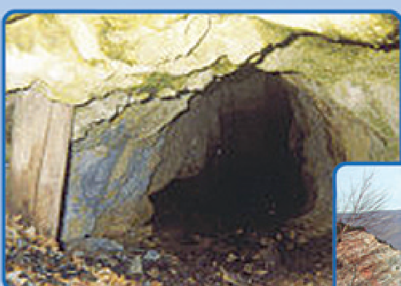
MINING, MINING WASTE AND RELATED ENVIRONMENTAL ISSUES: PROBLEMS AND SOLUTIONS IN CENTRAL AND EASTERN EUROPEAN CANDIDATE COUNTRIES

A report of JRC Enlargement Project

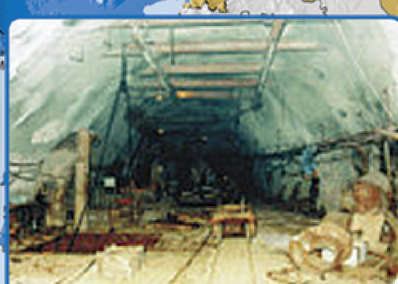
PECOMINES

Inventory, Regulations and Environmental Impact of Toxic Mining Wastes in Pre-accession Countries

G. Jordan and M. D'Alessandro Editors







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Preface

Mining for resources to satisfy energy and raw material requirements can seriously alter the composition of the landscape, disrupting land use and drainage patterns, contaminating soil and water resources, and affecting habitats for wildlife, often with trans-boundary effects. Recent events have brought back to the attention of the media, public and decision-makers the problem of potential emissions from thousands of mining sites in Europe, highlighting the priority of prevention as opposed to aftercare. In this context, the European Commission has taken the initiative for the preparation of a proposal for a Directive on the management of waste resulting from prospecting, extraction, treatment, and storage of minerals.

The understanding of the full range of pressures from mining sites can be first achieved through the compilation of inventories for closed and abandoned mines and quarries. Screening and ranking should be then based on impact assessment and prevention of water and soil pollution.

On European level, there is a substantial gap in information on the location and management of mining and quarry wastes. The relative share of mine and quarry waste in the total solid waste generated is known to be much higher in Candidate Countries than in the EU Member States. Involvement of these countries in the development and implementation of new EU legislation is therefore very important. Country reports in this book demonstrate that relevant mining and environmental information is not lacking, but it is often scattered among different institutions and available in different formats not easily comparable.

This publication is a result of the PECOMINES project, which contributes to the Enlargement Action launched by the JRC to support the implementation of the acquis communautaire through focused research initiatives. Country reports have been contributed by national experts of the PECOMINES Steering Committee. Country reports are an important tool of the PECOMINES mine waste inventory methodology: they provide a means of including expert knowledge in the inventory both at the national and site scales.

The ten contributions together with the introduction and concluding chapters in this book give the reader an overview of the status of mining, mining waste and related environmental problems and solutions in Central and Eastern European Candidate Countries.

Giovanni Bidoglio
Head of the Soil and Waste Unit
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About This Book

In order to provide an efficient way for communicating mining waste related problems on the European scale and to facilitate the review of current situation, the PECOMINES project publishes the present volume on the status of mining, mining waste and related environmental problems and solutions in Central and Eastern European Candidate Countries. Each country represented by PECOMINES Steering Committee (SC) members contributed a chapter to the volume published by the Soil and Waste Unit, IES of the Directorate General Joint Research Centre, European Commission. The objectives are (1) to obtain a country summary on total mining waste streams and associated environmental problems at the national level, and (2) to develop detailed descriptions of a few selected 'hot spots' that are mining sites or areas having significant proven or potential environmental impacts of major concern in the country.

Section 1 Introduction: 'Mining and Mining Waste: Pressures, Impacts and Responses in the European Union and Candidate Countries' provides an overview of the key environmental issues associated with mining and mine waste management. The chapter follows the Proposal for the Mine Waste Directive and discusses its three main points of reasoning for new legislation: scale of the problem, problems of accidents and problems of abandoned mines. A description of the most important ways of addressing related problems, such as impacts, remediation and long-term monitoring follows. Response to these problems by European legislation and the industry is then discussed, and finally the PECOMINES integrated research approach is presented briefly. The last section describes the inventory approach of the PECOMINES project because the present volume is an integral part of the inventory strategy and results of the project. Throughout the presentation emphasis is put on illustrative examples from the Candidate Countries in the context of discussed topics. The objectives of the chapter are (1) to raise some new points and highlight some special aspects of mining not commonly presented elsewhere, and (2) to set the scope and framework for the presentation of Candidate Country Country Reports on mining and mining waste in Section 2.

Section 2 contains the Country Reports. Each country chapter starts with a report on mining waste situation at the national level followed by the detailed characterisation of a few selected 'hot spots' for the contributing Candidate Countries: ***Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.***

Each country report begins with summary data and statistics for the country on the mining waste and description of related environmental and socio-economic problems at the national level. This is followed by scope of the problem describing the environmental and socio-economic scale of the problem and giving priority in relation to other environmental problems. Next, a list and brief description of national databases on mining, mining waste and relevant environmental information is provided. Finally, investigation methods for (1) the inventory of mining sites and for (2) the assessment of active and abandoned mining sites and related environmental problems are presented.

In the second part of a country chapter illustrative cases of selected 'hot spots' are provided. This enables the demonstration of investigation methods and the presentation of the scale of problems in terms of waste quantities, socio-economic aspects, spatial extent, potential risks and financial needs for environmental management. These detailed case studies should be useful for the non-expert of mining to see closely and to understand 'on-hand' the problems of mining. For each site mining history and investigation methods including past and present investigation efforts, data and databases and monitoring efforts are described. This is followed by description of the hazard source, as well as the conditions of the receiving environment and the impacts on hydrosphere, soil, ecosystems and atmosphere. Regional socio-economic impacts are also described for the selected sites, and an outlook for future tasks and needs for mitigation of mining waste environmental risk and impact is provided.

Finally, each chapter is concluded for on-going major efforts and plans at the national level, and future tasks and needs for mitigation of mining waste environmental risk and impact in the country. 'References and important sources of information' are intended to list documents and web sites that provide further important information not detailed in the text. Abundant charts, tables, maps and photos make each report and the whole volume easy to read.

Section 3 Summary: 'Mining and Mining Waste: Problems and Solutions in the Central and Eastern European Candidate Countries' presents conclusions drawn from the country reports and the PECOMINES project. Experiences of the recently closed historic mining in the Candidate Countries summarised in this volume provided an excellent ground for identifying some of the most important characteristics specific to mining. This is briefly presented in section 'Problems: why mining?' The following section 'Solutions: research and methodological development' briefly reviews major national and international efforts and their results and presents a summary of the main environmental research methods that have been applied and tested for assessment of mining for environmental decision support. This section provides a state-of-the-art review of current efforts, methods and results that can be used to identify major trends and to develop the necessary tools for supporting new European legislation. This methodological framework helps the reader to put in context the final section of the chapter 'Solutions: experiences in Eastern European Candidate Countries' that tries to summarise efforts and results in these countries for answering mine waste problems using selected illustrative examples. References are intended only to provide some key links to further detailed information.

For receiving the mine waste inventory information, a crucial role was given to the Steering Committee of the project - 18 experts from 10 Candidate Countries, who assisted in finding and interpreting appropriate information sources. The present volume consists of country reports on mining and mining waste contributed by SC members.

The final format of the volume was agreed on the 3rd PECOMINES Steering Committee Meeting held in Ispra in January, 2003. The ten contributions together with the introduction and summary in this volume is intended to provide an overview of the status of mining, mining waste and related environmental issues, problems and solutions in Central and Eastern European Candidate Countries for the mining and environmental professionals and non-expert policy and decision makers.

The Editors
Gyozo Jordan
Marco D'Alessandro

Ispra, 14 September, 2003

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SECTION 1

INTRODUCTION

Mining and Mining Waste: Pressures, Impacts and Responses in the European Union and Candidate Countries

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Introduction

Mining waste is known to be amongst the largest waste streams in the European Union and it ranks first in the relative contribution of wastes in many Central and Eastern European Candidate Countries. There is a substantial gap in consistent information on European level, how mining wastes in EU member states and Candidate Countries are managed, what are their major hazards and where the sites generating the greatest hazards are located, including abandoned mines. This information is needed to assess the whole range of environmental impacts caused by mining waste in a coherent way across the different policies related to the protection of water and soil resources, for instance. Presently no reliable synoptic picture of number, extent, distribution and emission quantities from mining waste sites exists, neither for EU member states nor for the Candidate Countries. Therefore, the core task lies in the harmonised collection, standardised compilation and uniform evaluation of existing and new data and in connecting these to data systems compatible with other relevant European spatial data sets.

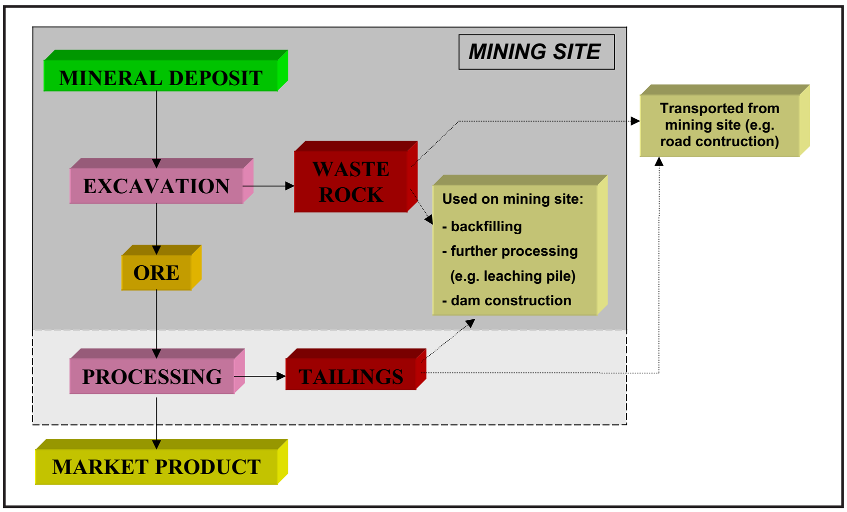


Figure 1. *Mine waste streams in the extractive industries. Dashed line indicates that processing can take place inside or outside of the excavation site (e.g. for bauxite mining) as well. Red colour indicates mining waste (waste rock and tailings).*

The key problems hindering sustainable environmental management of mining and mining waste are the following: (1) existing datasets are not comparable, (2) a lack of standard methods for collecting inventory data for baseline assessment, (3) a lack of standard methods for ranking mine sites on the basis of environmental risk assessment, (3) a lack of standard methods and networks for harmonized long-term monitoring, and (4) a lack of specific EU legislation that also considers trans-boundary problems. These lacking tools should be developed to address the most important aspects of mining and mining waste management [1]: (1) the spatial-temporal and material flow problem of mining and mining waste, (2) the problem of abandoned mines, (3) the problem of mine waste facility accidents, and (4) the long-term monitoring and aftercare of closed mines.

The scope of this chapter is waste resulting from the extraction, treatment and storage of mineral resources and the workings of quarries (***Figure 1***). Wastes of smelters and power plants are not included. However, environmental problems associated with mine wastes cannot be separated from the life cycle and material flow analysis of the mining industry. Also, for the efficient management of mining wastes relationships of industrial and environmental systems have to be considered. Therefore, in this chapter environmental issues are discussed in the context of the whole mining cycle and complete material flow pathways in order to establish a framework for the understanding of problems and possible solutions for mine waste management. This approach should also enable the comparison of various mine waste problems as well as problems associated with certain points of waste streams. The present chapter provides a framework for the detailed country reports in the volume.

The 'Proposal for a Directive of the European Parliament and of the Council on the Management of Waste from the Extractive Industries' [1], which was based on wide survey of European mining experts, identified three main reasons that justify harmonised legislation and the need for a separate EU Directive for mining waste management: (1) the large amount of wastes produced, (2) the catastrophic impacts of tailings dam accidents, and (3) the wide-spread problems caused by abandoned mines. The discussion below details these problems based on results of geo-scientific research and mine engineering developments.

Scale of the Problem

The three relevant scales to be considered for the control and regulation of mining waste are the scale of material flow, the three-dimensional spatial scale and the temporal scale.

Scale of material flow

Development of the society is impossible without mineral resources. Most of the elements used by our society come from the mineral extraction industry (76 out of 90 frequently used elements). These elements have natural global bio-geochemical cycles that are modified by human activity. In order to understand regional and global impacts, the liberation of elements from Earth's crust by the extractive industries has to be put into the context of these **global biogeochemical cycles**.

Understanding the global biogeochemical cycle of sulphur (S), for example, has an enor-

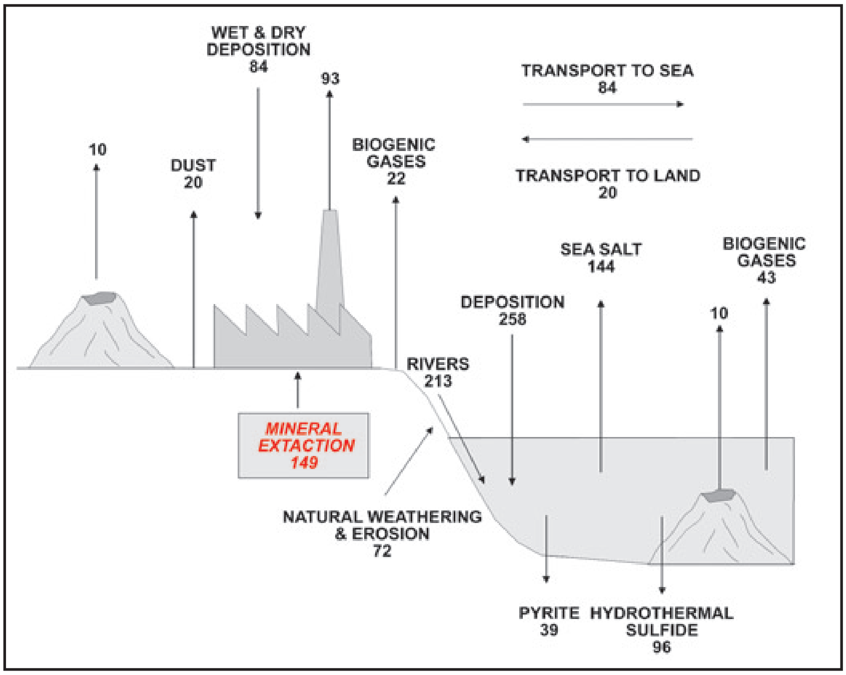


Figure 2. *The global S cycle emphasising role of extractive industries (after Schlesinger [2]). Figures in Mt/y. See text for details.*

mous economic significance. The major pool of sulphur in the global cycle is found in the crustal minerals, gypsum and pyrite (***Figure 2***) [2]. Many metals are mined from sulphide minerals. Sulphur is an important constituent of coal and oil, and large amounts of SO_2 are emitted during the smelting of copper ores. Understanding relative contributions of natural and anthropogenic SO_2 to the atmosphere is important for the evaluation of acid rain and acid rain impacts on natural ecosystems. Coal and petroleum extraction mobilises 149 Mt/y sulphur, more than double 100 years ago [3]. This amount is almost twice the naturally liberated sulphur from the earth's crust. Of this, about 93 Mt/y is released to the atmosphere, about twice the natural (volcanic, dust and biogenic gases) emissions (***Figure 2***) [2]. Human contribution is the largest to atmospheric sulphur releases. At the same time, 28% of the current SO_4 content of rivers is of anthropogenic origin, and Ivanov et al. [4] suggested that the present river sulphur transport (from air pollution, mining, erosion, other sources) of 200 Mt/y is about double that of pre-industrial conditions. In turn, excess acidic deposition is likely to cause changes in rock weathering, and in mobilisation of heavy metals in soils and sediments. Thus, global cycles of heavy metals [5] are coupled to the sulphur cycle primarily by liberation from metal sulphide ores by mining, metal-sulphide precipitation in anoxic conditions, and metal mobilisation due to sulphate-induced acidification in terrestrial environments. Analysis of global copper cycle shows, for example, that despite the relative insignificance of human inputs to the global copper cycle, anthropogenic atmospheric emissions due to smelting, fossil fuel combustion and other activities are 13.6 times more than from natural sources [5].

The European mining and extractive industry contributes about 7% of the EU GDP and feeds essential raw materials to all other EU industries at local, regional and EU-wide scales. The mining industry is not large in real terms (around 93bn Euro of raw metal production), but mineral raw material extraction is the first and most fundamental step in the

Table 1. Mine waste produced in the EU and Candidate Countries

10 EU Candidate Countries		Waste generation, 1000 tonnes: Mining and quarrying	Total
Bulgaria	1997	220,395	230,395
Czech Republic	1999	2,484	41,453
Estonia	1994	5,489	13,650
Hungary	1998	182	79,980
Latvia	1999	1,201	6,234
Poland	1999	49,48	138,572
Romania	1999	48,05	80,217
Slovakia	1998	no data	19,800
Slovenia	1995	70	2,659
EU Member States			
Austria	1993	3	39,200
Belgium	1996	619	34,852
Denmark	1998	0	12,233
Finland	1997	28	106,830
France	1992	75	213,700
Germany	1993	67,813	338,500
Greece	1995	3,9	33,130
Ireland	1998	3,51	58,410
Italy	1997	350	87,482
Luxembourg	1995	no data	1,987
Netherlands	1998	333	34,482
Portugal	1998	4,691	22,359
Spain	1999	22,757	77,000
Sweden	1998	63,818	87,600
United Kingdom	1998	118	378,000

life cycle of many products. The extraction of non-renewable mineral resources feeds a wide range of minerals and metals into the world's economies. Some minerals enter socio-economic systems as a source of energy such as coal, uranium and petroleum, some may enter the food cycle such as salt, fluorite, iodine and zeolites, and others are used for producing tools and structures. Mineral resources represent about 30% of the global world trade. At the same time the extracting industry produces extremely large amounts of waste. For example, the annual EU and Candidate Countries waste production from the mineral extraction industry is estimated to be around 400 Mt (***Table 1***). It is estimated that such waste amounts to about 29% of total waste generated in the EU each year [1].

Extractive industries produce their own **specific wastes**. These include materials that must be removed to gain access to the mineral resource, such as topsoil, overburden and waste rock, as well as tailings remaining after minerals have been largely extracted from the ore. The amount of waste depends on the type of mineral commodity, deposit type, geological conditions including thickness of overburden, and the mining and processing technology. For example, where only a pure vein is mined almost no waste may be produced. In the case of coal about 75% of the extracted material is coal and the other 25% are tailings, in general. This means that in Europe (EU-15 and Candidate Countries), where yearly 220 Mt marketable coal is produced, a total of about 70 Mt tailings is generated each year [1]. In certain lignite mines the ratio of overburden to lignite is around 5:1. That means that in the case of the largest lignite site about 200 Mt overburden is removed every year in order to extract some 40 Mt lignite. Gold ore contains only a few grams of gold per ton of mined material, e.g. a gold content of 5 g/t means that in order to extract a ton of gold about 200,000 tons of ore have to be mined with it and will end up as tailings in the pond [1].

Data from EUROSTAT and OECD surveys show that mining wastes rank first in the relative contribution of wastes in many Central and Eastern European Countries (***Table 1***). For instance, mining activities in the former Czechoslovakia generated ten times the amount of waste produced by the industrial sector [6]. About 400 Mt/y mineral resources have recently been exploited in Poland, the most important are hard coal and lignite, about 110 Mt/y and 62,5 Mt/y, respectively. Output of lignite in Poland is in 4th place in world's production [7]. The mining industry produces in total 57 Mt mining and processing waste yearly in Poland. Mining and processing waste is more then 73% of total amount of industrial waste collected in Poland. Uranium mining and processing in Bulgaria, for example, has been carried out during the period of 1946–1990, altogether at 391 sites (exploration, mining, processing and other supporting facilities). This has generated 13.1 Mm^3 of waste stored in 551 waste dumps and 19 Mm^3 tailings [8].

The above data lead to two conclusions. First, there is a **large amount of waste** produced by the extractive industries that forms a significant proportion of the total waste produced both in terms of volume and weight. Due to high specific weight of this waste type the waste cannot be easily transported and it has to be treated in situ. Second, this waste is produced from non-renewable resources at mineral deposits. Therefore, knowing the potential deposits and mining technology, the amount and location of waste produced in the future can be predicted. For example, referring only to metal mining, exploitable geological reserves total 40 Mt gold and silver ores, 90 Mt poly-metallic ores and 900 Mt copper ore in Romania [9]. Thus the related **location, quantity and possible impacts of waste are fairly predictable** for the extractive industries. In the context of demand and environmental pressures, global increase of population and mass production-based economies create a demand for mineral raw material quantities never seen before. On the other hand, recycling and technological developments result in material-efficient methods and in synthetic materials that reduce the pressure on mineral resources and exploitation, thus decreasing the amount of wastes created.

Spatial scale

The *global* aspect of mining is related to the globalisation of economy. While use of raw materials is the highest in industrialised countries and, at the same time, mines are closed down in Europe, mineral raw materials are imported from the less developed parts of the world. Since the locations of major deposits are known and extractive industries create mostly local environmental impacts, the location of future mining and mining waste and associated environmental problems can be reasonably predicted.

The *regional* aspect of mining is given by mineral **deposits** that can be very large and trans-boundary in nature. Geological areas including genetically related mineral deposits are classified according to size as either metallogenic provinces or districts. Very large and economically important mineral deposits are classified world-class ore deposits. One example is the large iron, copper and nickel ore deposits of the Precambrian Fennoscandian shield. Many of the Fennoscandian ore deposits are situated along the border zone of Archaean and Proterozoic terrains, SE-NW through central Finland into Sweden, including the Outokumpu region, Pyhäsalmi and Vihanti deposits, and the Swedish Skellefte district. In the Outokumpu region alone the total amount of Cu metal, extracted and reserves, is about 1 Mt. Another example of a regional trans-boundary deposit is the Erzgebirge, which is a major polymetallic mineral province in Europe, on the border between the Czech Republic and Germany. This has numerous hydrothermal mineral deposits associated with Variscan and younger granite intrusive bodies. More than 1,000 polymetallic ore veins run through the crystalline basement in two roughly perpendicular systems, filled with a variety of sulphides, sulphosalts and native silver. Among the many mines in this area, some are of historical importance. Regional-scale deposits often determine regional natural background concentrations of elements and compounds that can lead to regional **trans-boundary** natural pollution.

Mines and associated waste sites are however point sources of pollution and impacts are mostly on the *local* scale. The most important spatial aspect of mineral extraction is that it is the only natural resource sector, besides groundwater extraction, that both its activities and its environmental impacts are in the **three-dimensional underground space**. One of the key characteristics of the global mining sector from the mid-20th century onwards has been the dramatic expansion of surface mining, which currently accounts for around 80% of global mineral production. As surface mining necessarily involves excavation of overburden (in contrast to deep mining, which delves beneath it) it is not surprising that more than 70% of all the material excavated world-wide is waste, and that more than 99% of all mine waste rock is being generated by surface mines [10]. Although the size of individual mine sites is essentially a point characteristics at the regional scale, the **number of mines** in a region can be significant. For example, there are 7,836 registered mineral deposits in Poland and 2,841 of them have been exploited. In Slovakia 17,260 mine sites including shafts, adits, tailings ponds and waste rock piles have been inventoried. Another national project in Hungary has registered 15,008 quarries. In Bulgaria there are 391 uranium mine sites.

Although most of the **impacts** are on the local scale, air pollution from mining dust and smelters and regional groundwater subsidence (typically due to bauxite mining in karstic terrains) can have regional implications. In spite of individual mines being point sources with restricted spatial impacts, historic mining of several centuries can lead to an overall regional anthropogenic pollution. Although surface water pollution is often confined to a narrow strip of watercourse and floodplains, pollution can affect riverine environments over a very long distance that can be also regarded as regional impact.

The **aggregated area** affected by mining can also be significant. Mining areas cover 271,000 ha or 2.4% of the total area of Bulgaria. 487 aggregates quarries affected about 9,800 ha of utilized lands, and total mining waste is estimated to damage about 40,000 ha of agricultural land in the country. Generally, 88,000 ha of agricultural land were destroyed by mining and quarrying until 1990 in Bulgaria [8]. In Hungary, for instance, mining waste dumps cover approximately 1% of the total productive land area. At least 25% of the population of the Czech Republic lives in areas of a geological environment classified as highly degraded by mining [6].

Temporal scale

In terms of material flow analysis (MFA), besides introduction of new material flow pathways and new compounds, the main effect of industry on the global geochemical cycles are the **increase of material fluxes** [11]. Mining indeed accelerates release of elements such as heavy metals into the geochemical cycles. It is therefore worth again taking a look at the global element cycles and studying material contributions due to mining. For sulphur, for example, the **rate of liberation** has doubled due to industrial mineral extraction [2]. This, in turn, leads to an increase of global atmospheric sulphur emissions. Human-induced emissions have led to a net flux from land to sea through the atmosphere, where 100 years ago the net flux was the reverse. The global cycle of sulphur is not at a natural steady state at present. Although human activities have caused only a minor change in global pools of sulphur, there are massive changes in the annual flux through the atmosphere [2].

Due to great volumes and slow chemical processes, mining waste can **release toxic compounds for a very long time** on the scale of centuries and even thousands of years. This has two practical consequences. First, abandoned mines in historic sites pose a particular problem due to the long-term deterioration of the environment. Second, closing active mines and the remediation of mine sites requires long-term technological solutions.

Accidents are on the shortest time scale of material flow in mining: an abrupt tailings dam bursting can lead to sudden releases of polluted material and can cause environmental catastrophes. Dam accidents can release polluted water such as cyanide solutes for gold extraction (like in the Baia Mare accident), they can release polluted sediments, or both such as in the Aznalcollar accident in Spain. It should be noted that slow but long-term pollution such as acid drainage seepage can lead to exactly the same amount of pollution. In some respect these slow processes can have higher risks since they can have cumulative effects that are harder to notice.

In terms of asset life cycle, mining has some unique features that cannot be found in other industries. First, mining is among the few industries with the longest history of impacts. These old impacts, such as heavy metal pollution, are essentially the same in character as modern mining impacts. For example, lead mining and smelting activities by the ancient Greeks and Romans have led to measurable increases in the lead concentrations of ice cores in Greenland [12] [13]. Therefore, impact analysis and remediation strategies have to consider **historic time scales**. Second, due to long exploration and mine development, there are few other industries that have such a long time span (often a decade) between the permission for activity and the start. This makes extractive industry sensitive to sudden socio-economic and legislative changes. Third, because mines are very sensitive to changes in the actual commodity market prices, mining is unique among industries in that **long-term suspension** and restart of industrial activities happen quite commonly. This is typical at historic sites where re-opening of mines occurred due to market, socio-economic and technological changes over history. These can lead to changes in the mined commodity that result in turn in changes in waste composition. For example, as processing technologies were less efficient in the past, old ore waste dumps can be expected to have higher metal concentrations than new ones. Long-term suspension and potential reopening requires specific environmental strategies for the extractive industry. The Recsk copper mine area in Hungary provides an example. Due to abrupt fall in copper prices in the beginning of the 90's underground mines of an internationally significant deposit have been remediated for long-term suspension.

Abandoned Mines

Abandoned mines are a wide-spread problem in Europe where mining has a long history. For example, an inventory of old mining sites registered in total 17,260 locations in Slovakia [14]. Abandoned mines are more of a problem in areas with long historic mining like Europe, because mine closure practices have changed with time and environmental protection has not been considered for closed mines until recently. For abandoned mines that were closed before environmental legislation became common, there is a lack of clearly defined responsibility and remediation has often high cost. This leads essentially to no action. The Proposal for the EU Mine Waste Directive [1] prescribes an inventory of abandoned mines that should reduce the uncertainty due to a lack of this type of information.

Abandoned mines are the same as active mines in terms of types of hazard and potential impact on the environment. The major differences between abandoned and active mines are the following:

(1) engineering facilities such as dams, pumps, etc. are unattended and not-maintained, leading to a lack of control of emissions and to accidents;
(2) in the absence of industrial management, there is a lack of information and knowledge about abandoned mines that leads to high uncertainty about their stability, potential hazards, and potential and existing environmental impacts; uncertainty in turn gives rise to risk;
(3) in the case of any emerging environmental problem, implementation of environmental regulations is difficult in the lack of legal owner.

The major problems with abandoned mines are therefore **uncertainty** and **lack of control**. Hamor [15] classified abandoned mines among the most dangerous to the environment from a regulatory point of view (***Figure 3***). From an industrial point of view, if a new mining activity is proposed in an area of historic mining with abandoned mines, then there must be a recognition that the previous mining operation might have had an environmental impact. This requires the mapping of baseline pollution conditions that calls for detailed inventory and assessment of abandoned mine sites in the area.

Accidents

The collapse of tailings dams or heaps may have serious impacts on the environment, human health and safety. The greatest single concern about mine waste is the failure of tailings stor-

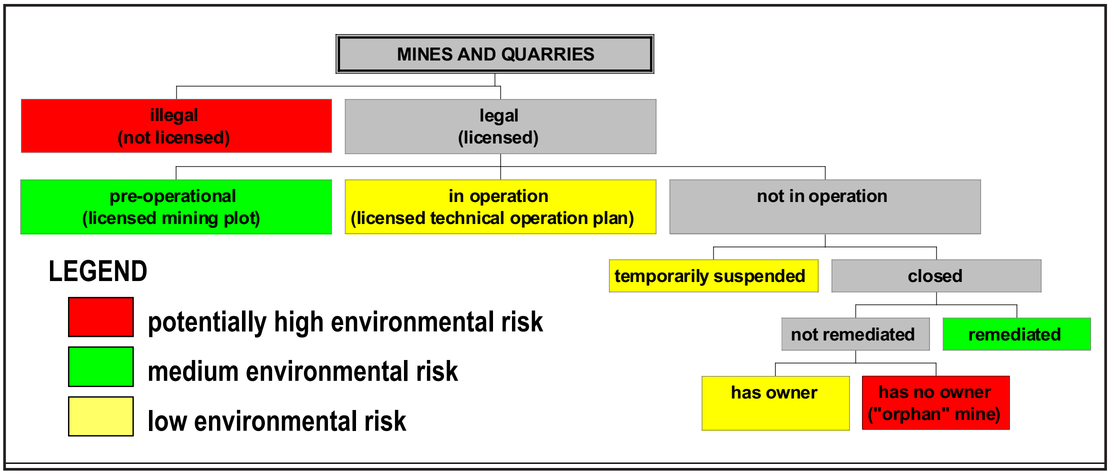


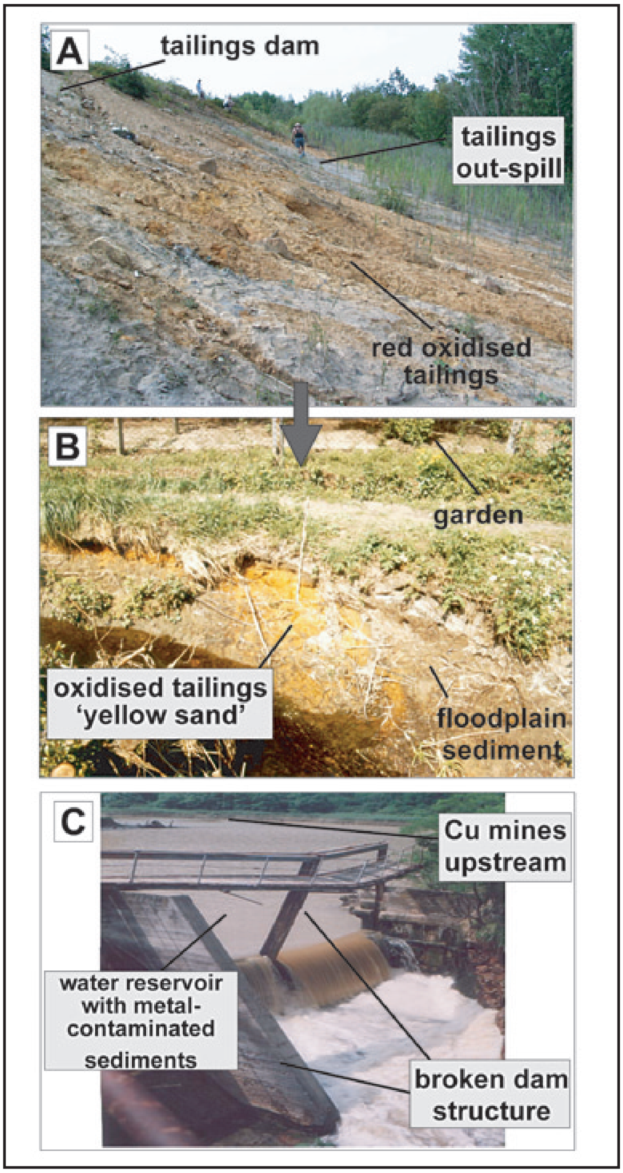
Figure 3. *Legal classification of mines [15]. Abandoned ('orphan') mines are characterised by uncertainty and lack of control.*

age facilities. Since 1975, tailings storage facility failures have accounted for around three-quarters of all major mining-related environmental incidents worldwide. Major accidents seem to occur on average once a year [1]. Most non-ferrous metal mines generate wet tailings in a slurry form that are stored in ponds. The coarse waste rock fraction is often used for dam construction (***Figure 1***). In the extraction of industrial minerals various tailings management facilities are used, such as large lake-size ponds, small ponds and large heaps.

The worst accident in the UK happened because of the collapse of a heap of inert waste from a coal mine in the town of Aberfan, Wales in 1966. It caused the death of 144 people, mainly children. In 1985 in Stava, Italy, a fluorite tailings dam failed and released 200,000 m^3 of inert tailings. This resulted in 268 deaths and the destruction of 62 buildings [1]. In a more recent accident in 1998 in Aznalcollar, Spain, with the rupture of the dam wall approximately 2 Mm^3 of pyrite sludge and another 4 Mm^3 of acid water containing high concentrations of heavy metals (zinc, lead, arsenic, copper, antimony, thallium and cadmium) flowed into the Guadiamar River. This, in turn, flowed directly into the marshlands of Donana. Consequently, a 62 km long section of the river, ranging from 500 to 1000 m in width, was affected [16]. A total area of 4,634 ha of land along the riverbed, including 2,656 ha that was part of the Donana Nature Park and 98 ha within the National Park was affected. In Romania in January 2000, the Tisza River pollution was caused by a cyanide spill following a damburst of a tailings pond in the Baia Mare accident. The burst released over 100,000 m^3 of process waste-water with cyanide compounds and heavy metals such as Cu and Zn, but also Fe, Cd, Mn. The pollution had a marked impact on the Somes/Tisza/Danube catchment [17]. The damburst of a tailings pond in Baia Borsa (Romania) in March 2000 spilled over 20,000 m^3 polluted slurry into the Tisza catchment affecting NW Romania, Ukraine and NE Hungary.

There have been many accidents that received less international attention but they still had deteriorative regional or local environmental impacts. Here two typical examples are provided to illustrate the significance of these 'unknown cases'. The base metal deposit of Gyongyosoroszi in the Matra Mts., Hungary has a 3x4 km^2 horizontal and about 400 m vertical ex-

Figure 4. *Accidents. A. Typical tailings dam burst showing heavy metal loaded sediment release next to the dam at the Gyongyosoroszi Pb-Zn mines, Hungary (photo: S. Sommer). B. Contaminated tailings deposited on floodplains downstream (photo: U. Fugedi). C. Mine water reservoir dam broken by flooding at the Recsk Copper Mines, Hungary (photo: A. Somody). See text for details.*



tension with 1.3% Pb and 3.5% Zn content [18]. The dams containing the flotation waste burst many times (***Figure 4.A***) and more than 100,000 tons of mud with 5% sulphide mineral content entered the valley and stream. The total tailings loss amounted to approximately 800 tons of galena(PbS)-sphalerite(ZnS) concentrates. The maximum heavy metal concentrations are found in the 'yellow sand' (oxidised tailings) deposited on the narrow floodplain of the stream (***Figure 4.B***) [19]. Escaped tailings mud was carried by stream water and more than 100,000 m^3 of contaminated mud was deposited in downstream industrial and agricultural water reservoirs. Flotation mud took 1/3 of reservoir capacity of a downstream agricultural reservoir that has to release water through a bottom release in flood events. Thus, contaminated mud is released from this reservoir as a secondary pollution source long after mine closure.

In July 1999 the dam of the water reservoir at the Recsk Copper Mines in Hungary was broken by a flood event (***Figure 4.C***). The organic rich sediment containing significant amounts of historic heavy metal pollution was re-suspended by the turbulent 200,000 m^3 of flood water and deposited downstream on the floodplain where agricultural activities are conducted. Although this industrial water reservoir was not a tailings pond, it served as a secondary source of pollution due to an accident. Thus, inventory of mine sites have to consider not only tailings ponds but also all reservoirs affected by mining.

Hundreds of similar 'small cases' have occurred in Europe that went unnoticed, except by the local authorities and people. This is largely due to environmental protection not being a major issue some years ago, typically in the Central and Eastern European Candidate Countries. With the lack of regulations and legal enforcement, industry did not report these events. The problem is that most of these ‘small cases’ had long-term impacts whose effects are still acting, like in the above described Gyongyosoroszi and Recsk cases.

Impacts of accidental pollution emissions have to be weighted against impacts of long-term pollution emissions. A large contamination event carried downstream with a flood wave might pose less risk than a long-term (unknown or illegal) pollution release exerting permanent pressure on the impacted ecosystems. Accidents have the positive feature that they are relatively easy to notice because they lead to an obvious change (burst of dam, sediment/water floods, etc). In contrast, long-term but small emissions might go unnoticed for years. These emissions can be well below regulatory limits but, since pollutants tend to accumulate in soils, sediments, biota and the human body, they can have delayed effects.

Impacts, Remediation and Long-term Monitoring

Mining activities impose harmful, usually irreversible impacts on the terrestrial and aquatic environments. The most important are the following.

(1) At the site scale:

- terrain deformation (including subsidence and slope failure);
- changes of landscape;
- impacts of unused pits and shafts;
- impacts of waste generation;
- (abandoned) waste rock and tailings dumps;
- land degradation due to loss of soil;
- soil contamination;
- changes in hydrogeological system;
- hydrological and hydrochemical transformations of surface and groundwater water flows;
- dust and gas contamination of atmosphere;
- change and contamination of vegetation.

(2) At the national scale:

- loss of productive land;
- loss or degradation of regional groundwater aquifers;
- loss or degradation of surface water resources;
- ecosystem damage, loss of biodiversity;
- fish affected by contaminated sediments;
- regional air pollution from dust or toxic gases;
- loss of landscape and recreational value;
- high costs to the public, growing community opposition to mining activities.

Through mineral extraction and subsequent mineral processing, metals and metal compounds in wastes tend to become chemically more available, which can result in the generation of acid or alkaline drainage. There are two other main contaminated areas at many of the mine sites: mine voids and backfill that are not considered as waste management facilities, but where chemical reactions often lead to concentrations of harmful elements or compounds [10]. For example, well over 90% of the total polluted drainage in the UK can be accounted for discharges from polluted mine voids rather than from old mine waste depositories [10]. Soils, surface water and groundwater are often contaminated by migration of harmful elements or compounds within the site. This makes those parts of the site to act as **secondary sources** for pollution, especially for historical sites.

Outdated practices pose unacceptable risk by mining operations such as the practice of using rivers for mine waste disposal, a practice that might be attractive because of its cheapness, but which places loads upon the riverine environment. The Best Available Technology documents [20] should guide operators and authorities to improve environmental protection and to help to meet legislative requirements.

A well-known example for regional impacts is the historic mining area of Silesia in Poland. Negative effects of mining activity are especially recognisable at the Upper Silesia Coal Basin, as hard coal has been intensively exploited there for about 160 years. In the 1980s, all of 62 hard coal mines using an area of about 1,600 km^2, produced 190-200 Mt/y hard coal. A substantial amount of hard coal extracted is burnt in several power stations and in the heating-power plants of the Silesia agglomeration, in an area of 6,650 km^2 (about 3% of the total area of Poland) with about 4 million residents [21] [22]. Another example for regional impacts comes from data in the UK. Some 400 km of watercourse are currently degraded by abandoned coal mine discharges, with a further 200 km or so similarly contaminated by abandoned metal mine discharges in the UK [10]. By rough extrapolation from these findings, weighted by the distribution of coal fields and ore fields in mainland Europe, it is likely that the equivalent figures for the current fifteen EU Member States will eventually prove to be in the order of 2,000 to 3,000 km of watercourses polluted by coal mine drainage, and 1,000 to 1,500 km polluted by metal mine discharges [10]. This suggests that the total length of watercourses polluted by mine drainage in the EU 15 may well prove to exceed 5,000 km [10].

These impacts can have lasting environmental and socio-economic consequences and be extremely difficult and costly to address through remedial measures. Adverse effects of polluted drainage from waste management facilities have the potential to create **long-term environmental impacts** persisting well after the mine or quarry has been closed. Wastes from the extractive industries have therefore to be properly managed in order to ensure in particular the long-term stability of disposal facilities and to prevent or minimise any water and soil pollution arising from acid or alkaline drainage and leaching of heavy metals.

Remediation of mine sites, including closed and abandoned mines, has to provide **long-term solutions** and thus remediation technologies have to be sustainable for a long time: they have to be effective and cost efficient. The Best Available Technology Document on 'Management of tailings and waste rock in mining activities' drawn up by the European IPPC Bureau [20] provides the state-of-the-art review of relevant techniques (***Figure 5***). The Mine Environment Neutral Drainage (MEND) Program in Canada developed a toolbox of technologies for sampling and analysis, prediction, prevention and control, treatment and monitoring technologies for acid mine drainage management [23]. Based on results of detailed studies, MEND concluded that water covers and underwater disposal in constructed lakes is the preferred prevention technology for unoxidised sulphide-containing wastes in Canada, for example (***Figure 5***). It was also concluded that there is still need for further research to confirm performance of technologies such as chemical versus passive treatment through large-scale applications and long-term data. Applied technologies of treatment and remediation have to consider site-specific factors and conditions based on site-specific research [23]. The Passive In-situ Remediation of Acid Mine/Industrial Drainage (PIRAMID) program suggested in the 'Final Report' and in the 'Engineering guidelines for the passive remediation' [24] that passive in situ remediation (PIR) methods for acidic drainage treatment using artificial wetlands and subsurface reactive barriers are cheap and sustainable remedial methods (***Figure 5***) [24]. Feoli suggested a more complex approach using bio-remediation of mine sites based on principles and techniques of industrial ecology [25].

Besides engineering methods for prevention and remediation, long-term **monitoring** networks should be an important part of mine waste control systems. Monitoring of sites and related catchments, surface and groundwater reservoirs has to be implemented for both active and abandoned mines. Monitoring of waste and the receiving environment in the catchment has to be carried out in harmonised way to allow comparison of hazards, impacts and risks of different sites in the EU in the support of the uniform regulatory requirements.

Impact mitigation, remediation and monitoring, therefore, have to be analysed and managed in compliance with a number of European legislative requirements such as the proposed Mine Waste Directive, Impact Assessment Directive, Risk Assessment Directive, Seveso II Directive, Landfill Directive, Water Framework Directive, the Habitats Directive, the Waste Framework Directive and the Environmental Liability Directive.

Response to Mine Waste Facility Accidents and Environmental Impacts

Legislation and industry

Historically, or even just a few decades ago, environmental awareness, legislation and management practise did not adequately consider the long-term safety and environmental risks involved in the mining waste management. The improvement of management practice, new environmental legislation and awareness over the last decades have completely changed the best practice of mining waste management and the decommissioning of mine sites. Following the Aznalcollar and Baia Mare accidents, public pressure increased and resulted in a number of new EU initiatives on the subject of mining waste management. Three legislative activities have been identified [1]:

- the inclusion of mining in the Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances (Seveso II Directive);
- the development of a separate Mine Waste Directive [1] on the management of waste resulting from prospecting, extraction, treatment, and storage of mineral resources; and
- the development of Mine Waste Best Available Techniques Reference Document [20] describing the best available techniques of waste management to reduce everyday pollution and to prevent or mitigate accidents in the mining sector.

In the light of disparities of rules at national level and the trans-boundary nature of environ-

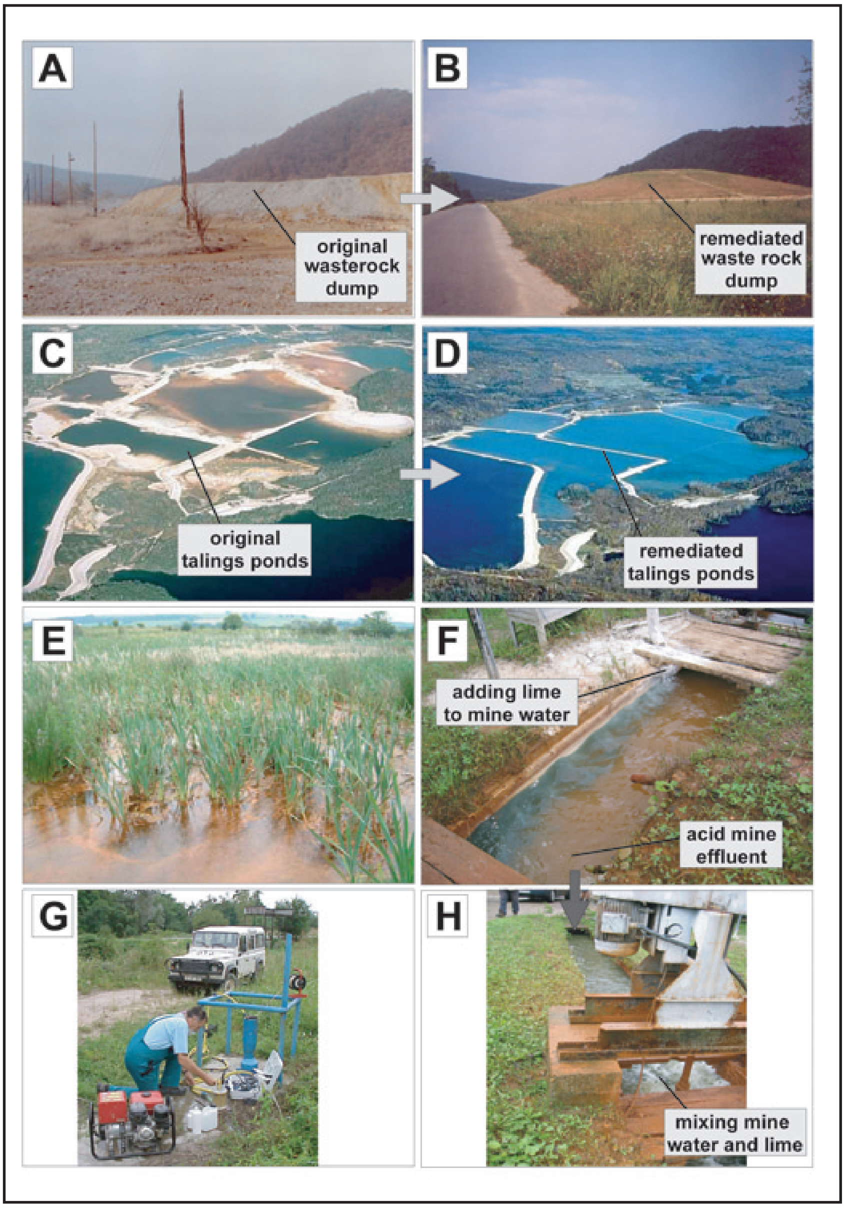


Figure 5. *Remediation and long-term treatment.A and B.Waste rock dump at the Recsk Copper Mines in Hungary before and after remediation (photo:A. Somody).C and D.Tailings before and after passive treatment with water cover [23]. E.Passive in-situ treatment.Aerobic reed-bed treating ferruginous overflow from abandoned underground coal workings at St Helen Auckland [24].F and H.Active treatment of acid mine drainage by neutralisation with lime at the Gyongyo-soroszi Pb-Zn mines, Hungary (photo:S.Sommer).G. Post-closure monitoring.Monitoring network at the Mecsek Uranium Mines, Hungary (photo:courtesy of the Mecsekerc Rt.).*

mental impacts from extractive industry waste, it is necessary to lay down minimum requirements at EU level in order to improve the environmental and safety aspects of the management of waste disposal facilities. The mining sector is a predominant source of waste generation with attendant environmental protection challenges and, thus far, has only been subject to a relatively narrow range of EU legislation with respect to health and safety at work and security of energy supply issues [1].

