologic problems, in particular ground water pollution and subsidence.

Although all other mines have been closed, some for more than 30 years, water pollution and acid waters can still be observed, especially around small dumps. This is due to deficient environmental practices. The most serious problems are linked to the presence of large tailings ponds (at Gavorrano, Campiano, and Fenice Capanne) and above all, the interruption of dewatering, leading to water table rebounds and flooding in the pyrite mines.

Table 3 characterises some of the large Tuscan mines that have groundwater problems. In particular, the mine pool in the Campiano mine, which closed down in 1995, feeds a spring with a discharge of about 16 L/s of acid mine waters (in this case, mixed with geothermal waters). The polluted water has a pH of 4 and elevated concentrations of sulphate and metals

Figure 16. Water sampling at the -110 m level of the Gavorrano mine

Table 3. Characterization of some Tuscan mine water issues

Mine	Minerals extracted	Mining method	Volume mined (mill. m^3)	Filling (mill. m^3)	Theoretical voids (mill. m^3)	Mine waters	Discharge (L/s)	Acid water
Gavorrano	Pyrite	Horizontal cut and fill	10.12	6.5	3.62	Pumped	60–120*	No
Niccioleta	Pyrite	Sub-level	5.06	0	5.06	Flooded	230	Yes/No
Campiano	Pyrite	Filled sub-level	1.5	0.64	0.86	Flooded	16*	Yes
Abbadia San Salvatore	Cinnabar	Horizontal cut and fill	6	3.18	2.82	Flooded	-	No

* Presence of thermal waters

(iron, copper, zinc, and arsenic), and produces serious environmental problems in the Merse river, which happens to be an area of particular natural and touristic interest.

The land above the decommissioned Gavorrano mine is affected by failure phenomena (subsidence and sinkholes) caused by the failure of overburden strata above mine voids or the collapse of drifts and shafts (Crosta and Garzonio 1998). It is anticipated that these problems will worsen due to the future water table rebound and the rebirth of hot springs (interrupted in 1957) in the Bagno di Gavorrano Village, where the ancient thermal springs site are now surrounded by a large urbanized area. At present, about 80 L/sec are being pumped out of the mine (Figure 15); when dewatering stops, the flow leaving the ancient thermal zone could be about 30–40 L/sec, which could provoke subsidence events and soil stability problems affecting the foundations of numerous buildings.

Ongoing Activities in Mining Areas

Over the last decade in Tuscany, the heritage of mining has been recognized as culturally important; the Elba mining area is included in a UNESCO provisional list of the world’s prominent tourist parks. Many of the mine sites are historically and geologically interesting. Others are part of a natural landscape, with archaeological, monumental sites, karst or woody areas, etc., and with important thermal springs or circulations. Recently, the mine park of Metalliferous Hills was instituted by a national law and, consequently, is sustained by national and European funds. In this area, the study of mine water quality, discharge and re-utilization is an important research topic (Garzonio 2000) because it is important to a profitable rehabilitation of the mining areas and its water resources (fresh and thermal waters; at present, the temperature of the mixed waters is 38 °C). The results of these studies and recent situations concerning the circulation, quality, and discharge of the mine water have highlighted the effects of the controlled water rebound and the complex measures necessary to stop dewatering safely. Water rebound is being analysed on the basis of available historical and recent data, both for its hydrodynamic influence and the consequences it will have on restoration of water resources. Different uses and possible actions are proposed, taking into account thermal, chemical, and discharge characteristics, as well as local planning objectives. A recent study (Garzonio and Affuso 2004) described all these aspects and highlights the great importance of continuously monitoring the water level and water chemistry changes, both during and after completion of mining (Figure 16). It stresses the need to install monitoring wells and automatically monitor the water levels, to perform new geophysical tests when the water table rebounds, and new chemical and isotopic analyses, pumping separately and contemporaneously in different pumping systems. This geognostic campaign started during the summer of 2004.

Many rehabilitation projects will be supported by Italy’s national “watershed planning” law and the regional environmental departments that are now responsible for water resource management planning.