The PECOMINES project [26] has examined the legislation and regulatory framework of mining in the Central and Eastern European Candidate Countries [15]. This allowed an in-depth comparison with the legal situation in the present EU member states and with the new EU

Directive in preparation. It became clear, that legislative and regulatory authority frameworks do exist in all Candidate Countries to supervise mineral extracting activities. The adoption of the Community waste legislation is at an advanced stage and the mining-related hiatus of the acquis are already introduced to national legislation. Regulations on mining vary according to mineral types and mining traditions. However, the regulatory control and sanctions are not efficient in most of the countries. Countries with long-standing underground mining traditions and significant production figures have detailed regulations on mining safety. However, tailings pond safety does not seem to be considered a priority policy issue. The opening and operation of mines are well regulated, but closure and aftercare including monitoring are less prescribed. While geological and production data are well recorded, mining operation and waste data are less accurately managed. Mining safety regulations do not focus on environmental impacts.

The proposed Directive [1] sets out the following main administrative procedures that are also expected to promote solutions to the above regulatory problems in the Candidate Countries:

- planning, licensing and eventual closure of waste management facilities associated with the extractive industry, with particular measures applicable to those facilities with the potential to create trans-boundary impacts;
- mechanisms for dealing with major accidents and unexpected events;
- the introduction of mechanisms for guaranteeing that all operators from the extractive industry put (and keep) in place sufficient financial guarantees to ensure the eventual full reinstatement of the waste management facilities for which they are responsible, whatever their status or financial health at the time when such reinstatement falls due.

Response of the industry to emerging regulations and public expectations is technological improvement and introduction of new waste management practices. Sustainable development has become a driving force in how the mining industry approaches all existing and future activities. Progress has been made to advance environmental performance and stewardship and provide benefits to civil society. Technologies are now in place to open, operate and decommission a mine property in an environmentally acceptable manner, both in the short and long term (***Figure 5)***. Moreover, mining companies, governments and consultants have acquired a great deal more capability to deal with environmental and societal issues such as water contamination from mine wastes, including acid generation. The main effort is to **prevent**, or minimise the impacts of accidents, and in particular to ensure the **long-term stability** of tailings dams and ponds. Modern methods have to replace outdated practices and eliminate unacceptable threats posed by mining operations. Technological improvement is particularly relevant in the Candidate Countries where development of environmental technology was not stimulated in the past due to lack of proper regulations and financial resources.

Integrated research: the PECOMINES project

The PECOMINES project is an initiative involving Central and Eastern European Candidate Countries (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia) in an EU research action on the environmental impact of mining waste in collaboration with Directorate General (DG) Environment and the European

Environmental Agency (EEA). This has to be seen against the background that DG Environment has prepared a proposal of a specific Directive on mining waste management and safety [1] in the context of the review of the existing regulatory framework related to waste management. Given the widespread nature of mining waste in Candidate Countries, DG Environment attached a particular importance to prioritisation in this area to consider appropriately the situation in the new legislation. The scientific objectives of the project are the definition and demonstration of methods:

- to conceptualise and demonstrate a standardised regional **inventory** of waste sites from mineral mining in Candidate Countries in relation to catchment areas, making it possible to develop a concept for **impact assessment** allowing to link the site/source related indicators with spatial information at catchment scale;
- to compare the legal criteria for the assessment and remediation of contaminated areas with **regulations** adopted by EU Member States and with the existing EU legislative framework in the area of waste management.

The approach of the PECOMINES project combines existing inventory data with remote sensing derived information and site assessment based on geo-environmental information, analysing them together in order to establish the criteria for ranking environmental impacts. Simultaneously, the regulations of the Candidate Countries and EU have been studied and analysed in detail [15]. With the team of 4 experts from Candidate Countries (Hungary, Romania and Estonia), a wide range of topics has been studied and analysed in order to describe the situation in 10 EU Candidate Countries, work out methodologies for comparative assessment on multi-country level, and provide both DG Environment and the countries themselves the results of the analysis.

The crucial role in the work has been lying on the members of the **Steering Committee** (SC), the representatives of the governmental authorities and geological organisations of the 10 countries involved, who assisted the project through accessing the existing information, converting some of the information into standard format, defining the gaps in the information, and reviewing the analysis results and methodological approaches of the project members. Country Reports by SC members in this volume form an important and integral part of the developed mine waste inventory methodology. In order to understand the role of the Country Reports in the context of inventory, a brief description of the methodology is presented in the following section.

PECOMINES Mine Waste Inventory in the Central and Eastern European Candidate Countries: Methods and Results

The objective of the inventory study was the development and demonstration of an inventory methodology to support risk assessment of mine waste. Implementation of complete inventory and creation of a full database was not the objective but rather to keep the approach simple for research and demonstration purposes. The scope of the inventory of this study was limited to environmental impacts of pollution emissions. Risk associated with engineering and technology was excluded.

In this approach, the mine waste inventory uses three tools to meet the above objectives:

	SOURCES ⟶	RECEPTORS
REGIONAL SCALE	TOOL 1: Questionnaire *whole country*	TOOL 2: Maps for the whole country
CATHCMENT SCALE	TOOL 1: Questionnaire *hot spot*	TOOL 2: Data & information on hot spots

***Figure 6.** Vertical and horizontal aspects of mine waste inventory data collection. TOOL 3 'Country Report' summarises all aspects. See text for details.*

1 **Questionnaire** for mining sites for pressure (pollution source or hazard) characterisation (TOOL 1).

2 **Environmental Information and Data** concerning the state of environment and impacts of mining and mining waste for characterisation of environmental receptors (TOOL 2).

3 **Country Report** for describing major mine waste streams, technologies and policies at the national level (TOOL 3).

The objective of dividing the inventory into separate parts is (1) to differentiate between hard data, soft data and expert judgement, and (2) to differentiate information between pollution source and receptor characterisation for risk assessment. Hard data on mining (mineral production, mining and processing technology, etc) and mining waste management is readily available from the industry and these data have the least uncertainties, therefore a standard questionnaire is the best method for data acquisition (TOOL 1). This data is used for potential **hazard assessment**. The receiving environment is much more complex and hard data of monitoring and assessment is rarely available or it is rarely complete. Therefore, information and data collection concerning the environment has to consider soft data, such as interpreted environmental, geological, soil, land use, contamination and land management maps and data (TOOL 2). Room for expert judgement is provided in the Country Report (TOOL 3) where national experts summarise mine waste situation and problems in their country, describe general waste streams, provide prioritarisation of associated problems and identify 'hot spots' of major environmental concern in their countries.

In order to achieve efficient data collection a **tiered approach** has been adopted. The two spatial scales for mining waste assessment and information collection in this study are the following: (1) regional (national) and (2) catchment scale of mining sites. This is the 'vertical' aspect of information acquisition (***Figure 6***). Collection of data was also divided according to environmental assessment: (1) source characterisation for **hazard assessment**, and (2) characterisation of the receiving environment (receptors) for environmental **impact** and **risk assessment**. This is the 'horizontal' aspect of information acquisition (***Figure 6***).

The inventory has been designed in a tiered structure to support decision making and environmental management at the national and local (mine site and catchment) scales. Accordingly, in the first phase of inventory, completion of a questionnaire (TOOL 1) for the fast screening of mine sites is requested. This questionnaire contains only a limited number of parameters but for all the known sites in the country, including the question if a site is a 'hot spot' or not. The questionnaire is designed in such a way that the same form can be used for nation-wide screening and for detailed site characterisation. A detailed Guide with worked-out examples and a Glossary establishing consistent terminology are provided to help with completing the questionnaire. For standardised data acquisition a digital MS Access® data entry application has been developed for the questionnaire. A brief guide for the Access® application was also provided to Candidate Country partners represented by SC members. Data on the environment at the national (regional) scale (TOOL 2) was also required in this phase, including data on highly protected areas such as national parks, regional groundwater aquifers, densely populated areas, etc. In the second phase, a detailed questionnaire is completed for selected 'hot spots' (TOOL 1) and detailed information for the (potentially) impacted environment surrounding the 'hot spot' is requested (TOOL 2).

Three means of **quality control and quality assurance** are applied in the questionnaire. First, the structure of the form has been designed to reflect increasing uncertainty. The questionnaire proceeds from location and identification data, and extraction data to information on waste management and emissions. Second, there are three categories of data uncertainty distinguished in the questionnaire which are the following in the order of decreasing uncertainty: 'non-existing' if data does not exist, 'non-accessible' if the information exists but it is not accessible, and 'estimation' if the data is available but it is an estimation. If the latest is the case, the confidence interval of estimation is to be indicated, when possible. Third, expert comments on the provided information, data reliability, etc. are invited at any point. The questionnaire relied on SC expert knowledge and professional experience in this study. A further means of quality control and quality assurance is the development of a **metadata questionnaire**. A 'Metadata Inquiry' has been developed for existing data and information sources in the Candidate Countries relevant to mining waste inventory and environmental risk assessment. A detailed Guide for the Metadata Inquiry form is provided. Metadata is asked for (1) data sources used for the inventory 'TOOL 1 Questionnaire', (2) data sources for the inventory 'TOOL 2 Environmental Data', and (3) extra data that partners found relevant and important for specific mine waste assessment.

In order to provide an efficient way for including **expert knowledge** in the inventory and to facilitate the communication of mining waste related problems on the international scale **Country Reports** (TOOL 3) have been developed to be published as a summary report on the status of mining, mining waste, waste streams and related environmental efforts in each country. Case studies in Country Reports provide means of expert evaluation of 'hot spots' that were inventorised by the Questionnaire. The list and brief description of national databases on mining, mining waste and relevant environmental information in the reports provide a fast screening tool for the metadata inquire and gives room for the expert evaluation of data sources relevant to mining assessment.

A further tool of inventory is **remote sensing** to identify sites which are characterised by anomalous concentrations of both ferro-oxi-hydroxides (Fe-Ox) and OH-bearing secondary minerals by applying selective principal component analysis (PCA) to geo-referenced Landsat-TM reflectance channels. Co-occurrence of both types of anomaly is significantly indicative for most cases of waste material from metal mining or ore processing but also for other types of mineral deposits (e.g. lignite) where frequently associated pyritic material leads to acidification. Application of the standardised remote sensing allows large area coverage. Overlaying of remote sensing results with existing data sets such as CORINE Land Cover, GISCO topographic data, European Soil Data Base and others facilitates the spatial assessment of mine waste sites [27].

The major **results** of PECOMINES inventory are the development of a comprehensive mine waste inventory methodology, including a questionnaire, that was implemented for the 10 Candidate Countries. Detailed questionnaires for hazard characterisation of 68 selected 'hot spots' have been received and evaluated for hazard classification. All relevant databases have been reviewed in the metadata inquiry part of the inventory. Methods of mine site characterisation and ranking have also been reviewed and evaluated [26]. Background spatial data and maps were obtained through the inventory (TOOL 2) and those representing national methods for hazard, impact and risk assessment have been reviewed and compared from the viewpoint of applicability to support the new Mine Waste Directive [28]. The remote sensing PCA-based method has been successfully tested and applied on large areas of Slovakia and of Northern and Western Romania (total area covered in the test is approximately 120,000 km^2). The reliability of the results has been demonstrated and validated against the site-specific inventory information provided by the Romanian and Slovakian SC members in the questionnaire as well as by detailed background environmental and geological maps [27].

Conclusions

Soon the EU will comprise up to 27 member states embracing the countries of Central and Eastern Europe, and containing 500 million people. These countries possess some of the richest natural areas and diversity of species on the continent. At the same time, historic and modern mining exerts significant existing and potential impacts on these reserves. Recent close-down of large-scale industrial mining has lead to significant socio-economic impacts in these countries, too.

Mining and its products are clearly necessary for a high quality of life, indeed minerals and metals will play an important role in improving sustainability. Mining industry have some **characteristic features** including large volume of wastes produced, catastrophic pollution events, problems of abandoned historic mine sites, multiple pollutions, and secondary impacts posed by the polluted surrounding lands. **Long-term pollution release** from wastes requires long-term monitoring and treatment solutions that are cost effective at the same time. **Trans-boundary** nature of mineral deposits, natural and historic pollutions and recent impacts are also characteristic to mining in Europe. The objectives of new EU regulation on mining waste are (1) to minimise the adverse effects of polluted drainage from waste management facilities, which have the potential to create long-term environmental impacts persisting well after both the facility and the associated mine or quarry have been closed, and (2) **to prevent, or minimise the impacts** of accidents, and in particular to ensure the long-term stability of tailings dams and ponds, given that dam bursts have the potential to create widespread environmental damage, including threats to human life. Mine waste facilities and management schemes require not just good design but also close, consistent and routine monitoring and supervision over a long period.

Elaborate **material flow analysis** and **life cycle assessment** of mine waste and mine projects is required for the understanding and efficient management of mine waste impacts on the regional, national and continent-wide scales in Europe. At the site scale, engineered solutions implemented by the industry according to legislative requirements are the means for long-term control of mine wastes.

Understanding development and efficient implementation of legislation of mining waste requires first of all appropriate and sufficient data and information. Despite significant national efforts there is a **lack of harmonised inventory** data on mines and mine wastes in particular for abandoned mines [29]. Data on state of and impacts on the surrounding environment in mining catchments are even less available. Both pollution source, controlling engineered facilities and the environmental receptors have to be inventorised for the **risk assessment-based ranking** of mine waste sites. Uniform ranking should provide the basis for unbiased law enforcement and distribution of environmental financial resources for the benefit and protection of the European citizens.

The approach to collect standardised information on mining sites and related wastes from existing data bases and new surveys through a harmonised and guided **questionnaire** appears to be a feasible option to compile a regional scale, geo-referenced inventory of potentially hazardous mining waste sites. The inventory should be focused clearly on identifying and ranking hazards and impacts, and on selected details of the mine and quarry sites to assist remediation design. Such an inventory should characterise possible pathways and impacts of pollution originating from waste and waste management facilities.

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SECTION 2

COUNTRY REPORTS

Mining, Mining Waste and Related Environmental Issues in Bulgaria

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Introduction

Ongoing political and economical changes in the Eastern European countries led to the decommissioning of mining operations, which were not economically and technically viable anymore. In due course these defunct mines were abandoned and, in order to close them down in an orderly manner, have to be rehabilitated or at least secured to prevent negative effects on the surrounding population.

Mining and metalworking in Bulgaria goes back to ancient times with mining in Europe originating in this region. The territory of Bulgaria, known at that time as Thrace, was important

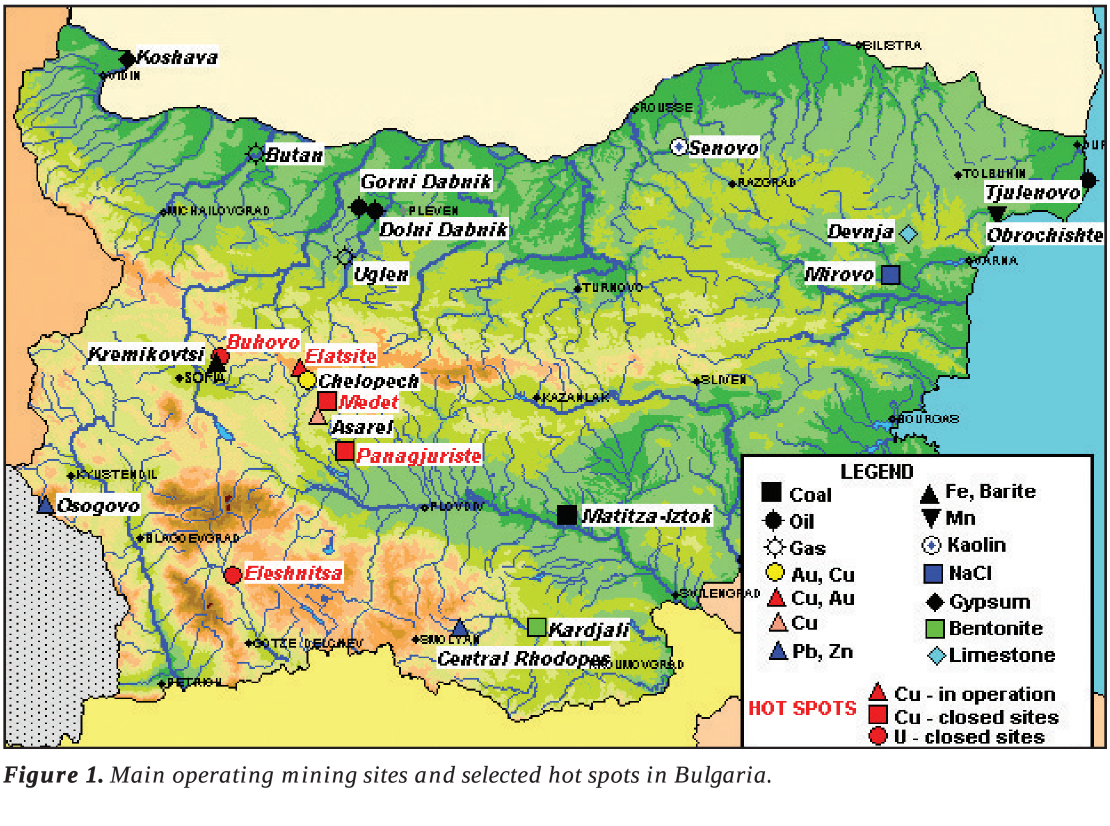

Figure 1. *Main operating mining sites and selected hot spots in Bulgaria.*

source of base and precious metals, as it is well documented by Roman times. In the recent years in period of transition from state planed economy to market economy a lot of mines have been closed. The mines still in operation were privatised or are in process of privatisation.

The new Underground Resource Act is in force since 1998. It provides for claims by domestic and foreign companies for the development and operation of mineral deposit for up to 35 years with additional 15-year extension to be approved. Exploration rights to private companies could be granted for up to 3 years with possible two extensions for two years each.

At present, the Bulgarian mining industry consists of extraction of ferrous and nonferrous metals, mineral fuels, industrial minerals and construction materials (***Figure 1***). The metallurgical branch smelts and refines copper, gold, iron and steel, lead, silver and zinc. Most of the Bulgarian minerals requirements are met by domestic production, but the country depends on imports of iron, steel, and mineral fuels. The total area of the Republic of Bulgaria is 11,100,190 ha. The mining areas cover 271,086 ha or 2.4% of the total area.

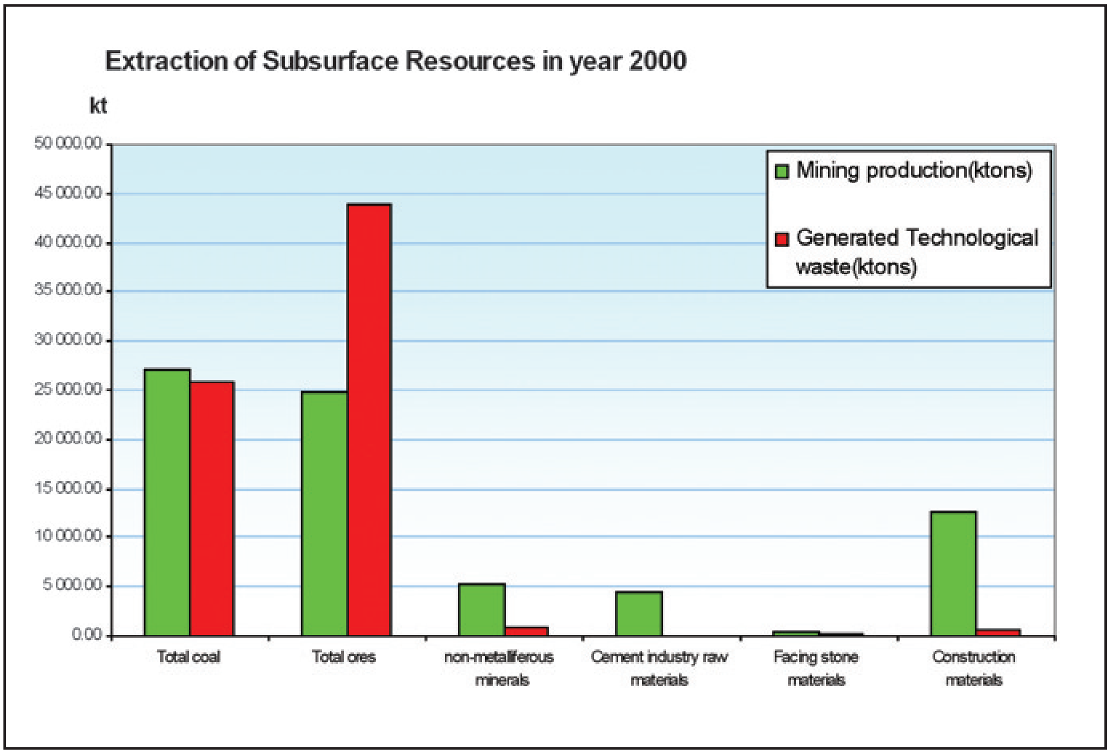

Figure 2. *Extraction of mineral resources in 2000.*

The amount of extracted subsurface resources in 2000 was almost 75 Mt (***Figure 2***). Coal and ore mined together constitute 52 Mt or 70% of total mined resources. The rest 30% is for non-metalliferous minerals, raw materials for cement industry, facing stone materials and construction materials. The total generated technological waste from mining industry is 71.3 Mt. The waste generated from coal and ore mining is 69.6 Mt or almost 98% of the total waste generated.

The generated waste from industry in Bulgaria for 2000 (the waste resulting from exploration, mining, dressing and further treatment of minerals and quarry are not included) is reported to be about 2.2 Mt. The waste from the mining and processing industry occupy the largest share of about 97% in the waste generation structure in Bulgaria.

Mining and Mining Waste

Energy resources

The amount of extracted energy resources is as follows [1]:

Coal	27 Mt
Oil	0.04 Mt
Gas	15 Mm^3.

During the year 2000 the coal mining industry generated 25.8 Mt of waste. 21.9 Mt of the accumulated waste were utilized. 24 Mt of wastes from exploration and extraction were generated, 21 Mt were utilized. The wastes generated in primary processing were 0.3 Mt with only 0.002 Mt utilized. The non-metalliferous waste from the physical and chemical processing in coal mining were 1 Mt, 0.042 Mt were utilized.

Ores

In 2000 the total ores extracted in the country amounted to 24.7 Mt:

Fe ore	0.6 Mt
Cu ore	23 Mt
Au ore	0.6 Mt
Pb-Zn ore	0.5 Mt

As a result of mining activities 43.8 Mt of waste was generated. The utilized amounts were 0.008 Mt. In the ore mining industry during the year 20.7 Mt of waste was generated as a result of exploration and extraction of subsurface resources. The metal containing wastes from the physical and chemical processing were 23.1 Mt.

Non-metalliferous subsurface resources

In 2000 the extracted non-metalliferous subsurface resources were 5.4 Mt. The most important are:

Kaolin	1 Mt
Quartz sands	0.7 Mt
Bentonite	0.3 Mt
Barite	0.9 Mt
NaCl	1.7 Mt

0.9 Mt of wastes have been produced in the extraction and primary processing of non-metalliferous resources. 0.1 Mt of the waste was utilized. The total amount of accumulated wastes is 8.1 Mt.

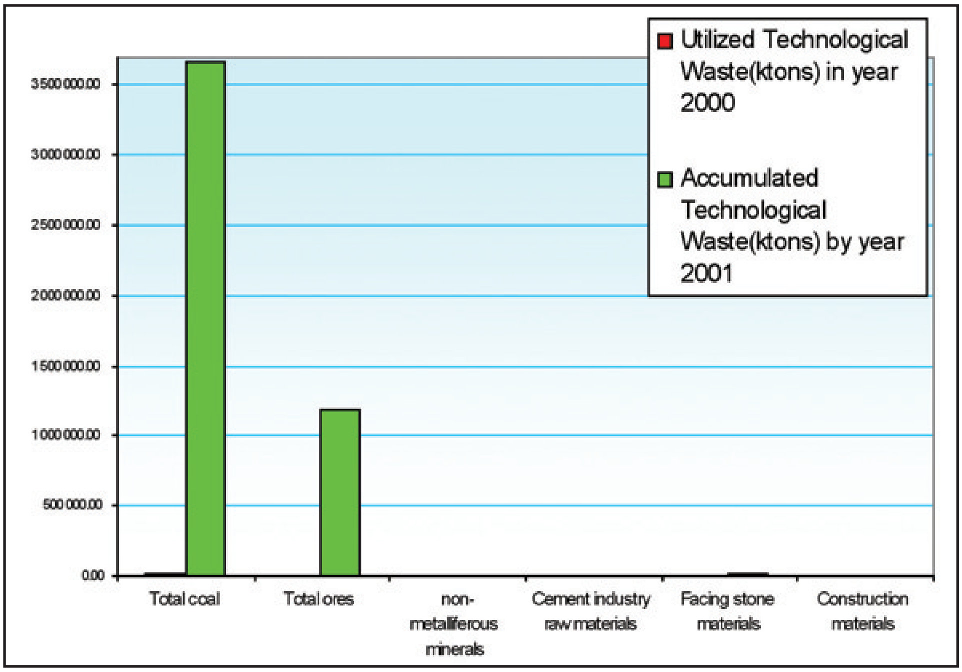

Figure 3. *Total accumulated technological waste from the mining industry in 2001.*

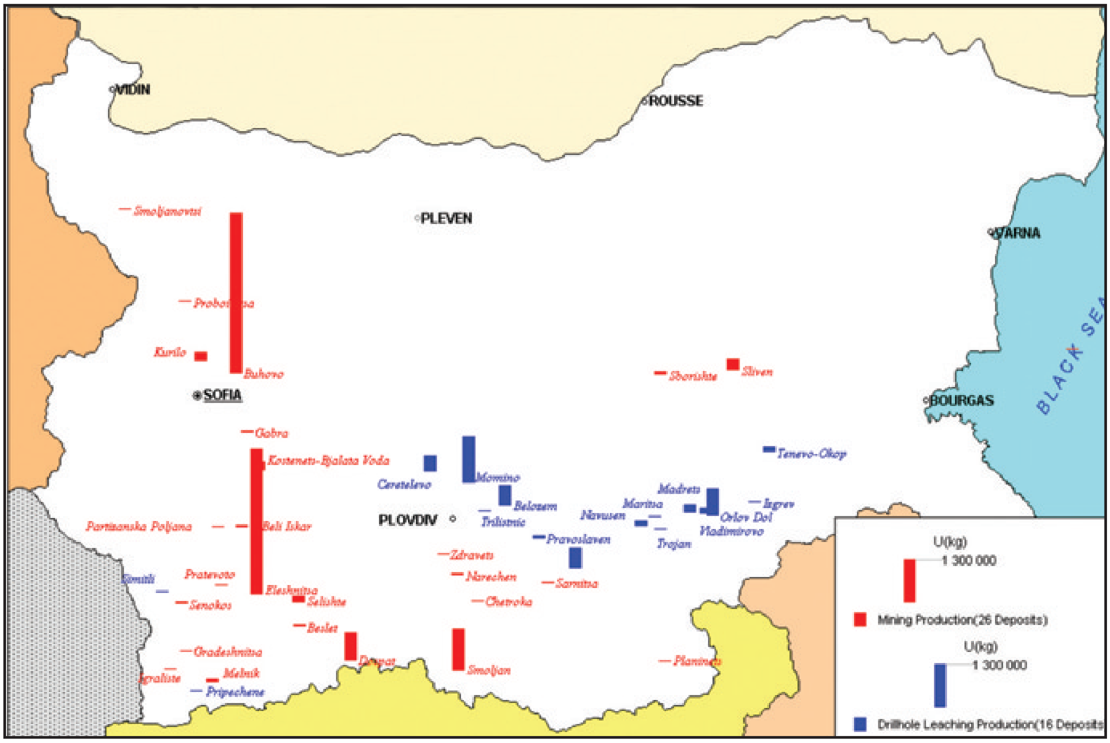

Figure 4. *Main uranium deposits and production in Bulgaria.*

Raw materials for cement industry
In 2000 the extracted raw materials for the cement industry were 4.4 Mt. No waste was generated. The total accumulated waste by 2001 was 7.4 Mt.

Facing stone materials
In 2000 the extracted facing stone materials were 0.5 Mt.

Limestone	0.07 Mm^3.
Marble	0.08 Mm^3.
Granite and granite-diorite	0.009 Mm^3.
Quartz monconite	0.002 Mm^3.
Gabbro, andesite, monconite	0.002 Mm^3.

For the facing stone materials the generated, utilized and accumulated wastes amounted to 0.3 Mt, 0.05 Mt and 18.9 Mt, respectively.

Constuction materials
In 2000 in the extraction of construction materials were 12.6 Mt. 0.6 Mts of technological waste was produced, nearly 0.35 Mt were utilized and the total amount of accumulated waste by 2001 was 5.1 Mt.

Total accumulated technological waste
The total accumulated technological waste from the mining industry by the year 2001 is 4,885 Mt. 99.2% of it or 4,845 Mt is coming from coal and ore mining. 22.4 Mt of waste was utilized in 2000 (***Figure 3***).

Uranium production
The information about uranium production in Bulgaria is not included in the above stated data (***Figure 4***). Uranium mining activities in Bulgaria were in operation from 1946–1992 [2]:

ore mined	18 Mt;
waste generated	13.1 Mm^3 (in 551 waste dumps);
three tailing ponds	19 Mm^3.

Databases

National databases concerning mining, waste and relevant environment information in Bulgaria are created by different organizations. Briefly bellow are described the existing databases in National Geofund of the Ministry of Environment and Water:

1. Map of Mineral Deposits of Bulgaria, 1:100,000 - Unpublished map series, consists of point objects that represent location of mineral deposits, occurrence and indication;

2. Oil and Gas Wells - Data set for all the oil and gas wells drilled on the territory of Bulgaria, onshore and offshore;

3. Aeromagnetic and Gamma Ray Spectrometer Data - Regional aero data: Location of digitised data points along flight lines and calculated values of magnetic fields and U,Th, K;

4. Exploration Drillholes and Mining Workings - Data set consists of information from drillholes and mining workings of mineral exploration programs;

5. Map of Delimited Areas of Gold Deposits in Bulgaria - Computer map, produced from digitised series of maps of scale ranging from 1:1,000 to 1:25,000;

6. Map of Uranium Mineralization in Bulgaria - Computer Map with uranium deposits, occurrences and radioactive anomalies, digitised from maps of scale 1:200,000;

7. National Balance of Reserves and Resources - The data set consists of reserves and resources of all metallic, industrial minerals, oil and gas, coal deposits in Bulgaria;

8. Register and Cadastre of Prospecting and/or Exploration Permits - Register and cadastre of permits for prospecting and/or exploration of underground resources issued by the state authorities according to the "Underground Resources Act";

9. Specialised Cadastre of Deposits and Register of Discoveries - Data set contains maps of mineral deposits and information about the discoveries of underground resources made as a result of geological research.

Environmental Impacts: Problems and Solutions

Several different approaches and methodologies for Environmental Impact Assessment (EIA) of the mining industry are applied in Bulgaria:

1. EIA is made for all active facilities (that differs from the usual European approach for EIA of facilities that are to be built). Every EIA contains inventory data and hazard assessment of a certain activity, generated and accumulated waste, and also two specific annexes: Program for compliance of the enterprise with the environmental legislation in force, and Program for environmental monitoring.

2. For the economically non-effective, ecologically hazardous, and other mines since 1992, with Decrees of the Council of Ministers, several national programs for inventory of mining liabilities (including accumulated waste, consequences of liquidation, and environmental restoration) in coal, ore, and uranium mining are designed.

3. For the mines under privatisation, according to the Bulgarian environmental legislation, a national methodology for historical contamination assessment and environmental restoration has been developed.

4. Different approaches and methodologies for inventories, environmental and human health risk assessments are applied along with the implementation of the Phare projects for "Buhovo" and "Eleshnitza", and along with the implementation of the project for the uranium objects not in the scope of the Decree for uranium mining consequences liquidation.

As a good example for inventory and investigation at a national scale, the approaches and results for the uranium mining are given in the following. The rehabilitation of abandoned or defunct mining operations has become a major environmental concern in Bulgaria. The environmental damage and the hazards connected to defunct and not properly secured mining operations is a potential source of health risks. This is of particular relevance to uranium mining operations, since they not only pollute the surrounding environment with metals and salted effluent of mine water and leachate from dumps, but also emit radioactive material through the ground water path, exhale radioactive gas due to the ventilation of underground workings and wind borne dust particles containing radioactive material.

The environmental hazards generated by the specific problems of radioactive materials are, however, in some cases even superseded by harmful effects of the mining waste and/or by-products such as heavy metals, arsenic and sulfosalts, which in most cases were not recovered due to their uneconomic concentrations and metallurgical bonding in the uranium-ore. In addition to these, some agents have been added intentionally into mining and processing (and finally dispersed into environment) and sudden shutdown of the mining operations has not solved properly their safe disposal. This applies for instance to chemical agents used for in-situ leaching.

Uranium occurrences in Bulgaria were known before World War II. Systematic uranium exploration started in 1945, when the first uranium deposits in the Buhovo area were explored. Intensive extraction of uranium commodities was conducted in the period 1946–1991 by a state owned company “Redki Metali” (Rare Metals) with about 13,000 employees. During this period, several thousands of uranium occurrences and anomalies were discovered, on several tens of them detailed exploration and experimental works were conducted, and the sites with approved industrial uranium resources were developed as uranium mining sites for classical, geotechnological (in situ leaching) and combined extraction of uranium. In Bulgaria there are 392 uranium industry objects (***Figure 4***), including:

- 377 uranium exploration, experimental, and extractive sites;
- 2 hydro-metalurgical plants (“Buhovo” and “Eleshnitsa”) with tailings ponds;
- 7 dumping stations;
- 2 repair stations;
- 4 others.

With a Decree of the Bulgarian Council of Ministers, uranium mining in Bulgaria was officially ceased in 1992, and a process of uranium mining consequences liquidation was commenced. The process started with the preparation of hydroecological and radioecological assessments of the uranium mining and processing sites, and includes technical liquidation (dismantling) and recultivation of those sites, treatment of polluted water, and environmental monitoring, basically financed by the state budget and conducted by the divisions of “Redki Metali” Company. Since year 1998, the state organisational and controlling functions on the process have been conducted by a state owned company “Ecoengineering – RM”, and in the liquidation of uranium mining consequences, financed by the state budget, are involved no more than couple of hundreds persons. During more than 10 years of uranium mining consequences liquidation, several important projects, financed by the European Union, were accomplished:

- “Remediation concepts for the Uranium Mining Operations in Central and Eastern

European Countries", financed by the Phare Multi-Country Environmental Sector Program;
- "Management and Clean-up of Ground- and Surface Waters, Polluted with Radio nuclides, as a Result of Uranium Mining and Processing Activities in the Buhovo Area", financed by the Phare Multi-Country Environmental Sector Program;
- "Complex Program for Clean-Up and Monitoring of Bukhovo Mining Area, Affected by the Uranium Mining and Processing Activities", financed by the National Phare Programme.

At the moment, a project for sealing of "Eleshnitza" tailings pond is under implementation. The project is financed through the Cross Border Cooperation Bulgaria–Greece Programme. Financed by the state budget, a project for inventory and preparation of remedial program for objects that are not included in the state program for uranium mining consequences liquidation is also under implementation.

Figure 5. *Buhovo processing plant and "old" tailings pond.*

Case studies – characterization of selected "hot spots"

Site 1: Buhovo –Uranium mining site

The Buhovo mining site is located about 20 km NE Sofia (***Figure 1***) and occupies an area of about 30 km^2 [3,4,5].

Mining history

Mining of uranium ores started in 1936 in the mining field Goten. In 1938 about 100 tons of uranium ore was shipped to Germany. Mining was halted in 1939 and unofficially started again in 1944. The year 1946 is the official year of foundation of the SBMC (Soviet-

Bulgarian Mining Company). The SBMC as a two-country entity was in operation until 1956, the successor company is “Redki Metali”. Conventional mining both open pits and underground workings were used for extraction of uranium ore. In result of the mining works in the mountain part of the area there are located more than 158 adits and 7 shafts, more than 198 waste rock dumps. The total ore extracted is about 5 Mt and generated waste is 4 Mm^3. Enrichment was realized in the early time period near Buhovo by percolation technology. The processing plant “Metalurg” (***Figure 5***) was constructed in 1947 and was in operation until uranium production was closed in 1992. During the lifetime of the plant about 10 Mt of ores from the deposits in the Buhovo mining area and other areas were processed. The processing included acidic as well as alkaline schemes of leaching. For the storage of waste from processing two tailings ponds were used.

The so-called “old” tailings pond was constructed in 1956 and the “new” pond in 1962. Both ponds are located in the valley of the rivers Buhovo and Yaneshniza. The construction was basically a dam in the river valley without a base sealing. However, a drainage system for the seepage/infiltration water was constructed. Also, a draw aside installation (internal and external) was installed. The volume of tailings is 11 Mm^3. Prior to construction of the dams, all tailings were simply discharged in the valleys of the rivers. The quantity of tailings that flew down the valley of the rivers is unknown. Prior to the construction of the tailing pond, the processing plant had a total throughput of roughly 2,5 Mt of ores. The resulting tailings were partly disposed of at a dump inside the processing plant. The other part was discharged into the river valleys. Along the rivers there is a contaminated strip of about 8 km in length.

Investigation methods

All past investigation methods during exploration and exploitation were recorded in reports that are stored in National Geofund of the Ministry of Environment and Water. According to these reports Bedrock geology comprises of Ordovician, Silurian and Devonian metamorphic rocks (shale and quartzite) and an alkaline intrusive massif body in the central part of the area (gabbro, monzonite, syenite). The uranium ore is mainly concentrated in metamorphic Ordovician slates with coal-clay slates. Generally, the ore is in the form of sulphide-carbonate formations with a content of carbonates 3-12% in shale and 20-30% in the syenite. The ore structure is dispersed rarely in the form of several mm thick veins. Principal uranium mineral is pitchblende. In oxidation zones occur autunite and torbernite.
Reclamation strategy for underground mines in the Buhovo field is presently adopted. It is outlined by the following main features:

- The juridical basis of the applied strategy of closure and remediation was laid by decree No. 163 of the Council of Ministers of 1992, amended by decrees No. 56 and No. 74 of 1998;
- Technical and biological reclamation - 198 dumps with a volume of 5 Mm^3 over an area of 181 ha, having heterogeneous material and radiation potential have to be recultivated;
- Water management and treatment;
- Monitoring of soil, water and air. This monitoring will be a part of the national system.

Observing the decrees for closing-down and liquidating the consequences from the uranium production and processing in Republic of Bulgaria a report has been prepared

“Radioecological and hydroecological expertise with forecast assessments for the environmental impact of the uranium production” for the platform of “Metalurg” and the tailings ponds, as well as for the dumps by the different ore deposits in Buhovo. Additionally projects, financed by the Phare program, for ecological liquidation of the consequences from the uranium production in the Buhovo ore field and the Processing plant “Metalurg” were prepared, but not yet implemented.

Data and databases for the mining site:

- Reports that are stored in National Geofund of the Ministry of Environment and Water;
- In “Ecoengineering – RM” - hydroecological, radioecological and soil investigation data, projects for remediation and results from the implementation, result from environmental ongoing monitoring;
- In Environment Executive Agency of the Ministry of Environment and Water – ongoing radiation monitoring.

Monitoring efforts were realized in the former years by control sampling and measurement in different years and on different media - water, soil, biological material and air. These actions were not systematic and cannot be repeated. For the objective assessment of the current situation it is necessary to create a Monitoring system corresponding with existing national regulations and instructions.

Hazard source description

The main sources of environmental influence are the tailings ponds and the dumps. The influenced milieu is in the first range water, as well as groundwater and surface water. The air is influenced by dust and by radon exhalation. The soil is influenced by contaminated water and dust. The food chain could be influenced by drinking water, by pasture of animals and by using of lands for gardens.

The recovery of the processing plant at Buhovo was in the magnitude of 95%. This implies that an average U-concentration of 0.05 to 0.5% approximately 0.0025 to 0.025% (25 to 2.5 g/t) U remains in the tailings. Since the uranium extraction process selectively removes only U from the ore, all other chemical compounds remain in the tailings in the same concentration as in the ore.

Most dangerous from the radiological point of view is radium. By its decay the inert gas radon is generated. It penetrates easily through the grinded rock into the atmosphere and could be spread by the air at distances up to 500-800 m. However, radon is easily soluble in water and, thus, is usually retained in any aqueous phases. Chemical reagents used in the uranium extraction together with the waste from the uranium processing are also deposits in the tailings ponds. Consequently the slime as a whole is a complex system containing inert rock matter ground to small grain sizes (90% between 0.25 mm to 0.01 mm in diameter), radionuclides from the uranium and thorium decay series, K-40 and a lot of chemical substances, mainly sulphates, carbonates, nitrates and complex salts of metals and alkali-earth elements and heavy and rare metals. In order to assess the chemical composition of the tailings, the historical composition of the different ores processed at Buhovo were assessed.

Environmental risks and impacts
The contaminated water systems in their present state represent a considerable radiological hazard. The environmental risk potential is based on three main factors:
- contamination of the "clean" groundwater by radioactive mine water effluent in the course of flooding;
- uncontrolled seepage from mine dumps, from tailings ponds, and from open pits;
- additional dose exposure of critical groups from the population;
- intensive agriculture on polluted soils;
- usage of radioactively polluted water from adits for irrigation.

Socio-economic impacts
The closure of the uranium industry in the region caused unemployment of a significant rate. The mining area is densely populated, agriculturally intensively used, and situated close to an industrial and residential area close to Sofia.

Outlook
After the closure of mining and processing activities in 1992, the remediation of the sites in the Buhovo mining area was and still is a priority task in order to improve the environmental situation in the area. For some districts of the site the underground water has been restored almost to their natural hydrostatic level, and are drained by some of the decommissioned mining workings. After the technical liquidation of the mining workings, the waters are captured and lead by pipelines under the dumps. The mining waters from the other districts of the site are highly contaminated and are subject to treatment.

In connection with the necessity of mining waters cleaning, it was assumed that the first stage of the remediation has to be construction of a treatment plant, water treatment, and discharge of cleaned water according to legal requirements. The contaminated mining water from the site has been caught and cleaned through sorption with ion exchanging resin. In that way about 2000 m^3 in 24 hours are processed, but only the uranium is separated from the waters and other parameters (SO_4, Ra, alpha-, beta- and gamma-activity) remain in the water and over the limited norms.

Site 2: Eleshnitsa –Uranium mining site

The area of Eleshnitsa mining site is located in the southwest part of Bulgaria, about 120 km south of Sofia and approximately 50 km north of the border to Greece [3,4,5].

Mining history
Uranium production in Eleshnitsa mining site started in 1956. Uranium ore was mined south of village of Eleshnitsa by underground mine workings to a depth of 600 m as well as by quarrying. During operational period (1956-1992) were driven 66 adits, 6 shafts, and 4 large quarries were developed. Since 1965 a processing plant has been in operation. Ores from the remote sites were also processed in the plant. The total ore extracted is about 8.8 Mt and generated waste is 4 Mm^3. The plant is now included in the Bulgarian mining consequences liquidation program. At present, the mining operations near Eleshnitsa are ceased but the treatment of ionic exchange resins is still continuing and is in connection with the radioactive water treatment facilities. The ongoing treatment of resins is based on the des-

orbtion of uranium-enriched resins from other mining districts. The tailings pond was built by damming off the valley downstream the processing plant. At present, the pond contains between 8 and 12 Mm^3 of tailings material (***Figure 6***). A total of approximately 8 Mt of ore were processed at the Eleshnitsa mill. The processing residues including chemical and neutralizing agents as well as eluted resins were deposited in the tailings facility.

Figure 6. *Eleshnitsa tailings pond.*

Investigation methods

All past investigation methods during exploration and exploitation were recorded in reports that are stored in National Geofund of the Ministry of Environment and Water. The "Eleshnitsa" deposit is a sandstone type. The uranium ore is located among monowedge-like sandstone, alevrolites and conglomerates. The uranium mineralization is made up of nasturanium, coffinite and uranium mica. The uranium ores date back to the Oligocene period. Reclamation strategy for underground mines in the Eleshnitsa field presently includes:

- The juridical basis of the applied strategy of closure and remediation was laid by Decrees No No. 163/1992, 56/1994 and 74/1998 of the Council of Ministers;
- Technical and biological reclamation - 55 dumps with a volume of 2.4 Mm^3 over an area of 14.7 ha, having heterogeneous material and radiation potential have to be recultivated;
- Water management and treatment;
- Monitoring of soil, water and air. This monitoring will be a part of the national system.

Data and databases

- Reports that are stored in National Geofund of the Ministry of Environment and Water;
- In "Ecoengineering – RM" - hydroecological, radioecological and soil investigation data, projects for remediation and results from the implementation, result from environmental ongoing monitoring;

- In Environment Executive Agency of the Ministry of Environment and Water – on-going radiation monitoring.

Monitoring efforts were realized in the former years by control sampling and measurement in different years and on different mediums - water, soil, biological material and air. These actions were not systematic and cannot be repeated. For the objective assessment of the current situation it is necessary to create a Monitoring system corresponding with existing national regulations and instructions.

Hazard source description

Radon concentrations in ground-level air range from 370 to 600 kBq/m^3. These high values are related to outcropping uranium mineralisation, waste rock piles and exhaust air from mine workings. The sources, however, can not be quantified due to the lack of data, i.e. specific activity of ^{226}Ra, surface areas of waste rock piles, radon concentration in mine air, exhaust air expulsion rates, etc. The effective dose of the inhabitants of Eleshnitsa from radon and radon daughters are in the order of 1.3 mSv/a for adults and 2.6 mSv/a for children. The exposure to radiation from long-lived alpha emitters is not taken into account. The reason for this is the insignificance of dust burdens.

Environmental risks and impacts

- potential risk of failure of the existing main tailings dam during periods of very heavy rainfall in combination with seismic activities. Such a failure could cause a spill of contaminated water and tailings material downstream into the Mesta River, which flows across the border into Greece. Its water is used extensively for irrigation purpose;
- contamination of the “clean” groundwater by radioactive mine water effluent in the course of flooding;
- uncontrolled seepage from mine dumps, from tailings pond, and from open pits;
- additional dose exposure of critical groups from the population;
- intensive agriculture on polluted soils;
- usage of radioactively polluted water for irrigation.

Socio-economic impacts

The closure of the uranium industry in the region caused unemployment of a significant rate. The mining area is situated in the vicinity of Eleshnitsa village and is agriculturally intensively used.

Outlook

After the closure of mining and processing activities in 1992, the remediation of the sites in the Eleshnitsa mining area was and still is a priority task in order to improve the environmental situation in the area. The underground water has been restored almost to their natural hydrostatic level, and is drained by some of the decommissioned mining workings. To prevent the health of the local population, mitigation measures are urgently needed for:

- pollution with radioactive dust as a result of wind erosion of waste dumps near the village, open pits and the tailings pond;
- contamination of surface and ground water as a result of flooding of the mining workings;
- radon exhalation from the open mines and waste dumps.

Conclusions

There are a number of activities going in Bulgaria addressing environmental problems associated with mining and mining waste:

- National projects for environmental restoration in the regions with coal, ore, and uranium mining objects;
- Environmental monitoring of all uranium and most of the coal and ore mining objects;
- National project for inventory and design of a program for environmental restoration in the regions of 34 uranium objects not in the scope of the Decree for uranium mining consequences liquidation.

Other activities that may play an important role in impact assessment and mitigation of mining are still in the planning phase:

- Preparation of extensions of the national mining remedial programs;
- IPPC Directive implementation for some mining objects;
- Investigation on the present environmental state of already environmentally restored uranium mining sites in SW Bulgaria;
- Design and maintenance of a Geoecological cadastre of the mining industry in Bulgaria.

In conclusion, Bulgaria has significant problems associated with past mining, and uranium mining in particular. Significant efforts have been made for the inventory, assessment and remediation of mine sites, often in the lack of sufficient funds.

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Mining, Mining Waste and Related Environmental Issues in the Czech Republic

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Introduction

A large area of the Czech Republic has been affected by relics of old mining and mineral raw material processing activities. Hundreds of square kilometres have been impacted. At least 25 percent of population of the Czech Republic live in areas of a geological environment classified as highly degraded. Undermined areas pose a very serious risk for the environment and people, mainly in areas of old and more recent mining of hard and brown coal and also in the old mining districts where silver and polymetallic ores were extracted (***Figure 1***). Uranium mining processed at least as large amount of material as the exploitation of the rest of metals in the whole mining history of the Czech Republic. Recently, positive trends in the preservation of the Czech environment have

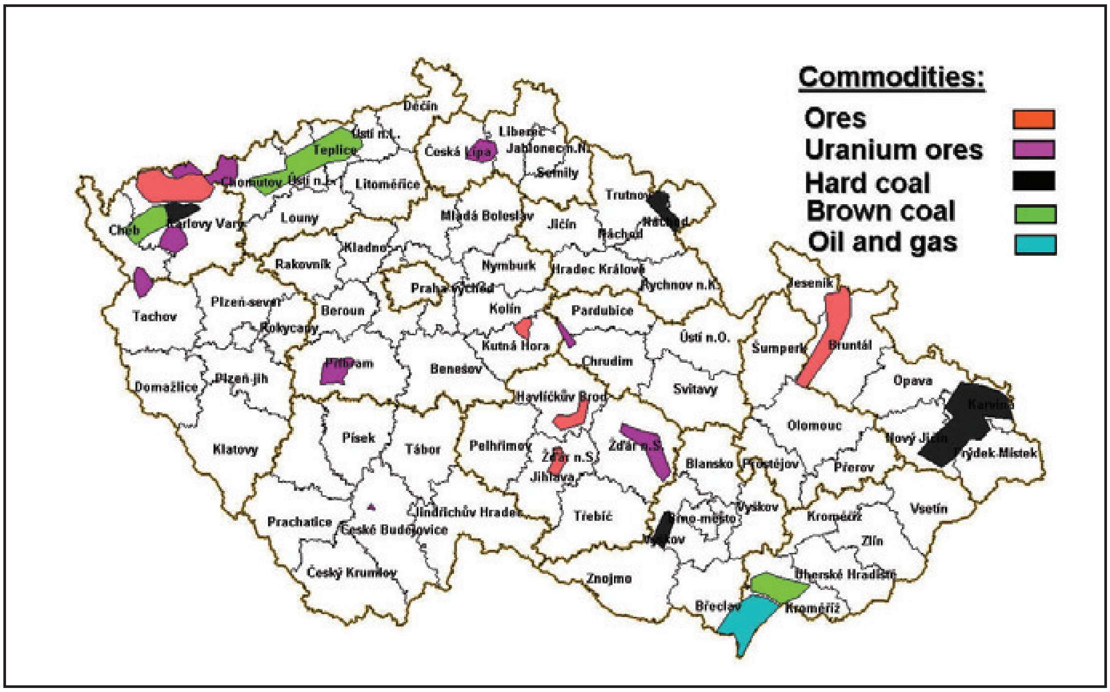

Figure 1. *The most important areas of present and historical mining activities (2001).*

Table 1. National institutional framework of mining.

Organisation	Main activity
Ministry of the Environment (MoE)	Protection of mineral deposits, resources, permitting and registration of geological prospecting claims, state grants for mineral prospecting programs, environmental conditions for mining activities, database of reconnaissance of mineral resources, EIA, management of geological research
Ministry of Industry and Trade (MoIT)	Supervision of exploitation, extraction and dressing of mineral deposits resources, mineral planning policy, management of the state programme of coal, ore and uranium mining abatement
Czech Mining Bureau (CMB)	Supervision of all mining activities (including safety and mining hazards), mining permits and mining areas, inspection and controlling mining activities, mining fees and charges
Czech Geological Survey (CGS)	Regional geological and mineral resources, exploration, registration of mining related risks, geochemical and hydrogeochemical investigations
CR Geofond	Geological information centre, mineral resources databases, evidence of exploration, reserves and mining sites
Mining University Ostrava	Theoretical investigations on raw materials dressing and study of mining and remediation of mining areas
DIAMO s.p.	State enterprise focusing on uranium mining activity incl. dressing, radioactivity monitoring and remediation of mining areas. Since 2002, also supervision of all ore mining
OKD a.s.	Brown coal deep mining, remediation of mining areas. The main area in Northern Moravia – Silesia
MUS a.s.	Brown coal opencast and deep mining, remediation of mining areas
SD a.s.	Brown coal opencast mining, remediation of mining areas
SU a.s. –Sokolovska uhelna	Brown coal opencast mining, remediation of mining areas
MND a.s. – Moravske naftove doly	Oil and gas mining in Southern Moravia

been observed. The exploitation and export of mineral resources have decreased and surface excavation is not so extensive. Groundwater resource protection and the regulation of waste and mining waste deposition have significantly improved during recent years (***Tables 1 and 2***).

Table 2. Mineral deposits and mining in the Czech Republic (kt).

Item/Year	1995	1996	1997	1998	1999
protected deposit areas	841	902	969	1046	925
mining claims - total number	1073	1066	1066	1053	1054
area (km^2)	1650	1704	1649	1642	1682
number of exploited deposits (a)	591	632	594	588	572
mining output, Mt (b)	145	150	152	136	127
organizations managing the deposits	344	364	378	377	380
organizations mining the deposits (a)	260	262	287	260	256

Note:

a) Data for reserved deposits only; 137 more organizations exploited 158 non-reserved deposits in 1999

b) without radioactive minerals; conversion to tons: natural gas – 1,000 m^3 = 1 t, dimension and building stones – 1,000 m^3 = 2,700 t, gravel sand and brick clays – 1,000m^3 = 1,800 t

Mineral Resources and Mining

Metallic ores

Ore mining has a very old tradition in the territory of the Czech Republic. The oldest archaeological evidence on gold wash dates back to the 9th century B.C. In the Middle Ages Bohemia became the centre of European gold and silver mining. A long mining activity has made the territory of the Czech Republic rich in marginal ores only. The mining boomed in the Cold War period after 1948 when the ore deposits were exploited even at considerable economic loss so that an independence of mineral imports from the western countries could be ensured. After 1989, the exploitation was abated and a closure of mining in the polymetallic deposit with gold at Zlate Hory discontinued the ore mining in the territory of the Czech Republic in 1994. State grants for abatement programs directed at social costs, technical liquidations, savings (maintenance) and remedying reached 2.09 M CZK during 1990-1999.

Mineral fuels

Significant geological reserves of mineral fuels can be found in uranium ores, hard coal and brown coal in the territory of the Czech Republic. Geological reserves of these raw materials noticeably contribute to the world reserves. Coal production originated in the

Table 3. Uranium deposits of the Czech Republic.

Year	1995	1996	1997	1998	1999
Deposits					
Total number	17	16	13	13	13
Exploited	2	1	1	1	1
Total reserves, t U	141,534	141,069	139,396	139,528	139,141
Mining output, t U	611	589	624	611	605

Czech countries in the 19th century at the beginning of the industrial revolution. Uranium ore mining boomed after the World War II, while production of mineral fuels reached its peak in the second half of 80s. Later on, a recession occurred resulting from a decline of U-ore and coal mining. State grants for abatement programs directed at social costs, technical liquidations, savings and remedying reached 22,500 M CZK in coal industry and 18,200 M CZK in uranium industry in 1990-1999. Grants for the coal industry abatement programme will continue with the estimated total granted amount of 4,020 M CZK However, half of this sum is reserved for social compensations. The quickest decline affected the uranium ore mining. As for U-ore and coal, all requirements of the Czech Republic are secured by the domestic production (hard coal and brown coal are also exported), but the dependence upon oil and gas import reaches nearly hundred-per-cent.

Uranium

The most frequent genetic types of uranium deposits are hydrothermal (mostly vein), sedimentary, infiltration, metamorphic and albitite (***Table 3***). Uranium forms several types of minerals. The most important are, from the economic point of view, uranium oxides (uraninite - pitchblende), phosphates (torbernite, autunite), silicates (coffinite) and organic compounds (U-bearing antraxolite). An ore grade of about 0.1% U_3O_8 is a metal contents limit for the ore to be mined profitable. This depends on the deposit type, volume of reserves and the method of mining. Processed products of U-ore yield contents of 70-90 weight % of uranium oxides.

Deposits of profitable grade and/or historical important deposits are concentrated in the following regions, including brief characteristics of the mineralization:

- northern Bohemian region - mineralization in the Cretaceous sediments,
- the Moravian region - mineralised fracture zones and hydrothermal veins,
- the Krusne Mts. region - mineralization in the Tertiary sediments and exhausted hydrothermal veins (Jachymov, Slavkov),
- the western Bohemian region - metasomatic mineralization,
- the central Bohemian - metasomatic hydrothermal veins exhausted to-date (Pribram).

Mined deposits at Hamr and Straz in the Bohemian Cretaceous basin and mineralized fracture zone at Rozna in 1999 were of the balanced deposits. Underground mining takes place at Rozna (0.202% U grading in proven reserves in average), whereas Straz deposit (grading 0.037% U in proven reserves in average) was extracted by means of in situ leaching (operation terminated in 1996). All ore extracted was chemically processed to provide concentrate (yellow cake). Czech power plants were the sole customers of U-concentrates. A tailings pond located at Straz pod Ralskem, where waste leach of deposit with 0.030-0.063 weight % rare earths was accumulated for 30 years, is a possible source of not only rare earths (lanthanum - gadolinium), but also scandium, yttrium and niobium. The reserves have not been evaluated yet. Current uranium consumption (Dukovany nuclear power station) reaches 330 tons per year. A surplus of production was deposited as state material reserves. The annual consumption should reach 690 tons after starting two blocks of Temelin nuclear power plant.

Hard coal

Hard coal is a phytokaustobiolite exhibiting a higher degree of coalification, i.e. more than 73.4% carbon, less than 50% volatile matter and dry (ash free) caloric value exceeding 24

Table 4. Black coal in the Czech Republic.

Year	1995	1996	1997	1998	1999
Deposits					
total number	73	72	68	67	69
Exploited	21	17	20	18	17
Total reserves, kt	13,932,934	13,942,239	13,954,950	13,941,612	16,305,887
Mining output, kt	21,309	21,784	20,847	19,521	17,227

MJ/kg (***Table 4***). The internationally recognized boundary between lignite and hard coal is the value of vitrinite reflectance (R=0.5%). Coking coal is a hard coal that allows producing coke for blast-furnace production of pig iron and/or for heating. Other coal is defined as steam coal (40% of electric energy in the Czech Republic is generated by burning of coal).

Both the coking coal and the steam coal occur in the territory of the Czech Republic. The coking coal occurs mostly in the Upper Silesian basin. About 15% of reserves are in the Czech Republic and about 85% in the territory of Poland. The mining in Ostrava part reached the depth of about 1,000 m. This fact, accompanied by complex and unfavourable mining and geological conditions, have made profitable mining extremely difficult. Consequently, Ostrava mines have gradually been abandoned. The majority of mines in the eastern part have enough reserves that can be mined at a much lower cost. However, this coal is of lower grade, as far as coking properties are concerned. The production of hard coal has been renewed in the Trutnov region in 1998. Some other deposits of hard coal in the Plzen (Pilsen) and Brno regions have become non-profitable.

Brown coal

Brown coal is a phytokaustobiolite exhibiting a lower degree of coalification, i.e. having less than 73.5% carbon, more than 50% volatile matter and dry (ash free) caloric value less than 24 MJ/kg (***Table 5***). Brown coal is used mainly in the energy industry, and to a lesser extent, in chemical industry.

The majority of brown coal is still used for power generation in the Czech Republic. The major Bohemian brown coal basins originated and are located in the furrow along the Krusne Mts. following NW boundary of the Czech Republic. The total area of the coal-bearing sedimentation is 1,900 km^2. The following single basins are recognized in the whole area of

Table 5. Brown coal in the Czech Republic.

Year	1995	1996	1997	1998	1999
Deposits					
total number	72	71	66	62	61
Exploited	17	16	14	13	13
Total reserves, kt	10,443,206	10,376,959	9,893,368	9,741,936	9,637,410
Mining output, kt	57,954	59,539	57,395	51,283	44,858

the Krusne Mts. furrow (from NE to SW): North Bohemian, Sokolov and Cheb basins. The largest North Bohemian basin is then divided in three partial basins. It has been a major source of brown coal, which is now extracted by huge open pit mining operations.

There are several coal seams in a part of the North Bohemian basin (Chomutov basin). In the major part of the basin, the seams are so close to each other that the open pit mining is feasible for all of them. Lignite shows a low degree of coalification and high contents of ash (up to 50%). As the contents of sulphur and arsenic are high, the burning of this brown coal in large power plants poses an issue of environmental concern. Due to the low caloric value, a part of the reserves exceeds formerly used limits laying down a maximal amount of sulphur denoted in grams related to a unit of net caloric value.

Brown coal in the Most part of the North Bohemian basin shows a higher degree of coalification and lower contents of ash. However, it is very high in the tenor of sulphur and arsenic in some parts. Currently being about 150 m deep, the open pit mines continue to increase. The production in the Teplice part of the North Bohemian basin was stopped in 1997. The remaining reserves of almost sulphur-free brown coal located under the town of Chabarovice are likely to be abandoned because of a conflict between environmental and landuse interests. Similar conflicts may occur even in other parts of the basin. The Sokolov basin west of Karlovy Vary has two brown coal seams. The major reserves are confined to the thickest and the uppermost seam called Antonin. The brown coal is of xylitic characteristics, high in water and relatively low in sulphur contents. The seam is extracted by open pit mining and used for power generation (sorted brown coal for burning in power plants, lighting gas production). The Cheb basin has about one billion of reserves of stratigraphically latest lignite of high contents of water (about 50 to 55%), high in liptodetrite, and consequently high in mineral tar content. The brown coal is suitable for chemical processing. Mining operations in this basin have not been allowed because they are likely to affect sources of mineral water for nearby Frantiskovy Lazne Spa. The Zitava basin extends into the Czech Republic from Poland and Germany. The upper seam has already been extracted. The remaining two lower seams are difficult to be mined underground because of overlying quicksand and tectonic problems.

Industrial minerals

Second to mineral fuels, industrial minerals represent the most important group of raw materials in the territory of the Czech Republic. The largest reserves are those of limestones, kaolin, clays and natural sands. Other industrial minerals represent smaller, but important material potential in the scale of the national economy. Kaolin, dimension stone, natural sands, clays and limestones are also important export commodities.

Environmental Impacts: Problems and Solutions

Mining impacts according to the main mining sectors

Uranium mining activity is in abatement at present. There are two active districts, many abandoned mines from the 50s, waste rock dumps and tailings ponds. Problems with radioactive acidic wastewater and waste rocks pose an important risk. The most important districts in sensitive areas are:

- Hamr, Straz: in situ acid leaching, tailing ponds, processing plant;

- Rozinka: dumps, tailing ponds, processing plant;
- Mydlovary: former processing plant, tailing ponds;
- Pribram, Jachymov, Horni Slavkov, Z. Chodov: abandoned uranium districts with typical impacts at a scale of km^2.

Ore (Cu, Pb, Zn, Sn, W, Ag, Au) mining activity finished in CR. Risk is posed by undermined areas, dumps, contaminated mine waters, soil contamination by heavy metals. Regional impact can be classified according to the history of mining activities:
- Middle Ages: Kutna Hora, Jachymov, Jihlava, Zlate Hory, Pribram, Jilove, and Kasperske Hory ore districts;
- 19th Century: Pribram;
- 20th Century (2nd part): Pribram, Zlate Hory, Horni Benesov, Kutna Hora, Stare Ransko, Cinovec, Horni Slavkov, Jilove. Tailing ponds in Pribram, Kutna Hora, Zlate Hory, Cinovec. Processing plants in Pribram, Bruntal, Sobedruhy (fluorite).

Hard coal was mined in huge operations in Ostrava region. Dumps, mud ponds, detonating gas casues the most siginificant environmental impacts. In Zacler and Kladno old mining dumps and dust, radioactivity, self-inflammation processes are the major threats to the environment.

Brown coal mining in the Northern Bohemian Brown Coal Basin is a black spot in the heart of Europe, part of "The Black Triangle". Problems include total landscape destruction, ponds, secondary impacts and acidification of large areas.

Gas and oil mining in Southern Moravia causes problems of salty water.

Pyrite mines are abandoned now in Chvaletice where a big pond releases acid drainage with heavy metals into the Labe River. In Lukavice and Hromnice acidification of surface waters, indications of Se contaminations are well known for mining impacts.

Mining in protected natural reserves

Activities in special protected areas of the Czech Republic (national parks, protected landscape areas, national nature reservations, nature reservations, national nature monuments and nature monuments) are regulated by Act No 114/1992 Coll. on nature and landscape protection. According to this Act, all mining in national parks (with exception of building stone and sand mining for construction within the territory of the national park) is prohibited in the 1st zone of protected landscape areas and in national nature reservations. Although the mineral resources mining is not prohibited by law in other areas (protected landscape area zones), mining activities would not be probably launched because of civil activities in the field of environmental protection.

The area of special protected large-scale areas (NPs and PLAs) accounts for 11,535 km^2 (14.6% of the territory of the Czech Republic), of which the area of prohibited mining is 19.3%. Reserved mineral deposits have been mined also in the territory of 19 PLA in the last years, but nearly all mining claims were determined before the establishment of the protected areas. The mining output in PLAs has declined after 1989. In 1999, mining only occurred in a territory of 18 PLAs. As for mining impacts on protected landscape areas, an unfavourable condition is typical of Cesky kras PLA (Czech Karst - limestone mining).

The most important national programmes, projects and inventories related to mining, mining waste and related environmental issues

1. *The National Mineral Resources Information System for Mineral Raw Materials* (SURIS Information System) is owned by CR Geofund, information system with inforamtion of all known profitable mineral resources, excluding building materials in a GIS relational database. It is continuously updated. Data includes mineral reserves and national balance, stage of using of mineral resources, reserves in protected areas and mining claims. Also, information on abandoned mining sites, old dumps, undermined areas, radioactive anomalous areas, landslide hazard areas, geochemistry are included.

2. *Mining Impacts Information System* (owned by CGS) is under development and it is characterised by national coverage, information on morphological and geochemical effects of mining on landscape and ecology. Data is organised in GIS relational database. Pilot studies are carried out in model areas.

3. *Mapping the Geochemistry of Surface Waters and Stream Sediments* is a national programme aiming at providing indicators for a varied land contamination problems. Results are available in the Geochemical Database owned by CGS.

4. N*orth Bohemian Brown Coal Basin Project* (1995) resulted in a GIS-based information system mapping all possible mining effects in the region.

5. *Environmental Geology of Land Affected by Mining* (1999) focused on radioactive risks in the Pribram district.

6. *The Waste Deposit Database* is owned by CGS and it is a catalogue of the waste deposit sites, describing hydrogeological, engineering geology and waste characteristics.

7. *Thematic studies by MIT* is carried out at the regional range (e.g. Western Bohemian Mining Waste Usage). Studies on mining depressions and on mining waste management are the main thematic.

8. *Thematic studies by ME* cover mining impacts in important areas (e.g., regions of Hamr, Dolni Rozinka, Pribram, Kutna Hora AND Zlate Hory), regional registration of mining dumps, and safety of tailing materials, safety of underground and surface waters.

9. *EIA Documents* on mining projects created under MoE supervision, such as EIA for the Mydlovary uranium processing plant.

10. *Dangerous Waste Deposit Site Database* has been developed as a GIS system mainly for industrial wastes at the national level. Metal processing waste, and in some cases mining waste, is included.

Databases

The main geoscientific databases stored at Geofond are briefly described below.

Database of undermined areas (digitised maps, 1: 50,000 scale)
It contains basic information on areas with a history of an underground exploitation or prospecting for mineral resources. Such areas are inherently prone to a large-scale subsidence and other risks arising from the underground excavation. The information also contains an assessment of possibilities to employ the underground space for dumping, and whether there are any unsurveyed mineral resources remaining. The database comprises technical reports, mine maps and documents concerning the research, prospecting and mining. The identification number is based on the number of the map sheet of the 1: 50,000 scale set and the order number of the drawing on the map sheet. It provides a link to the coordinate part of the register. The database was created between 1985-1988. In 1992, it was supplemented with data obtained from records on prospecting and exploitation of radioactive deposits. The original drawings were updated in 1994-1995. As a result, the general outlines of mining areas were in many cases replaced by lines showing the exact limits of the undermined areas, which were based on detailed maps. The database contains 4,605 entries (1998).

Database of old mine workings (digitised maps, 1: 25,000 scale)
It contains the “Register of Old Mine Workings“ set up in 1988 under Section 35 of Act #44/1988 Coll. (Mining Act). It files all reported workings (429 reports total), which have been included after inspection in the category of old, abandoned or other workings (i.e. natural subterranean openings or workings made for objectives apart from prospecting or exploitation of mineral resources). An environmental liability for a remediation of potentially dangerous old mine workings, for which there is no owner, or the ownership is unknown, is assumed to lie with the state (MoE). The register contains files of correspondence concerning individual reports. The documentation also includes supporting reports and statements, security plans and final technical reports. In 1993, this register was transferred into a database that includes all reported sites, then divided into groups of old mine workings (as defined in terms of the Mining Act), abandoned mine workings with known owners or their legal successors, and other subterranean caverns and excavations. The database is created from records of the basic characteristics of the site and other relevant documents. It also includes all correspondence, statements, and plans of technical security, final technical reports and records on the remediation of the sites concerned. The database of old mine workings is linked to the database of undermined areas through the site number, which consists of the map number (1:50,000 scale), the number of the undermined area and the order number of the drawing of the old mine working in the undermined area. The database contains 429 sites, of which 339 are old mine workings in terms of the Mining Act 1998).

Database of landslides (digitised maps, 1: 25,000 scale)
Basic data on previously recorded and currently active gravitational movements (landslides, rock avalanches, mudflows), especially those considered as hazardous. The database was created from the original register completed in 1962-1963 as part of a state-wide survey of these phenomena in the territory of the former Czechoslovakia. The record of phenomena was compiled in a file of maps at 1:25,000 scale, together with a file of re-

cord cards, which included the basic descriptions of topography, geology, morphology, geo-technical and economic data. In 1976, the register was transferred to a database. Both versions are being continuously updated, especially by using results of geological mapping undertaken by CGS and reports and expert statements containing results of geological work submitted to CR Geofund. Before 1997 floods, the database contained almost complete information on residential areas with high frequency of landslides (northern Bohemia, the Cheb area, the Jicin Uplands, the Trebov Mezihori Mts., The Beskydy Mts., the Hostyn, Vsetin and Vizovice Hills, the Chriby Mts., the White Carpathians Mts. and the Pavlovske Hills). The coverage of the remaining area of the Czech Republic is not complete. Up to date, the number of registered sites has reached 6,598. Since 1999, the database has been being substantially updated, including new phenomena caused by 1997 floods. The process of updating was initiated in 1998.

Database of radiometric anomalies (digitised maps, 1: 50,000 scale)
The results of the project: “Collection and Processing of Data obtained from Prospecting of Radioactive Materials for Environmental Purposes“ which was undertaken by the survey organizations of the former CSUP (Pruzkum Pribram, s.r.o. and DIAMO o.z. GEAM o.s. Dolni Rozinka), on behalf of MoE, in 1991-1994. The database consists of three compartments:

- Radioactive sites - location and shape of individual radiometric anomalies, which were discovered during surface prospecting for radioactive materials. The data include geographical, archival, geophysical, structural, petrographic and mineralogical information with a total of 15,960 entries. These data were used in constructing the 1:50,000 scale maps of radiometric anomalies in the Czech Republic;
- Areas with radiometric anomalies - contoured groups of radioactive anomalies related spatially or genetically, produced by digitising of maps of radiometric prospecting – 3,420 entries;
- Information on radiometric mapping - contours of areas where prospecting for radioactive materials has been carried out using various survey methods or contours of areas with various map scales - 466 entries.

The radioactivity of the areas with radiometric anomalies and of radioactive sites was measured and these areas were divided into three categories according to the abundance of anomalies, their measured values, size, structural-tectonic position and contents of uranium in rocks.

Database of geochemical investigations (digitised maps, 1: 50,000 or 1:200,000 scale)
It contains classified data related to the geochemical reconnaissance and survey work carried out in the territory of the Czech Republic. The original sources of information are chiefly reports archived by CR Geofund and the cooperating organization Geomin Jihlava established in 1989. The database contained data on 693 activities and 1,510 geochemical projects as of December 31, 1998.

Specialized database of geochemistry (digitised maps, 1: 50,000 scale)
The database was created in 1992-1993 in cooperation with the Centre of Applied Geochemistry GMS Jihlava and the Faculty of Science of Charles University Prague.
It consists of three parts:

- Rock geochemistry (lithogeochemistry) - silicate analyses of rocks and contents of trace elements from various parts of the Bohemian Massif, especially from granodiorites and metamorphic rocks of the Moldanubicum. Apart from the location and I.D. of samples, the records include complete silicate analyses, contents of trace elements and relevant references to expert statements or publications. This part of the database contains 3,041 entries.

- Soil geochemistry (metallometry) - contains chemical and mineralogical analyses of samples (contents of selected heavy minerals - scheelite, baryte). This part of the database includes 112,698 entries.
- Geochemistry of stream sediments - includes a set of selected elements. This part of the database contains 1,825 entries.

Databases of mineral raw materials information system (SURIS) Database of mineral reserves (digitised maps, 1: 25,000 scale)

It contains information on special and common natural metalliferous and industrial mineral deposits that could be profitably extracted using appropriate technology, depending on market conditions. It also contains prognostic data concerning mineral deposits, areas with low potential for discovery of mineral deposits, unsuccessful surveys and the geographical location of deposits. A value of a mineral reserve can vary with time, depending on periodic recalculation subject to changing costs of extraction and changes in market value. This calculation is made once a year in the statement of balance of supplies. Apart from this information, the database has been enlarged to incorporate relevant facts from the register of mineral deposits including general, technical and qualitative data concerning resources of raw materials in the Czech territory. The database contains information on 8,418 sites (1998). Of these, 1,706 are special deposits for which reserve calculations exist, 470 recorded common deposits, 1,033 other deposits without assessed reserves, 154 approved prognoses, 1,010 recorded prognoses, 1,324 areas in which prospecting has proved unsuccessful and deposit locations and 2,721 entries for declassified deposit.

Database of protected areas with reserves of mineral resources

Information on areas of known and predicted reserves in special mineral deposits (as defined by the Mining Law of the Czech Republic) is stored in this database, which are designated as protected reserves. Such information must be taken into account in land use planning. Delimitation of areas of protected reserves in accordance with Act 44/1988 Coll. and consequent modifications and amendments (Sections 16-19) ensure protection of the mineral resources of the Czech Republic. The incorporation of this information in a computer database was undertaken by a decision of the state administrative bodies (1998).

Database of Territories of Exploration (Mining Claims)

All objects were located by geodesic methods having a coordinate accuracy of 1 m. The database contains information on Territories of Exploration (including application for exploration) comes from CMB. The database contains details on 1,103 sites (1998).

Database of areas with exploitable mineral resources (PU)

It contains information concerning permits to undertake geological works for prospecting and surveying of special mineral deposits issued in accordance with Act 62/1988 Coll., included in Act 543/1991 Coll. The database contains details on areas for which exploration licenses have been granted, together with an identification of the minerals for which the exploration license has been granted. Records of validity of licenses and administrative organization are also kept. The database contains details on 434 sites (1998).

Database of preliminary licenses for exploitation of minerals in delimited areas (digitised maps, 1: 50,000 scale)
It contains details of permits issued by the Ministry of Economy (MoE since 1997), in accordance with Act 44/1988 Coll. and further modifications and amendments (Section 24). An application must be made, and a preliminary license must be granted by the state mining administration before an organization can apply for a delimitation of an area for exploitation of minerals. The database contains details of the areas delimited for future exploitation of mineral resources and information on the organizations to which the preliminary license has been issued. The database contains data on 423 licences (1998).

Database of areas affected by the exploitation of mineral resources, remedied, revitalized, and recultivated areas
This forms part of the database of areas of mineral exploitation. It contains basic information on the mineral deposit, area of exploitation, land use prior to mining, layout of the area affected by exploitation, volumes of overburden topsoil and sub-soil materials in dumps, plans of remedied areas and plans for a further land use in the abandoned workings. In addition, the database includes information on mining activity in the claim, and general plans for closure of mining operations and remediation. The database contains data on 612 sites (1998).

The creation of the database resulted from the conclusions of defence of project #02 PPZ/630/1/96 “Analysis of Impact of Mineral Resources on Rock Environment and Land Capacity“. The database contains basic information on land use prior to extractive operations and after their termination, a general plan of remediation, and dates of the beginning of the extractive operations and predicted termination. The data refer to the area within the contours of exploitation. The building of the database was launched in 1997 by collecting data from the organizations that file records on information on special mineral raw materials in the areas of Chomutov and Central Bohemia. In 1998, more data were added from other parts of Bohemia (the areas of Plzen, Ceske Budejovice, Hradec Kralove and Liberec). The database was completed in 1999. Since January 1, 2000, the database has been being updated according to the „Annual Report of Mining, Technical and Operation Data and Data on Remediation, Rehabilitation and Damage due to Activities of Mining Organizations and Associated Processes“. The draft of this report has been prepared by CMB in cooperation with MoIT, MoE and CR Geofund and is subject to an approval by the Czech Statistical Bureau. The draft suggests that the database should be enlarged to include details on common mineral deposits of the Czech Republic.

Case studies – characterization of selected “hot spots”

Site 1. Mydlovary, South Bohemia District – Uranium mining site

Mining history

The site (103.5 km^2) comprises an area of tailing ponds of a chemical processing plant for uranium ore located about 20 km north-west of Ceske Budejovice, west of Mydlovary village. The area elevation is about 380–420 m. The uranium ore treatment plant (both acid and alkaline leaching) was in operation between 1962 and 1991, processing ores from Western Bohemia, Okrouhla Radoun and Pribram deposits (with the total of about 16.8 Mt of ore). About 35.8 Mt of sludge has been disposed of at the tailings ponds in an area of 285 ha. The tailings ponds were constructed in exploited lignite seams of Miocene age ("Mydlovary" strata). Up to date, the processing technology has been removed, and the area of the processing plant has been decontaminated. The tailings ponds are currently being remedied and rehabilitated.

Environmental issues

The main problem is caused by polluted surplus water in the tailings ponds after hydrometallurgical processing of the ores.

Tailings pond water charactertics:

Major pollutants:	U, ^{226}Ra, DS
Minor pollutants:	SO_4, NO_3, NO_2, NH_4, Mg, Mn, V

The tailings pond water has an annual drainage amount of 111,700 m^3.

Major pollutants:	U, ^{226}Ra, DS
Minor pollutants:	SO_4, Cl, NO_3, NO_2, Fe, Mn, Mg, NH_4

An extensive removal and remediation is performed on the site, aiming at covering of the tailings ponds, consequent rehabilitation of the area, and minimizing of possible groundwater pollution development. A thorough underground monitoring is a constituent part of these works. In spite of the fact that on-site removal and remediation works are of the highest priority, the whole process is, due to the lack of funds, not extensive enough to meet demands of the relevant competent authorities. The proposed inclusion of the site in the MINEO II Project aims at clarifying the extent of the pollution during the on-site removal and remediation works and obtaining grounds for an evaluation of the remediation effectiveness.

Site 2. Kutna Hora, Middle Bohemia District - Polymetallic ore mining site

Mining history

The site is an old environmental hot spot. The historical mining and polymetallic ore processing allowed pollutants to develop in the environment. Despite extensive monitoring and measurements, there is no comprehensive map of environmental impacts in the mining district and the vicinity yet. In 1982, an airborne geophysical survey focusing on magnetic field and radioactivity was performed in order to help with a comprehensive evaluation of environmental impacts.

Environmental issues

The site (33.25 km^2) is located about 50 km east-southeast of Prague in the Polabska Lowland, elevated between 200 – 350 m. The site is one of the oldest ore mining areas in the Czech Republic. The deep mining on the site dates back to the 13th century. The mining boomed in the 14th century. Several ore veins containing Ag-bearing ore, Ag-galena, copper ore, and sphalerite were mined. About 2,230,700 tons of ore containing 2% of zinc (44,624 tons of Zn total) was extracted during 1958-1991. The Kutna Hora ore district is a vein hydrothermal plutonic polymetallic deposit of pyritic association of Upper Variscan age. The sulphide ore mineralization comprises pyrite, sphalerite, pyrrhotine, and arsenopyrite, occasionally with galena, chalcopyrite, and stannite. Silver is associated with all kinds of sulphides. Zn, Cu, (Ag) mineralization was mined in several vein belts. The mining was finished in 1991.

The mine has been liquidated. A partial rehabilitation has been performed on the mine surface and the mining district has been inundated. Acid mine waters are high in dissolved solids. The waters are pumped through a water shaft ("Kank") to the surface, then treated at a mine water treatment plant. The tailings pond and waste rock dumps are partly covered with pioneer species. Possibly profitable reserves of 861,000 tons of polymetallic ore are recorded at the deposit. The undermining of the area poses one of the most important environmental issues. There is no surface levelling monitoring performed on the site. The total amount of both historically and recently excavated rock is estimated 1.9 Mm^3. Aggressive mine water is still pumped through a water shaft to the water treatment plant, which is situated on the surface in the area of a former mining pit. The water is high in Fe, SO_4, and As. ADR is neutralised with the use of calcium hydroxide. The mine water is the main environmental issue currently. About 3.4 Mt of sand (a waste stream from the ore processing) have been disposed of in the tailings pond. The pond is partly covered with pioneer species. Main characteristics monitored in the environment: Fe, Zn, Pb, Cu, As, Ca, Cd, Cr, Mn, Mg, F, Cl, pH, SS, DS, SO_4, NH_4, COD, BOD_5.

Site 3. Pribram, Middle Bohemia District– Uranium mining site

Mining history

The site (127.5 km^2) is located about 50 km southwest of Prague. The uranium ore mining took place between 1950-1991. There were 41 mining shafts (including 14 drop-shafts), 42 prospecting shafts, 4 adits, and 2,188 km of horizontal mine works. The area of the mining was 57,6 km^2, reaching 1,400 m b.g.l (the deposit evaluated to the depth of 1,750 m b.g.l). About 48,432 tonnes of uranium was extracted. The ore was physically upgraded on the site, and also at Mydlovary chemical processing plant from 1962.

The vein polymetallic Pb, Ag, Zn mineralization in the vicinity of Pribram (mainly in the parts of the deposit – at Brezove Hory a Bohutin) was exploited for pure silver from the Middle Age. At the beginning of the 18th century 17 shafts of the total length of 11,325 m was excavated, 405,128 m of drifts and crosscuts were excavated and the total volume of excavated area (including horizontal and vertical works) accounts for 9,590,220 m^3. The deep mining and physical processing of the uranium ore occurred at the deposit. The deep mining of polymetallic veins was active as of 1979. The mines were removed after the mining was finished, the underground area is currently being inundated (until 2010), and the surface partly rehabilitated. Some of the waste rock dumps are processed into crushed stone. Utilizable objects/installations and mine areas are ready to be sold or removed. Surface water in a nameless watercourse is treated in a WWTP. Other types of water–seepage, drainage, and surplus water from the tailing pond are discharged into the mine works. Former mine works from the polymetallic ore mining have been removed or secured in the terms of the relevant legislation governing mining activities. Bohutin and Brezove Hory mining districts have been inundated.

The total of 21,502,919 tons of waste rock was excavated at Brezove Hory and Bohutin deposits. The metal assay was 2.41 % Pb and 178 ppm Ag. The total metal output during the lifetime of the mining is estimated 453,000 tons of Pb and 3,378 tons of Ag. The ore was upgraded using gravity or flotation methods (or both). The ore veins are non-uniform, forming ore-bearing vein nodes. There were 20 vein nodes in 9 sections. In fact, the deposit can be described as an ore field with distinctive, linking-up mining areas. The minerals are of Upper Variscan polymetallic, uranium, and sulphide (-selenide) carbonate association.

Environmental issues

Due to the fact that the uranium mines have been inundated, contaminated mine waters outflow on the site. These waters are drained to a WWTP and treated. Due to the mining activity a considerable loss of water in watercourses (“Pribramsky” creek, “K Sazkam” creek) has occurred.

Tailings pond after uranium ore processing:

Labelled	Area (m^2)	Volume of material (m^3)	Condition
KI	330,000	98,800	not rehabilitated
KII	111,000	152,500	partly rehabilitated

Tailings pond after polymetallic ore processing:
“Hutske” and “Na Vrsich” tailing ponds have been rehabilitated. “Na Vrsich” tailing pond has been cancelled as a waterwork. “Hutske” tailings pond remains a waterwork, representing an environmental hot spot. The amount and quality of the water outflow is monitored.

Waste rock dumps:

Area:	1,457,700 m^2
Volume of material:	30,071,800 m^3
Condition:	currently being removed, not rehabilitated, (processed into crushed stone)

Main characteristics monitored in the environment:

Mine waters:	U, ^{226}Ra , suspended solids, DS
Surface water:	U, ^{226}Ra , SS, DS, CODCr, BOD_5, heavy metals
Seepage waters from the waste rock dumps:	U, 226Ra , DS, suspended solids, pH, SO_4, heavy metals
Air:	dust deposition U, ^{226}Ra
Volume activity:	^{222}Rn

The site features the highest volume of waste rock dumps after the mining of polymetallic and uranium ores in the Czech Republic. The on-site removal and remediation works are gradually enhanced and improved based on the comprehensive assessment and evaluation of the airborne geophysical monitoring. An airborne survey focusing on radioactivity was performed in 1976.

Site 4. Jachymov, Karlovy Vary District – Polymetallic, and uranium mining site

Mining history

The site (40.5 km^2) is located about 15 km north-northeast of Karlovy Vary Spa, about 10 km south of the German border. The area is rough with an elevation ranging between 700-1000 m. The silver mining in the area dates back to the 16th century, continuing with additional Ni, Co, Bi, As ores and Pb-Zn ores mining until 1945. From the 19th century also uranium ores were mined–about 550 tons of uranium was extracted until 1945. The last stage of mining activity began in 1945 by expropriating of the mines in operation (“Rovnost”, “Svornost”, “Bratrstvi”). The mines were reviewed and reconstructed. An intensive survey and prospecting works followed (1946-1961), with fast opening of new mining fields. Intensive mining activity (1946-1964) boomed in 1955–1957. The ore was hand sorted at the beginning, and upgraded by gravity at “Elias” and “Bratrstvi” processing plants. A production of the chemical concentrate by acid leaching began at Nejdek processing plant in 1952. Together with the opening works, there are 33 shafts, 42 smaller shafts and 163 vertical works. In 1946-1964, 9,600 pits, 178.8 km of chimneys were excavated. The area of the mining claim reached 29.8 km^2. About 6,500,000 m^2 of the vein area was excavated, the active backfills were constructed from an area of 250,000 m^2. During 1946-1964, the mining activity affected 8,890,000 m^2 of the vein area, with the average output 0.89 kg/m^2 (i.e. 7,950 tons of uranium). The tailings pond of a former “Elias” physical processing plant in Jachymov area was in operation between 1949-1962.

Environmental issues

The ores are a complex of metamorphic rock of “Jachymov” group of Lower Palaeozoic age (Cambrian–Ordovician), divided into “Klinovecke”, “Jachymovske”, “Barborske”, and “Potuckovske” strata. The first three strata are represented by mica schist interlain with calcium rock, amphibolite, and quartzite. “Potuckovske” strata are represented by phyllite with quartzite and amphibole.

Mineralised faults are divided into two groups:

- veins in east-west direction, more stable, minor mineralization, complex Ag, Bi, Co, Ni, As, and sulfidic, rarely uranium, mineralization,
- veins in north-east to north-west, mainly north-south direction, the main bearer of the uranium, younger complex and sulfidic mineralization, (simple and more complex vein structures are distinguished accordingly).

The mining of silver, polymetallic, and uranium ores used to occur on the site. The sludge from the gravity upgrading of the uranium ores was disposed of. Since the mining of the uranium ores was finished in 1964, “Svornost” and “Josef” shafts have been in operation, pumping thermal water for Jachymov Spa. The processing technology has been removed. The area has been partly afforested. The site is an old environmental hotspot.

Conclusions

The Czech Republic has a great amount of relicts of old mining and processing of mineral raw materials. The relics of gold and tin washing cover many hundreds of square kilometres of alluvial plains as well as old dumps ands setting pits. At least 25 percent of population of the Czech Republic lives in the areas with the geological environment, which is classified as highly destructed. Undermined areas represent very serious risk for the environment, mainly in the areas of old and more recent mining of hard and brown coal and also in the old mining districts where mainly silver and polymetallic ores were exploited. The uranium mining alone reworked at least as large amount of material as the exploitation of the rest of metals in the whole mining history of the Czech Republic. In the last years positive trends in the preservation of the Czech environment can be observed. The exploitation and export of mineral resources decreased and thus the superficial removal of materials is not so drastic as before. The protection of groundwater resources improved as well as the policy of waste and mining waste deposition. During cooperation with the PECOMINES project 14 localities were chosen as “hot spot“ according to their location, material and remediation problems.

The systematic evidence of other localities is in progress. Old mining dumps are systematically registered and paper-registering sheets are converted into GIS database. The number of registered dumps is more 1000 objects at this time. Special database for registration of tailings ponds is in progress and proposal of this project was given to the Commission for Geological Projects of Ministry of Environment. Many projects for remediation of mining dumps and tailings materials are financed by Ministry of Industry and Trade during the closure processes of ore, uranium and coal mines.

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Mining, Mining Waste and Related Environmental Issues in Estonia

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Introduction

Estonia is still rather unknown mining country, as its specific mineral resource – oil shale – is often not included in the overviews and comparisons. On the other hand, oil shale mining that peaked during the Soviet time (beginning of 1980's, exceeded 30 Mt per year) and now has decreased to about 10 Mt, is still very large (decreased from 20 tons to 7 tons per capita per year), as oil shale is the main resource for power and chemical industries in Estonia.

This report gives an overview of the main mineral resources, provides information about the on-going activities and gives examples of two mining sites as case studies.

Mineral resources

Geologically, Estonia is situated in the north-western part of the East-European Platform. Precambrian structures of the Fennoscandian Shield continue under the Baltic Sea and further into Estonia, forming the crystalline basement covered with sedimentary formations. In E-W direction, starting from the North, stripes of Cambrian, Ordovician, Silurian and Devonian sedimentary rocks crop out, determining together with Quaternary sediments (mainly Pleistocene deposits) the pattern of mineral resources (Puura and Raukas, 1997).

Oil shale deposits are concentrated in the north-eastern part of the country, phosphorite deposits in the northern part. Locations of the deposits are presented in ***Figure 1***. In ***Table 1***, production of different commodities in 2002 and data on the reserves are given.

Oil shale – the main Estonian mineral resource

Oil shale mining, power generation and chemical industry based on oil shale can be considered as a national symbol of Estonia, remaining for Estonia as an EU Member State only possible local fossil fuel. Oil shale mined in Estonia called 'kukersite' 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%). Oil shale has an average density 1750 kg/m^3, calorific value 8,6 MJ/kg, typical ash

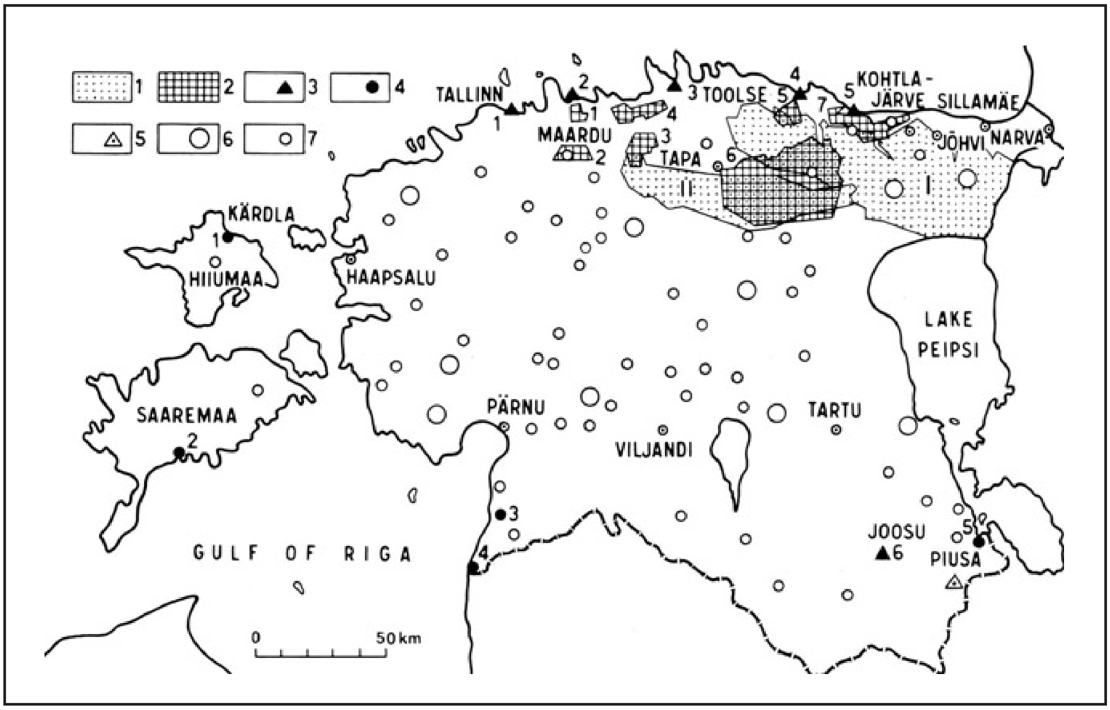

Figure 1. *Mineral resources of Estonia. 1 – Oil shale (I – Estonia Deposit, II – Tapa Deposit). 2 – Phosphorite deposits (2.1 – Maardu, exhausted; 2.2 – Raasiku; 2.3 – Kehra; 2.4 – Tsitre; 2.5 – Toolse; 2.6 – Rakvere; 2.7 – Aseri). 3 – Clay deposits (3.1 – Kopli, exhausted; 3.2 – Kallavere; 3.3 – Kolgaküla; 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; 7 – Peat bogs with area between 50 and 100 sq km. From Puura and Raukas, 1997.*

content 50% and total sulphur content 1,7%. The oil shale seams have total thickness of 2,2-3,8 meters, intercalated with limestone strata.

Oil shale has been used for 85 years, totally 900 Mt has been extracted and either burnt in power plants (ca. 85%) or chemically processed (ca. 15%). ***Figure 2*** and ***Table 2*** present data on oil shale extraction, that has dropped from the peak in 1980 roughly 3 times due to the decrease of the consumption of Estonian-produced electricity in the western part of Russia and restructuring of economy.

It is expected that during the next 10 years, the extraction figures will stay on the level of 10-12 Mt per year. At the moment, Estonian oil shale production costs are approximately 20% less than imported hard coal price (the difference of calorific values is roughly taken into account).

Table 1. Mining and reserves of Estonian mineral resources (source: Estonian Ministry of Environment, Committee on Mineral Resources).

			As on 01.01.2003		
Mineral resource	Unit	Mining in 2002	Active reserves Proved reserve	Probable reserve	Potentially economic reserve
Oil shale	mln t	10,513	1179,8	270,2	3510,6
Phosphorite	- " -	-	-	-	2935,7
Limestone	mln m³	1,51	116,7	407,5	345,5
Dolomite	- " -	0,339	30,5	125,9	86,2
Crystalline rocks building materials	- " -	-	1245,1	1723,9	-
Clay	- " -	0,168	27,5	250,6	15,1
Gravel	- " -	0,652	24,6	75,9	14,8
Sand	- " -	1,402	141,8	467,2	163,1
Curative mud	th t	1,7	3683,9	698,0	732,6
Lime	th m³	-	808,0	3457,0	833,0
Peat	mln t	1,508	302,8	778,2	531,9

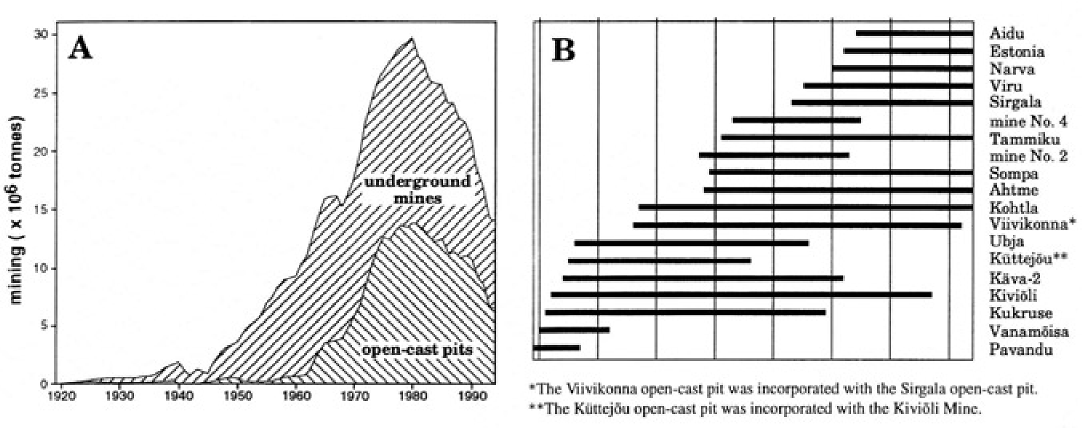

Figure 2. *Output of kukersite oil shale in Estonia since 1919 (A), including list of all present and past opencast pits and underground mines (B).Black bars show the years of activity.From Geology and Mineral Resources of Estonia (1997), with permission of the Institute of Geology of Tallinn Technical University.*

Table 2. Decrease of oil shale extraction in Estonia during 1980-2001.