Received June 6, 2004; revised manuscript received November 21, 2004; accepted November 22, 2004

PADRE – Partnership for Acid Drainage Remediation in Europe

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Introduction

Acid drainage is the single greatest environmental challenge in the mining sector. Within Europe, the problem is manifest at both active and abandoned mine sites, from as far north as Spitzbergen (only 640 km from the North Pole) down to the arid regions near the Mediterranean coast. Given the present status of mining in Europe, it is not surprising that most European mine water problems are associated with abandoned mines, thousands of which can be found in nearly all European countries. Similar problems have been recorded worldwide, though in most other continents, a greater proportion of the problems are being tackled at active mining sites.

When policy makers within the European Commission began the ongoing process of preparing a European Union Directive on mining wastes, they had little awareness of the nature and scale of acid drainage problems associated with mine voids and bodies of mine waste. Fortunately, a process of awareness-raising soon ensued, facilitated in part by two very timely research projects of the European Commission's 5th R&D Framework Programme (PIRAMID and ERMITE), in which the authors were heavily involved. The experience of engaging with policy making made it abundantly clear that future mine drainage research within Europe needs to be coordinated in order to avoid unnecessary duplication of effort, both within and beyond Europe. A similar realisation at the global scale led to the formation first of INAP, and then of the Global Alliance, in which INAP is partnering with relevant organisations from several continents, most notably ACMER (The Australian Centre for Mining Environmental Research, Australia), MEND (Mine Environment Neutral Drainage, Canada), and ADTI (Acid Drainage Technology Initiative, USA). The latest member of the Global Alliance is PADRE (Partnership for Acid Drainage Remediation in Europe).

What is PADRE?

PADRE is a "Permanent Commission" of IMWA, the International Mine Water Association. It was established by a formal vote by the IMWA General Assembly in October 2003. PADRE now has its own statutes and bye-laws, which are based on (and therefore consistent with) those of IMWA as a whole. PADRE's five objectives are:

1. To promote international best practice in the stewardship of water and soil at European sites subject to the generation and migration of acidic drainage.
2. To foster collaborative, international research and development into techniques for characterisation and abatement of acidic drainage in Europe.
3. To promote dissemination of knowledge of current best-practice and innovations relating to acidic drainage prevention and remediation, with particular reference to European conditions, including the evolving framework of relevant EU legislation.
4. To advance the training of present and future generations of European professionals who will engage in the art and science of acidic drainage prevention and remediation.
5. To actively collaborate with a Global Alliance of organisations based in other continents which share similar objectives.

Membership is open to all individuals and institutions working in acid mine drainage remediation and research, and all European IMWA members are automatically members of PADRE, unless they request not to be. Currently PADRE has 140 members, of whom the majority are working in acid mine drainage remediation or research.

What has PADRE done so far?

PADRE was publicly launched during IMWA's Mine Water 2004 conference, in Newcastle Upon Tyne (UK) in September 2004. In the run-up to that Conference, founding members of PADRE were engaged in the production of the ERMITE and PIRAMID guidelines, as well as a passive treatment database, which are all available through the internet. Furthermore, course notes of a mine water remediation course within the EU IMAGE-TRAIN network have been produced and engagement with several symposia and congresses were initiated.

Planned Activities

To educate junior researchers and practitioners in the acid mine drainage field, PADRE plans to seek funding from European Commission sources (including the EU objective 4 "Know-How Fund") to organise training courses at various locations in Europe.

PADRE will actively contribute to the IMWA 2005 Congress in Oviedo/Spain and the IMWA 2007 Symposium in Portugal. The founder-Chairman of PADRE serves on the Scientific Committee of the 2005 "Securing the Future" conference to be held in Skellefteå (Sweden). Furthermore, PADRE will co-organize the Bergakademie Freiberg Meeting on "Mine Water Treatment" in June 2005.

All PADRE information will be disseminated through the IMWA journal "Mine Water and the Environment" and the PADRE web page www.PADRE.IMWA.info. Furthermore, the European knowledge gathered within PADRE will be disseminated through the Global Alliance, which was launched in July 2003 for collaboration between various institutions word-wide. Until the next General Assembly of IMWA, at which the membership of the PADRE Council will be put to a vote, the provisional Executive Council of PADRE will consist of Paul Younger (UK; Chair), Rob Bowell (UK; Treasurer and Vice-Chair), Christian Wolkersdorfer (Germany; Secretary), Ingar Walder (Norway), and Ludo Diehls (Belgium).

If you are interested in obtaining up-to-date information about acid mine drainage issues in Europe, or if you want to contribute actively to the partnership, feel free to contact the PADRE Councillors through PADRE@IMWA.info.

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