Year	1980	1990	1995	1999	2000	2001
Volume (Mt)	31	22,5	12,1	9,6	11,7	11,8

Case studies – characterization of selected “hot spots”

Site 1: Oil shale mines

Location of the oil shale deposits in Estonia and the border region in Russia are presented in ***Figure 3***. Only Estonia deposit has been exploited in Estonia by state-owned company Eesti Põlevkivi. Active and potential mining area is almost 3,000 km^2. About 45% of the extraction is open cast mining having common impact pattern of large-scale open extraction, 55% being underground mining from relatively shallow depth, impacting water reserves and leading to land subsidence. Mineral processing is undertaken as close to the mine field as possible (not more than 10 km). The tailings from 3 open cast mines (Narva, Aidu, Kohtla-Vanamõisa) and 2 underground mines (Estonia, Viru) are the coarse tailings, which are disposed off as heaps commonly after hydromechanical enrichment.

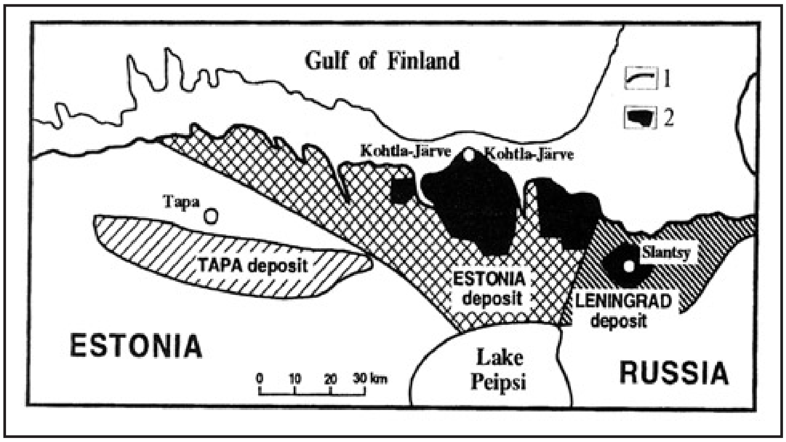

Figure 3. *Location of oil shale deposits in the Baltic Oil Shale Basin: 1 – Recent erosional boundary of kukersite oil shale; 2 – mined out areas and fields of active mines. From Geology and Mineral Resources of Estonia (1997), with permission of the Institute of Geology of Tallinn Technical University.*

Key environmental issues

Discharge of mine waters

Approximately 200-240 Mm^3 mine waters per year are pumped out from mines and discharged to the surface waters. The pumped-out water is near-neutral, containing elevated concentrations of sulphates. The level of ground water in the surroundings of mining areas has been dropped and 300 deep wells have be been drilled in the countryside for drinking water supply.

Impact of mining on quality of ground water

Mine waters are highly mineralized with sulphates and can be locally polluted with impurities from maintenance of equipment.

The management of solid waste/spoil heaps and mined-out areas

The heaps are large (up to 50 m height) with negative visual impacts. Older spoil heaps (about 13 Mt of residues) may spontaneously ignite and cause air and water pollution with burning products. Spontaneous combustion occurs due to high oil shale content (up to 6%) in limestone waste rock and too large height of the spoil heaps. Residues in the heaps of working mines amount at 138 Mt. More effective waste minimization (better mining techniques) and management of spoil is necessary, recultivation should be strengthened and some older sites need to be remediated. Totally, from the mined-out area of 12 050 ha by opencast methods, 9,840 ha have been remediated – mainly turned into forest, about 160 ha into agricultural land.

The protection of sensitive areas

Mining creates problems for nature protection areas by affecting habitats and surface water.

Subsidence is caused by instability of rock roof of underground mines (especially for closed ones). Land surface has dropped 0,5-1,5 meters on 600 hectares. Socio-economic problems, especially unemployment issues in the region are extremely important. Accompanying and in many cases more serious environmental problems in the same region are created by power generation and oil chemical industry using oil shale as raw material (fuel or source of oil). It should be obligatory to manage full life cycle of oil shale industry.

Site 2: Maardu phosphate mine

The Maardu phosphate mining site is located in northern Estonia 10 km east of Tallinn, close (3 km) to the southern shore of the Finnish Gulf and in the vicinity of a local urban centre (the town of Maardu) and Lake Maardu (***Figure 4***).

The opencast mining of sandstone containing phosphate was carried out by the Eesti Fosforiit company during 1964-1991. Altogether, 7 large plateaus were formed with heights

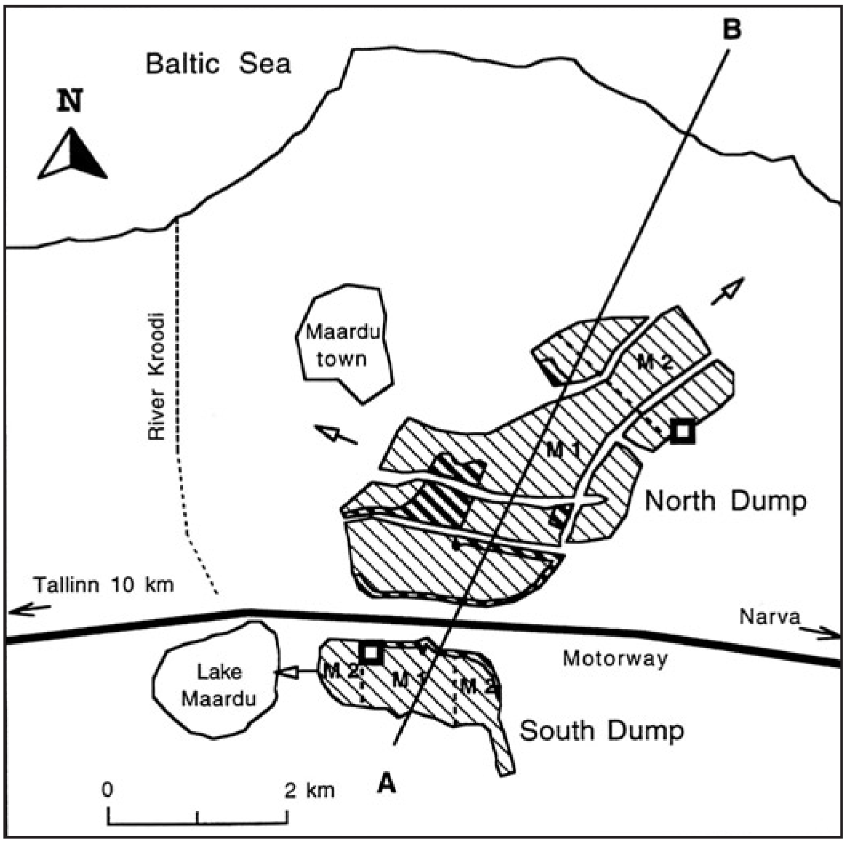

Figure 4. *Site plan of the Maardu waste rock dump area.The arrows near the waste rock plateaus indicate the main ground water flow directions.M1 – disposal method of random mixing;M2 – selective disposal method (from the bottom - layers of limestone, alum shale, and mixture of sandstone and sandstone).From:Puura, 1998.*

varying between 5 and 25 m, over a total area of 10.6 km^2. Large trenches separate plateaus from each other and from the surrounding areas.

Maardu phosphate mine case 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 (***Figure 5***).

Laying in sedimentary beds below the groundwater table and covered by tens of meters of sediments and rocks, the clayey shale forms a low permeability layer and the shale has remained unoxidised over hundreds of millions of years. Exposed to the atmosphere however, pyrite in the shale tends to oxidise at high rates and release acidity and sulphates.

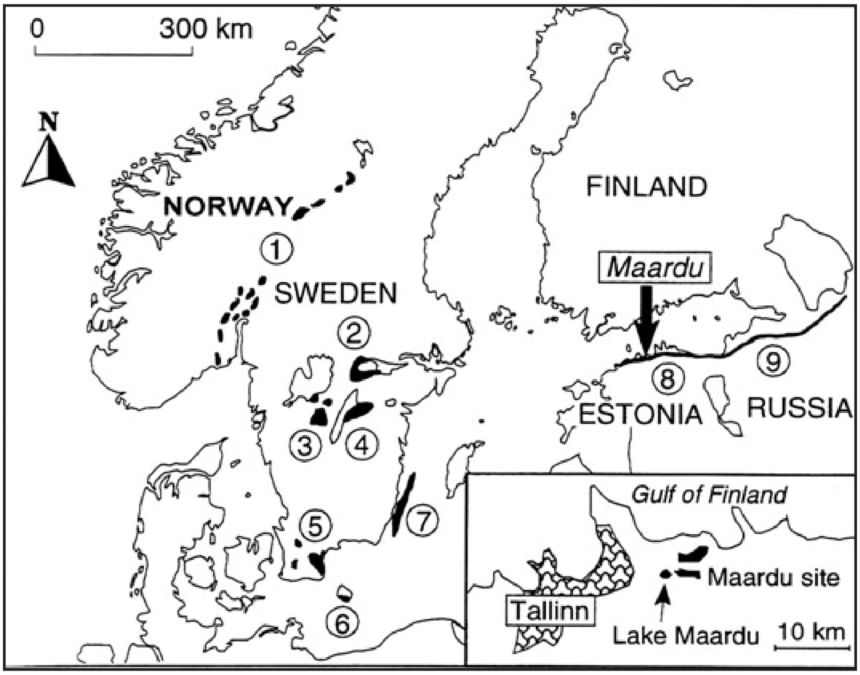

Figure 5. *Occurrence of alum shales in Baltoscandia close to the surface (<30m) and the Maardu site location plan.The locations: 1 – the Scandinavian Mountain range, 2 – Närke, 3 – Västergötland; 4 – Östergötland, 5 – Skåne, 6 – Bornholm, 7 – Öland, 8 – North Estonia, 9 – St Petersburg region.From Puura, 1998.*

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 other problem often accompanying shale pyrite oxidation is spontaneous combustion of the shale. In cases where there is good access to oxygen, and where pore water is present, and heat removal is slow, the exothermal reaction of pyrite oxidation causes the temperature to rise in the order of tens of degrees and triggers a high oxidation rate of organic matter, with subsequent pollution of the atmosphere and destruction of the newly established vegetation. In fact, the spontaneous combustion phenomenon increased public awareness of the Maardu problems and initiated the current research.

The average thickness of the alum shale layer in the overburden before mining was 3.9 m. The total amount of the shale opened to oxidative weathering is 71.7 Mt with the potential to produce more than 5 million tonnes of sulphuric acid during low-temperature oxidative weathering, on the basis that each m^2 of the waste rock dumps contains, on average, 7 tons of the shale with 4-6% of pyrite and 9-12% of kerogen-type organic matter.

Key environmental issues

Low-temperature oxidation of alum shale, leads 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 is the thinnest, there is a possibility for breakthrough of contaminants.

A further problem is the spontaneous combustion of alum shale. Many burning areas and hot spots occurred in 1970s–1980s, the reason being too steep slopes of the heaps and trenches, and critically high content of the shale in dumped material.

Mining activities have modified surface and groundwater pattern and they have a negative visual impact, as the surface of the area was left partially uneven.

National programs, projects and organisations related to mining and mining waste

Estonian main national programs and projects are presented in ***Table 3***. The website of Estonian Geological Survey is available at http://www.egk.ee. Closure of Sillamäe uranium tailings pond (project led by AS Ökosil) is still on-going. The Soviet uranium production plant started its operations in Sillamäe in 1948, and during the first years, production was carried out on the basis of locally mined alum shale (the same shale that is causing problems in Maardu case). Later, the raw materials were imported. Altogether, 12 Mt of the mixture of tailings and oil shale ash has been disposed. After remediation, one of the main hot spots in the Baltic Sea region has been removed from the list. More information is available from the website http://www.ecosil.ee/?page=101. Information about the GIS systems of Estonian mining areas developed at the Department of Mining of the Tallinn Technical University is located at http://www.ttu.ee/maeinst/mining.html.

National institutional framework related to mining and mining waste and their roles are presented in ***Table 4***.

Conclusions

Estonian mining pattern is rather unique, with oil shale mining and industry dominating over other smaller scale activities. Still, phosphate mining site in Maardu and uranium tailings pond in Sillamäe (currently under remediation) are the sites of comparable importance. The existing and potential impacts of all other sites (limestone, dolomite, clay, sand, gravel quarries) are orders of magnitude less important. The frameworks of projects and activities are also concentrated mainly around major issues.

Table 3. National programs and projects.

Program, project	Brief description
Mineral recourses register (Estonian Geological Survey)	Collects all information from the resources, incl. mining amounts etc.
Closure of Sillamäe uranium tailings pound (40 ha)	1998 began the internationally financed closure project, finishing 2006
GIS of mining areas of oil shale region (Tallinn Technical University)	GIS-maps of all on-going and closed mining areas, opencast and undersurface

Table 4. National institutional framework.

Name of the organisation	Address	Main activity areas
Ministry of Environment	Toompuiestee 24, 15172 Tallinn	Formulates national policies in its field of activities and prepares the bills of respective legal acts.
- Environmental management and technology dept. (incl. mining issues)	(see above)	Licensing of prospecting and exploitation, environmental impact assessment procedures
- Waste management department	(see above)	Waste act- related issues
Estonian Environment Information Center	Mustamäe tee 33, 10616 Tallinn	State environmental registers and data management
Technical Supervision Inspection	Aru 10/ Auna 6, 10317 Tallinn	Supervising and controlling of exploitation
Geological Survey of Estonia	Kadaka tee 82 Tallinn, 12618	Databases of mineral resources and mining and processing wastes
Tallinn Technical University, The Mining Institute	Kopli 82, 10412 Tallinn	Mining technology, GIS applications on mining
Tartu University, Institute of Geology	Vanemuise 46, 014 Tartu	Mining waste research projects, modeling of the processes

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Mining, Mining Waste and Related Environmental Issues in Hungary

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Introduction

Transition to market economy during the last decade had a huge impact on mining including environmental and socio-economic problems in Hungary. Liberalisation of mining and mineral prospecting resulted in increased activity of mining industry. At the same time, however, several (mostly underground) mines that proved uneconomic have been closed. The mining sector has undergone a traditional privatisation procedure. As a result, a mixed structure now exists, in which the important or strategic commodities, such as oil and gas are managed by the state in most of the cases. Blue-chip commodities have been purchased by foreign investors while local operations are run by small enterprises.

The most important mining laws and regulations are the following:

- The Concession Act (Act XVI/1991);
- The Company Act (Act VI/1988);
- The Foreign Investment Act (Act XXIV/1988);
- The Mining Act (Act XLVIII/1993).

The Mining Act covers major environmental problems related to mining. Supervised by the Regional Mine Authorities, these include protection of air quality, natural waters and fertile lands. Practically every mining operator is required to carry out environmental impact studies as described in the 86/1993 Governmental Decree.

Hungary's mineral row material reserves and supplies show a fairly average picture. The reserves of the industrial minerals and construction materials satisfy the requirements for a long time, but considerable oil, natural gas and metallic commodities import is necessary (e.g. 75% of natural gas and approximately 77% of oil of the total consumption was derived from import in 2002). At present, the Hungarian mining industry produces hydrocarbons, coals, bauxite, manganese ore, industrial minerals and construction materials. Locations of mining activities are quite evenly distributed in the country (***Figure 1***). The number of operating, abandoned and suspended mines and the mineral deposits without mine opening are shown in ***Table 1***. ***Table 2*** contains only those abandoned and suspended mines that have registered mineral resources in the National Mineral Inventory at present. In the course of many centuries-old history of Hungarian mining, about 5,000-6,000 mining objects have been operated. The largest parts of these ones are unknown at present, therefore ***Table 2*** does not contain these old mines.

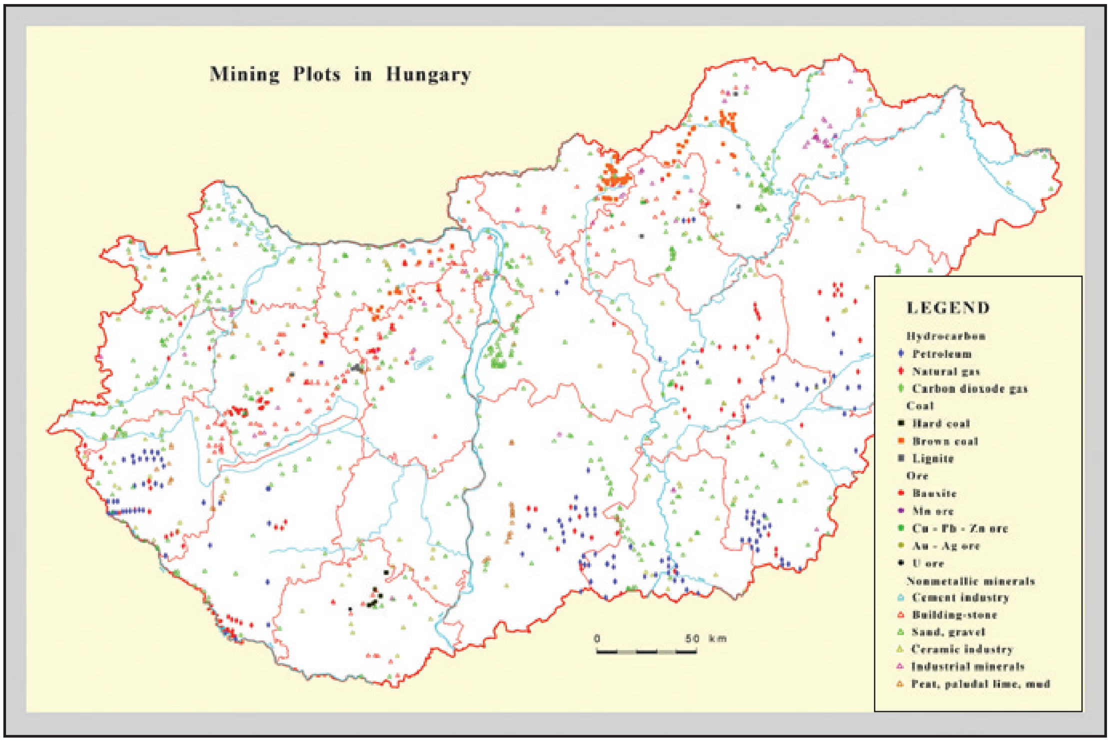

Figure 1. *Locations of active mines in Hungary (2001).*

Table 1. Mineral production in Hungary (2001).

Commodity	**Production**
(in million tons)	
Petroleum	1.06
Natural gas (1,000 m^3 gas=1 ton)	3.29
Carbon dioxide	0.10
Black coal	0.64
Brown coal	5.39
Lignite	8.04
Bauxite	1.00
Manganese ore	0.04
Industrial minerals	3.18
Cement minerals	6.07
Building & decoration stones	8.64
Sand & gravel	32.24
Ceramic minerals	9.72
Peat, lime mud	0.13
Total	**79.54**

Table 2. Number of operating, abandoned and suspended mines and mineral deposits without mine opening in Hungary (2001).

RAW MATERIAL	NUMBER OF OPERATING MINES (Mining Plots)	NUMBER OF ABANDONED AND SUSPENDED MINES	NUMBER OF DEPOSITS WITHOUT MINE OPENING
Coal	24	91	126
Hydrocarbons	122	33	61
Bauxite	8	38	217
Ores	1	24	8
Industrial Minerals	65	35	102
Other Nonmetallic Commodities	840	494	741
TOTAL:	**1060**	**715**	**1255**

Mining and Mining Waste

As a consequence of former mining activities, more than one thousand Mt mining and processing waste were generated. The area of mining waste dumps covers approximately 1% of the total productive land area. The yearly mining waste output is more than 10 Mt, the utilized volume is about 0.7-1.0 Mt/y at present.

The number of mining and processing waste dumps (including tailings ponds) can be estimated about 6,000-7,000. The last country-wide survey (1987-1991) identified and registered 3,540 mining waste dumps and tailings ponds. Detailed survey has been made for 1,220 dumps of these, including the following parameters: mining site name, administration unit, coordinates, material(s) of the waste dump, area, volume, actual or proposed way of the utilization and references to the available chemical, geological and technological studies and reports. More recent survey of waste dumps has not been made and yearly material balance-based inventory has not been carried out since 1991. The largest part of the mining waste dumps and tailings ponds are or may become secondary mineral commodities but some of these contain hazardous toxic components. These mining waste dumps contain overburden rocks, separable barren materials associated with the mineral deposit and row material of low grade.

According to the national survey, processing waste dumps and tailings in Hungary include (1) red mud near aluminium plants, (2) flying and bottom ash of electric power plants, (3) clinker, (4) slag from smelters, (5) slurry ponds near (closed) uranium ore dressing plant and (6) slurry ponds near a (closed) Cu-Pb-Zn ore dressing plant.

Mining waste dumps and tailings ponds are known to cause significant environmental problems but dedicated programmes for the reclamation and mitigation of environmental impacts are ongoing. Two of the above environmental problems have priority in relation to the mining waste at the national level: tailings ponds and waste dumps of closed uranium and base metal ore mines. Both of these are under reclamation at present.

Databases

1. **National Mineral Resource/Reserve Inventory** and regular annual balance is made by the Hungarian Geological Survey. The Inventory contains data of more than 3,000 known deposits. This gives approximately 34,000 database records processed for the yearly report.

2. **Map Series of Mineral Deposits and Mining Plots** (1:500,000) made by the Hungarian Geological Survey. The map series was made by type of mineral resource groups (fossil fuels, ores, industrial minerals, other nonmetallic minerals) and status of mine (operating, suspended, abandoned mines and deposits without mine opening).

3. **Mining Waste Database,** described above, is stored at the Hungarian Geological Survey in printed papers, of which 260 mining waste sites and 8 'hot spots' are in the digital database.

4. **Dangerous Waste Material Sites Database** at the Ministry for Environmental Protection and Water Affairs contains detailed information on the mining waste dumps and tailings ponds, too.

5. **National Landscape Wounds and Quarries Database** at the Ministry for Environmental Protection and Water Affairs contains detailed survey information for 15,008 sites, of which 5,300 has been field investigated. The database contains more than 70 parameters for each site. Topographic data and landuse information are also parts of the GIS database.

Investigation methods

The data collection from of the former survey (1991) is shown in the previous section. Last year the Hungarian Geological Survey analysed 260 mining waste sites (total waste quantity is 310 Mt), which are only a little part of the total mining waste dumps. The database of the mining waste sites contains among others: identification data, coordinates, description of contamination source, sensitivity to the contamination of the surroundings, area of contamination source, material and origin of the mining waste dump and tailings pond, volume of mining waste, place of storage and its documents, protective and monitoring system of contamination, burden on the environment (soil, underground water, streams, air, population, flora and fauna, man-made environment), socio-economic impacts, available studies of the contamination source.

The 'National Landscape Wounds and Quarry Database' is a result of a project between 1992-1996. For the inventory of artificial holes in the surface ('landscape wounds') 1:25,000 topographic maps were used because preliminary investigation showed that remotely sensed images were not efficient in finding small holes and holes covered by vegetation (that includes most of the holes). Also, for quarries that turned into ponds could not be distinguished from natural lakes using remote sensing. The more than 70 parameters obtained during field investigations include location, accessibility, size of hole, size and composition of waste rock dump and tailingss, size of pond, buildings on site, environmental data including protected areas, location in administrative units and status of remediation. According to the survey, there are 600 quarries located in protected areas. Based on the results of the survey the Ministry of Environment started a programme for the recultivation of sites based on environmental priorities (***Figure 2***). Each year a tender is issued for the recultivation and sustainable use of quarries and quarry ponds such as recreation ponds, openair theatres, geological openair exhibitions, landfill locations, remediaton, etc.

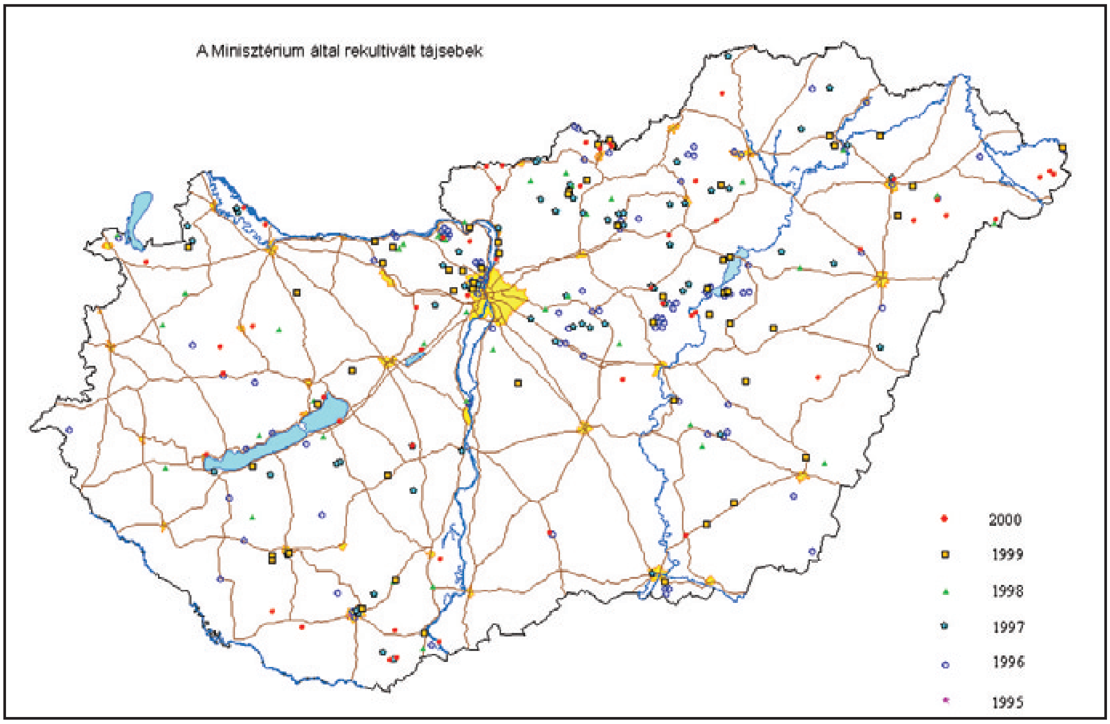

Figure 2. *Quarries recultivated by the Ministry of Environment.*

Case studies – characterization of selected "hot spots"

Site 1. Recsk-Lahoca ore mines

Mining and mining waste

Historic mining of the Lahoca Upper Eocene hydrothermal deposit started at the Recsk copper mines in 1852 and it was closed in 1979. During this period Cu, As and Ag ore hosted in biotite-amphibole andesite and polycyclic breccia was exploited in underground mines producing a total estimated exploited quantity of 3 Mt ore. 2 Mt of waste rock was produced, of which 0.5 Mt was disposed on site as waste and 1.5 Mt used for backfilling in the mine. An about 500,000 m^3 tailings were disposed on site. The chemical characteristics of the solid tailings are Au=0.8-1.0 ppm, Cu=0.05-0.2%, Fe=1-3%, with traces of As, Sb, Cd, Zn, Pb.

Mining started in the nearby Recsk Deep Complex in 1970 and operation came to an end in 1996. The Upper Eocene porphyry copper, skarn copper-zink, metasomatic polymetallic deposits were mined for Cu, (Mo), Zn, (Pb) and Fe ore. Due to market price changes the mine was temporarily suspended in the development stage in the early 90s. 0.8 Mt waste rock was produced for the 70,000 tons exploited ore quantity. Of the total waste, 0.7 Mt was disposed on site as waste, 50,000 t used for construction and 50,000 t transported out of the site.

Environmental impacts

The Lahoca shallow mine shafts and adits together with associated waste rock dumps emit acid mine drainage and solid material of waste and tailings due to erosion (***Figure 3***).

Figure 3. *Erosion on waste rock dumps at the Lahoca mines in Recsk, Hungary (photo: T. Kemper).*

Quantities and composition of the emissions observed in groundwater are typically pH 1.9-3, containing 984-5,760 mg/l SO_4, Fe solvent 56-866 mg/l, Zn 1-7 mg/l, Cu 0.1-74 mg/l, Ni 0.01-1.25 mg/l; Cd 9-33 g/l, As 37-443 µg/l and Fe oxy-hydroxides. The main environmental impacts of acid mine leachate include destruction of vegetation and landscape, high intensity corrosion of linear object of infrastructure and acidification of soils and groundwater with heavy metal pollution of Cu, As, Cd, Co, Zn and Fe.

Recsk Deep Complex produces limited acidification due to the high buffer capacity of the host Triassic carbonates. Na, Cl and SO_4 emissions from mine water are however significant. CO_2 and H_2S gas emission from boreholes is also of environmental concern. Quantities and composition of the mine water emission is characterised by 10 g/l dissolved salt content (including 3 g/l Na and Cl, 1.3 g/l SO_4 and 20 µg/l As), CO_2 and traces of H_2S and CH_4, at a 1.5-2 m^3/min pumping rate (pumping stopped in 1996). Wastes produced are not dangerous due to specific geological conditions and careful waste dump remediation. The estimated area of landscape destruction is 100,000 m^2, including 5 km^2 complete ecosystem destruction and 4 km^2 surface water impact with NaCl and SO_4.

Site 2. Gyongyosoroszi Polymetallic Pb, Zn ore mines

Mining and mining waste

Historic underground mining of the Gyongyosoroszi Middle Miocene polymetallic hydrothermal vein deposits commenced in 1400, and modern mining started in 1925. Mining

Figure 4. *Oxidized heavy metal-bearing tailings deposited on the floodplains below the Gyongyosoroszi tailings dump (photo: S. Sommer).*

operation ceased in 1986. During this period Pb, Zn, Au, Ag and Cu ore hosted in pyroxene andesites was exploited producing a total estimated exploited quantity of 3.7 Mt ore. 1.42 Mt of waste rock was produced, of which 0.14 Mt was disposed on site as waste, 0.36 Mt used for backfilling in the mine, and 0.92 Mt was transported out from the site. An about 1.17 Mm^3 tailings were disposed on site. Chemical treatment used xantathes. The chemical characteristics of the solid tailings are acidic with significant heavy metal pollution.

Environmental impacts

Besides natural surface anomalies, the main sources of metal pollution are waste dumps, flotation tailings, different water reservoirs and mine water. Technological neglect and breakdowns, the open storage of the concentrates, erosion by rain, wind, and surface run-off, etc., all contributed to the spread of contamination (***Figure 4***). The dams containing the flotation waste burst many times and more than 100,000 t mud with 5% sulfide mineral content entered the valley and stream. The total tailings loss amounts to approximately 800 t galena(PbS)-sphalerite(ZnS) concentrates. The maximum heavy metal concentrations are found in the 'yellow sand' (oxidised tailings) deposited on the narrow flood plain of the stream (***Figure 4***). Escaped tailings mud was carried by stream water and more than 100,000 m^3 of contaminated mud was deposited in downstream industrial and agricultural water reservoirs.

Site 3. Mecsek Uranium Mines

Mining and mining waste

In compliance with the geo-chemical characteristics of uranium and the changing redox conditions in the „productive formation" (alongside the redox front) there are oxidised (red) and reduced (grey) ore types. Besides these two redox types there are altogether another 6 morphological types of mineralisation. The main ore minerals are uranium oxides, which belong to the uraninite-pitch blende-uranium series. The thickness of the productive formation is in the 5-120 m range. The ore bodies are found in sandstone in different layers and at several levels. Their size also varies i.e. they can be some meters or some tens of meters large (sometimes can even reach a few hundreds of meters) and their slips and slants can also be significantly different. Their average thickness is about 1 m and the range of difference alters between 0.3-0.5 m. The average quality of the locality can be described as 0.13 U%, but the range within which it can change is 0.03–3.0%. The quality range of the individual ore bodies is 0.06–0.35 U%. The size of the squats depends on the sizes of the micromorphogenetic elements and that of the related elements, but generally the size can be described as extremely diversified.

There were three areas suitable for industrial development designated by the end of 1955. Regular industrial exploration activity started at the first two sites (no. I and II mine camps) in 1956 and production started in 1957 and 1958 at Kovagoszolos I and Bakonya II mine camps, respectively. As a result of further research the production of mine camp III started in 1959. No. IV and V mine camps started in 1971 and 1983, respectively. There was some search in the "prospective" VI mine camp area, too, but owing to the economic changes that have occured since then there has been no development or production started. There was 175,300 m^3 rock stripped during this work. The total length of the vertical shafts open to the ground level is 6,300 m. The total length of the blind shafts amounts to 3,300 m (***Figure 5***), and the quantity of stripped rock was 61,130 m^3, which was taken

Figure 5. *Underground workings at the Mecsek Uranium Mines.*

up to the refuse dumps. About 50% of the ore stock has been extracted. In the course of extraction there was about 18 Mm^3 rock (46 Mt) and 10 Mm^3 ore (25,4 Mt) stripped and taken up to the surface. The produced ore contained 810 t metal, which yielded 20,8 thousand kg uranium in metal form. Within the framework of the operations there were social and other service facilities built, energy and telecommunication providing systems which constituted integral parts of the mine plant, but belonged to an independent operational and plant control system.

The rock suitable for uranium recovering was crushed below 30 mm then it was placed in form of 10–13 m high prisms into adequately built basins insulated by plastic liner for heap leaching (***Figure 6***). For uranium dissolution sodium carbonate solution was leached through the rock and uranium was removed from the accumulated liquid. This procedure was carried out on two sites involving 2,2 Mt and 5 Mt of rock, respectively. Altogether approximately 500 t uranium was recovered in the two heaps.

The total quantity of waste rock produced amounts to 34.2 Mt, of which 33.9 Mt was disposed on site as waste and 0.3 Mt was used for backfilling in the mine. Chemical treatment used H_2SO_4, HCl, MnO and ion exchange resins, and processing altogether resulted in 16.2 Mm^3 neutral solid tailings.

Environmental impacts

Mining activity has caused radical changes in several hydrogeological parameters. There is still water removal going on to protect quality of the Tortyogo stream (in 1995 it amounted to 2,400 m^3/day) and the removed water is returned after due purification. Mining activity caused significant changes in the quality of the water as well. Deep mine water and the water pumped out as industrial water has 500-1000 mg/l dissolved material content. These waters are generally calcium-magnesium-hydro-carbonate type, but sometimes increased sodium and sulphate contents can also be experienced. The dissolved uranium content of the mine water is 500-2800 mg/l i.e. it may exceed the permitted values. The water seeping through the refuse dumps and escaping from the percolation basins has a harmful effect on the quality of the underground waters. These problems have been partly eliminated already. The quality of karst water is not affected directly by the mining activity. Pannonian sedimentary strata waters can be adversely affected by the solutions escaping from percolation or by the solutions that flow through the basin area and seep in.

From the middle of 1950's in the course of exploitation a cavity system of about 18 Mm^3 was formed in the ground. Today, the vast amount of rock material excavated from it can be found in waste rock-piles and tailings ponds and they pollute the environment in various ways. Though elimination of the biggest danger has been done also in the previous decades, the full and systematic remediation of environmental damage was started a few years ago only.

During its activity the Mecsek Ore Mining Company deposited about 18,5 Mt caked waste-rock on an area of 45 ha. One part of it originates from shaft sinking and as a natural material it does not cause considerable pollution. The other part is the so-called mine waste-rock which, because of its low uranium content, did not get into the system of ore processing technology. Parameters of waste-rock piles are the following:

- U-content: ~ 20–70 g/t;
- RA 226 content: ~ 0.3–1.6 Bq/g;
- Rn 222 exhalation: ~ 0.1–0. 5 $Bq/m^2/s$;
- Gamma dose intensity: ~ 400–2000 nGy/h.

During remediation of waste-rock piles the radiological parameters adequate to requirements can be assured by a soil-covering layer of 50 cm. The landscaping work on eastern side of waste-rock pile of plant III. is currently being carried out. Soil covering of surfaces having their final morphology will start and planting will also begin. This waste-rock pile

Figure 6. *Heap leaching piles at the Mecsek Uranium Mines. See buildings for scale.*

serves for disposal of materials and scraps that cannot be decontaminated.

Concerning the heap leaching piles (***Figure 6***), it was important to desalinate and destroy technological solutions present in large quantity. In order to protect Tortyogo potable water catchment area the waste-rock from Leaching Heap II was relocated (about 2.66 M m^3) onto the hydrogeologically safe eastern side of waste-rock pile III. Near heap leaching areas lower degree uranium and other types of pollution could be found.

During ore processing starting in 1962 about 19.5 Mt tailings was produced and stored in two tailings ponds. Together with the tailings more than about 30 Mm^3 technological solution with about 700 thousand tons of dissolved compound also got into the tailings areas. A considerable part of it is magnesium sulphate, a smaller part of it is sodium chloride. It does not contain toxic elements. Since the tailings ponds were not insulated some parts of them escaped into the environment. According to the data provided by the monitoring service uranium and radium content of ground water did not increase considerably but the total dissolved solid content increased to a great extent. It can endanger the neighbouring potable water catchment areas that play significant role in drinking water supply of town Pecs.

During and for a long time after remediation work contaminated water discharge is expected. These waters can be classified into two groups: (1) waters of high dissolved uranium content, and (2) other waters contaminated with inorganic salts. The first group involves mine waters, waters escaping from waste-rock piles while the second group involves technological solutions of heap leaching and tailings ponds and contaminated ground waters escaped into the environment endangering the neighbouring water catchment areas. Water treatment has been done since the end of 1960s. At present 0.8–1.2 Mm^3/y water is pumped and treated. In the future, presumably 0.7–1.1 Mm^3/y groundwater has to be pumped and its dissolved salt content is to be reduced by lime milk treatment.

Figure 7. *Monitoring system at the Mecsek Uranium Mines. Water and radiological monitoring on and around the mine site.*

The Hydrogeological Monitoring System extends through the West-Mecsek Mts. consisting of about 500 sampling points (***Figure 7***). The Radiological Monitoring System has been installed to monitor the state of environment before, during and after remediation and to keep the planned radiological parameters. Monitoring includes observation of air, soil, waters, flora and fauna.

Conclusions

In conclusion, Hungary has some significant problems associated with past and present mining and processing. During the last two years 260 mining waste sites and 8 'hot spots' were selected for detailed investigation. These results together with the former mining waste survey promote mitigation of mining waste impact and solution of reclamation and support ongoing environmental activities on some of the sites.

The matter flow balance-based mining waste inventory, together with pre-feasibility and feasibility studies and plans for each dump and pond is necessary but their realization is hampered by the lack of funds at the moment. In addition, it would be important to carry out more detailed surveys and research for environmental risk assessment and risk management of mine waste sites. The new initiative of the Ministry of Economy and Traffic on the utilization of solid mining waste for construction of highways is a considerable incentive for improvement of the existing mining waste survey.

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Mining, Mining Waste and Related Environmental Issues in Latvia

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Extraction of minerals in Latvia

The occurrence of different types of mining waste and their quantity are determined predominantly by the types and volume of minerals extracted in the country. The list of minerals, which are produced in Latvia, is rather short. These minerals are mostly used as either construction materials or as raw materials for their production: gypsum, limestone, dolomite, clay, sand-gravel mix, sand (including quartz sand). Loam is extracted for some auxiliary purposes. Besides, there is considerable peat production and small-scale sapropel and medicinal mud extraction.

Table 1 gives a general impression of the extraction and uses of minerals in Latvia for year 2001. The data regarding the volume of extraction were taken from the Balance of Mineral Reserves, which is prepared every year by the State Geological Survey of Latvia (SGSL) [1].

Table 1. Yearly production of minerals in Latvia in 2001.

Mineral	Yearly production Unit	Total	Main uses of produced minerals
Gypsum	thousand m^3	80	Manufacture of construction gypsum, interior building materials, portland cement.
Limestone	thousand m^3	147	Manufacture of portland cement, lime.
Dolomite	thousand m^3	786	Manufacture of crushed dolomite, lime, and ground dolomite.
Clay	thousand m^3	94	Manufacture of roofing tiles and bricks, portland cement.
Sand and	thousand m^3	1269	Manufacture of construction sand, gravel, gravel mix crushed stone. Use of natural sand and sand-gravel mixes for road construction and repairs.
Sand	thousand m^3	877	Manufacture of construction sand. Used for road construction and repairs.
Sandy loam	thousand m^3	9	For auxiliary purposes – remediation of dumps of residential waste, backfilling of pipelines, repairs of local roads etc.
Peat	thousand ton, 40% water content	468	Manufacture of cut peat and peat chunks for agriculture, cut peat and peat chunks as fuel, export.
Sapropel	thousand ton, 40% water content	0.2	In agriculture.
Medicinal brines	thousand ton, 40% water content	0.5	In medicine.

The tendencies in the change of the volume of mineral extraction in Latvia are similar for the mined commodities starting from 1991 (***Figure 1***). These tendencies are characterised by a drastic drop in the extraction volume in 1992-93 (associated with the change of the economic and property system) and its gradual recovery later. Considerable variations in the peat extraction in 1998–2000 are explained, predominantly, by fluctuations in weather conditions.

Only opencast mining is used for the extraction of minerals in Latvia. For example, in 2001 such extraction was carried out at 309 mining sites (quarries, peat deposits under production). The reserves of minerals of mined deposits, as well the scale of mineral extraction at separate mining sites vary considerably, as shown in ***Table 2***. Besides operational mining sites, there are over 2,000 abandoned mining sites in Latvia. The majority of them were earlier used for the extraction of sand-gravel mix and sand. Most of the above sites were aban-

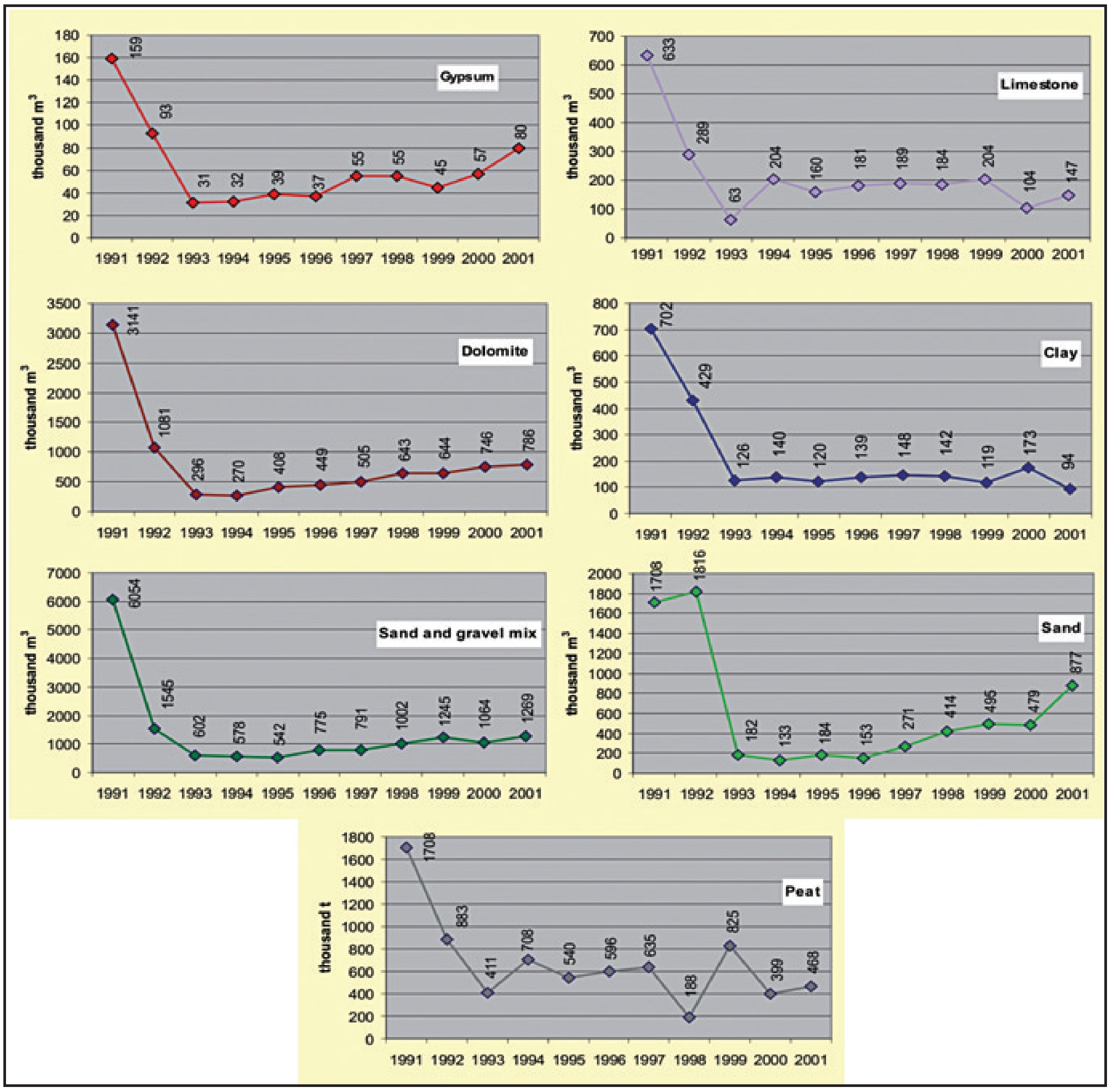

Figure 1. *Extraction of main minerals in Latvia, 1991-2001 [2].*

Table 2. Characterisation of mineral mining sites in Latvia in 2001.

Mineral	Amount of mining sites	Measurement unit	Mineral reserves of deposits under production (at the beginning of year)		Yearly production at mining site	
			min	max	min	max
Gypsum	1 quarry	Mm^3	0.8		0.08	
Limestone	1 quarry	Mm^3	234		0.15	
Dolomite	9 quarry	Mm^3	0.1	87.5	0.01	0.3
Clay	5 quarry	Mm^3	0.3	77	0.002	0.04
Sand, sand and gravel mix	228 quarry	Mm^3	0.002	188	0.00001	0.2
Sandy loam	2 quarry	Mm^3	0.04	0.045	0.001	0.008
Peat	61 deposits under production	Mt, 40% water content	0.120	27	0.00001	0.07
Sapropel	1 quarry	thousand ton, 40% water content	199		0.2	
Medicinal muds	1 quarry	thousand ton, 40% water content	819		0.5	

doned after 1991 due to changes in land ownership and liquidation of many enterprises. Recently, mineral extraction has been gradually resumed at some of those sites.

There is no enrichment of the extracted minerals at mining sites in Latvia. At the same time, at some dolomite quarries, dolomite is crushed to produce crushed stone, which is washed during production. Gravel and boulders, extracted from the sand-gravel mix, are washed and sometimes crushed, too.

Mining waste

The solutions of problems in connection with environmental impact of different types of waste is one of the priorities of the Latvian national environmental policy. Still, mining waste management is not defined separately as a priority of the above policy. Due to the lower priority compared to other environmental problems, there were no specialised operations aimed at the investigations and inventory of the mining sites in connection with the studies of mining waste and associated environmental problems in Latvia so far. As a whole the situation with the mining waste in our country can be characterised as follows.

Mineral extraction in Latvia is accompanied by the occurrence of the following main types of mining waste:

- overburden and host rocks, stored in external dumps, as well as waste resulting from the crushing of dolomite during the production of crushed stone;
- drainage water removed from the quarries;

- gaseous waste (carbon and sulphur monoxide, nitrogen dioxide) and aerosol (dust) emissions in the atmosphere as a result of blasting operations (in the quarries where dolomite and gypsum are extracted), operation of machines and equipment used at the mining sites and due to the formation of dust at the dumps.

Some of the above types of waste are present at every extraction site, but no serious environmental risks resulting from that were discovered so far. It is essentially due to the environmental protection measures taken by mining companies in compliance with the licence requirements and mining projects, as well as the requirements of regional environmental boards.

Dumps of overburden and host rocks at the mineral deposits under production in Latvia do not contain components that could be of serious environmental hazards. During the initial stages of production of the majority of deposits, the overburden and host rocks are stored in external dumps, but, as soon as the area with fully depleted reserves appear, such rocks become to be stored, predominantly, in internal dumps. Usually, rocks from dumps are used for the remediation of quarries. Often, sand-gravel mix, sand, loam and sandy loam, which are a part of overburden during the extraction of gypsum, limestone, dolomite and clay, are used as construction materials, while peat is used in agriculture. Screenings of dolomite have different practical uses.

Drainage water from the quarries and sewage, resulting from washing dolomite crushed stone and gravel, do not contain hazardous components either. As a rule, no considerable impact of the above water, entering the hydrologic network, upon the water quality in surface water bodies was observed. Sewage is often used as circulating water after treatment in settling ponds.

No serious negative environmental impact was observed as a result of gaseous and aerosol emissions in the atmosphere, resulting from mining enterprises.

As a whole, the Latvian mining waste situation gives no reason to make conclusions on the existence of “hot spots” associated with mining waste.

In compliance with the Latvian “Law on natural resource tax”, such tax is imposed on waste and contaminants resulting from any kind of economic activities. This tax is imposed on the water and air pollution as a result of extraction and processing of minerals. The amount of contaminants entering the environment is usually determined by calculations, based on the volume of extraction at the mining enterprises.

Remediation of mining sites

Extraction of minerals, which is represented by opencast mining only in Latvia (and which is not accompanied by enrichment processes on site), leads to the deterioration of some land in terms of contamination, loss of forests, agricultural lands, loss of habitat, ecosystem degradation and soil erosion. However, the effect and spatial extent of land degradation caused by mineral extraction is rather small in Latvia. According to the report "Environmental Indicators in Latvia 2002" [3], the total area of quarries comprises about 6,000 ha or about 0.1% of the territory of the country. Slightly over 25,500 ha (about 0.4% of the Latvian territory) are occupied by mined peat deposits or those prepared for production.

Remediation is necessary for about 30% of the Latvian quarries. These are the quarries, where the minerals are depleted or their further extraction is not feasible. Before making a decision about remediation of this or that mining site, it must be investigated in order to evaluate the remaining mineral reserves and feasibility of continued extraction or remediation. Remediation of abandoned quarries is important in view of the fact that they are illegally used as dumps of residential waste, especially if they are located near towns or villages.

During several years after 1991, there was no remediation of mining sites whatsoever. Such remediation was resumed in 1994 and the volume of remediation has grown gradually in recent years (***Figure 2***) although, as a whole, it is still insufficient.

Databases

SGSL has databases as regards deposits of construction raw materials and peat deposits. The database of deposits of construction raw materials contains information regarding 2,030 deposits and prospective area, while the peat database contains information regarding 3,600 deposits. Each deposit is characterised by a standard set of data, incorporating the location of a deposit, source of information about it, characterisation of minerals, hydrogeological conditions, morphology of the deposit, information about reserves and volume of mineral extraction, existence of specially protected nature areas. Databases provide a basis for the generally available cadastre of mineral deposits and yearly balance of mineral reserves. When the above databases were planned, incorporation of information about mining waste and environment was not envisaged.

The Latvian State Environmental Agency has operational databases regarding state statistical documentation, which is provided by companies, about hazardous waste, emissions in the atmosphere, water intake and discharge of sewage. These databases contain information about the types and quantities of waste resulting from the companies' economic activities (including mining companies), as well as the quantities of destroyed, recycled, buried waste, and waste, which entered the environment. The data in the databases are, predominantly, generalised providing general information about the waste resulting from the industrial activities of concrete companies.

Conclusions

Latvia is not a country where extensive mining takes place. The list of minerals produced in Latvia is rather short, mostly these are minerals used as either construction materials or as raw materials for their production, as well as peat, sapropel and medicinal muds.

In general, no cases were observed of serious harmful impact of mining waste, resulting from the extraction of minerals, including gypsum, on the environment. Therefore, taking into consideration the fact that there is waste in Latvia with a much greater environmental impact (residential, packing, oil products, asbestos, used batteries and cells, etc), there are no tasks or plans regarding mining waste on the national level at the moment. At the same time, the tasks of continuous control of the environmental contamination level at the existing mining sites, remediation of those sites and associated dumps of overburden rocks and waste, resulting from the crushing of minerals, are still important. Regulations of the Cabinet of Ministers “The procedures of identification and registration of contaminated and potentially contaminated sites” (2001), based on the “Law on contamination”, could seriously influence that process. Remediation of abandoned mining sites is equally important, especially if the reserves are depleted or non-commercial (i.e. after the evaluation of feasibility of further mineral extraction or remediation).

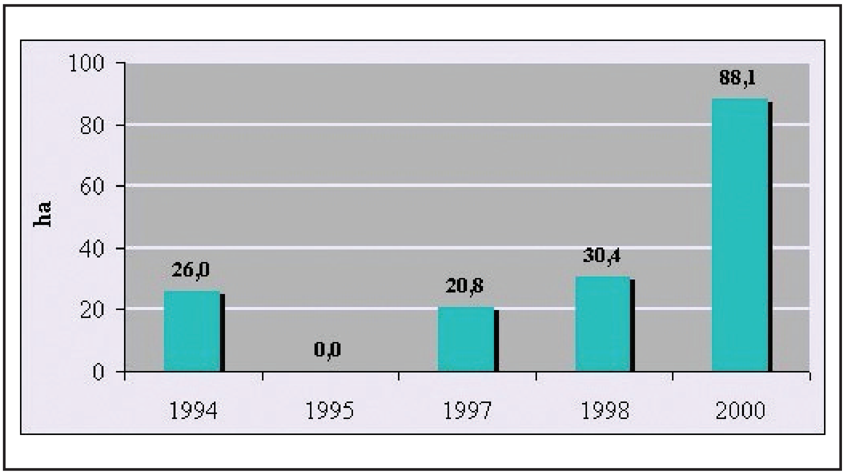

Figure 2. *Quarry remediation in Latvia in 1995-2000 [2].*

Future tasks in connection with the minimisation of the impact of mining waste and environmental hazards will be defined mostly by the requirements of the EU Directive on the management of waste from the extractive industry, which is under development.

Important sources of information

http://vgd.gov.lv/ Homepage of the State Geological Survey of Latvia.

http://varam.gov.lv/ Homepage of the Ministry of Environment of the Republic of Latvia.

http://lva.gov.lv Homepage of the Latvian Environment Agency.

References and Bibliography

1. Balance of mineral reserves (construction raw materials, peat, sapropel and medicinal muds) for 2001. Riga, SGSL, 2002, 134 p.

2. Report on the Latvian environmental indicators for 2001. Latvian Environmental Agency, 2001, 124 p., Riga.

3. Report on the Latvian environmental indicators for 2002. Latvian Environmental Agency, Riga.

Mining, Mining Waste and Related Environmental Issues in Lithuania

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Mineral Resources and Mining

The subsurface of Lithuania hides a sufficient amount of mineral reserves. These are mainly construction mineral materials or raw materials intended for their production, however, by the amount of their extraction and consumption as well as their value in world, they are the most significant and main mineral resources (after energy resources).

Currently in Lithuania 17 kinds of mineral reserves/resources have been explored to various degree of detail (***Figure 1***). Eight of these 17 kinds (limestone, dolomite, sand, gravel, clay, chalky marl, peat and oil) are under exploitation, and the exploitation of two kinds of

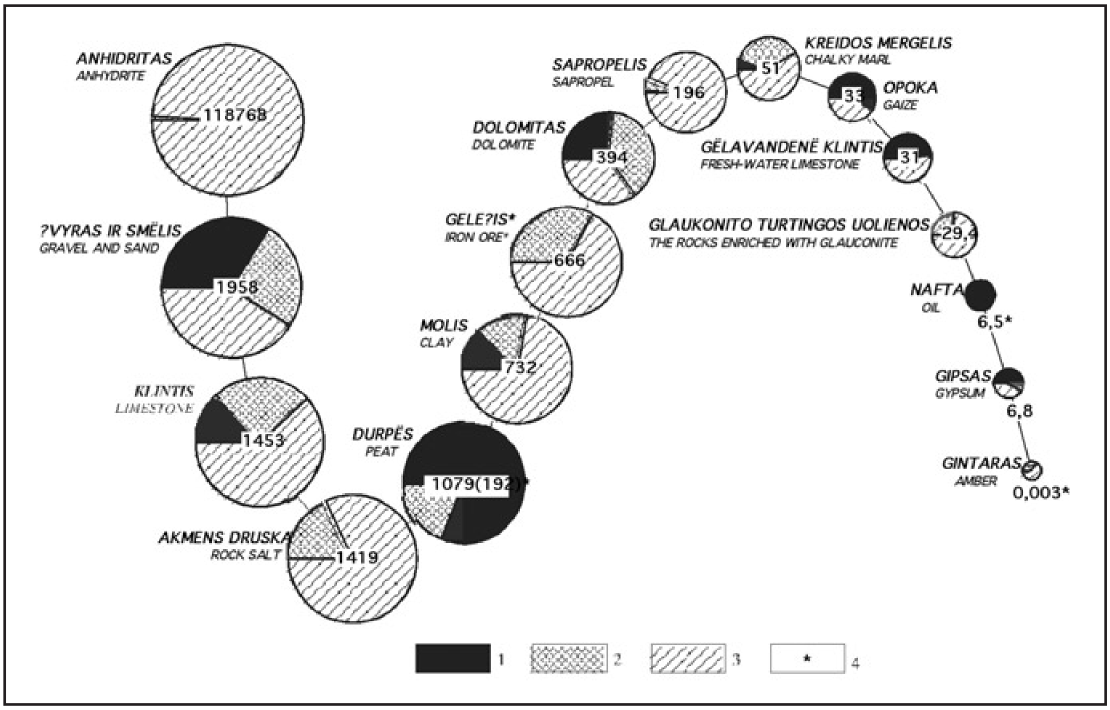

Figure 1. *Lithuanian mineral resources (Mm³) and degree of their investigation. Key: 1– reserves explored in detail; 2 – reserves explored in general; 3 – prognostic resources; 4 – reserves/resources (Mt).*

mineral resources – gaize (opoka) and sapropel – was suspended in the 1990's. Anhydrite is one of the most perspective mineral resources that have no exploiter yet. The use of anhydrite could give a double benefit – anhydrite as raw material could be widely applied and the repositories could be installed in the mine cavities at the depth approximately 300 meters. On the basis of geological information, use of iron ore, rock salt, marl, glauconite-rich rock and fresh-water limestone can be problematic in relation to economical and environmental conditions, therefore, pre-feasibility studies are required for assessment of the economic and environmental viability of these deposits. Gypsum resources explored in general in the active karst region are inapplicable due to influence of its extraction on karstification process. Moreover, our underground contains other mineral resources insufficiently investigated or supposed to be there on the basis of geological models.

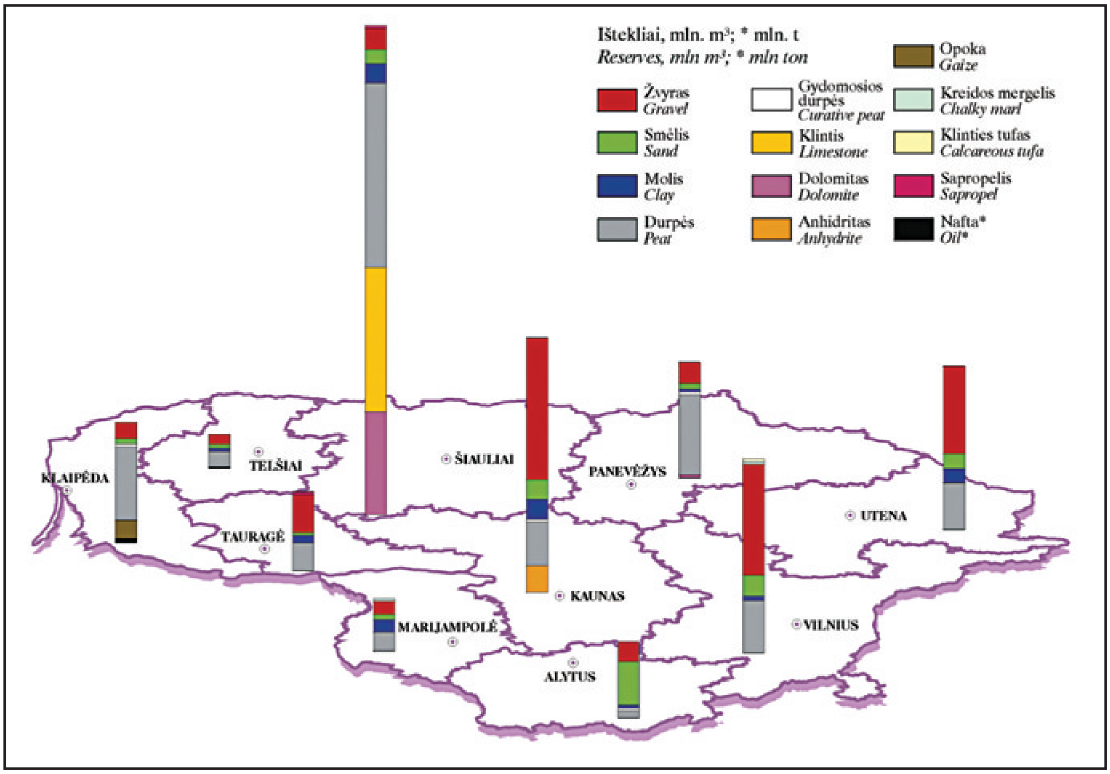

Figure 2. *Explored mineral reserves in the provinces.*

Lithuanian regions are unevenly provided with the main mineral reserves explored in detail. This distribution is presented in ***Figure 2***. According to the legal acts, only the reserves explored in detail could be used. Today, 611 mineral deposits (mostly earlier explored at the expense of State budget) could be used: 10 oil deposits, 69 peat deposits, 3 sapropel deposits and 529 deposits of construction mineral commodities (limestone, dolomite, anhydrite, gravel, sand, clay, chalky marl). The licenses to consume under-

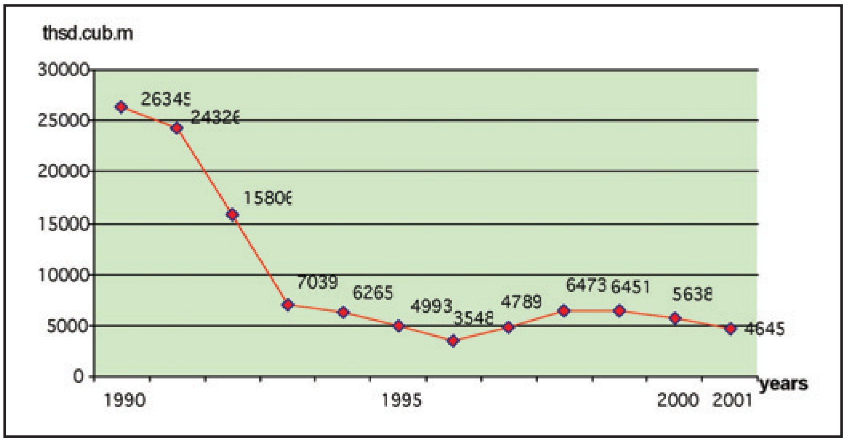

Figure 3. *Extraction of solid mineral resources (without peat and oil).*

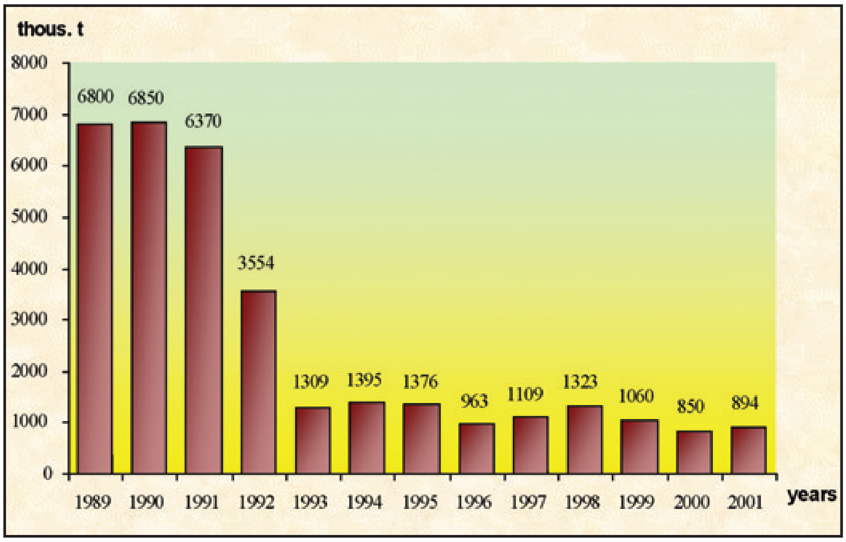

Figure 4. *Extraction of limestone.*

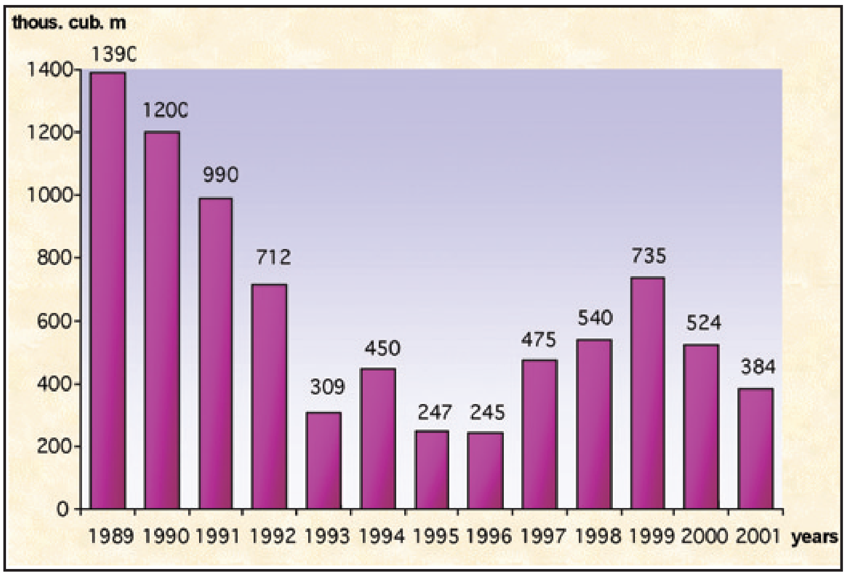

Figure 5. *Extraction of dolomite.*

ground reserves in 336 mineral deposits have been given to 180 enterprises. Thus, only as much as 55 per cent of earlier explored mineral deposits are under operation, whereas the rest of them are out of use.

Significant changes in the construction sector, increased import of the construction materials, growing prices of energy resources, a lack of funds for modernization of energy-consuming technologies, increased transportation expenses, a decrease in local demand and limited possibilities of the external market determined seven times decrease in extraction of mineral resources from 1990. Extraction decreased sharply from 1990 to 1996, later it increased insignificantly and became stabilised (***Figures 3, 4*** and ***5***).

In contradiction to this general decrease in extraction of mineral commodities was extraction of oil. Started in 1990 oil extraction increased from 12 thousand tons to 471 thousand tons in 2001. Unfortunately, the explored oil resources in main oilfields are small and at the present rate of extraction, it would come to end within less than 10 years. Perspective onshore and offshore resources are investigated insufficiently, the state does not finance such prospecting and plans to start open licensing rounds.

Changes in the country's economy during the past decade adjusted the strategy of all mineral resources investigation – only the stages of initial investigation (reconnaissance, prospecting of new resources) could be financed from state budget, whereas prospecting and exploration of ordinary mineral resources must be financed by the consumer.

Environmental Impacts: Problems and Solutions

All mineral commodities, with the exception of oil, are mined only in the open pit mines in Lithuania. The depth of gravel, sand, clay, peat and dolomite quarries usually amounts to 6-12 m, that of limestone and opoka (gaize) – up to 15-20 m, only the deepest quarry where Triassic clay is extracted is as much as 50 m deep. The thickness of overburden rocks in all quarries range from 0.5 m up to 7-10m. All these rocks (overburden, useful mineral resources and tailings) are the rocks of our daily living environment, inert from a chemical point of view. The groundwater level is lowered by means of self flowing or pumping up in several quarries only (peat, limestone, dolomite). There is no tailings and mining wastes. Thus, in Lithuania there is no "hot spots" associated with quarrying activity.

After excavation of the mineral resources, conditions to recultivate the damaged areas appear. Then mining consequences could be neutralised and the aesthetic value of landscape restored to some extent. Though deposits of solid mineral resources in Lithuania have often different geological structure and are found in different natural conditions, the mining poses relatively small threat to the stability and integrity of geosystems. The impact is most often short-term and can be compensated by rational and effective recultivation.

Only abstraction of groundwater from quarries, technology of the extraction and technogenic load in the vicinity of quarries (cement factory, crushing plant) could be classified to factors causing comparatively significant impact on environment. The technogenic load in the vicinity of quarries increase vibration, it can increase air pollution and create some landscape changes. Explosions in quarries could cause essential changes in the hydraulic properties of a deposit, its permeability to water and porosity. Continuous pumping-out of water could destroy the water balance and form constant depression cone. For instance, intensive abstraction of groundwater from two largest Lithuanian limestone quarries (Karpėnai and Menčiai) has lowered the Quaternary groundwater level and caused a large depression in Permian groundwater layer. Its radius in the Karpėnai deposit depends on the bed structure and on average exceeds 2 km, i.e. the depression cone occupies more than 13 km^2 areas and somewhat less in the Menčiai. Similar situation, but less in scale is observed in Petrašiūnai and Klovainiai dolomite quarries where groundwater depression in the Devonian is also developed. These impacts are monitored by enterprises according to special monitoring programs.

Databases

1. According to "The Statute of Underground Register" (Governmental decree, 2002) the Underground Register is a part of the State Geological Information System. The Underground Register consists of three parts: Boreholes Register, Underground Resources Register and Register of Underground Investigations. At the end of the year 2002 all mineral deposits explored in detail were included in the Underground Resources Register part (611 units);

2. Groundwater monitoring data are collected in the Boreholes Register;

3. The information on mineral resources deposits explored in general and prognostic resources areas are collected in Geological Survey's database, too (879 units).

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3. Gasiūnienė, V., 1998. Lithuanian solid mineral resources. Geological Survey of Lithuania, Vilnius.

Mining, Mining Waste and Related Environmental Issues in Poland

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Introduction

In 2001, 7836 deposits of different mineral commodities have been recognised in Poland and 2,841 of them were exploited. They produced about 326 Mt of raw materials (***Figure 1, Table 1***) and 57 Mt mining and processing waste yearly (***Table 2***), except exploited overburden of lignite mining. 21% of the mining waste (12 Mt) has been used for reclamation of ground, engineering work etc. Due to data of the Central Statistical Office, near 1,5 billion tons of mining and processing waste were collected in the tailings ponds and dumps (end of 2000). Mining and processing waste is more then 73% of total amount of industrial waste collected in Poland (***Figure 2***).

After 1989, production of raw materials in Poland decreased rapidly by about 40% due to change to market economy. Parallel, production of mining waste also decreased (***Figure 3***). Balance of export/import raw materials goes to be negative since 1994 (***Figure 4***).

Mining, Mining Waste and Environmental Impacts

Energy raw materials

Oil is produced in Poland from 72 deposits. Total production in 2001 was 480 thousand

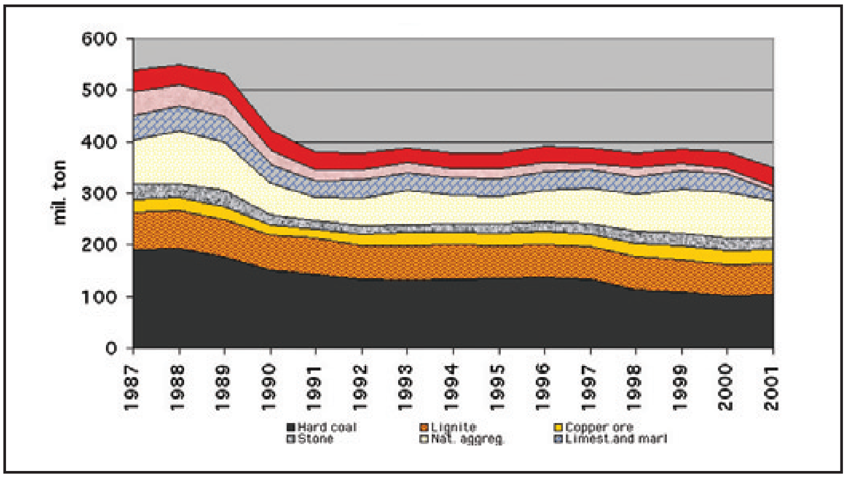


Figure 1. *Outputs of solid mineral commodities in Poland, 1987-2001.*

Table 1. Deposits, reserves, production, import and export of main mineral commodites in Poland in 2001 (after: Przenioslo et al., 2002).

Mineral commodity	Number of deposits		Reserves/resources (Mt)		Production (Mt)	Import (Mt)	Export (Mt)
	Total	In exploitation	Total	In exploitation			
Natural gas (bln cubic meters)	244	180	138.7	118.4	4.78	6.10	0.06
Oil	85	72	12.8	12.3	0.48	17.56	0.44
Hard coal	132	45	45 899.9	16 045.0	102.48	1.90	23.03
Lignite	77	9	13 923.5	2 077.1	59.55	0	0.02
Zinc and lead ores	21	3	180.3	41.2	4.77	0.18	0.26
Copper ores	14	5	2 446.7	1 528.5	28.79	0.01	0.26
Sulphur	17	4	501.8	42.5	0.94	0.08	0.99
Rock salt	20	4	80 346.2	8 422.6	3.23	0.23	1.22
Natural aggregate	4455	1598	14 436.0	3 184.5	73.11	0.07	0.39
Clays	1208	412	3996.6	653.9	5.4	0.07	0.00
Limestone and marl	178	37	17 385.3	6 197.2	18.78	0.00	0.00
Chalk	186	64	194.7	47.0	1.87	0.05	0.00
Dimension and crushed stone	523	209	80 75.8	3 872.7	22.11	1.72	617.00
Total	**7160**	**2642**	**187 538.3**	**42 242.9**	**326.29**	**27.97**	**643.67**

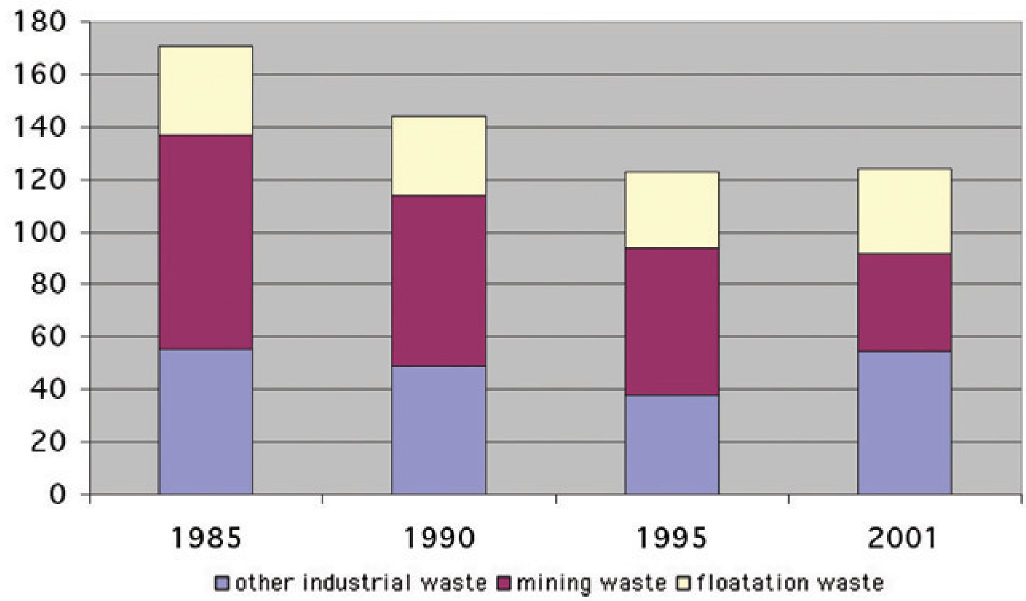


Figure 2. *Output of industrial waste (Mt) (partly after: Budna, 1999).*

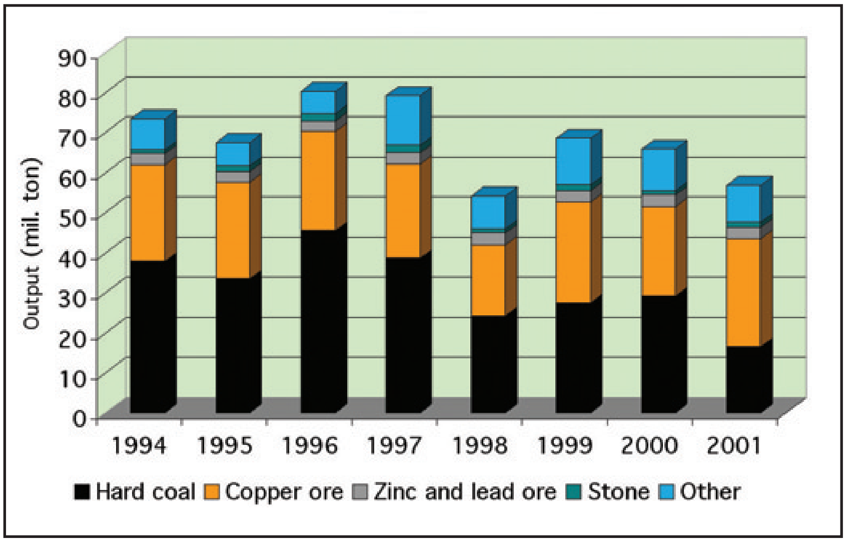


***Figure 3.** Output of mining and processing waste, 1994-2001 (Mt) (after Przenioslo 1997).*

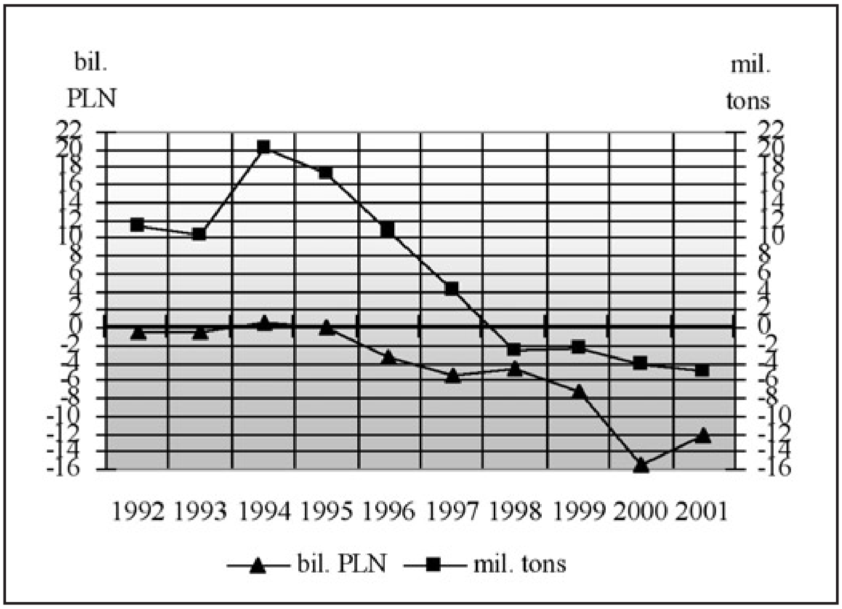


***Figure 4.** Balance of import and export of mineral raw material in Poland, 1992-2001.*

tons, and near 97% of the request has been covered by import. Low volume of oil production is a reason of lacking of mining and processing waste.

Natural gas mining (4.78 billion m^3 in 2001) covers about 44% of total requirement covered from 180 exploited natural gas deposits. There are practically no mining and processing waste related to this production.

Hard coal is the main source of energy in Poland. It is exploited in 45 underground mines. During last years, production of hard coal decreased dramatically, from more than 192 Mt in 1988 in 72 mines to 102 Mt in 45 in 2001. During this time 27 of mines were

Table 2. Waste from prospecting, mining and processing of mineral raw materials in Pola

Waste category	Waste production in 2000	
	Used	Neutralised
		in this: for industrial purposes
	Thou. tons	Thou. tons
1	2	3
Waste from exploitation of raw materials	1 834,1	388,2
Waste of exploitation of metal ore (except copper mining)	70,9	-
Waste of exploitation of raw materials different then metal ore	1 763,2	388,2
Stone waste of copper mining	-	-
First stage processing of output	1 067,8	931,9
First stage processing of metal ore	931,9	931,9
First stage processing of other raw materials	135,9	-
Waste from physical and chemical processing of metal ore	21 181,9	21 160,1
Enrichment waste (except floatation enrichment non-ferrous metal ore)	35	35
Dust and powder waste	0,3	0,3
Waste from processing of sulphuric metal ores causing self-acidification of environment in storing	21 122,1	21 122,1
Other waste	24,5	2,7
Waste from physical and chemical processing of raw materials different then metal ore	35 992,3	6 841,8
Gravel waste and crushed stone	2 532,6	218,6
Waste sands and loams	903,1	138,1
Dust and powder waste	9	0,9
Raw materials cutting, rinsing and cleaning waste	268,9	257,8
Waste from coal enrichment	30 396,8	5 420,1
Waste from flotation enrichment of coal containing dangerous substances	1 746,2	675,2
Waste from flotation enrichment of sulphur ore containing dangerous substances	-	-
Other waste	135,7	131,1
Drilling mud and other drilling waste	-	-
TOTAL	**60 076,1**	**29 321,2**

closed and over 100 thousand of miners have lost their jobs. In 2001, exploitation of hard coal was accompanied by production of 16,539 thousand tons of mining waste. 9,907 thousand tons of it has been used for different ways of utilisation (e.g. ground levelling, construction work, etc.), while 6,632 thousand tons was dumped on coal mine dumps or so-called central waste storages. In this, processing waste related to hard coal enrichment and desulphurisation technologies, which contain high capacity of pyrite and coal, are particularly hazardous for the environment. Mining and processing waste of hard coal industry load particularly the whole area of Upper Silesian Coal Basin and also area of Lower Silesian Coal Basin (abandoned in 1994). In the Lublin Coal Basin, hard-coal waste impacts natural environment only in the local scale because only one mine is active there.

Poland in 2000 (after: Krieger and Sroga, 2002. Data source: Central Statistical Office).

disposed on the own and other disposals	neutralised on another way	together (4 + 5)	Temporary gathering	Total (2 +6 +7)	Waste collected on the own disposals
Thou. tons	Thou. tons	Thou. tons	Thou. tons	Thou. tons	Thou. tons
4	5	6	7	8	9
390,7	-	390,7	125,2	2 350,0	45 705,4
-	-	-	-	70,9	1 582,3
390,7	-	390,7	125,2	2 279,1	39 526,3
-	-	-	-	-	4 596,8
12,6	-	12,6	-	1 080,4	41,9
-	-	-	-	931,9	-
12,6	-	12,6	-	148,5	41,9
6 598,7	-	6 598,7	591,8	28 372,4	556 241,8
-	-	-	-	35	4 480,0
-	-	-	0,1	0,4	-
6 597,2	-	6 597,2	591,7	28 311,0	551 761,7
1,5	-	1,5	-	26	0,1
5 622,8	26,3	5 649,1	115,3	41 756,7	867 328,9
36,7	-	36,7	26,6	2 595,9	39 419,2
101,4	-	101,4	0,2	1 004,7	3 070,7
-	-	-	-	9	-
76,7	26,3	103	39,1	411	18 242,5
5 017,9	-	5 017,9	22,9	35 437,6	723 318,8
377,6	-	377,6	-	2 123,8	39 496,8
-	-	-	-	-	43 226,0
12,5	-	12,5	26,5	174,7	554,9
9,4	-	9,4	-	9,4	29,7
12 634,2	**26,3**	**12 660,5**	**822,3**	**73 568,9**	**1 469 378,8**

Moreover, total mine drainage reached in 2001 about 176 Mm^3 water. 60 Mm^3 (34%) of drainage water have been utilised, and 116 Mm^3 have been dropped to the rivers of the Vistula and Odra river catchments. This salt water drainage, which impacts one third of the Poland area, is very hazardous for natural environment and it should be treated as a kind of mining waste. Total water volume included about 135 Mm^3 salt water (salt content of 0,5-35 g/l) to brine (salt content over 35 g/l) (***Figure 5***). Only 28% of salt water and 13.5% of brine have been utilised. However, due to decreasing of exploitation total amount of salt decreases substantially from 6,000 tons salt per day in 1992 to 3,000 tons per day in 2000.

Lignite is exploited from 10 deposits in 5 mines (***Figure 6***). Total production of lignite in 2001 was 59.5 Mt. Almost whole mining production is used for power generating, what

Figure 5. Water drainage from hard coal mines.

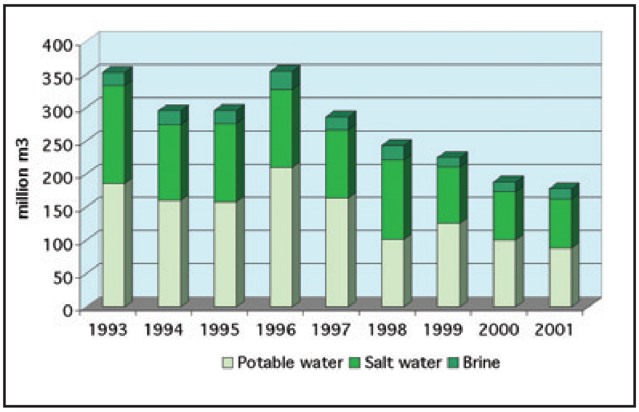
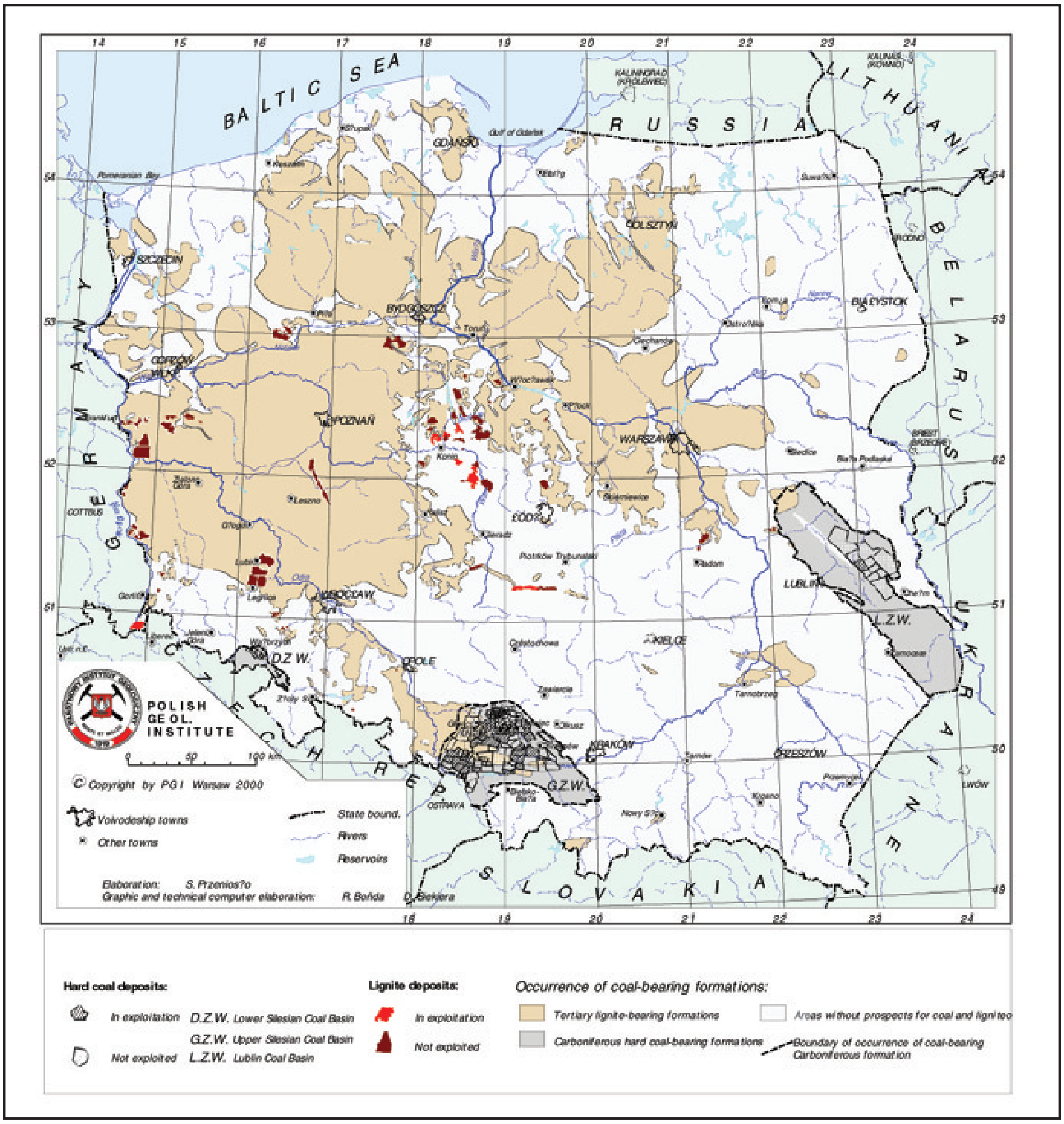


Figure 6. Solid fuel deposits in Poland.



covers about 35% of total power requirement in Poland, and it also provides the cheapest energy. Lignite is exploited in large opencast mines only. Total yearly volume of overburden output is more then 280 Mm^3.

However, from the formal point of view, lignite production does not affect any mining waste, because of, after the Polish regulations, overburden from lignite mines is not a waste. In all the lignite mines it is recently used for infilling of abandoned open-pits. Almost whole volume of lignite is utilised in the mining place in the mine- mouth power plants and it is practically a semi-product for power generation. Therefore, both (1) gases and flying ash emitted to the atmosphere and (2) ash and slag from power plant, which are usually stored in lignite open-pits, should be also treated as processing waste. 43.4 Mt of ash and slag has been disposed recently within 6 special storages. Sulphur oxides and volatile trace elements (mercury, arsenic) are particularly hazardous for environment in emitted gases. Sulphur sulphides, which cumulate some toxic trace elements in lignite, are hazardous in stored ashes. Moreover, capillary and covering water in ash storages is usually highly alkaline (pH 11-12), what may be also hazardous for local aquifers. Lignite mining and utilisation influence mostly areas located closely to the power plants, i.e. Belchatów, Konin and Turów regions.

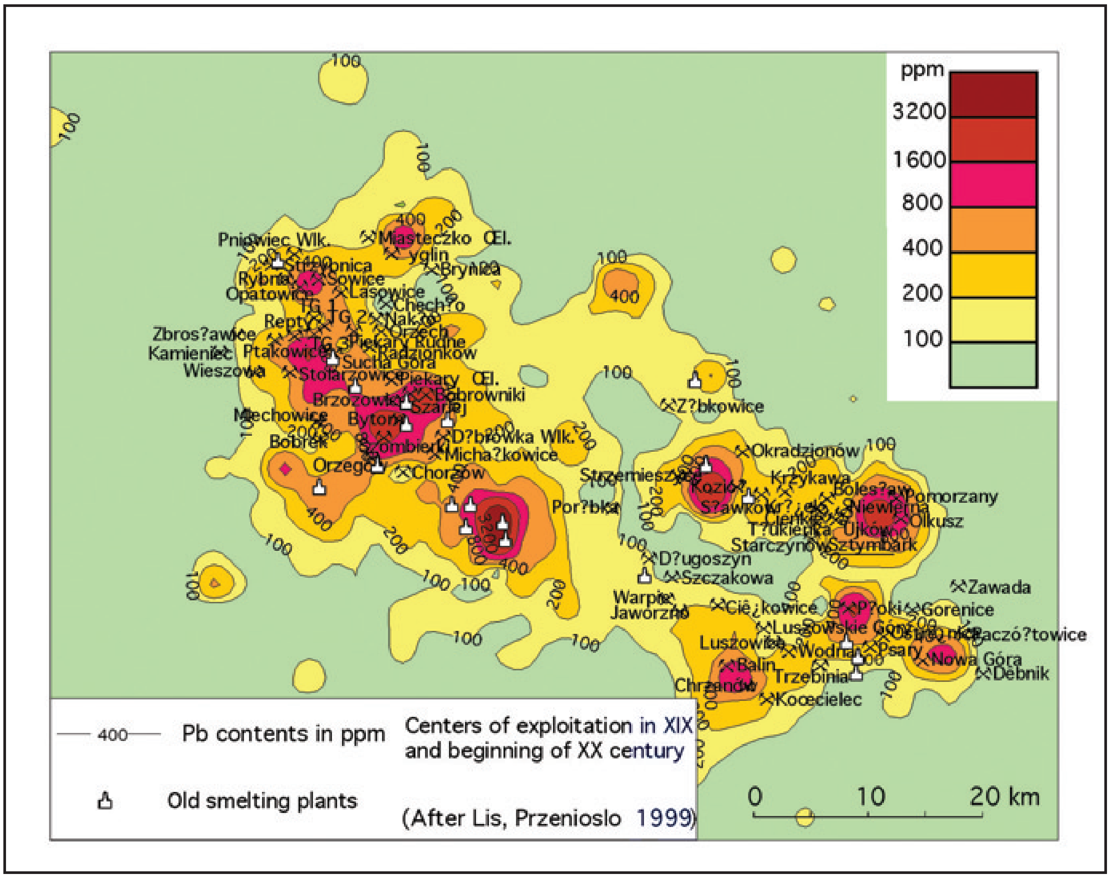


Figure 7. Lead-zinc mining areas on a background of Pb content in soil.

Figure 8. *Map of occurrence of metal ore deposits in Poland.*

Uranium is not exploited in Poland recently. Some small deposits in the Sudetes Mts. (Lower Silesia) were exhausted during the sixties of the 20th Century. The old dumps and tailing ponds after prospecting and exploitation of uranium deposits are evidenced mostly in Kowary and Radoniów areas. Their influence on environment has only local character because limited scale of former exploitation has been limited.

Metallic raw materials

Lead-zinc resources began to be exploited in Southern Poland in the 12th Century, when galena for lead and silver production was mined there. According to documents from the Mining Authority archives, 620 mines with 2,508 shifts were active only in Tarnowskie Góry area (northwards of Katowice) in 1559. Recently 4.76 Mt of lead and zinc ore is exhausted from 3 exploited deposits in the Olkusz area only. This ore contains 182 thousand of tons of metallic zinc and 74 thousand tons of metallic lead. In 2001, 2.82 Mt of processing waste were produced. From this capacity, 0.63 Mt were used, and the rest was disposed in tailing ponds and dumps. Other industrial and communal wastes are commonly stored on these dumps.

Except recent mining waste, plenty of historical dumps, stockpiles and tailings ponds, containing mixed waste material from the mining, processing and smelting plants, create a substantial problem. Their impact is observed not only in the Olkusz area, also in the Bytom and Chrzanów surroundings. Generally, more than 15.9 Mt of mining and processing waste has been disposed in the Bytom area, more than 13.2 Mt in the Chrzanów area and more than 24.4 Mt in the Olkusz Area. These values consider the known sites only; important part of the historic disposals has been lost. Average values of heavy metals in mining and processing waste within all the regions are: Zn: 0.85-2.47% and Pb: 0.36-0.38%. Extremely high content on zinc (up to 6.90%) is related to some historical dumps, where whole zinc component of polymetallic ores has been disposed as waste. However, the highest content of lead and cadmium in soils in Upper Silesia is related to the old smelting plants, working in the end of 19th and the beginning of 20th Centuries, while mining and processing waste involve a little lower content of toxic metals (***Figure 7***). Content of heavy metals in soils is lower also even in areas of occurrence of ore-bearing dolomites, parent rock of zinc and lead ore.

Iron ores were exploited in Central Poland in the Częstochowa and Łęczyca regions since 18th Century. The last mine was closed in 1982. About 70 underground mines operated in these regions. More then hundred dumps and stockpiles of mining and processing waste have been left after finishing of mining. They are not large, and collected material is neutral for environment.

Copper ores (with addition of silver) are exploited in 5 operating mines. Mining output in 2001 was 28.78 Mt of ore, containing 536 thousand tons of copper and 1457 tons of silver. Processing (flotation) waste of the copper mining is particularly hazardous for natural environment; its amount is about 27 Mt yearly. Flotation waste has been disposed within some tailings ponds in three former exploitation areas: Lubin-Glogów Copper District, Grodziec Copper District and Zlotoryja Copper District (***Figures 8*** and ***9***). Recently exploitation is continued in the Lubin-Glogów Copper District only, and processing waste is disposed in the Zelazny Most tailings pond (119.50 Mt of disposed waste). A few abandon and closed tailings ponds in three areas of exploitation include together 127.67 Mt of processing waste. Copper content in the flotation waste is 0.17-0.20%. However, geochemical soil monitoring displays pollution of soil in the copper-mining districts that is determined mostly by location of copper smelting plants.

Nickel ores were exploited only in one point in the Szklary Area (Lower Silesia). Recently exploitation is abandoned (***Figure 8***). 11.03 Mm^3 mining and processing (flotation) waste, which may influence natural environment on the local scale, have been disposed in 6

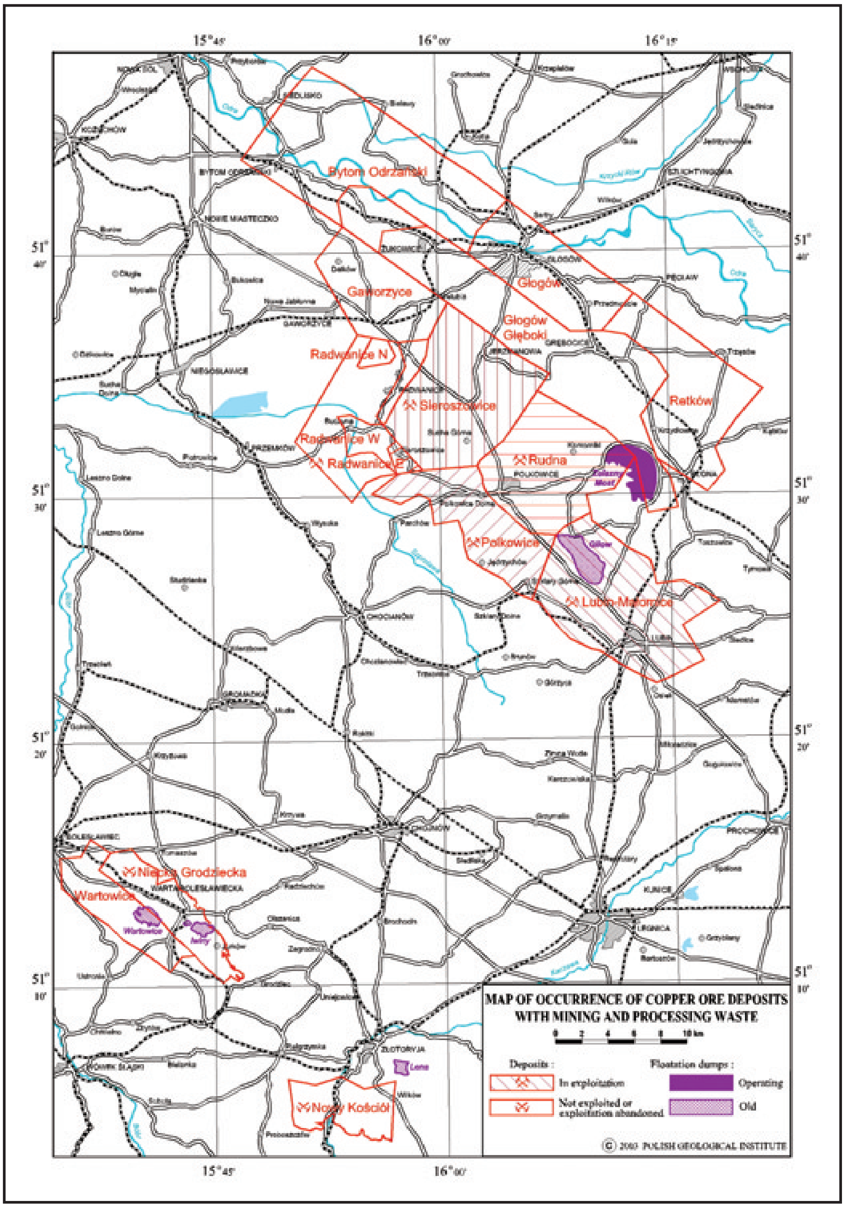


Figure 9. *Copper ore deposits in Poland.*

dumps and the tailings pond near the abandoned mine. Average nickel content within mining and processing waste is 0.35%. For small volume of disposed waste it may influence natural environment only on a local scale.

Chemical raw materials

Arsenic ore exploitation, formerly exploited also for gold extraction, has also been abandoned recently. It was provided in one point in the Zloty Stok area (Lower Silesia), where mining waste with arsenopyrite mineralisation has been disposed inside two dumps near the ancient gold/arsenic mine. This environmental impact may have only a local character.

Sulphur is exploited in Poland recently only with the well method and volume of mining is 0.94 Mt. This is only one region of sulphur exploitation – the Tarnobrzeg Area in SE Poland. Only one kind of processing waste, the sulphur “kek” being a remnant of sulphur rafination may influence natural environment in small level. Fine quantity of “kek” is disposed in a dump near an the abandon “Machów” sulphur open-pit. Oxidation of “kek” involve sulphur oxides emission to atmosphere. However, eruptions of hot H_2S-rich water, common in the areas of sulphur exploitation, bring a much more substantial impact on natural environment. Therefore, the hot H_2S-rich water should be regarded as a kind of mining waste.

Rock salt is recently exploited only in one “Klodawa” salt mine, which produced 3,23 Mt of salt in 2001. Mining waste of salt exploitation, disposed in the “Klodawa” mine dump, is less hazardous for the natural environment.

Carbonate raw materials for lime production and smelting technologies were in 2001 exploited in capacity of 18.78 Mt. Only waste from exploitation of ore-bearing dolomites, which are mineralised with lead and zinc sulphides, may be hazardous for natural environment. Average content of zinc in this waste reaches up to 0.35%. This kind of mining waste occurs only in the areas of zinc/lead ore exploitation in Southern Poland, and their influence is difficult to delimit from the influence of zinc/lead mining.

Stone, aggregates, ceramic clays
Natural aggregate was exploited in 2001 in quantity of 73.11 Mt. Mining waste of this exploitation is neutral for the natural environment.

Ceramic clay was exploited in 2001 in quantity 5.40 Mt. Mining waste of this exploitation is neutral for natural environment.

Chalk was exploited in 2001 in quantity 1.87 Mt. Mining waste of this exploitation is neutral for natural environment.

Dimension and crushed stone was exploited in 2001 in quantity 22.11 Mt. Mining waste of this exploitation is also neutral for natural environment.

Databases

There are three major sources of information on mining and processing waste in Poland: (1) MIDAS database on mineral resources, (2) Central Statistical Office data, and (3) Geoenvironmental Map of Poland database.

MIDAS database
The MIDAS database, created and guided by the Polish Geological Institute, is a main database on mineral resources and mining data. Since 1992, it contains informations on waste, produced in exploitation of mineral deposits. Data on mining waste produced and disposed earlier are not complete. Data from the MIDAS database are a source for annual publication of the “Balance of mineral deposits in Poland”. This report contains evidence on mining and processing waste, which could be used as waste raw material (***Table 3***).

Table 3. Balance of waste raw materials in 2001 in Poland (after Prezniosl o et al., 2002).

Type of rock waste	Waste (thou. tons) output in 2001	Waste (thou. tons) used in 2001	Number of mines producing waste
FROM LIGNITE DEPOSITS			
Sandstone, mudstone, siltstone	1.10	-	1
FROM HARD COAL DEPOSITS (only mining waste)			
Sandstone, mudstone, siltstone	16 539.74	9 906.65	21
FROM COPPER ORE DEPOSITS (processing waste)			
Siltstone, mudstone. schist	26 954.98	-	3
FROM ZINC AND LEAD DEPOSITS (processing waste)			
Dolomite	2 816.30	627.70	2
FROM SULPHUR ORE DEPOSITS			
Limestone and marl	1.40	-	1
FROM ROCK SALT DEPOSITS			
Gypsum, anhydrite	5.55	-	1
FROM DOLOMITE DEPOSITS			
Dolomite	100.00	-	1
FROM GYPSUM AND ANHYDRITE DEPOSITS			
Clay	408.70	-	1
FROM REFRACTORY CLAY DEPOSITS			
Silt, clay	604.00	-	1
FROM DIMENSION AND CRUSHED STONE DEPOSITS			
TOTAL	1295.85	284.14	
FROM NATURAL AGGREGATE DEPOSITS			
Sand	5 478.36	869.26	21

Central Statistical Office Database

The Central Statistical Office data are published in annual “Statistical Yearbook” (Dmochowska 2002) and in some special periodical publications (Budna et al. 1999). This balance is prepared on a base of international waste classification. Some balances of mining and processing waste on the basis of these data have been published (***Table 3***).

Geoenvironmental Map of Poland

Geoenvironmental Map of Poland is currently prepared by the Polish Geological Institute for requirements of edition of the “1:50,000 scale Geoenvironmental Map of Poland”. According to rules to the map preparing (Instrukcja... 2002), the data on disposed mining and processing waste and waste disposals, and also recent waste circulation should be collected. In 2002, these detailed data were collected for about 55% of the territory of Poland.

Data comparability is practically not complete, because the data of balances the MIDAS database and the Central Statistical Office consider different classifications and categories of waste. Hard coal mining/processing waste may be a good example of this: in this branch

Type of rock waste	Waste (thou. tons)		Number of mines producing waste
	output in 2001	used in 2001	
FROM VEIN QUARTZ DEPOSITS			
Gneiss, migmatite	61.31	-	1
FROM REFRACTORY QUARTZITE DEPOSITS			
Quartzite	87.40	-	1
FROM MAGNEZITE DEPOSITS			
Quartzite	136.64	16.84	1
FROM BACKFILLING SAND DEPOSITS			
Silt, mud	203.90	-	1
FROM CERAMIC CLAY DEPOSITS			
TOTAL	45.27	0.02	
FROM KAOLIN DEPOSITS			
Sand, mud	119.19	-	1
FROM GLASS SAND DEPOSITS			
Sand	324.84	-	4
FROM LIMESTONE AND MARL DEPOSITS FOR CEMENT INDUSTRY			
Weathering waste of lime and marl	534.15	0.10	4
FROM LIMESTONE AND MARL DEPOSITS FOR LIME INDUSTRY			
TOTAL	1048.58	-	

of mining (1) the MIDAS database considers only stone from mining galleries in mines – not particularly loading the environment, used for construction works, ground levelling, etc, while (2) the Central Statistical Office database includes waste from enrichment of coal (sorting and floatation) which is hazardous for the environment.

Case studies – characterisation of selected "hot spots":

Site 1: Konin Lignite-Bearing Area - surface lignite mine

The Konin Lignite-Bearing Area is situated in Central Poland, ca. 200 km westwards of Warsaw. The "Konin" Brown Coal Mine, joint stock, with headquarters in Kleczew, is recently the second producer of lignite in Poland. The yearly production in 2001 was 11,38 Mt. Lignite is exploited from four open-pits, situated north- and westwards of the town of Konin. Almost all the production (98.3%) is used by two large thermal power plants ("Konin" and "Pltnów" ones) working in open-water circulation cooling technology and using water from some neighbouring lakes.

Mining history

The mining activity (surface mining) in the region started in 1942, during the World War Two. Systematic exploitation has been entertained by the "Konin" Brown Coal Mine in 1945 within the "Morzyslaw" open-pit (extremal output 199 Gg in 1950). New excavations were opened in every few years (1953, 1954, 1957, 1962, 1969, 1982, 1994), and total mining output exceeded 10 Mt in 1969. Open-pits on exhausted deposits have been abandoned successively. Mining activity was not practically disturbed during changes of economic in 1989 (lignite as been all time the cheapest power source) and mining output has been stable last years. After general energetic strategy of Poland (Kasztelewicz, 1997) the "Konin" mine will be active up to 2037.

Power-plant ash storage in abandoned open-pit "Gos?awice" started in 1977. Ashes are transported in form of hydrosuspension with pipelines and deposited within an lignite excavation infilled with groundwater. The storage processing changed water quality to high-mineralised and extremely alkaline one (pH = 11-13). Recently a new safe ash storage protected with ionic-exchanging geomembrane is under construction at the mine dump.

Investigation methods

Data and databases: the geological information related to the Konin Lignite-Bearing Area has been collected by The Geological Survey of Poland (Polish Geological Institute), Voivodeship (Province) Authority and archive of the "Konin" Brown Coal Mine. Data related to mining activity and environmental impact have been collected by the Ministry of Environment and Head Mining Authority.

Monitoring efforts: all the open-pits and the power-plant ash storage (tailings pond) have detailed monitoring system for measuring and evaluation of amount and quality of mine waters and parameters for evaluation of geodynamic and undermining aspects. No continuous monitoring of waste waters, but their chemical composition is practically the same since 1985 (***Table 1***).

Hazard source description

Source of major environmental hazard (including environmental impact of power-plant activity, which should be treated as processing plant of the mining/power production complex) are as follows (Kasiǹski et al. 1998, 2002):

- dewatering of mining fields (the most important impact) generating deep changes of the hydrological and hydrogeological conditions of the region related to development of a large depression cone; mine waters are polluted with organic suspension only and they are removed to surface streams after cleaning within sedimentary ponds;
- increase of water temperature (ca. 5 ^oC) in few natural lakes, included into the power plant water cooling circulation;
- emission of contaminants (As, Sr and SO_3) to atmosphere due to lignite combustion in the power plants;
- emission of contaminants (Na, K, Cl, SO_3) to groundwater (***Figure 10***) due to power plant ashes storage within a tailings pond (hydrosuspension); water covering ash is highly alkaline (total alkalinity amounts 26,2 mval/dm^3) and it contains high concentrations of Ca, CO_3, and the contaminants mentioned above.
- activation of geodynamic processes on slopes and soil subsidence (induced by dewatering) inside large area of the depression cone (ca. 400 km^2).

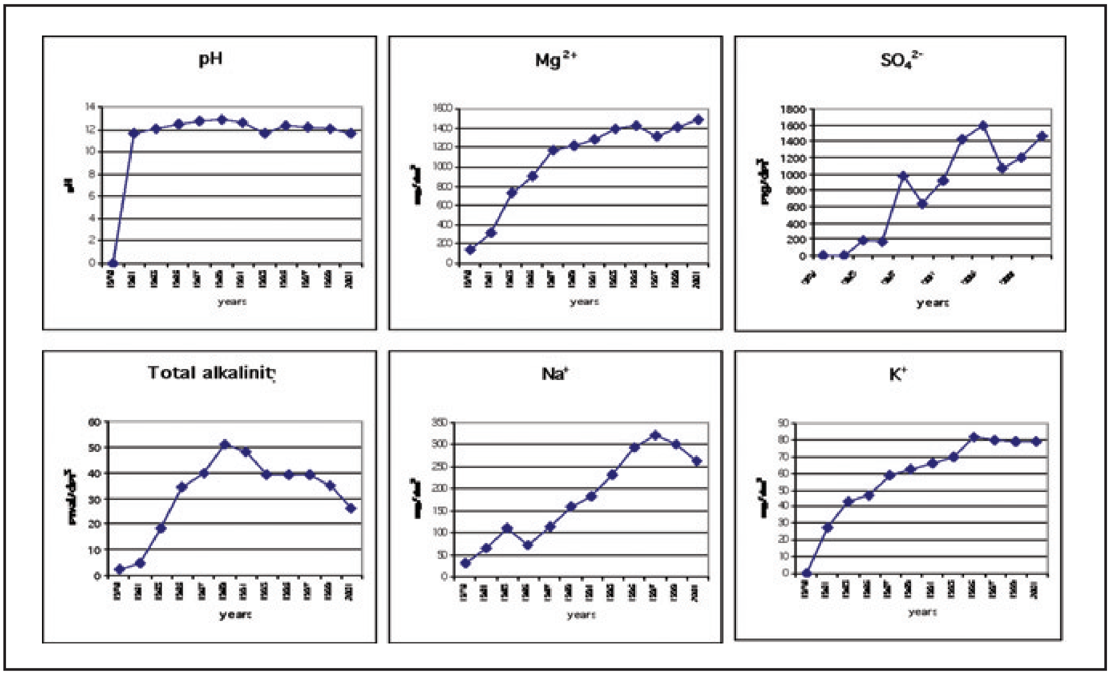


Figure 10. *Mineralisation of ash-covering water within the "Goslawice" ash storage (after: Kasiǹski et al. 2002).*

Environmental risks and impacts

Hydrosphere: dewatering of aquifer involves deep changes in hydrologic regime of ground and surface water, however mining activity practically does not impacted water quality. However, processing of lignite in the power plant caused (1) thermal water contamination within the lakes belonging to the cooling circulation, (2) potential contamination of groundwater with pollutants from the power-plant ash storages (particularly in future) is also possible due to filling of the tailing ponds with ashes and increasing of ash-covering water level there. Thermal water contamination is not properly solved: water temperature is higher with 5-6 ^{o}C there and these lakes do not get frozen up during winter. Problem of contamination with ash-covering high-mineralised water is just solving with construction of new special ash storages protected with ionic-exchanging geomembranes; the "Goslawice" storage after final filling will be remediated by forestry.

Atmosphere: no substantial changes in air quality are caused straight by mining activities. On the other hand, ecological damages related to emission of are caused by burning of brown coal in two power plants (1200 MW and 540 MW).

Soil: arable land is limited in usage during mining periods in individual deposits. Non-arable land and forests are impacted by activated geodynamic processes.

Ecosystems: ecosystems are substantially influenced and deeply changed. They are totally transformed closely in mining areas (new ecosystems originate after reclamation of open-pits) and impacted also in the result of dewatering processes.

Socio-economic impacts

Except of good economic results, mining of in the Konin Lignite Bearing Area has got also an important social aspect, because the Konin Lignite Mine and two power plants connected with it are the major employers in the region.

Outlook

Future tasks and needs for mitigation of mining waste environmental risk and impact on the site of mining activity touch the horizon more than 30 years ahead with almost the same yearly exploitation volume. Programme of environment protection and remediation of environment represents substantial part of overall development of mining and processing activities and fulfils legislative requirements of the obligatory law included within the Mining and Geological Act and other regulations. Some specific ways of activity are/will be used to improve environmental situation:

- remediation of groundwater conditions; rest-water reservoirs have been constructed for this goal since 1974 after finishing of exploitation of every individual open-pit;
- utilisation of thermal waters for technological goals (heating of Konin and some smaller towns);
- increasing of emission of contaminants to atmosphere due to lignite combustion in the power plants after closing of old installations and more effective installation of desulphurization. Finally combustion within a fluidal deposit.
- elimination of potential aquifer menaces after finishing of deposition of power-plant ashes within the rest-water reservoir in the abandoned excavation and deposition of them within storages constructed with high environmental-protecting technology – procedure in course;
- remediation of land surface in areas of opencast mining – procedure continuously in course with the results of improving soil quality up to two-three quality classes.

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Site 2: "Boleslaw" Mine - zinc/lead mining site

The "Boleslaw" Zinc/lead Mine is situated in the Olkusz Zinc/lead Bearing Area in southern Poland, ca. 30 km eastward of Katowice and about 6 km westward of the town Olkus1z. The mine has been abandoned since 1997, and the production of polymetalic ore before the closing was 250-300 Gg per year. Sulphide ores, containing mostly galena and sphalerite, was exploited in underground excavations, and oxidic ores (galmei), too.

Mining history

Area in the Boleslaw Mine vicinity is important from the viewpoint of historical mining. It started to be a field of polymetalic ore of silver and lead underground mining since 12th Century. To the first half of the 16th Century, ores was mined within numerous small shafts above groundwater table. During the second haft of the 16th Century, system of gallery dewatering has been introduced; the galleries, working as dewatering as well as ventilation ways, allowed to continue mining in deeper parts of the deposits below groundwater table (Grzechnik 1978). Exploitation volume of lead and also zinc ore quickly increased after 1813, when mechanical pumps were applied for dewatering system. Two underground mines: "Boleslaw" and "Ulisses" worked then in this area. During the first half of the 20th century opencast exploitation of shallow-located oxidate ores (galmei) started too. However, both mines were closed in 1931 due to low profitability. In 1940, abandoned mines were dewatered and put in motion again. Ore mining was stopped in 1997 and the mines are curently under closing.

During historic exploitation in the described region, only lead and silver contained within sulphidic ores was extracted, and oxidic lead ores and whole amount of zinc was treated as waste. Part of those wastes was reprocessed during the last two centuries. Therefore, most of them have been partly dispersed and partly used for backfilling.

After the World War II, processing and smelting plants were installed in the close neighbourhood of the mine. 33.3 thousand tons of post-flotational processing waste containing 1.02% Zn, 0.36% Pb and 67 ppm Cd on average have been deposited within two tailings ponds and one dump, occupying an area of 1.04 km^2.

Investigation methods

Past and present investigation efforts: polymetallic deposits of zinc/lead (historically also silver) ores are situated in the eastern part of the Silesia-Cracow Monocline occupied by the Upper Silesian Coal Basin. Ore occurs within the ore-bearing sedimentary dolomites of Middle Triassic age.

Data and databases: the geological information related to the Olkusz Zinc/Lead Bearing Area has been collected by The Geological Survey of Poland (Polish Geological Institute), Voivodeship (Province) Authority and archive of the “Pomorzany” Zinc/Lead Mine. Data related to mining activity and environmental impact have been collected by the Ministry of Environment as well as the Head Mining Authority.

Monitoring efforts: the “Bukowno” tailings pond, the only operating mining/processing waste storage facility, has detailed monitoring system for measuring hydrogeological parameters. After closing of mining, detailed geochemical examination (geochemical map of 1:25,000 scale - Lis and Pasieczna 1999) has been made. There is no continuous monitoring of waste waters, but general composition of soils, surface waters and bottom sediments are monitored.

Hazard source description

Main environmental impacts are related to the following processes:

- contamination of surface water, ground water and soil (***Figures 11a, b, c, d***) by dispersed waste, mine waters and leakage from tailings ponds and waste rock piles (stockpiles) (the most important impact);
- changes in rock environment caused by surface and mainly underground mining and dewatering of the area with negative influence on environment;
- potential risk is posed by the disruption of tailings dams.

Strong influence of neighbourhood industry (hard-coal mining and iron smelting plants of Upper Silesia, machine industry of the Olkusz region, and a large paper plant in Klucze) is also visible.

Acidification of environment (soils, waters etc.) takes no place in the described area (***Figure 11d***), due to the alkalinity of ore parent rock (dolomite).

Environmental risks and impacts

Hydrosphere: dewatering of water-bearing horizons influences hydrologic regime of surface and ground water. Contamination of surface water with heavy metals (opposite to

water bottom sediments) is not high (Lis and Pasieczna 1999). The whole region was deforested with charcoal production for lead smelting plants during Middle Ages. This as well as mine dewatering caused an origin of the small desert nearby (Błędowska Desert).
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Soil: extensive contamination with heavy metals, particularly cadmium content > 15 ppb makes most of the area unsuitable for creating parks, gardens, allotments and recreation areas (***Figure 11 f***). Also non-arable land and forests are impacted by extensive mining and processing activ-ities.

Ecosystems: substantially impacted and changed because of contamination with heavy metals, particularly with toxic cadmium. Damages in the region are solved by legislative way between mine management and local administration. Atmosphere: ore processing caused contamination of air by ash and emissions of SO_2.

Socio-economic impacts

Mining Zn/Pb ores finished in 1997 because of changes in economical deal and transition to market economy in the result of closing the state subventions to ore mining. This decision caused increasing of unemployment in the region. However, this negative socio-economic aspect was estimated as less-important one than economic criteria and environmental impact. The state has to recover the territory and pay for damages to some subjects.

Outlook

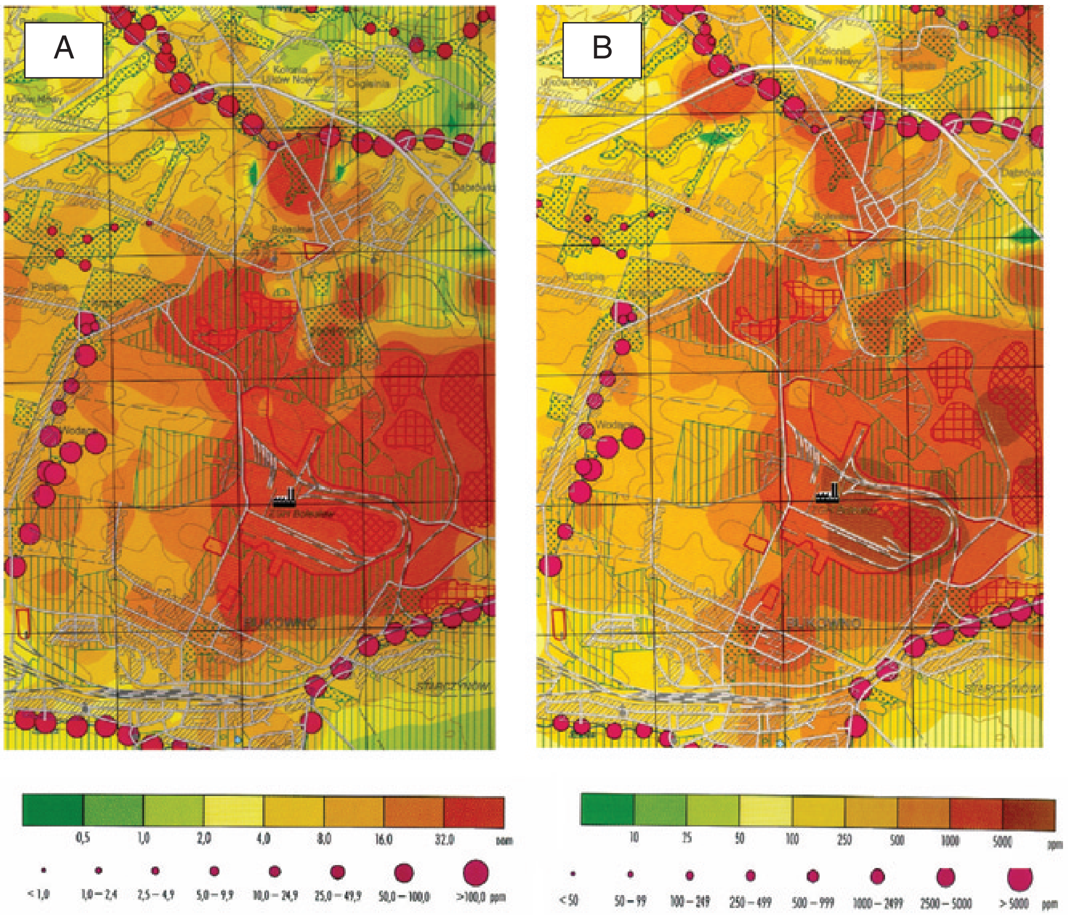
Mining activity of the "Boleslaw" zinc-lead mine is just under closure and a substantial part of mining and processing waste storages has been reclaimed. Open excavation of the oxidic ores has been completely infilled, partly with material of the waste dumps. Recently, the communal park exists on the most part of the former excavation and dump area.

The "Bukowno" tailings pond, where mining/processing waste from the "Boleslaw" mine were stored before, is recently used to storage of waste from the other underground mines ("Olkusz" and "Pomorzany"). It is the only one mining/processing object working to this time. The project of reclamation of the pond area after mine closure has been just elaborated.

Contamination of soils and surface waters with dispersed Pb, Zn and Cd compounds, related to mining/processing waste (in an important part of historical origin) as well as smelting industry one, is a substantial problem today and in future and only passive procedures (proper land use) are provided. However, most part of the mining waste/processing waste has been stored within ancient carriers at natural exposures of the parent rock (ore-bearing dolomite), content of heavy metals is there lower than in parent rock. On the other hand, environmental impact of smelting affects the environ ment much more than mining/processing ones.

Conclusions: Environmental Impact Assessment, Programmes and Plans

During the last years, numerous works related to mining and processing waste were accomplished in Poland. There are two major directions of progress: (1) considering waste classification and preferred methods of its storage, and (2) considering environmental impact of selected mines and sites of mining and processing waste (case studies).



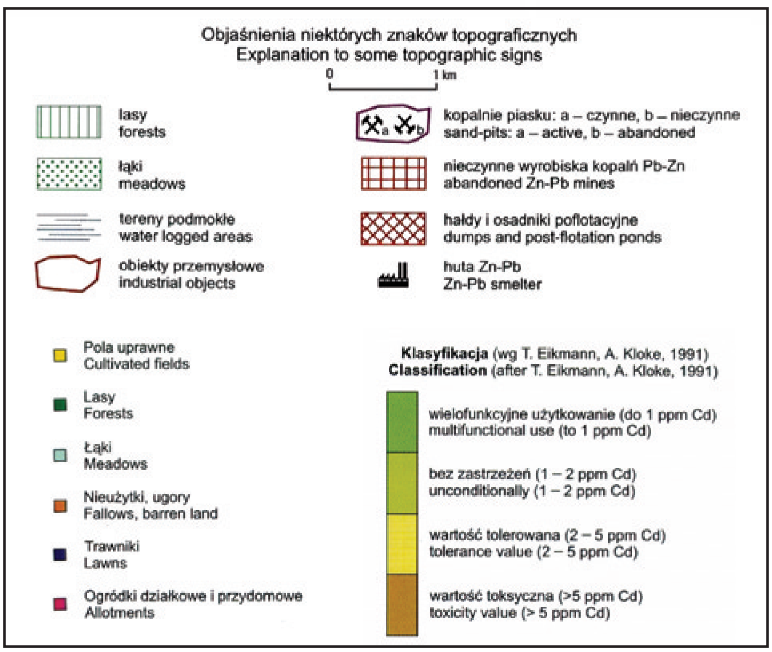
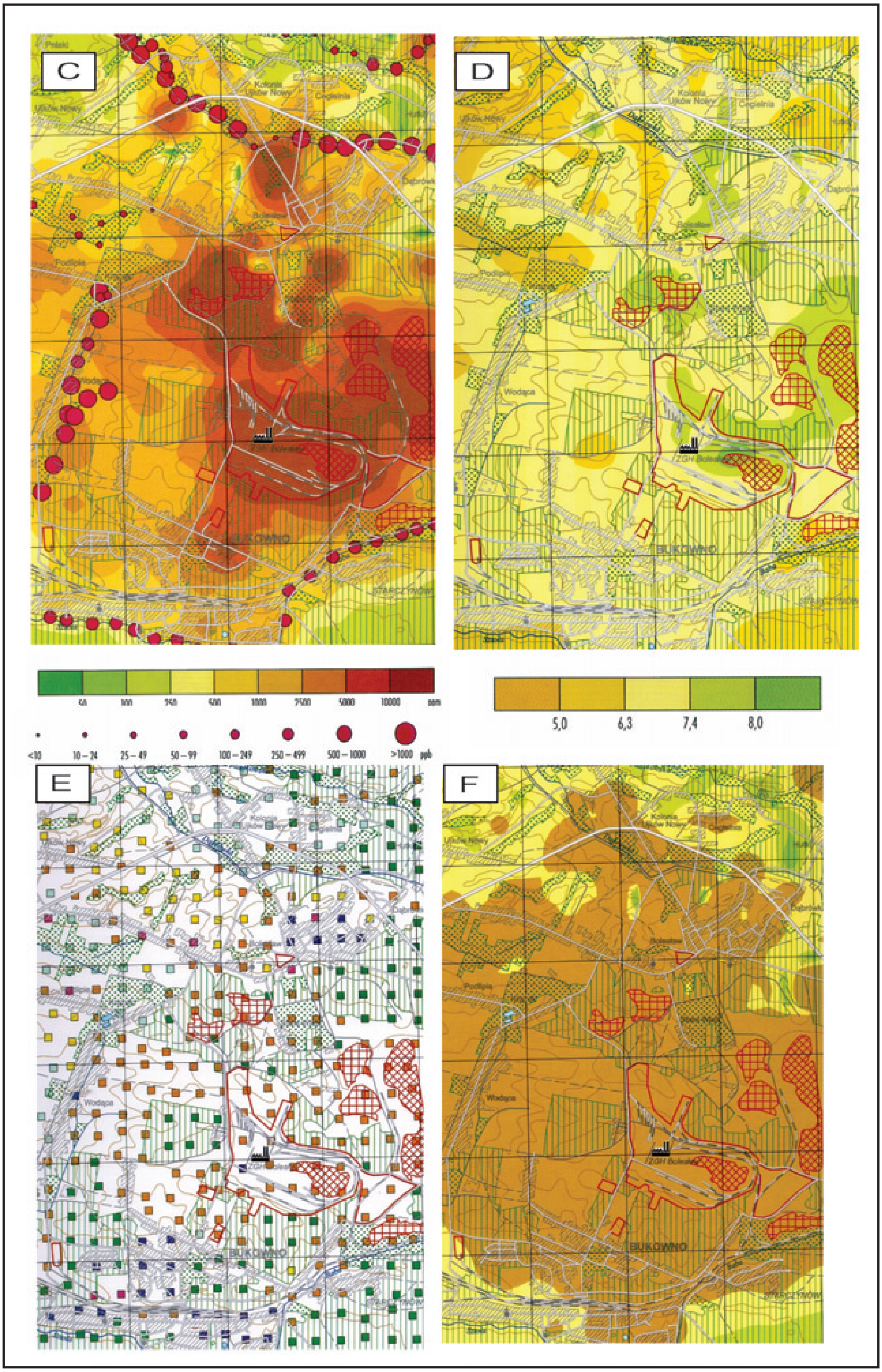


Figure 11. *Zinc/lead mining and smelting industry contamination of soils at the depth 0.0- 0.2 m (after: Lis and Pasieczna 1999): a) Cd, b) Pb, c) Zn, d) pH of soil, e) land use, f) Cd-evaluation of soils for allotments.*


C
D
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BUKOWNO
50 100 250 500 1000 2500 5000 10000 ppm
<10 10 – 24 25 – 49 50 – 99 100 – 249 250 – 499 500 – 1000 >1000 ppb
5,0 6,3 7,4 8,0

The “National Plan of Wastes Management”, prepared by Polish Geological Institute in co-operation with the Institute of Waste Management and Institute for Ecology of Industrial Areas, was a basic document realised according to the first progress direction. It was accepted by the Polish Government in 2002 as a formal basis for waste management. Mining and processing waste are one of its topics. Some complex elaborations and case studies have been done in the results of the works developing on the second way. Also large interdisciplinary “National Program for Fundamental Research # 04.10: “Protection and Forming of Natural Environment” (1984-1990), coordinated by the Agricultural University in Warsaw, included an important part related to an inventory of mining and processing waste and environmental impact (Szczęśniak 1988, 1990a, 1990b).

The “Geoenvironmental Map of Poland in 1:50,000 scale” (Sikorska-Maykowska et al. 2003) coordinated by the Polish Geological Institute, is the most complex regional project. It covers the whole territory of Poland and includes evaluation of all the deposits from the viewpoint of their environmental impact (Instrukcja 2002). On the basis of ecological criteria, as: (1) underground water, (2) forests, (3) landscape protection, (4) human sites and infrastructure, (5) soils and (6) general environmental charge, three categories of the deposits have been established:

A **less conflicted deposits** (exploitation possible without any restrictions);
B **conflicted deposits** (exploitation possible after fulfilling special requirements);
C **very conflicted deposits** (exploitation prohibited).

The works of the project include also an inventory and characteristics of disposals of mining and processing waste and waste disposals, with the data of recent waste circulation. It considers all kinds of deposits, both exploited and unexploited, and for the unexploited deposits potential environmental impacts are evaluated. Among the mining/processing waste, also historical dumps (if possible) are considered. The project started in 1997 and it should be finished in 2007.

Interdisciplinary program “Lithosphere Protection”, guided by the Polish Geological Institute during 1989-1998, contains numerous case studies related to selected deposits and groups of raw materials. They took into consideration some details of specific environmental aspects, like acidification of water and soil in areas of copper and lead/zinc mining, alkalisation of water in disposals of coal/lignite ash (Piwocki and Kasiński 1994), contamination of soil by heavy metals and detail stocking of mining/processing waste in the areas particularly loaded by mining activity. Also the “Geochemical Atlas of Poland” (Lis and Pasieczna 1995a) on the 1:2,500,000 scale is an important result of this way of study. Some detailed regional/local geochemical atlases (Lis and Pasieczna 1995b, 1995c, 1999a, 1999b) have been prepared and published in the frames of this program.

Some other important case studies, made by the Polish Geological Institute partly with international co-operation with the Geological Survey of Saxony, have been related to environmental impact of mining activity in the so-called “Black Triangle”, bad-reputed area of the crossing of borders of Poland, Germany and Czech Republic. Evaluation of influence of mining waste for damaged environment was an essential part of the project. The regional case studies made possible to select some areas of extensive recent and historial mining/processing waste storages, which have been evaluated as really and potentially hazardous ones, so-called “hot spots”. They are related mostly to mining of (1) coal and lignite, (2) metallic ores (Mizera 1990, Zajac 1990), and (3) sulphur, and in lower grade also to historical mining of uranium (Piestrzyński et al. 2001) and arsenic. Environmental impact of recently produced hazardous waste is currently monitored, but stocking and evaluation of influence of many of historical wastes is really not easy (Grzechnik 1978).

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Mining, Mining Waste and Related Environmental Issues in Romania

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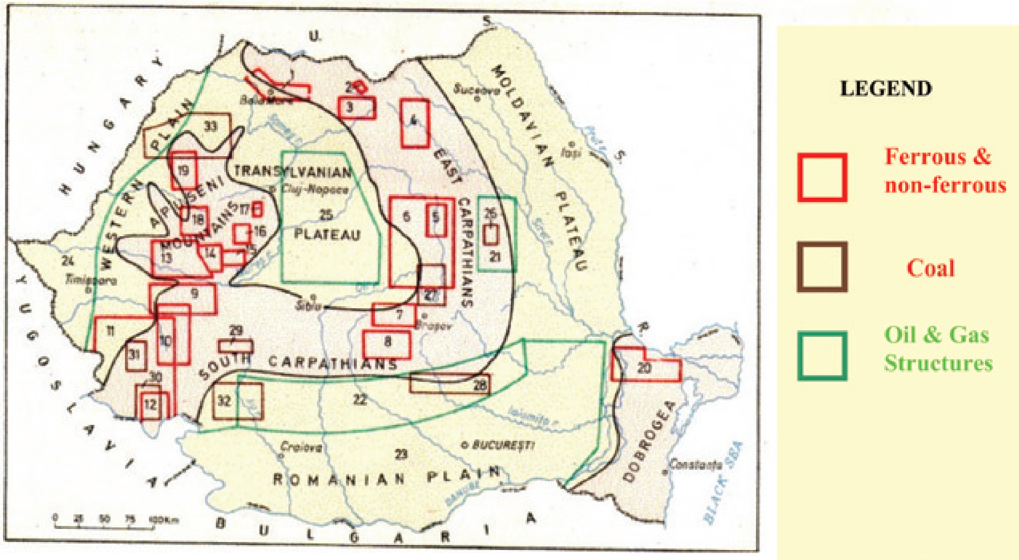
Introduction

Romania, with 22.4 million people (2001), is the second most populated country in Central and Eastern Europe. In 2001, the gross domestic product (GDP) of Romania was $132.5 billion (purchasing power parity). During the last twelve years, the country has undergone dramatic changes: the authorities are looking forward to open more ambitious development goals. Mindful of the need to effectively exploit the country's economic potential, its strategic location and its vital role in the regional and international economies, the authorities have been working hard both to achieve NATO membership and to join the EU in four years time.

As per provisions of the Constitution of Romania – Art.135 (4), "*…the mineral resources from the Romanian soil and subsoil and located on the continental shelf and the economic area of the Black Sea are exclusively public property and belong to the Romanian State*. Romania has separate laws on mining (No.85/2003; "Mining Law") and on hydrocarbons (No. 134/1995; "Petroleum Law"). The Competent Authority responsible for the application of the provisions of the laws is the National Agency for Mineral Resources (NAMR), *"…organized as a public institution of national interest and acting under Government subordination"*. Hazardous mining waste is registered with the Ministry of Industry and Resources (General Directorate for Mining and Geology). Mining waste inventory, for active mining exploitations, exists with the Ministry of Industry and Resources. The State-owned Company "CONVERSMIN" is dealing with conservation, mine closure and post-closure monitoring works since 2002. Special regulations for remediation methodology and technology are stipulated in the "Mining Closure Manual" issued by the Ministry of Industry and Resources.

Mining licensing and controlling is performed by the National Agency for Mineral Resources (NAMR). Regional and local controlling is accomplished by county inspectors. Geological Institute of Romania (Geological Survey of Romania) produces all kind of national geological and geophysical maps and, by its own publications, spreads the geological information to the public.

As part of economic reform measures since 1990, the mining sector was reorganized by establishing two types of state enterprises: Regies Autonomes (RAs) for the production and supply of mining products, and Commercial Companies (CCs) for mining activities



Keys: 1-Ilba-Baiut District; 2-Baia Borsa District; 3-Rodna Mts.; 4-Bistritei Mts.; 5-Balan District; 6-Neo-volcanic Gurghiu-Harghita area; 7-East-Fagaras Mts.; 8-Iezer-Papusa-Leaota Mts.; 9-Poiana Rusca Mts.; 10-Voislova-Teregova Zone; 11-Laramian metallogenesis from South Banat; 12-Gabbro-peridotite massif from South Banat; 13-Western Metalliferous Mts.; 14-Brad-Sacaramb metallogenetic district; 15-Zlatna-Sacaramb metallogenetic district; 16-Rosia Montana-Bucium-Baia de Aries metallogenetic district; 17-Baisoara-Lita metallogenetic area; 18-Brusturi-Halmagiu-Poiana metallogenetic district; 19-Padurea Craiului Mts.; 20-North Dobrogea; 21-East Carpathians Flysch; 22-Diapir folded zone and Getic Depression; 23-Moesian Platform; 24-Pannonian Basin; 25-Transylvanian Basin; 26-Comanesti Basin; 27-Baraolt Basin; 28-Dacic Basin (Valahian zone); 29-Valea Jiului Basin; 30-Sirinia Basin; 31-Resita Basin; 32-Dacic Basin (Oltenia); 33-Pannonian Basin.

Figure 1. *Location of representative areas with mineral resources accumulation.*

and support services. This enabled the government to separate policy and regulation from operational functions, to bring accountability and to institute commercial practices in the mining sector. RAs were state holding companies for sectors considered strategic by the Government of Romania including metallic and non-metallic minerals, lignite, and coal. CCs are joint stock companies established under the “Company Law” (1990). RAs, including these mining companies, were reorganized into National Companies in 1997, when the privatisation of mining sector started. At present, 96 companies operate in the mining sector, grouped according to their activities and the deliverability. Altogether, there are eight National Companies (NCs) comprising 105 mining exploitations, namely:

- Coal: 3 NCs and 1 CCs with 40 mining exploitations;
- Metallic minerals: 2 NCs with 44 mining exploitations;
- Radioactive: 1 NC with 4 mining exploitations;
- Salt: 1 NC with 7 mining exploitations;
- Non-Metallic: 7 CCs from which 2 private;
- Mineral waters: 1 NC.

Besides these, from the initial RAs there were separated 94 CCs carrying out auxiliary activ-

Table 1. Mineral resources and mining areas.

Mining commodities			Location of the ore deposits (local mining name and county)
Mineral fuels	Coal	Anthracite	Schela Vezuroiu (Gorj)
		Bituminous coal	Anina (Caras Severin), Campu lui Neag, Valea de Brazi, Uricani, Lupeni, Vulcan, Aninoasa, Petrosani, Lonea, Petrila (Hunedoara, Valea Jiului basin).
		Brown coal	Comanesti, Asau, Leorda, Lapos, Vermesti (Bacau); Mehadia (Caras Severin).
		Lignite	Pescareasca, Godeni, Boteni, Cotesti, Aninoasa (Arges); Doicesti, Sotanga, Margineasa (Dambovita); Filipesti de Padure (Prahova); Rovinari, Motru, Jilt (Gorj); Berbesti-Alunu (Valcea); Husnicioara (Mehedinti); Capeni (Harghita); Tebea (Hunedoara); Borod-Borozel (Bihor), Sarmasag, Chiejd, Bobota (Salaj).
		Peat	Dersca-Lozna (Botosani); Poiana Stampei, Neagra Sarului (Suceava).
	Sand and schists	Bituminous sands	Derna, Tartarus, Suplacu de Barcau (Bihor).
		Bituminous shale	Anina, Doman (Caras Severin).
Metallic ores	Ferrous	Iron	Teliuc, Ghelar (Hunedoara); Ocna de Fier, Ruschita, Dognecea (Caras Severin); Capus (Cluj); Lueta, Vlahita (Harghita).
		Manganese	Vatra-Dornei, Iacobeni, Argestrut, Dadu-Carlibaba (Suceava).
	Non-ferrous	Copper	Deva (Hunedoara); Balan (Harghita); Lesu Ursului (Suceava); Baia Borsa (Maramures); Rosia Poieni (Alba); Moldova Noua (Caras Severin); Altan Tepe (Tulcea).
		Polymetallic (Cu, Pb, Zn)	Muncelu Mic, Boita Hateg (Hunedoara); Baia de Aries (Alba); Ruschita (Caras Severin); Baia Sprie, Cavnic, Baiut, Ilba, Nistru, Baia Borsa (Maramures); Lesu Ursului (Suceava).
		Gold	Barza, Certej (Hunedoara); Rosia Montana, Zlatna, Baia de Aries (Alba); Suior, Sasar (Maramures)
		Mercury	Santimbru (Hunedoara); Izvorul Ampoiului (Alba)
		Uranium	Stei (Bihor); Ciudanovita (Caras Severin); Tulghes (Harghita).
		Molybdenum, bismuth	Baita Bihorului (Bihor)
Non-metallic ores		Salt (NaCl)	Ocnele Mari (Valcea); Slanic (Prahova); Tg. Ocna (Bacau); Ocna Mures, Ocna Dej (Cluj); Praid (Harghita); Cacica (Suceava).
		Potash salt	Tazlau (Bacau)
		Barite	Somova (Tulcea); Ostra (Suceava).
		Bauxite	Alesd, Padurea Craiului (Bihor).
		Kaolin	Harghita, Aghires (Cluj).
		Refractory clays	Suncuius (Bihor); Anina (Caras Severin).
		Chalk	Basarabi (Constanta).
		Disten	Negovanu (Sibiu).
		Calcite	Cazanesti (Hunedoara).
		Bentonite	Tufari (Mehedinti); Valea Chioarului, Razoare (Maramures); Gurasada (Hunedoara).
		Feldspar	Muntele Rece (Cluj); Armenis, Teregova (Caras Severin).
		Muscovite	Brezoi (Valcea); Bautari (Caras Severin).
		Talc	Lelese, Cerisor-Zlasti (Hunedoara); Marga (Caras Severin).
		Sulphur	Negoiul Romanesc, Calimani (Suceava)

ities like transportation, maintenance of mining facilities, etc., out of which 9 CCs have already been privatised.

Romania's territory occupies a surface of 237,500 km^2 exhibiting a very complex geological structure. Two thirds of the territory belongs to Alpine orogenic area with late Tertiary and Quaternary volcanism. Mineral deposits in Romania have the main characteristics of small to medium size, low grade, complex geological and mining conditions, and difficult mechanical and metallurgical processing characteristics. Exploitable geological reserves total 3 billion tones of lignite and brown coal, 1 billion tones of mineral coal, 40 Mt of gold & silver ores, 90 Mt of poly-metallic ores, 900 Mt of cooper ores, 1 billion tones of salt. Also, there are ore deposits of rare and radioactive metals, iron-manganese, bauxite, and diverse non-metallic ore deposits (***Figure 1, Table 1***). Extraction and processing of minerals were known since the Roman time and mining is a traditional practice in this region of Europe.

Mineral Resources and Mining

Coal mining

The activities of capitalisation of energetic resources as coal through extraction in mines or open pits represent some of the main fields that lead to the degradation of the environment. Technologies adopted for coal exploitation and processing by micro-open pits developed on coal strata outcrops, seriously affected the whole air-water-soil eco-system by a variety of mineral, chemical and acoustic pollutants. However, it must be observed that these pollution sources related to coal mining have a low degree of toxicity and they do not represent a major risk factor for population in the surroundings. Among the pollution sources of industrial dust and gases have to be mentioned: gas emission emerging from the coal mines ventilation systems; atmospheric pollutants from electric and thermal power

Table 2. Coal Production in Romania (Mt), 1989–2000.

Indicator	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total net coal	61.5	37.6	32.4	38.4	39.7	40.5	41.1	41.8	33.3	26.2	25.0	26.6
Lignite and brown coal	53.2	33.7	28.6	34.3	35.5	35.7	36.2	36.5	29.0	23.0	21.0	23.5
Net hard coal	8.3	3.9	3.8	4.1	4.2	4.8	4.9	5.3	4.3	3.2	4.0	3.1
* Energetical	5.1	2.6	2.9	3.1	3.7	4.4	4.5	5.0	4.0	3.0	3.7	2.9
* Cokable	3.2	1.3	0.9	1.0	0.5	0.4	0.4	0.3	0.3	0.2	0.3	0.2

Note: components may not add to total due to rounding

stations and dressing plants; spreading of the dust from waste dumps and dust resulted from coal transportation. Measurements performed at 13 coal mines detected six types of gas in the air outgoing from the ventilation systems: CH_4 (330 to 4000 mg/m^3), CO (0.4 to 7.5 ppm), SO_2 (0.1-2.9 ppm), NO_2 (0.1-2.0 ppm), HCl (0.1-2.1 ppm), H_2S (0.1-4.5 ppm).

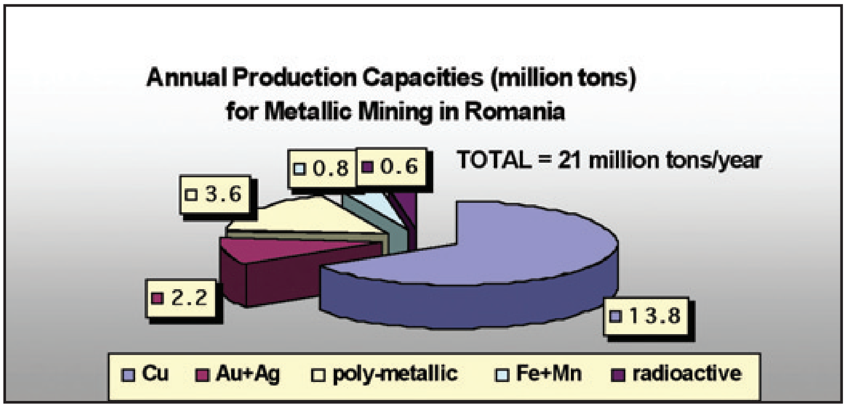


Figure 2. *Annual production capacities for metallic mining in Romania (Mt).*

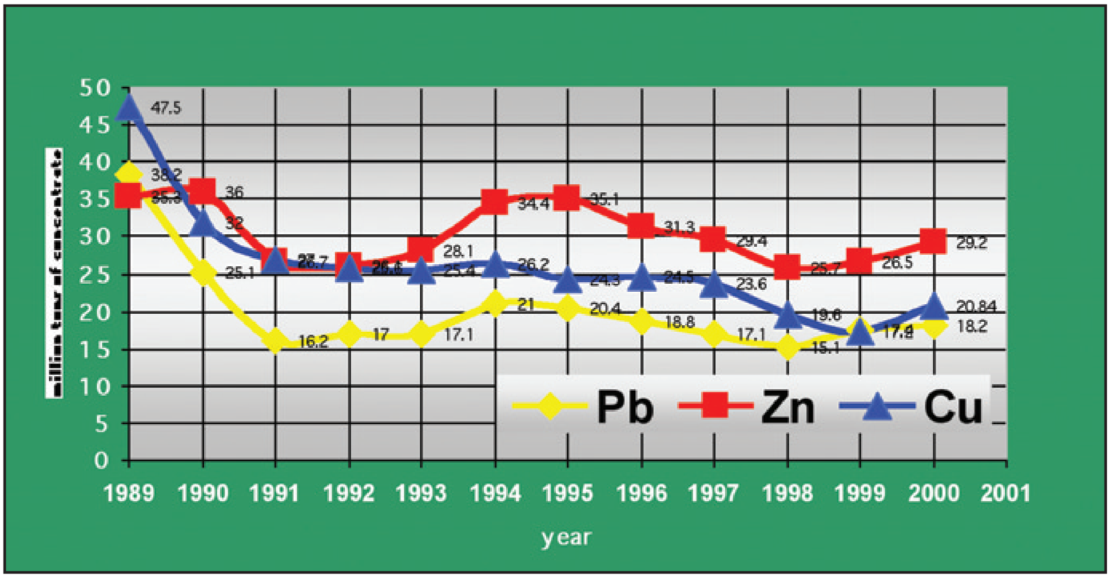


Figure 3. *Evolution of extracted metalliferous minerals (Mt of concentrate) for interval 1989-2000.*

Metal mining

Metallic ore deposits are characterised by complicate tectonics, high exploitation depth, thin ore veins, low content of metals, difficult hydrogeological conditions.

Although Romania has significant reserves of copper, lead, zinc, gold, silver, bauxite, manganese and iron ore, the country produces only relatively small amounts of non-ferrous metals and small quantities of iron ore (***Figures 2 and 3***). **Copper** is mined mostly in two districts: the Northwest, with mines at Baia Mare, Baia Sprie, Cavnic and Lesul Ursului, and the Southwest, with major mines at Moldova Noua, Rosia Montana and Rosia Poieni. The ore grade is generally low, with major producing mines at Moldova Noua and Rosia Poieni. The ore is grading only about 0.35% of Cu or less. Concentrates from these areas are smelted and refined at Baia Mare and Zlatna.

Lead and **zinc** are produced at underground mines in Baia Mare, Baia Borsa, Certej, and Rodna districts (***Figure 1, Table 1***). They are low-grade ores grading 0.4-1.2% of zinc, with associated cooper (0.35%), antimony and bismuth, cadmium, gold and silver. Due to complex mineralogy of the lead and zinc ores, concentrates produced from them are uneven. Metal recovery in concentrates ranges between 50% and 75% for lead and zinc, respectively. Smelting and refining of lead and zinc from domestic and imported ores and concentrates are carried out at Copsa Mica and Baia Mare.

Romanian **gold** resources are mainly located in Transylvania's Golden Quadrilateral, a major gold mining region comprising the cities of Baia de Aries, Brad, Sacaramb and Zlatna (***Figure 1***, ***Table 1***). Gold production in this region was reported to be about 140,000 ounces in1966. The Rosia Montana opencast and the Brad underground gold mines belong to the joint venture of foreign and state companies. Feasibility studies on developing the Rosia Montana and reprocessing tailings from both mines have been undertaken. Rosia Montana's output is reported from 10,000 to 12,000 ounces per year. Another potential area for gold exploration is the Bucium intrusive complex in the Metaliferi Mts. Since 1999 gold has been processed from old tailings in the Baia Mare region by foreign companies.

The prospecting for **uranium** in Romania was initiated in the 1950s. Since then, some 13 deposits and 9 occurrences were discovered in three major uranium provinces: Apuseni Mts., Banat Mts. and Eastern Carpathians. Deposits are of endogenous origin, mainly formed by pitchblende and associated sulphide mineralization. Currently, no uranium is imported or exported from Romania.

Bauxite open cast and underground mines are operated at Dobresti (Oradea). Alumina is produced by the Tulcea and Oradea refineries. The country's only primary aluminium smelter is at Slatina, in Southwest Romania.

Small quantities of **iron** are mined in Romania. Most feedstocks of ores and concentrates for the country's steel industry, however, have to be imported. The privatisation process is playing an important role in development and modernisation of the steel industry, attracting foreign investments as well as bids for stock in the sector.

Industrial minerals

Romania also has an extensive output of industrial minerals. Barite, bentonite, diatomite, feldspar, graphite, gypsum, kaolin, limestone among others, are mined at about 60 deposits throughout the country. The modernization of Romania's economy and infrastructure has increased the demand for many of these commodities. The privatisation of mining companies producing industrial minerals is more advanced than that of other sectors of the mining industry.

Environmental Impacts: Problems and Solutions

Background

Romania has a long history of mining, in particular of non-ferrous metals, coal and uranium. Diffuse pollution from areas where mining has been going on for centuries has had a long-term impact on the environment. The activities of capitalisation of the natural metallic mineral resources through geological exploration, extraction operations, mining metallurgy etc. represent only some of the main fields that lead to the degradation of the environment. Results of pollution occur directly or indirectly and may have an immediate or long-term character. Due to underground and surface excavations also the neighbouring areas suffer adverse influences such as changes in the flow of underground waters, modification of geochemical nature of the elements, erosion etc.

The impact of mining activities of prospecting, exploration, mining and concentration ("dressing minerals") involves assessment of various impacts based on the following aspects:

- mine wastes;
- residual waters – polluted waters as a result of mining and processing of ores;
- physical stability of the areas where underground or surface mining voids are present as a result of mining activities;
- visual impact as degradation of the landscape.

Mining waste impact management

Romania's major deposits of non-ferrous metals have copper, lead and zinc materialisation in the form of sulphides, together with pyrite and marcasite. Under aerobic conditions and in the presence of bacteria, sulphuric acid is formed by the oxidation of sulphides. This process results in the formation of acid mine drainage, which is a major source of acute environmental pollution in mining areas. Due to the low pH of these waters (1.5 to 3.0), heavy metals such as copper, zinc, cadmium, arsenic and lead can be leached from the rock and mobilized, causing severe contamination of water soil and vegetation. Moreover, heavy metals can enter the food chain. As pyrite oxidation takes place only under aerobic conditions and the reaction is rather slow, acid mine drainage is a mainly long-term problem of abandoned mining sites (waste rock piles and tailing ponds). Currently Romania has many non-active tailing ponds and mining waste dumps, which are potential sources of heavy metal contamination by acid mine drainage (***Figure 1; Table 3***).

In Romania, particularly in the Maramures County, the problem of acid mine drainage is aggravated by the high amounts of pyrite and marcasite in the sulphide ore, which are not separated by milling and flotation processes, but deposited with the tailings. Assessments made by the national agencies have shown that the river system in the Maramures mining region has been highly contaminated with toxic metals for many years. In addition, leakage from pipelines and dam safety problems pose environmental and health risks. In 2000 two accidents (Baia Mare and Baia Borsa) occurred due to cyanide and heavy metals spills in the Tisa River. A risk assessment study for NW Romania, pointing out 11 risky tailings deposits, has been complemented by an inventory conducted by the International Commission for the Protection of the Danube River. This inventory covers potential risk spots in the Tisa river catchments area, identifying in NW Romania 17 tailing ponds and deposits, 3 mining industries and one metallurgical industrial facility.

Abandoned waste dumps are also potential sources of air pollution due to their high content of fine particles, which can be spread by the wind. Unprotected waste dumps and tailings ponds contribute to the reported high concentrations of dust and heavy metals in the ambient air of some important mining regions in Romania.

Soil erosion is another problem related to wind and rainwater that can affect the mechanical stability of the mining waste dumps. These are common problems that can be minimized or stopped by "recultivating" old mining tailings, as one of the environmental management tasks of mining companies. However, recultivation is not yet a common practice in Romania; it is done only sporadically and on a small scale with the exception of lignite open-pits of Oltenia coal basin where, from a total of 17,000 ha affected area, about 2,000 ha were rehabilitated and returned for agricultural and forest purposes and the remaining land will be restored in the near future.

Table 3. Waste dumps from metalliferous mining in western Romania.

Waste Dumps from Metalliferous Mining in Western Romania

MINING DISTRICT	No. of Waste Dumps	Volume (million m^3)	Occupied Surface (ha)	Located near	Technical state
"Avram Iancu"	32	57	146	Industrial buildings; Access routes;	Stabile
"Balan"	15	2	26	Access routes;	Stabile
"DevaMin"	78	15	144	Residential areas; Access routes; Industrial buildings;	Relative Stabile
"Moldova Noua"	7	32	84	None	Stabile
CLOSED MINES	47	1	18	Industrial buildings; Access routes;	Stabile Inactive
TOTAL	179	107	418		

Due to economic constrains, investments into environmental facilities by Romanian mining companies have been reduced to a minimum. As a result, many **mining wastewater** treatment plants are currently operating manually with obsolete and ineffective technologies. Under the present conditions, huge volumes of wastewater containing heavy metals are discharged into the environment without adequate treatment, with severe consequences for local ecosystems.

Radioactive wastes from uranium mining pose risk to the environment and human health in Romania. The environmental impacts of uranium exploitation and milling activities include radioactive liquid effluents, waste rocks from mining and tailings from ore processing. Another environmental hazard is the storage at mining sites of low-grade ore with uranium content of 0.02-0.05%, which is currently processed. In addition, during the exploitation and processing of radioactive minerals, the risk of contaminating metal waste and the mechanical filters (wood and textile) with radioactivity is high. Many mining dumps and tailings do not have an environmental management system in place. At present, various mines have storage places that should be properly closed to prevent environmental contamination. There is a general need to build or enlarge water treatment plants for uranium mining and milling in mining sites located in the Apuseni and Banat Mts. and Eastern Carpathians.

Databases

National inventories and registries concerning land, surface, surface and underground works, tailings ponds, waste from extractive industries and information about the mining and environmental information in Romania, are kept by National Agency for Mineral Resources (NAMR), by DG Mineral Resources (MEC-DGMR, Tailings Ponds Commission) at the Ministry of Economy and Commerce, by the Environment Department at the Ministry of Agriculture, Forests, Waters and Environment, and different research institutes. The most important are the following:

1. **Mining Cadastre** is the specialized cadastre representing a subsystem for keeping records and systematic inventory of the fixed assets related to mining activity (land, surface and underground constructions and installations) from a technical, economic and legal point of view as well as other important information about the perimeters. It is kept by NAMR.

2. **Mining Book** is a component of the Mining Cadastre that includes all data about the legal regime of the areas related to prospecting, exploration and exploitation activities, mineral resources, reserves and production, being kept by the NAMR.

3. **Mineral Resources Register of Romania** is managed and kept by the NAMR in its database and archive.

4. **Inventory of mining residues and waste** resulting form mineral extraction and processing that is evacuated in barren dumps and tailing ponds is managed by the Ministry of Economy and Commerce, Directorate General of Mineral Resources. Programs for care, maintenance and closure of (1) state-owned mines and quarries, (2) exploration works, (3) mines that ceased before the Mining Law came into force, (4) mines not subject to an existing license, as well as (5) Post-closure Mine Monitoring Programs, are ensured by the Ministry of Economy and Commerce-Directorate General of Mineral Resources.

5. **Inventory of all kinds of waste** is created and updated by the Ministry of Agriculture, Forests, Waters and Environment, Environment Department. The information on protected areas where no exploration or exploitation works are allowed, are stored in the database of the ministry.

6. Geological Institute of Romania produces all kind of national **geological, geochemical and geophysical maps** (e.g.: geological maps of Romania, scale 1:000,000 up to scale 1:50,000, map of mineral resources, etc) and, by its own publications, spreads the geological information to the public. All mentioned data and information are registered in IGR database.

7. **Other Research Institutes -** there are a number of Design and Research Institutes in Romania (Bucharest, Deva, Baia Mare, etc) which deal with collecting of information on mining waste, tailing ponds, environment issues (ICEMIN-Mining Research and Design Institute, Bucharest, INSEMEX, Petrosani, etc).

Case studies – characterization of selected "hot spots"

Site 1. Rosia Poieni Cu and Mo mines

Geology and Mining

Porphyry copper mining site location of Rosia Poieni is in the South Apuseni Mts., (Metaliferi Mts., Volcanic zone). Mineral commodities mined are Cu and Mo. The extraction is performed by surface mining, being the largest open pit in the country.

Mineralogical composition comprises felspar, chlorite, biotite, pyrite, chalcopyrite, epidote, magnetite, quartz, clay minerals, galena and the main constituents are pyrite, molibdenite, sphalerite, galena, chalcopyrite, calcite. Mineral deposit type is as impregnations and depositions on microfissures or veins hosted into the Neogene volcanics of Sarmatian age. Host rock is represented by amphibolic andesites in subvolcanic facies.

Copper concentrate (20% Cu; 0.5% Mo) represents the market product leaving the processing plant. Chemicals used in the treatment are xanthats, Dawfort, metal isobuthil carbinol and foaming agent.

Environmental risks and impacts

Disposed tailings are contained into two tailing ponds with the following chemical characteristics of solid tailings: 0.2 % Cu, 0.003% Mo, 3.37% S, 0.1 g/t Au, 6 g/t Ag. Usually there is no water on tailings except very confined zones. However, in the surroundings of the open pit chemical analyses show that stream waters contain significant amounts of heavy metals that are potentially dangerous to the environment and this mine is an active acid-rock drainage producing site. Emissions from the processing plant contain S and Pb pollution.

Another problem is posed by large waste rock dumps that release acid leachate and heavy metal polluted sediments are transported from the dumps into the environment by intense erosion (***Figure 4***).

Site 2. Motru lignite mines, Oltenia coal basins

Geology and Mining

The geological setting of this Pliocene age unit is defined by the Getic zone of the Dacic Basin. Mineral commodity mined is lignite. Mining operation started in 1967 as open pit, the main constituent being the soft brown coal. The mineralogical composition is formed by textinite (10-15 %), ilminite (20%), atrinite (30%), cutinite (10%) and mineral substances (25%). Beds of lignite with thickness up to 10 m are located over and under the hydrostatic level in an alternation of gray-yellowish clays and fine sands. The type of overburden encountered in the surface mining is a sandy clay horizon of 10-30 m thick.

The waste resulting from processing on the mining site of excavation is disposed as dumps having a total volume of approximatelly 223,900,000 m^3 and covering an area of 944 ha. The market product leaving the processing site is soft dull coal.

Figure 4. *Waste dumps exhibiting intense erosion at the Rosia Poieni open-pit mine.*

Environmental risks and impacts

As for mining wastes environmental impact, it is important to observe the surface water on tailings which has the following characteristics: pH: 6.0-8.4; suspensions: 0.4-416 mg/l; residual: 211-1259 mg/l; SO_4: 692 mg/l; Cl: 14-84 mg/l; Ca: 40-116 mg/l; carbonates: 4.0-26.4 mg/l; CO_2: 36.3 mg/l; HCO_3: 158.6-518.5 mg/l; amonia: 0.01-18 mg/l; CBO_5: 15.8-33.8 mg/l. Also, the emissions of gases (amonia 0.1 mg/m^3/day; nitrogen dioxide 0.1 mg/m^3/day, sulphur dioxide 0.25 mg/ m^3/day) and suspensions in air (sedimented dust 17g/m^2/month; dust in suspension 0.15 mg/m^3/day) made the open pit to be an environmental "hot spot". Some tailings deposits represent a potential source of pollution due to their eqilibrium at the mechanical stability limit.

Conclusions

Romania's present authorities became seriously involved in the reform and rationalization of the country's mining sector. A new Mining Law (no. 85/2003) came into force, establishing modern rules for management of mineral resources. The Government also decided to close unprofitable operations, including state-owned enterprises such as coal mining companies, and planned to cut subsidies to the mining sector. Small and medium-sized state-owned enterprises, before the privatisation, should be restructured. Romania has identified the principal areas in need of urgent action in the industrial sector, including the mining industry:

- renewal of existing production units to respond to energy, mineral raw material and environmental constrains;
- adoption of non-polluting production processes and technologies at national level;
- support of existing industries through the introduction of emission-reducing equip-

ment and technologies;
- establishment of a national integrated monitoring system for environmental quality;
- environmental training at all levels.

Most of the above considerations were incorporated in the National Environmental Protection Strategy and National Environmental Action Plan (NEAP). The NEAP was based on the premise that much of the environmental degradation in Romania was the result of inappropriate economic and related policies. It was assumed that market liberalisation, privatisation and other reforms would penalize the excessive use of energy and other resources, reducing the environmental damage. These gains would be reinforced by the effects of market-driven industrial restructuring, which would shift production from inefficient plants towards more efficient and less polluting ones. Priority areas were the reducing of emissions of lead and other heavy metals from mineral industry and the minimization of water contamination by heavy metals and other toxic substances.

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Mining, Mining Waste and Related Environmental Issues in Slovakia

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Introduction

In Slovakia minerals and mineral-based products are the basis of production for metallurgical, electricity, chemical, brick, ceramics, tile, glass and other industries. Mining and quarrying of minerals (including extraction of crude oil and natural gas) contributed 7,523 million SKK, or 0,92% to Gross Domestic Product (GDP) at factor cost in 1999 (slow growth from 0,87% of GDP in 1998). Minerals and mineral-based products represent an important item of foreign trade of the Slovak Republic. Because of a large import volume of

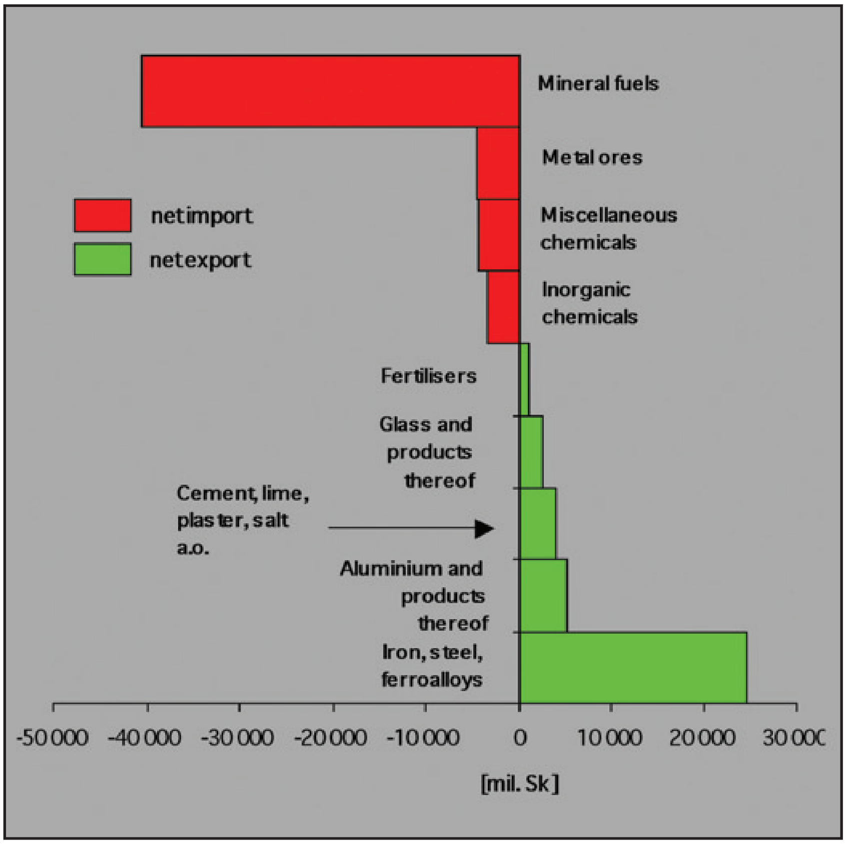


Figure 1. *Balance of trade in selected minerals and mineral-based products in 1999 (Source: Statistical Yearbook of the Slovak Republic 2000).*

mineral fuels (crude oil, natural gas, hard coal) and metals (iron ore, zinc, materials for aluminium metallurgy) foreign trade balance has been permanently passive (***Figure 1***). Domestic consumption of these minerals is covered mainly by import. The Slovak Republic is long-term dependent on import of mineral fuels, especially crude oil and natural gas, according to the amount of reserves and capacity of exploitation.

Exploitation of crude oil covered only approximately 1% of domestic consumption, exploitation of natural gas satisfied about 3% of consumption in 2000. In the matter of brown coal and lignite, mining output covers about 80% of domestic consumption. Slovakia has no economic deposit of hard coal or anthracite and dependence on import of this commodity is traditionally permanent. Majority of domestic consumption of **metals** is cov-

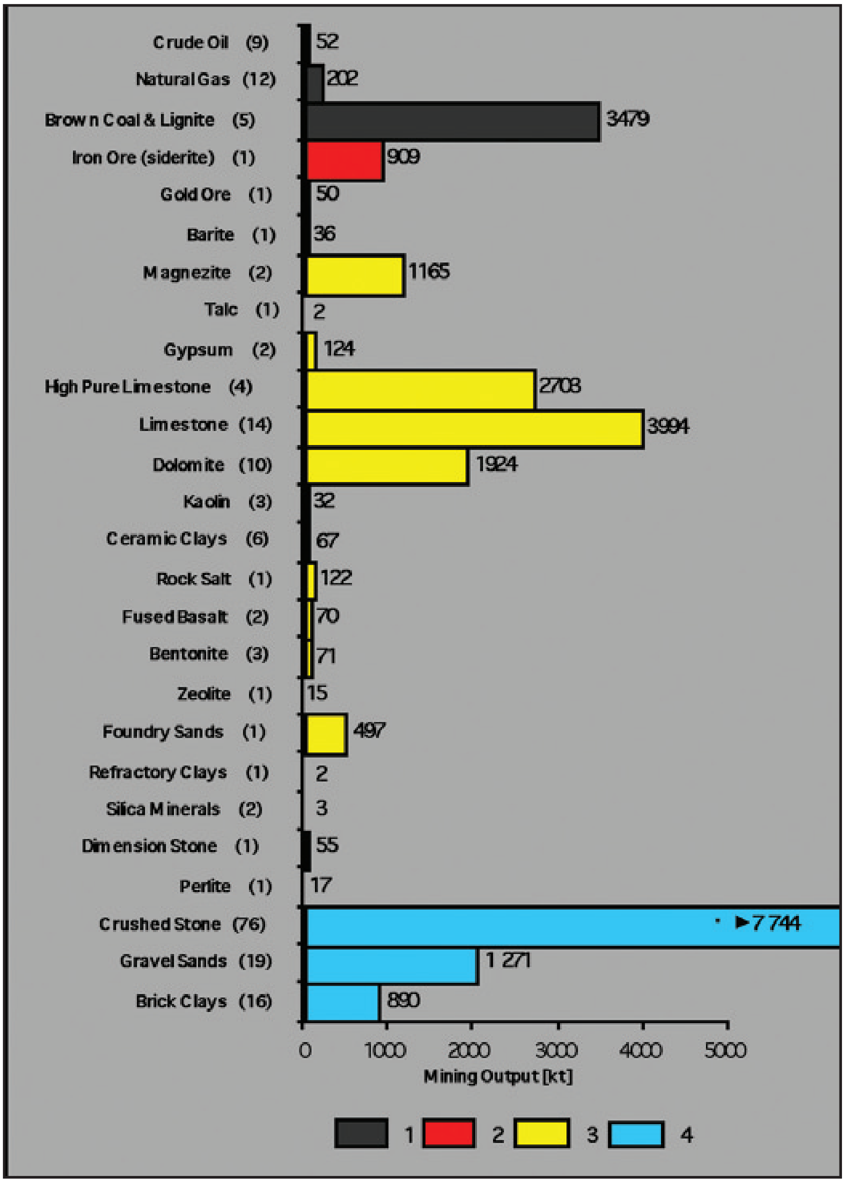


Figure 2. Mining output of minerals in 2000. Figures in brackets represent number of mined mineral deposits. (1 - mineral fuels, 2 - metals, 3 - industrial minerals, 4 - construction materials).

ered by import. Domestically produced iron ore covers only small portion (about 15%) of needs of the Slovakian iron and steel industry.

Industrial minerals mining share on total mine production reached 43% in 2000. The most important industrial minerals (in terms of export in 2000) were limestone and cement materials (cement and lime; 3,300 million SKK), magnesite and magnesia (2,100 million SKK), dolomite (216 million SKK), salt (111 million SKK), bentonite (73 million SKK) and barite (65–70 million SKK). A perspective group of industrial minerals is the so-called “ecological minerals”, i.e. zeolites. An important export commodity could be talc from the Gemerska Poloma deposit. Production of industrial minerals covers in substantial volume domestic consumption.

Construction materials represent the majority of mineral deposits with significant share (more than 55%) of total exploitation of raw materials in the Slovak Republic. Resources of crushed stone, gravel sands and brick clays cover all domestic needs.

In 2000 the exploitation was accomplished in 282 active mines. Total amount of mined raw materials is presented in ***Figure 2***. The basic parameters of development in the mining sector are shown in ***Figure 3***.

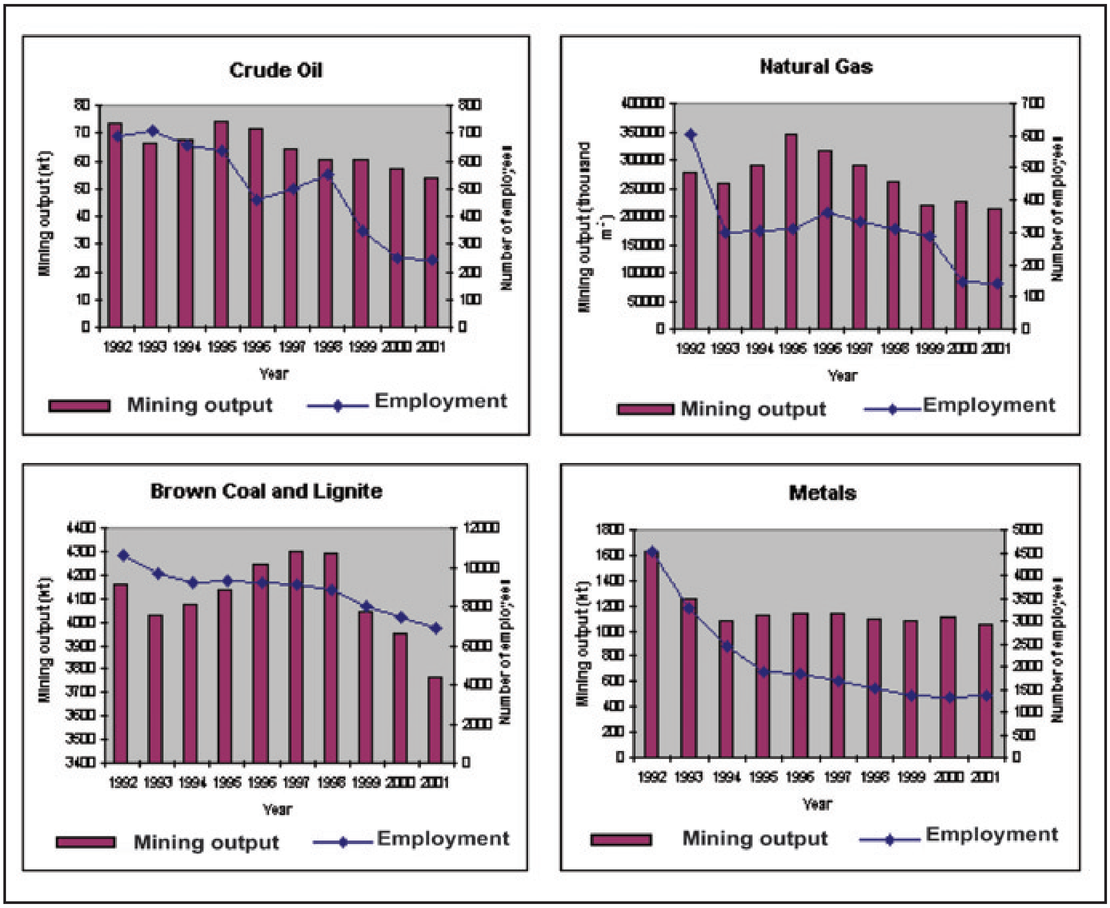


Figure 3. *Main indicators of mining output development in Slovakia between 1992 and 2001.*

Employment in the mining industry of the Slovak Republic has been continuously decreasing in the last decade, which continued in 2000 as a consequence of decline of mining industry, especially in the metal sector and in the last years in the energy sector, too. Slovakia belongs to the countries with extensive historical mining. This fact along with mining in the past few decades caused many environmental problems, with severe ecological consequences in some cases. At present, in relation to active mines, the following can be stated:

- in total (active and abandoned) 138 waste rocks stockpiles or tailings, of which 109 waste rocks stockpiles are in extraction areas and 29 out of them, covering an area of 2, 556 km^2 with a volume of 37,422,91 m^3. The number of active waste rock stockpiles is 87, abandoned waste rocks stockpiles reach number of 51;
- in total there are 114 tailings ponds (storing tailings from ore processing) of which 91 are in extraction areas and 23 out of them, covering area of 2,976 km^2, (69 active, 45 non-active).

Several waste rock piles are utilised for quarrying materials for construction industry, or as backfill material for mining pits and underground mines. Information on development in mining plants, tailings and tailings ponds in the 1999-2001 period is presented in ***Table 1***. Proportion of mining waste contribution to total waste production was 4,21% in 2000.

Table 1: Development in mining plants, tailings and tailings ponds in 1999-2001.

	1999		2000		2001	
	Number	**Area (km^2)**	**Number**	**Area (km^2)**	**Number**	**Area (km^2)**
Mining plant	443		282		266	
Tailings	139	2,473	132	2,132	138	2,556
Tailings ponds	152	2,916	107	2,945	114	2,976

Mining has a historic tradition in Slovakia. The oldest evidence of mining activities dates back to the Celtic era of 4th century B.C. An intensive development of mining activities started mainly in 12th century and continued up to the present. As a result of historical mining activities, there are many abandoned mining sites in Slovakia causing environmental problems in the present. Negative impacts on environment of historical and present day mining activities and ore processing can be summarised as follows:

- changes of land configuration as a result of replacement of huge volume of rock, stability disturbances, development of fractures and faults, depression of terrain, non-even consolidation of sediments, subsidence, activation of landslides, etc.,
- changes of hydrogeological regime in undermined areas and surroundings,
- changes of chemical composition of surface and ground waters, as well as soils in mining sites and broader surroundings,
- disturbance of tailings dams with possibility of contamination of surface and ground water and soil by leakage from tailing ponds, waste rock stockpiles, etc.,
- development of deep and sheet erosion related to deforestation and removement of vegetation cover.

Remediation of damages caused by mining activities is solved in Slovakia in several steps, conditioned on the character of the problem, ecological criteria, but mainly on economic factors. The process includes following stages:

1. **inventory** and evaluation of active mining sites of raw materials at 266 localities,
2. complex inventory of **abandoned** mining site; this stage was finished in 1997, in total 17,260 localities were registered,
3. inventory and evaluation of impacts of all mining sites on environment, on-going project since 1998,
4. preparation of state **monitoring** of the most risky localities **('hot spots')** of mining sector (on going project, 20 localities completed by the end of 2002),
5. proposal and realisation of **remediation** activities, on going project with goal to finish works in 2005.

Database

Summarising the above information, three databases concerning mining sites, mining wastes, and relevant environmental information exist at present in Slovakia:

(1) **Register of Exclusive Deposits** of raw materials governed by the Ministry of the Environment. This important source of information is up-dated yearly and published as "Slovak Republic – Minerals Yearbook" by the Slovak Geological Survey under the direction of the Ministry of the Environment.

(2) **Register of old Mining Sites** was created by the Ministry of the Environment between 1992 and 1997. It contains the following:

- inventory of old mining sites (galleries, shafts, tailings, mining waste deposits, etc.) with individual "inventory list" and localisation in topographic maps of different scales, e.g. 1:400,000, 1:50,000, and 1:10,000. As the "old mining site" was taken such mining site of which owner or managing subject is not known or does not exist;
- old mining workings with negative impact on environment and proposed for remediation from the point of view of safety of inhabitants were specifically denoted in this inventory;
- proposal for remediation was elaborated on general level – no co-ordinating (competence aspects), legislative, and financial aspects were solved in this inventory;
- altogether 17,260 sites were inventorised - 496 shafts, 4,913 adits or galleries, 10 tailing ponds, 4,566 pings a ping belts, 6,418 waste rock piles or tailings and 857 other objects related to old mining activities. This database is managed by the Ministry of the Environment through the Department of Informatics, State Geological Institue of Dionyz Stur.

Database of old mining sites includes following information: location (registration number, map sheet, co-ordinates, name of locality, name of object, administrative unit – district of mining administration), type of object, extension, surface (land) impacts, type of mined raw material and its specification, host rocks, data on groundwater, proposal for remediation, proposal for possible use of object, owner or management of object, remarks on environmental impacts, radon emanation, sources of information, date of registration, name of expert preparing registration data.

(3) **National Monitoring Database**
The goal of the on-going project is to create a database of mining impacts on environment, being accomplished in two steps:

- the first step (1998–2000) focused on inventory in electronic (including GIS) form of all mining activities in the Slovak Republic (old or historical, as well as actual mining activities) and their prioritisation from the point of view of remediation – altogether 489 localities with several thousands of objects were evaluated in this process,
- the second step (2001–2005) is an on-going process focusing on creation of state monitoring system predominantly taking into account first group of 20 most risky localities with negative influence on environment ('hot spots'), with possibility to extend the system in future.

Investigation methods

In past few decades in Slovakia several studies of mining sites have been accomplished with the goal to describe in details specific environmental aspects, like alkalisation of soils in the area of magnesite mining and treatment (e.g. localities Jelšava, Lubeník, Hnúšťa – Mútnik, Hačava), acidification of soils and natural waters (e.g. localities Smolník, Šobov), contamination of soils by heavy metals (localities Rudňany - Poráč, Banská Štiavnica - Hodruša, Magurka – Dúbrava, Jasenie, Pezinok). So far there exist only few regional studies, e.g. complex evaluation of environmental problems in the Stredný Spiš area (complex pollution by heavy metals, radioactive substances, etc.) or in the Malé Karpaty Mts. (pollution by heavy metals). The most complex evaluation is being done in terms of on-going project of the Ministry of the Environment "System of evaluation and monitoring of impacts on environment originating from mining activities". This is a very complex project and it is scope is the following:

- the territory of the whole Slovakia,
- all types of historical and actual mining activities (metals, magnesite, industrial minerals, coal, gas),
- all aspects of environment (basically divided on engineering-geological, hydrogeological and geochemical aspects),
- prioritisation of localities according to their impact on environment, based on established evaluation criteria.

As a result localities were classified into 3 categories:

I. Category. Localities and mining sites where remediation is required as very acute step to prevent damages on human health, environment (water, soil, biota) and estate. The impact is documented and damages are of large extent.

II. Category. Localities and mining sites with transitional characteristics with partial knowledge on the sites and extent of impacts, but due to specific factors (e.g. type of ore and natural conditions, changes in technology, ceasing of mining) threat of damages is either not so critical or requires supplementary investigation to clarify situation (with possibility to re-categorise the mining site).

III. Category. Localities and mining sites with apparently low or minor impact on human health, environment and estates due to different factors like historical mining, temporarily suspended mines, etc., for identification of impacts, satisfactory national monitoring systems exist or there are specific conditions for management of accidents (e.g. gas deposits).

Environmental impact of mining activities is evaluated on the basis of the following criteria:

A Mining or ore processing is on-going, recently finished or historical
B Utilisation of chemicals (type, toxicity, amount or extent)
C Undermined territories (extensive and known, need of investigation, minor impacts, area and intensity of undermining is categorised)
D Geodynamic deformation (extensive and known, need of investigation, minor impacts, area and intensity of deformations is categorised)
E Other negative impacts on relief (regional and extensive character, local impacts, minor changes, impacts are classified according to agreed criteria)
F Hydrogeological and water economy conditions (extensive impact on drinking water sources of regional character, impact on local sources, minor influences, impacts on water courses is classified as well)
G Mine waters (classified according to amount and quality, as well as according to influence on surface water and hydrological conditions)
H Hydrogeochemical anomalies (geogenic or anthropogenic, regional, local or minor extent)
I Litogeochemical anomalies (geogenic or anthropogenic, regional, local or minor extent)
J Biogeochemical anomalies (geogenic or anthropogenic, regional, local or minor extent)
K Waste rock stockpiles (active, abandoned recently, historical)
L Tailings (active, abandoned recently or temporarily suspended, historical, fully or partially remediated or not remediated)
M Land use type (aspects of density of population, infrastructure, industry, agriculture, arable soil, forested areas)
N Monitoring (existence and need of monitoring, extent and frequency of monitored parameters, possibility of indication of impacts by more common state monitoring networks).

Ranking system of impact intensity allowed to differentiate among 489 localities in the scale from 44 (the lowest impact) to 231 (the highest impact) and on this base there were established 3 categories of localities (***Table 2***) as described above. Based on ranking system, Category I. (and another three localities of the Category II.) was denoted as “hot spots” for which monitoring system is being developed (***Figure 4***). The database for monitoring system will be open and according to economic possibilities other localities will be added to the system.

On the basis of the above described criteria and information a complex proposal of remediation measures will be compiled in 2005 to manage the problem of negative impacts of mining activities on the environment, including economic evaluation of the process.

Case studies – characterization of selected “hot spots”

Site 1: Horná Nitra – Brown Coal Mine

Hornonitrianske bane Prievidza Company represents the largest producer of coal in Slovakia. The yearly production in 2000-2001 was ca 2,847 kt. Brown coal is mined in “Hornonitrianska Coal Basin” from localities Bana Cígel, Bana Handlová and Bana Nováky (Bana Lehota, the only surface mine, was closed in 1993). Most of production (80%) satisfies the needs (more than 2,000 kt per year) of the main consumer, The Electric Power

Table 2: Localities of categories I. and II.

I. category		II. category	
Code: 150-		**Code: 100 - 149**	
Code	**Locality**	**Code**	**Locality**
231	Jelsava N1	148	Gelnica R12
231	Handlová P2D	142	Podrecany N3 Lovinobaòa
216	Banská _tiavnica R1	139	Spania Dolina R6
212	Cígel P2C	134	Dúbrava - Magurka R4
211	Rudnany - Porác R7 (inclusive: Zlatník N9)	129	Pezinok R5A
207	Hodrusa - Hámre R2	124	Hacava N6
198	Lubeník N2	112	Solivar N10
192	Slovinky R9	112	Sobov N25
192	Kremnica R3	111	Vceláre N27
187	Smolník R11	106	Lom.Lehota P2B
182	Nizná Slaná R8	106	Bana Záhorie P3
182	Roznava R10	102	Tisovec- Cremosné N30
179	Nováky P2A	102	Ladce - Budkov N33
179	Hnústa - Mútnik N5	102	Lietavská Lúcka N36
174	Bana Dolina P1	102	Kostiviarska N37
172	Novoveská Huta R16		
154	Kosice - Bankov N4		
altogether: 17 localities		**altogether: 15 localities**	

category: rest of localities
Code: 99 and less

Key: P – brown coal and lignite, R – ore deposits (mainly Pb, Zn, Cu, Hg, Sb, Fe, Au, Ag), N– industrial minerals (mainly magnesite, talk, asbestos, barite), P2C – identification code of locality in the particular mining area.

Station Novaky (Elektráren Nováky) and heating stations of some industrial factories (yearly more than 300 kt).

Mining history
The beginning of mining activities (surface mining) dates back 1825, intensive mining since 1912 (underground mining, at present most of mining works realised in depth of 250–400 m under surface).

Investigation methods
Past and present investigation efforts realised a brown coal deposit situated in the neogene basin related to tectonic-structural development of so-called Mid-Slovakian neovolcanics (Vtačnik Mts.). The coal bearing strata are of sarmatian age. From the geological point of view mines are documented mainly by archive of the Geological Survey of Slovakia (“Geofond”) and individual mining archives. The most important data on geology and technology of mines are published in special issues of mines or in geological and mining periodicals. Monitoring efforts include all individual mines developed and the detailed moni-

toring system includes measuring and evaluation of amount and quality of mine waters, waste waters, and parameters for evaluation of geodynamic and undermining aspects.

Hazard source description

Main hazards on environment can be summarised as follows:

- the most important is activation of geodynamic processes on slopes and undermining of area (extent more than 30 km^2) with straight impact on settlements and estates,
- the second most important impact is represented by de-watering of mining fields and changes related to hydrological and hydrogeological conditions of the region. Mine waters are mixed with waste waters and total amount of waters is measured and inventory is publicly available,
- emission of contaminants (e.g. arsenic and sulphates) to environment due to effluent of mining and waste water is eliminated to acceptable extent by operation of water treatment plants,
- specific impact is represented by potential influence of mining on Spa Bojnice – clarification of this relation was solved by detailed investigation and monitoring.

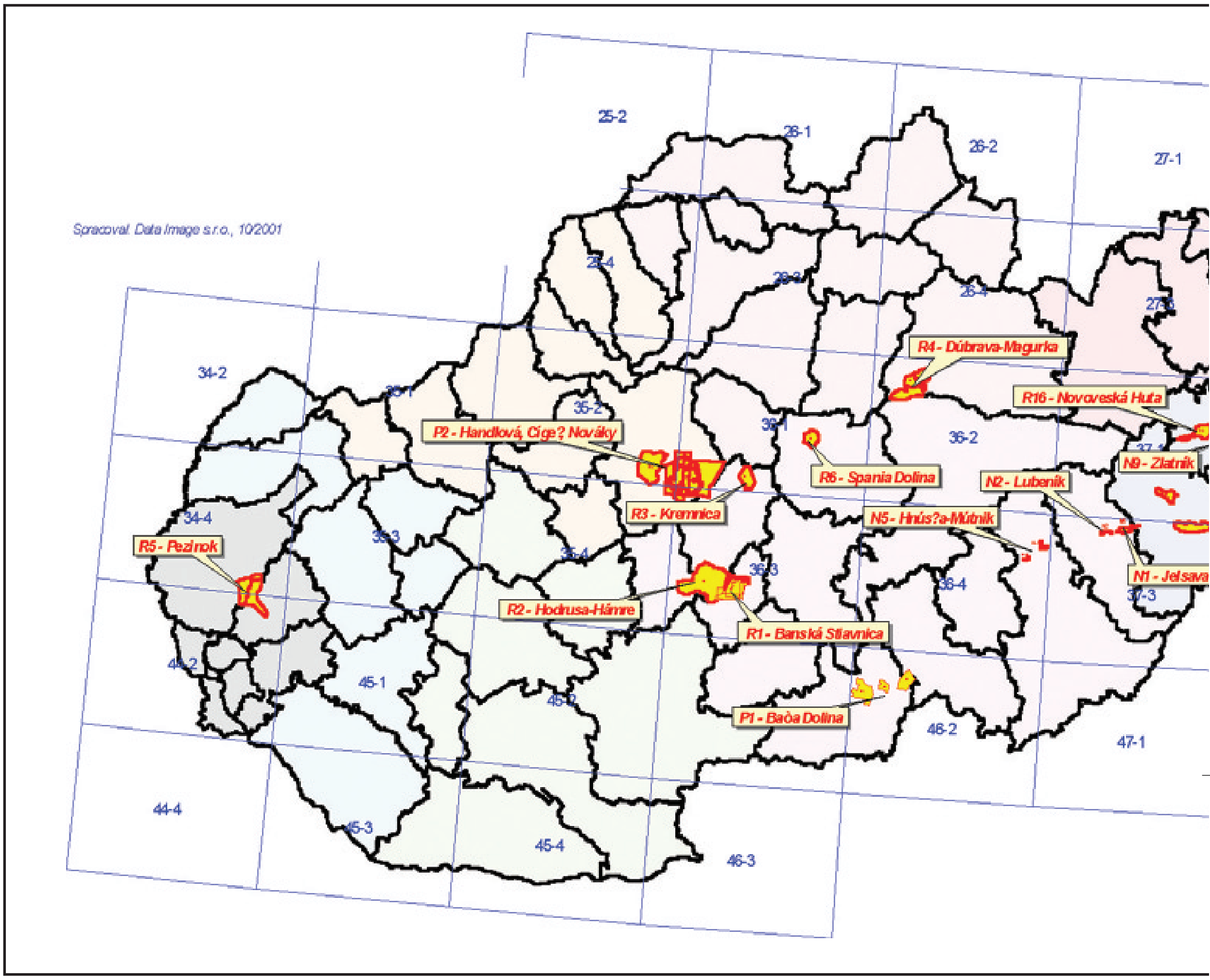
Environmental risks and impacts

- Hydrosphere: de-watering of water-bearing horizons, changes in hydrologic regime of surface and ground water,
- Soil: arable land is limited in usage during mining periods in individual fields, non-arable land and forests are impacted by activated geodynamic processes - damages are compensated as a part of current legislative process,
- Ecosystems: ecosystems are substantially influenced and changed. There is e discrepancy in evaluation of some changes in ecosystem because in several man-made depressions, which had developed as a result of underground mining, a new phenomenon occurred in relation to creation of wetlands with high quality biotop (from legislative point of view, according to Mining Act, depressions represent damages and have to be re-cultivated),
- Atmosphere: no substantial changes in air quality are caused directly by mining activities, on the other hand, ecological damages are caused by successive steps, i.e. burning of brown coal in Nováky Electric Power Station (arsenic, SO_2). However new technology rapidly eliminated ecological impacts hazards.

- Other:
  1. potential influence of mining on Spa Bojnice is a critical aspect of continuation of mining activities. Detailed investigation and on-going monitoring confirmed that springs and sources of healing mineral water can not be influenced by planned mining activities;
  2. damages on cultural heritage in the region are part of inventory of total damages cased by mining on society. Compromises are part of legislative solution of the problem. Technologically exceptional re-placement of historical church from the village Koš, can be mentioned as an example of compromise which enabled to extend mining activities.

Socio-economic impacts

Mining of brown coal in Hornonitrianska Coal Basin belongs to so called “social” mining, because state subventions are needed to keep mining acceptable. At this stage of economic devel-



opment questions of employment are taken into account as important socio-economic aspect.

Outlook

The agreed mining activities touch the horizon about 30 years ahead. The plan is to diminish step by step intensity of mining. Plan for remediation of the environment represents an organic part of overall development of mining activities and basically responds to legislative requirements of the Mining Act. Two specific activities were prepared to improve economic as well as environmental situation:

- utilisation of thermal waters for social (bathing, recreation) and technological (heating of air in the mine) goals. The second task was fulfilled;
- construction of "internal" Electric Power Station operated by the Hornonitrianske bane Prievidza.

Site 2: Smolnik – Cu, pyrite, siderite, and Au-Ag mine

Cu, pyrite, Fe, and Au-Ag mine is situated about 4 km ENE from the town Smolnik in the district Gelnica, Kosice Region in Eastern Slovakia. At present abandoned mine is managed by Rudne Bane, state enterprise, Banská Bystrica (State Administration of Mines).

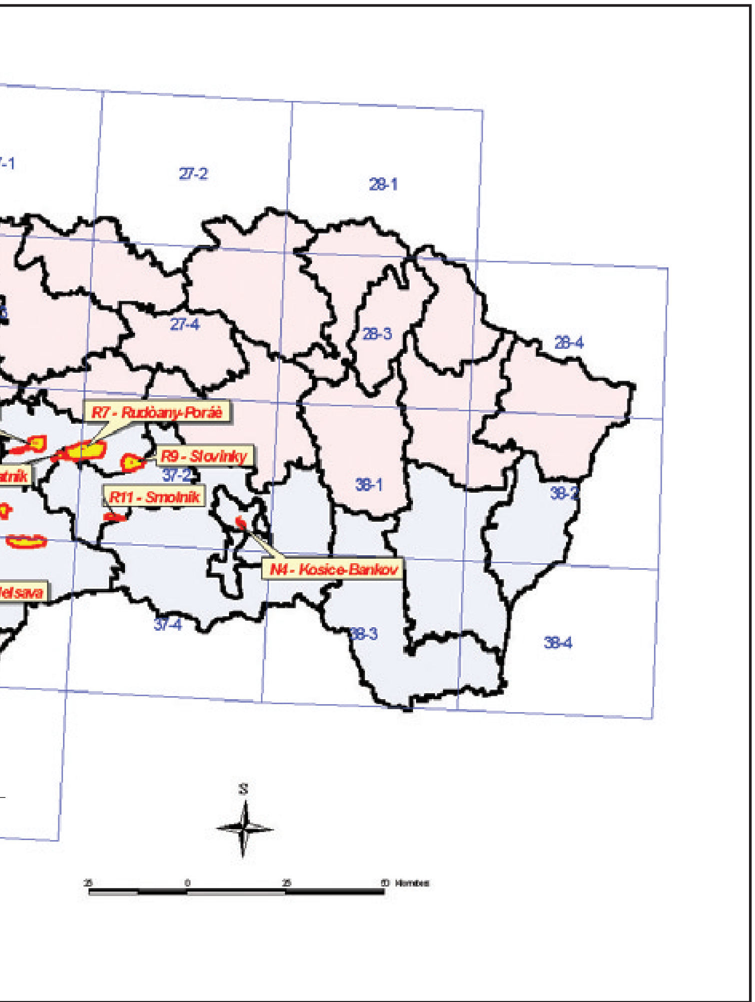


Figure. 4: *Selected "hot spots" in the Slovak Republic.*

Mining history

This abandoned mine is famous for historical mining and extensive mining in past few decades. First evidences on gold mining are known since 1243 and since 1412 quantitative data on Cu mining have been available. Mining of Cu, Ag, Au, Fe is known since 1350. The most extensive mine adits were realised after 1853. With exception of short periods, mining of pyrite ore lasted from 1874 to 1956 (***Figures 5*** *and* ***6***). From 1964 interest was focused mainly on Cu ore mining (renewed Cu mining after about 100 year period). This activity continued till 1989, but directive to stop mining activities originated from 1987. Mining finished completely in 1990 and the mine was flooded with negative ecological consequences. In 1985 recultivation of mining area started, and a complex project for remediation of "hot spot" area was prepared in 1996.

Hazard source description

Main impacts on environment can be summarised as follows:

- the most important is acidification of environment and contamination of surface water, ground water and soil by mine waters and leakage from tailings ponds and waste rock piles (***Figure 7***),
- the second most important impact is represented by de-watering and changes in rock environment caused by surface and mainly underground mining, including undermining of terrain, with negative influence on the environment. The main risk is the failure of tailings dams.

Environmental risks and impacts

- Hydrosphere: de-watering of water-bearing horizons, changes in hydrologic regime of surface and ground water, extremely aggressive mine water with pH 1,5–3,0 and high content of Cu, Fe, Mn, Zn, Al, As, Pb, sulphates (hydrogeochemical anomalies and geochemical anomalies concerning stream sediments are known from detailed mapping), important river Hnilec is impacted by acidification caused by mine water through the Smolnik stream. In 1990, the mine started to be flooded with negative

Figure 5: *View of Smolnik old mining town.*

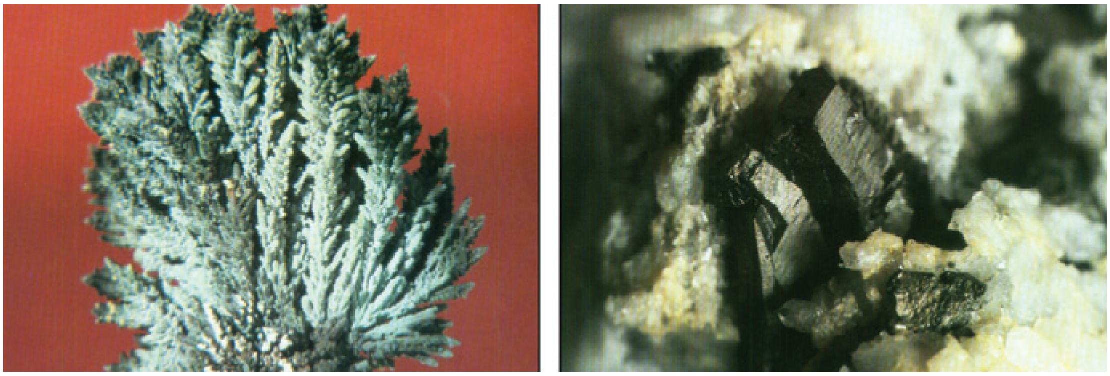


Figure 6: *Copper and pyrrhotine from Smolnik.*

ecological consequences. In 1994 there was an ecological accident when surface water of stream Smolnik and river Hnilec was acidified to such extent that huge number of fish died. Since this event new measures to prevent damages started to be prepared. Complex project for remediation of “hot spot” area was prepared in 1996.

- Soil: acidification and contamination by heavy metals, non-arable land and forests are impacted by extensive mining activities (shafts, galleries, open mine pits, tailings, tailing ponds, waste rock stockpiles, etc.

- Ecosystems: ecosystems are substantially influenced and changed mainly because of acidification of environment and damages on biotops. Surface water in surroundings of deposit exhibits pH 7,0–7,5 and acidified stream and river water below deposit reaches pH values 4–5 and very often below 4 with negative influence on biota. Damages on fishing in the region are solved by legislative way between mine management and local fishing administration.
- Atmosphere: ore processing caused contamination of air by ash (e.g. in 1985 about

2.2 t/yr) and emissions of SO_2 (4.4 t/yr in 1985).

Socio-economic impacts

Mining of sulphide Cu ores finished in 1990 because of changes in society (transition period to market economy) and stopping of state subventions to mine this type of ore. This decision lead to two consequences:

- firstly, questions of employment taken into account as important socio-economic aspect was less important than economic criteria and environmental damages;
- secondly, the state has to recover the territory (project of remediation in 1996) and pay for damages to some subjects in case of proved direct damages.

Outlook

According to project of remediation from 1996 two aspects have to be taken into account:

- to insure safety of inhabitants and estate (e.g. prevention to enter undermined area);
- to prevent environmental damages.

First aspect is related to the fact that some of the mine facilities are used by inhabitants to specific economic activities, in other words, people occupy the mine territory and the task is to prevent them against direct danger, e.g. by backfill of mining pits, shafts, etc. The second aspect requires measures which will mainly prevent acidification of the surrounding natural waters:

- to lower groundwater level to acceptable level and to remediate vertical mining workings (e.g. shafts). The goal is to prevent acid mine water to enter surface water,
- to prevent surface water to enter (infiltrate) mine area (drainage of surface waters out of mine area),
- to reconstruct hydraulic conditions in confluence of stream Smolnik with river Hnilec (the goal is to ensure conditions for effective mixing of waters),
- to monitor all systems (including tailings ponds) for the proper correction in remediation activities.

Figure 7: *Smolnik – outflow from sludge lagoon.*

Conclusions

Slovakia belongs to countries with extensive historical mining and this fact along with mining in the past few decades caused many problems in the environment, in some cases with severe ecological consequences. Elimination of damages caused by mining activities is solved in Slovakia in several steps. It is conditioned by character of problem, ecological criteria, but mainly by economic factors.

On-going efforts are concentrated at:

- evaluation of impacts of selected 489 mining sites (on-going project since 1998, inventory stage finished in 2000),
- prioritisation of localities according to risk and preparation of remediation activities,
- preparation of state monitoring of the most risky localities of the mining sector (on-going process 20 localities were prepared by the end of 2002).

Other on-going projects supported by the Ministry of the Environment of the Slovak Republic:

- evaluation of remediation activities efficiency after uranium mining in Slovakia,
- evaluation of potential impact of geochemical environment on health state of inhabitants in Spi_sko-gemerské Rudohorie Mts. (Spis-Gemer Ore Mountains) Region,
- evaluation of impacts of old mining activities on environment in Malé Karpaty Mts. Region,
- monitoring of environmental impacts in selected regions of Slovakia.

Future project concerning mitigation of mining waste environmental risk and impact:

- safety and elimination of old mining impacts in Malé Karpaty Mts. Region,
- L'ubietová – safety and elimination of old mining sites,
- Sb-As in waters in surroundings of Sb-deposits Dúbrava and Magurka (Nízke Tatry Mts.),
- sources of heavy metal contamination in the south part of Nízke Tatry Mts. Region,
- study of contamination mechanism from mining and processing of minerals,
- GIS of mine waters in Slovakia,
- application of remote sensing to the identification and monitoring of old environmental impacts,
- assessment of contamination risk of the Sb-Au-S deposit Pezinok and suggestion of remediation.

From the view point of State Environmental Policy mining activities represent only one of the activities with negative impact on the environment. To solve the problem in complex way the Slovak Republic will have to accept the Act on Contaminated Sites which will insure systematic solution of “old” environmental impacts, as well as present activities, including mining activities.

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Mining, Mining Waste and Related Environmental Issues in Slovenia

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Introduction

Slovenia is a country with a very long and strong mining tradition and with variety of mineral resources. Although the extent of Slovenian mining industry has been reduced significantly in the last decade and it represents just a small share in the total industrial production, it is an important industry for the country in terms of income and employment. Currently its share in GDP is 2,3% and it employs close to 3% of all industry labour force. At the moment, in Slovenia there are 155 concession holders on 204 locations. The extent of mining in the country can be described by the size of mining areas: total area of Slovenia is 20,273 km^2, of which the area of mining rights granted for exploration is 2,560 km^2 (11%), and the area of mining rights granted for exploitation is 293 km^2 (1,28 %). Total production of industrial minerals and rocks, construction materials and aggregates is not very high but it almost totally meets the needs of the country. Coal production covers approximately 90% of domestic consumption. Domestic production of crude oil and natural gas mean just a sample towards the needs, so Slovenia is dependent on imports. Also, Slovenia imports metals and ores for domestic aluminium, iron and steel production. State, as the owner of mineral resources, have to assure mineral resources management which means availability of mineral materials and preservation of accessibility of natural sources for next generations according to sustainable development. Therefore, exploitation of mineral resources in Slovenia is oriented to an adequate regulatory framework, implementation of modern technologies to achieve products with an adequate degree of processing, environmental friendly production and reclamation of degraded surfaces.

The objective of this country report is to give a country summary on mining and mining waste and associated problems at the national level. Therefore an overview of Slovenian situation in the area of mine and quarry waste management, inferred from existing data, such as those published by competent authorities, is presented.

It is noted that among mining sites presented in this paper no ‘hot spots’ (mining sites with significant proven or potential environmental impacts of major concern) can be identified in Slovenia.

Mining and Mining Waste

Mineral resources and production

1. Energetic mineral resources

Coal

Reserves of lignite and brown coal in Slovenia are significant, but their exploitation in the future depends on economics and environmental legislation. As the most important domestic energy resource, Slovenia extracts lignite and brown coal in two of operating mines (***Table 1***). Due to environmental legislation, whole production is used in energy sector, burnt in thermal power plants.

Table 1. Mining production in Slovenia in 2002 (source: Ministry of Environment)

Material	**Production in 2002 (in metric tons)**
Coal	4.684.709
Lignite	4.046.000
Brown coal	638.709
Hydrocarbons	
Crude oil	613
Natural gas	5.700.000 Sm^3
Industrial minerals and rocks	**775.572**
Bentonite	201
Calcite	204.603
Chalk	685
Silica sand	477.035
Tuff	65.041
Igneous rock	13.725
Ceramic clay	14.144
Sea salt	138
Construction materials	**2.024.581**
Brick clay	591.794
Building stone – limestone	33.140
Building stone – tonalite (granodiorite)	28.237
Building stone – other	25.223
Building stone	86.600
Raw materials for cement	1.346.187
Aggregates	**15.162.239**
Crushed stone – limestone	5.604.818
Crushed stone – dolomite	6.981.710
Crushed stone – other	14.970
Crushed stone	12.601.598
Sand and gravel	2.560.641

Restructuring of the Slovenian coal sector started in early nineties and is still continuing. From 1995, on the basis of specific law, adopted by the National Assembly, and in accordance of closure programmes, adopted by the Government, the three coal mines are in the phase of closing down. All three mines finished with production in mid 1996. Activities arisen from closure programmes are financed from the state budget. Funds are used for closing of pits, environmental reclamation of surface damaged by mine works, social affairs and human resources restructuring.

In the year 2000 the National Assembly adopted a special law that assures funds for gradual closing of Rudnik Trbovlje – Hrastnik (allowing production till 2007) and funds for regional development. The funds are assured in the state budget, and according to the closure programme, special attention is given to the reclamation of surfaces damaged by mining activities.

Crude oil and natural gas
There is almost no production of oil and gas, most of resources are exploited and higher production is possible to be reached only by secondary methods, which are too expensive. By adoption of new Mining law in 1999, there were dedicated funds for reclamation of about 210 old abandoned exploration and exploitation drill holes, pipelines and stations in northeast Slovenia, which were a real threat for the environment. The programme should be finished by the end of the ten years period.

Uranium
There was one operating uranium mine in Slovenia, which was the energy source for nuclear power plant Krško. Uranium production had been abandoned in the year 1990 because of economic reasons. After that a special law for closure was adopted and a programme of activities has been implemented with special attention on reclamation of surfaces damaged by mining activities, including processing plant and waste piles. The programme and legislation also require strict measurements and precautions for radioactive radiation and radon.

2. Metal ores

In Slovenia there are some locations with proven reserves of zinc and lead ore and mercury ore. For hundreds of years mercury ore had been exploited in Idrija but, due to economic reasons, a special law was adopted on closing the mine in 1987. The same happened with zinc and lead mine Mežica in 1988. Both mines are in the last stage of closure, programmes of activities are completely implemented and executed.

3. Non – metallic minerals

Industrial minerals and rocks
Volume of extracted industrial minerals meet the needs of industry, reserves are sufficient for future needs (***Table 1***).

Construction materials and aggregates
There are enough reserves of raw materials for cement and brick clay to meet the needs of cement and brick industries in next decades. Also we have many local authentic build-

ing stones, which are produced in small quantities. The consumption of aggregates has increased over the years, mostly due to expanded motorway construction in Slovenia. There are enough producers, spread through the regions, to meet all demands with reasonable transport costs (***Table 1***).

Strategic Documents and Regulation

Mining

Slovenia has a separate Law on Mining, which covers hydrocarbons as well (adopted in National Assembly 30.06.1999, OJ RS, No. 56/99 from 13/07/1999, entry in force on 28/07/1999). It covers geological survey, mineral resources management, exploration, exploitation, mining rights, permissions, technical documentation, mining inspection, break in operations, mineral processing, remediation of the environment, post closure control. Regulations cover all mineral resources including oil, gas, sea salt and geothermal energy, construction of underground facilities and, in some cases, deep groundwater exploitation. All mineral resources are state owned.

Environmental protection

The Environmental Protection Act (OJ RS, No. 32/93 and amendments) regulates the protection of living environment and the natural environment inseparably linked with it, and it also regulates the general conditions of the use of natural resources, declared as basic conditions for a healthy and sustainable development.

Waste management (recycling, recovery, disposal of waste) is prescribed by the Rules on the Management of the Waste (OJ RS, No. 84/98 and amendments) that govern the classification list for waste and hazardous waste, the obligatory management of waste, and other conditions for the collection, carriage, recovery and disposal of waste. The provisions of these Rules do not apply to waste resulting from the prospecting, extraction, treatment and processing of mineral resources.

The Slovenian legislation on environmental impact assessment (EIA) conforms with the EU EIA Directive with Decree on Categories of Activities for which Environmental Impact Assessment is Mandatory and with Methodology for preparing reports on Environmental Impact Assessment. EIA is required almost for all mining sites and it is one of the obligatory terms to get permission.

A separate law on prevention of ionisation radiation and nuclear safety regulates uranium-mining waste.

Institutional building

Ministry of the Environment, Spatial Planning and Energy (MESPE) is responsible for mining and for environmental protection. Licensing and controlling authorities, as MESPE bodies, are the following: (1) Mining Administration of the Republic of Slovenia (MARS), (2) Inspectorate of the Republic of Slovenia for the Environment, (3) Spatial Planning Inspectorate for mining (IRSESP-IM), (4) Environmental Agency of the Republic of Slovenia (EARS), and (5) Inspectorate of the Republic of Slovenia for the Environment and Spatial Planning – Environment Inspectorate (IRSESP-EI) for environmental protection.

Databases

National databases on mining, mining waste and relevant environmental information are listed and briefly described below.

Slovenia has a national mineral resources register that is managed by the Geological Survey of Slovenia (GSS) for MARS. The register is updated annually by production quantities and new stocks and every year a balance of mineral resources (only for internal use) is prepared. Owner of geological data is the company that operates exploration but have obligation to report all the data to the state and state should use them. All geological data gathered by exploration and data about mineral reserves, which are collected by state, are confidential by law for at least three years from the end of exploration or for the time of concession period in case of exploitation. Mining operation data is registered and archived by the company operating the site. Some of these data is proceeded to MARS, IRSESP-IM or to GSS. These data are mostly business secret.

For the purposes of site selection for low- and intermediate radioactive waste disposal, a register of over 80 old, mostly underground, abandoned mines was prepared in 1994. All of them, except Žirovski Vrh, Mežica and Idria mines, today represent no significant impact on environment.

A register of waste is developed by the EARS and according to the reporting requirements mining waste inventory, as a part, is in establishment:

- Database of mining rights holders and areas (MESPE),
- Geological maps (GSS), and
- Archive of State Commission for reserves of mineral resources (Commission).

Case studies – characterization of selected "hot spots"

The bellow described site is not treated as a hot spot, but instead it is mentioned here because of the use of good practises in environmental protection and land remediation, and because in the frame of closure programmes environmental impact studies and surface remediation projects were made and implemented.

Žirovski Vrh Uranium Mine

Background

Zirovski Vrh Uranium Mine is situated 45 km west from Ljubljana, the capital of Slovenia. The mine is located in well-populated farming area. The central mine waste pile is placed near the main mine tunnel elevation in the small side ravine. The mill was located in the valley of the Brebovscica river. The mill tailings are located on the southern slopes of Crna Gora mountain. Radioactive impact is small, the yearly dose contribution swings from 0.3 to 0.4 mSv/a (IJS 2002). Uranium and radium concentrations in nearby surface water flows are elevated.

The mine and its facilities are situated on the north-eastern slopes of the Zirovski Vrh ridge (Goli Vrh, 960 m). The underground mine elevation is from 430 m to 580 m. A total of

3,307,000 tons of crude ore was won: 633,000 tons of high graded ore; 206,000 tons of low graded ore; and 2,468,000 tons of mine waste. Uranium mineralization was discovered in 1960, the ore exploitation started in 1982 and yellow cake production in 1984. The uranium concentrate production ceased in 1990. Only 610.000 ton of ore with 0.7 kg of uranium per ton were processed and 450 ton of yellow cake was produced during an unusually short operation period.

After the submission of the last closing programme that the Government of Slovenia adopted in the year 2001 on the basis of changes and amendments of the fundamental act of the year 2000, it is necessary to implement the project of the mine close-out in a five year period. The total costs of the project implementation will be 37.3 million EUR.

Hazard source description

Underground mine area

About 60 km of underground mine openings were built mostly having a cross section to allow transport and production. Uranium ore was mined by room-and-pillar method. 10% of the total ore was won by top to bottom winning technology leaving extensive open mine space with height up to 15 m. 90% of uranium were won from bottom up with cut-and-fill mining leaving a minimal open space. The underground mine is connected to the surface by shafts and adits.

Water inflow into the mine mainly occurs on the fractures and cracks in sandstone and conglomerates along discontinuities and fault zones. The layers with ore deposit are less permeable. For a better collection of the inflowing groundwater and to avoid the contact of groundwater with the ore deposit, drainage boreholes of a length between 150 and 170 m were drilled in the deepest part of the mine in 1993, the uranium concentration in the inflowing groundwater decreased at the same time.

Ground water entering the mine becomes contaminated due to passing through ore-enriched zones. Another source of mine water contamination are exploration boreholes in the ore horizons. Some mine workings (blind tunnels) cannot drain and get flooded. The water in these tunnels has uranium concentrations exceeding 6 mg/l. The yearly average of the uranium concentration in the mine water discharged through the adit P-10 was between 250 and 350 µgU/l in the time period 1992 to 2000. The radium concentration (Ra-226) was between 30 and 100 Bq/m^3 during the same time. A decrease of uranium and radium concentration in the mine water was observed after uranium production ceased. Iron concentration in the discharged mine water is below the detection limit. The sulphate concentration is very low compared to the discharge observed in other mines.

Waste rock piles

Jazbec is the main waste rock pile of the site (1,5 Mt) situated in the Jazbec valley right below the entrance to an adit. Judged by the measured water levels in the mine pile, the supporting dam is less permeable than the stored material, but there is no seepage water observed on the pile face. The mine waste material is a very water-permeable material that consists of a quartz conglomerate, sandstone and aleurit. The red mud is a less-permeable material consisting of an aleurite clay fraction. The uranium content of the waste rock is the main source of contamination of the mine waste pile seepage.

In addition to waste rock 'red mud' from the uranium ore processing was disposed off on the waste pile. The red mud is a precipitate of the uranium leaching solution generated by neutralisation with lime. The main components are calcium, gypsum, iron hydroxide, uranium (0,5 Bq /g), Ra-226 (0,2 Bq/g) and Th-230 (62 Bq/g). Th-230 has a 8 times higher enrichment than the Ra-226 concentration in the tailings. The material was stored alternately in layers: on 80 cm of mine waste 20 cm of red mud follows. A 5 m thick zone on the aerial side of the pile consists only of coarse mine waste. Demolition debris from the remediation of the milling site was deposited on the waste pile as well. The sulphate and iron concentration of the waste rock is low. Acid mine drainage in the pile is unlikely to develop. The water discharged from the drainage channel at the bottom of the waste pile has an annual average uranium concentrations of 250 to 550 µUg/l (1991 to 1999). In the same period the sulphate concentrations were between 200 and 300 mgU/l which is about 10 times higher than in the mine water discharge.

The Jazbec valley is cut by the Hotavlje fault, with some wet moor areas on the surface. At the bottom of the Jazbec valley is dark grey karstic limestone formation. Along the main surface water, the Brebovščica river numerous springs exist fed by karstic groundwater. There is a 329 m long concrete channel at the bottom of the waste pile. This channel collects the water from three creeks in the upstream valleys as well as the drainage water from the pile. This water is discharged into the Brebovščica river. Pipes connected to the concrete channel dewatered small springs. At present the drainage channel is in good condition, however, the drainage pipes are mostly in a poor condition.

The groundwater is polluted because of the infiltration of meteoric water percolating through the uncovered waste pile and leaching the red mud. Various sampling points on and around the waste pile allow the evaluation of the groundwater. The water at the bottom of the waste pile contains up to 5000 µg/l uranium. Concentrations of about 150 µg/l uranium were measured in the deeper karst aquifer.

Mill tailings disposal (Boršt)

From the beginning of the operation till the end of uranium production at RUZV 600,000 ton of hydro-metallurgical tailings had been generated and deposited on the tailings pile Boršt. The volume of the deposited material is approximately 375 000 m^3. The tailings pile has an area of 4.11 ha. The tailings material is a relatively coarse ground sandy-aleuritic residue of the uranium ore processing with grain size under 0.5 mm, but more than 50% greater than 0.125 mm. The average contents of uranium is 0.9 Bq/g or 80 g/t U_3O_8 and 8.6 Bq /g of Ra-226. It mainly consists of SiO_2, calcite and sulphate salts. The tailings were deposited on site with water content of 20–24%. Presently, the tailings are in a solid state. According to the planning documents there is no danger of liquefaction. However, during deposition liquefaction of the material was observed. Due to the high radium contents in tailings, both the uncovered top surface area and the covered embankments are a considerable radon source; the exhalation was evaluated to approximately 5 Bq/(m^2.s) (in the range of 1 and 10 Bq/(m^2.s). Surface waters as well as water in tailings and underneath are contaminated by uranium and soluble inorganic materials (NH_4, SO_4, Cl). Ammonia and total inorganic materials are above the regulated discharge limits.

The storage site is about 2 km away from the former uranium processing plant. To allow access to the tailings ground with heavy machinery, regularly arranged roads were constructed on the tailings pile (at every 5 m of elevation) using 73 000 t of mine waste rock. The tailings are deposited on a natural slope. During deposition of the tailings the following principles were followed concerning the environment controls, water management and geotechnical stability of the tailings:

- diversion of surface waters out of the tailings pile to prevent contact with tailings,
- capturing of ground water and springs and their linking to the drainage system,
- sealing of the bottom of the tailings pile using clay material,
- capturing of (contaminated) surface and seepage water from the tailings and discharge into the retention pond,
- 20° embankments slopes with horizontal berms.

The tailings surface was covered after reaching the planned elevation with material that was previously removed from the base of the tailings pile and vegetation with grass. The slope was covered with 25 cm of topsoil and vegetated with grass. The top plateau of tailings pile is partly covered with waste rock from the construction of the drainage tunnel below the tailings pile. The immediate covering was done to reduce the radon exhalation. Before the placement of tailings started, the ground on the base of the pile was prepared using the material removed during the site preparation works. Drains and pipes were laid on the surface and covered with a layer of clay. The tailings were deposited in layers and at every 4-5 m elevation in series of nearly horizontal drains (slightly inclined to the surface) were placed. These drains are approx. 10 m long and drain only the face of the pile. The drained water is collected in surface water channels on the berms. Together with the precipitation water, the drainage water flows to the retention pond before it is released into the Todraščica brook.

The retention basin has a total volume of 4100 m^3, which allows retaining the centennial maximum precipitation for one hour. The bottom of the reservoir is reinforced and protected by a watertight asphalt layer. The reservoir is vegetated with reed. Sediments from the reservoir are regularly removed and stored on the Boršt tailings pile. In case of rainfall, the surface run-off water from the hinterland is diverted by ditches outside the tailings pile area to a torrent gorge on the western site of the pile. During dry weather these ditches are empty. A large number of sub-vertical faults disrupt the geological base of the Boršt tailings pile. After heavy rainfalls in November 1990 a crack with 20-30 cm of vertical movement appeared in the road on top of the tailings due to land sliding. The landslide occurred on the contact of the karstic and tuffaceous rocks. The evaluation of the borehole survey confirmed that the tailings pile was placed on an old landslide (paleoslide). The total amount of material moved by the landslide was 328,579 m^3 of tailings and 2,593,175 m^3 ground mass.

Outlook

The objectives regarding the remediation of the mine are defined as follows:

- reduction of radon emission from the underground openings,
- long term stability of underground mine facilities to prevent the inflow of surface waters to the mine resulting from the collapse of mine openings,
- permanent discharge of mine water through adit P-10 meeting the regulated limits for uranium,
- permanent discharge of uncontaminated groundwater through P-11 and P-9,
- protection of underground and surface water (within the regulated limits),
- reclamation of the surface area in the surrounding of shafts, raises and adits,

- prevention of unauthorised access to underground openings.

The objectives regarding the remediation of the mine waste pile (Jazbec) are as follows:
- limitation of the radon exhalation,
- limitation of leaching of contaminants and erosion protection of the mine waste pile by covering,
- limitation of the effect of surface and ground water from hinterland on the mine waste (erosion, wetting of waste),
- geomechanical stability of mine waste pile, erosion resistance by reshaping of mine waste pile,
- prevention of erosion and excessive wetting of the cover by means of a drainage system,
- relocation of the waste rock piles at P-1 and P-9 to the mine waste disposal Jazbec,
- prevention of excessive dusting.

The remedial objectives concerning the tailings (Boršt) storage are as follows:
- provision of permanent landslide stability by drainage channel, drainage screen and cover construction,
- provision of the tailings stability and enhancement of erosion resistance by reshaping of the tailings pile,
- prevention of the radon exhalation, the leakage of hazardous contaminants into water streams and the erosion of tailings by covering,
- protection of the tailings pile from the surface and ground water from the hinterland (erosion, increased infiltration through the cover and the tailings),
- prevention of the cover and the tailings from erosion by construction of a drainage system,
- prevention of excessive dusting.

It could be established that in the past the budget sources available were not sufficient for the performance of close-out programme in accordance with the planned schedule. Their irregular inflow made the work even more difficult.

There are three types of funds expected: origin budget sources, EIB loan funds and firm's own funds. The EIB loan will be used for mine close-out works and for mine waste pile and mill tailings remediation; the money which will come directly for the sources of the state budget will be allocated for other costs and VAT; own turnover will be used for costs for redundant employees and it is not incorporated in the estimated amount of investment costs):

- Original budget revenues: 17,3 million EUR
- EIB Loan: 20 million EUR.

Actually non-repayable PHARE funds have also been expected. At the beginning of the year 2002 RZV competed on grants amounting to 5,4 million EUR from PHARE programme Task force nuclear safety; unfortunately unsuccessfully. In that case both original budget funds and EIB loan would be needed in the smaller extend (EIB Loan and non-repayable PHARE funds in the extend of 23.9 million EUR would cover costs of mine close- out works and costs of mine waste pile and mill tailings remediation).

Conclusions

Slovenia has problems associated with past mining. Today, significant efforts have been made for the inventory establishment, assessment and remediation of mine sites, often in the lack of sufficient funds.

Ministry of the Environment, Spatial Planning and Energy is responsible for mining and for environmental protection.

Currently Slovenia has a separate Law on Mining, which covers hydrocarbons as well. All mineral resources are state owned. In the frame of mineral resources management there is a National Mineral Policy Programme that will provide state strategy in exploration and exploitation of mineral resources in the way to preserve the environment and to secure necessary supply of mineral resources for the state needs in the future. At the moment the document is under preparation to be adopted by the government.

There are not specific provisions of mining waste management in the mining legislation. Handling of mining waste should be defined in mining technical documentation in accordance with environmental standards.

In National Environment Action Programme that was adopted in Parliament in 1999 mining waste management is not among priorities.

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SECTION 3

SUMMARY

Mining and Mining Waste: Problems and Solutions in the Central and Eastern European Candidate Countries

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Problems: why the mines?

The Proposal for a Directive of the European Parliament and of the Council on the Management of Waste from the Extractive Industries [1] sets three main reasons to justify separate legislation on mine wastes:

- to control large material flows involved, i.e. great amount of waste generated;
- to reduce risk of accidents due to instability of tailings dams and ponds;
- to reduce environmental risk and secure long-term stability after mine closure and for closed (abandoned) mines.

In addition, it identifies significant water and soil pollution (acid mine drainage, for example), lack of harmonisation of relevant national regulations and establishment of financial security as further reasons for separate legislation on mine wastes. The Proposal for the Directive [1] requires (1) inventory of abandoned mines, (2) waste and facility hazard characterisation, and (3) impact and risk assessment of waste sites. In order to meet these requirements, mine waste management has to be studied in the context of complete material flow streams and total product and project life cycle analysis. This is also a prerequisite for efficient mine waste management on the local, regional and European scales.

Large material flows of waste and accidents causing environmental pollution are common in other industries such as the chemical industry. Closure is a problem for many other industries, too. Significant water and soil pollution, differences among national regulations and lack of financial security seem to be typical to most industrial sectors. Why then does mining need special attention and dedicated approaches for waste management? What are the environmental characteristics that are typical only to mining? Without the intention of giving an exhaustive analysis, answers to these questions are provided in this section based on conclusions drawn from the country reports in this volume.

In terms of the **DPSIR** (Driving force, Pressure, State, Impact and Response) environmental reporting framework of the European Environmental Agency (EEA) [2] the first specific characteristics of the mining industry to be mentioned is related to the time scale of **Demands** (***Figure 1***). Firstly, demand for mineral raw materials and thus mining is almost as old as mankind and this demand is likely to continue in the future, irrespective to socio-economic and technological changes. In turn, continuous demand leads to a long history of pressures and impacts. Therefore, impact analysis and remediation strategies have to consider historic time scales. Secondly, demand has fluctuated greatly during history and industrial development, due to changes in technology and socio-economic changes (wars, for example) resulting in fluctuating market prices of mineral commodities. Thus, long-term suspension and restarting of mining industrial activities is common, unlike in other industrial sectors. In many mining areas extraction activities have been going on for centuries or thousands of years with changes of mined commodities, closures and re-openings as demand and market prices changed. The main temporal characteristic of demand for mining is thus a long-term increasing trend superimposed by short term and sudden fluctuations. Types of demanded mineral commodities have not changed during history although the spectrum of minerals has increased as new technologies required new trace elements, including uranium for energy production. From a spatial perspective, although historic European deposits have been exploited, the demand by industry remained in Europe but the pressures have moved to producing mining areas elsewhere. Thus, the locations of demand and pressures have separated.

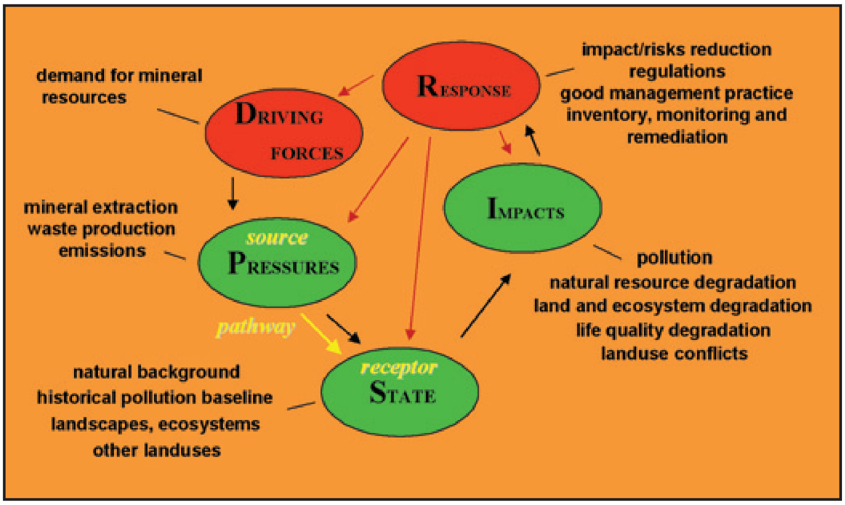

Figure 1. *Schematic EEA DPSIR framework for mining waste. Traditional pollution source-pathway-receptor relationship is also shown. Red and green boxes are related to socio-economic and environmental systems, respectively (compare to Fig. 2.) See text for details.*

Pressures on the environment from mineral extraction, mine waste and related emissions have also some particular features. Increasing demands resulted in increasing pressures: change from local to regional scale industrial mining and change from underground to large open pit mining contributed to development of regional pressures. The number of mines has also increased. The increased amount of extracted minerals and the liberation of elements such as metals and sulphur have tremendously increased global material flow fluxes and hence environmental pressures [3]. Sudden fluctuations in demand (as reflected in market prices) for minerals can lead to changes in type and location of emissions even for the same mine site, due to a change of the mined and processed mineral commodity or scale of mining.

In terms of emission types such as heavy metal pollution, dust, acid discharge and sediment load, mining industry is similar to many other industries. However, as mining extracts non-renewable resources complete exploitation has to be taken into consideration. For example, at the current rate of production, the estimated global oil reserve is enough for 40 more years, gas for over 55 years, and coal reserves for about 200 years [4]. Thus, in theory, pressures in the terrestrial environment by mining will cease in the far future. More importantly, the mining industry is unique in that it creates pressures in the three-dimensional subsurface space. This has two important aspects for pressures. First, major pollution problems are often not related to the extracted and processed materials and waste but to the altered physico-chemical conditions of created underground voids [5]. This has important implications for life cycle analysis and substance flow analysis because pressures are not created primarily along the material processing chains but where the material is actually missing from. Second, unlike other terrestrial environments, the subsurface can be studied only at a few discrete points such as bore holes that leads to very high uncertainties. Another specific feature of mining is that the location of pressures is very confined: mines can be found only at mineral deposits. This fact also makes possible the prediction of locations of future pressures: they are found simply at the geologically mapped potential deposits. These locations are potential ‘pressure time bombs’ since change in technology or market prices may make a potential deposit a valuable resource for mining. Three examples for potential mining pressures are mentioned. In Romania, referring only to metal mining, exploitable geological reserves total 40 Mt gold and silver ores, 90 Mt polymetallic ores, 900 Mt copper ores [6]. Also, there are ore deposits of rare and radioactive metals, iron, manganese and bauxite. The hard coal and lignite recoverable resources in Poland are 46,846 Mt and 14,050 Mt respectively, while the possible reserves are 54,000 Mt hard coal and 8,000 Mt lignite [7]. Number of deposit locations can be also significant: there are about 3,000 mined or potential mineral deposits in Hungary alone, for example.

Since huge weight and volume quantities of materials are involved, mine wastes cannot be transported and thus they have to be disposed on site. Therefore, pressures of industrial mining activities and pressures from wastes cannot be spatially separated.

Finally, the location of mining activities is very much confided by the geological conditions of deposits and there are usually no alternatives for location, unlike for other industries. The result is that mining cannot follow and utilise existing infrastructure but must bring infrastructure and other (traditionally heavy) industry to its location. Again, due to the large quantities of raw material, long-distance transportation is usually uneconomic, giving rise to industrial development close to the mining sites. Two of the many well-known historical examples are the Ruhr and Silesian mining and industrial areas in Europe. This feature of mining industry results in the creation of secondary pressures that come from the developed industry and not from actual mining activities. The secondary adverse effects are more obvious in the case of mine closure: industry, settlements (‘mining villages and towns’) and infrastructure collapses posing even larger pressures. Compared to long-term industry development, mine closing and collapse of related industry is a sudden action giving rise to socio-economic pressures. This is exactly the case of recent mining and industrial closures in all the Central and Eastern European Candidate Countries.

The **State** of the environment, i.e. landscape and ecosystem receptors are multiple and non-specific to mining. However, mines are often located in high relief mountainous areas where geological exposure provides easy access to deposits. Since deposits have no spatial alternatives, mines are sometimes located in ecological reserves and protected areas, as shown by geo-environmental maps [8]. What is really unique in mining is that the high natural background values or 'natural pollutions' are geologically determined and are found most often at mineralised deposits. Very often the terrestrial environment is already naturally polluted before mining (which in fact is actually a major tool for geochemical mineral exploration). Unfortunately, decision makers are not always aware that the natural background cannot be remediated to meet limits defined by law. It is interesting that the only way of 'remediating' natural pollution is actually mining: extraction of the mineralised rock formation eliminates the geological pollution source (Michal Gientka, personal communication). The state of the environment over mineral deposits and certain geological formations pose regional-scale risk to human health and ecosystems. Maps showing the distribution of elements on a regional scale have been fundamental in recognising empirical associations between trace elements and morbidity patterns in plants and animals [9]. For example, Irvine et al. [10] proposed a spatial link between multiple sclerosis cluster in Sasketchewan, U.S.A. and excess lead, zinc and nickel in the soil. Piispanen [11] compared geochemical maps of Finland to cancer maps. Tan et al. [12] found spatial correlation between high incidences of Keshan and Kaschin-Beck disease and selenium depleted areas as shown by the regional geochemical maps. Similarly, Haglund et al. [13] found a spatial correlation between childhood diabetes risk and zinc depleted drinking groundwater. However, actual health risk of metals is dependent on several environmental state factors such as soil organic matter, metal speciation, pH, etc. [14] [15]. Therefore, integrated local and regional scale multi-media environmental and geochemical baseline mapping is essential for the risk assessment of mining and mining wastes. Another specific mining feature related to the state of the environment is that pollution can be regionally dispersed already before the start of modern mining due to previous historic mining activities. It should be respected that not only pollution impacts, but pollution sources such as deposits and historic mine industries are already a trans-boundary problem. Historic pollution makes the mapping of baseline values essential before opening a mine. Pollution due to historic mining makes the separation of natural background from anthropogenic pollution very difficult.

Impact assessments have to consider disturbance of the surface and three-dimensional underground environment. Mines are point source pollution (local pressure or hazard), and impacts are mostly local, too. Regional aspects of mining pollution impacts are related to air pollution (dust, smelter discharge), regional aquifer pollution, natural elevated background levels, historic pollution of mining regions and regional pollution of stream water and flood plains.

Secondary pressures exerted by mining industry at mine sites in mining regions impose *secondary impacts* upon the environment, such as heavy metal polluted dust from smelters. After the closure and remediation of the mine site, far-field polluted lands remain and may become secondary sources of pollution. An example for the diverse *indirect impacts* of mining is the lowering of regional groundwater levels that directly impact upon wild life habitats. Pollution impacts are not only *long-term* but also can be *delayed*, thus acting as 'chemical time bombs'. This is the case when a change in environmental parameters causes the release of accumulated pollutants from surrounding lands. *Trans-boundary impacts* of Baia Mare case are well known calling for the attention of international regulations and standards. Too often in the Candidate Countries the *socio-economic impacts* of mining and mine closure are of a higher significance than the actual environmental effects.

Quarrying is a type of mining that deserves special treatment due to its unique characteristics. Quarrying differs from other types of mining in many respects, including the potential for alternate extraction sites which leads to the existence of numerous individual mine sites, large production quantities, a high volume to value ratio, regional importance, narrow economic transportation radius, and as a result the presence of extraction near urban areas.

In terms of **Response**, perhaps the most important feature of mining is that due to (1) the huge amounts of waste, (2) the fact that undeground can never be restored and (3) the presence of natural background pollution, perfect waste site remediation is virtually impossible. Since physico-chemical processes releasing contaminants is on-going after mine closure, on geological time scales, long-term stability, monitoring and financial feasibility of long-term remediation is essential. Major efforts and results addressing these problems are discussed in the next section. Wide-spread research suggests that passive in-situ remediation including engineered wetlands and flooding of tailings and mine pits may provide efficient cost-effective long-term solutions in many cases [16].

Society can respond to mining and mining waste problems in many ways (***Figure 1***). One way is the reduction of driving forces, i.e. decreasing the demand for minerals by substituting traditional materials with synthetic ones, for example. Demand for minerals can be further decreased by product recycling or by reworking of mineral wastes as secondary resources. Use of material-efficient technologies further decreases demand for minerals, which in turn relieves pressure on the environment. Pressures coming from wastes and emissions can be decreased by efficient waste management technologies and treatment of emissions. The state of the environment can be improved by wide-spread baseline mapping, harmonised monitoring and remediation of polluted lands. In order to reduce impacts, regulations can ask for EIA (Environmental Impact Assessment) and RA (Risk Assessment) of mine sites and preparation to possible accidents. Introduction of environmental management systems in the extractive industries can further decrease potential impacts. 'Design for closure' approach can minimise impacts after closure. Finally, responses can improve responses themselves within the society: changing local regulation to regional legislation that enables the comparison of sites and impacts, and ranking of and efficient resource allocation for the most problematic sites.

Solutions: research and methodological development

In this section some of the main international and national efforts for environmental assessment of mining are briefly described first to illustrate the main lines of research and some of their results. In the second part, the most important and widely used methodologies for the holistic impact and risk assessment of mining are outlined.

Environmental assessment of mining: efforts and results - some examples
Acidic drainage is recognized as the largest environmental liability facing the mining industry and, to a lesser extent, the public through abandoned mines. **The Mine Environment Neutral Drainage (MEND) Program** in Canada was implemented to develop and apply new technologies to prevent and control acidic drainage [17]. The objectives of MEND are (1) to provide a comprehensive, scientific, technical and economic basis for the mining industry and government agencies to predict with confidence the

long-term management requirements for reactive tailings and waste rock; and (2) to establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a predictable, timely, affordable, and environmentally acceptable manner. The objective of the MEND Manual [17] was to summarize methods and results completed by this programme and to provide a set of comprehensive working references for the sampling and analyses, prediction, prevention, control, treatment and monitoring of acidic drainage. The significance of the programme lies in that it was one of first large-scale programmes addressing the complex environmental problems associated with mining and mining waste and it was the starting point of the INAP programme (see below). It also served as a reference point for other projects such as the Swedish MiMi project (see below). MEND concluded that while the developed toolbox of technologies and knowledge base is adequate, there is a need for further research to improve understanding of processes, confirm performance of technologies through large-scale applications and long-term data, and a search for efficient technologies. According to MEND [17], acid mine drainage (AMD) is a complex problem and site specific factors and conditions add to this complexity, often requiring site-specific research.

The International Network for Acid Prevention (INAP) is an industry based initiative that aims to globally coordinate research and development into the management of sulfide mine wastes [18]. The objectives of INAP are (1) to promote significant improvement in the management of sulphidic mine materials, (2) to reduce liability associated with acid drainage, and (3) to share knowledge on research and development. Specific areas of research to be undertaken through INAP include work on flooded tailings, dry covers, and pit lakes. An important aspect of INAP is that it approaches the AMD problem from a management perspective. INAP has collected site studies from all over the world and hence addresses the problem of AMD generation under various physiographic conditions. INAP has recognized that diversity of mining terminology hinders comparison and harmonization of approaches and has developed the most elaborate glossary of mining terms presently available [18]. Another important INAP document provides an elaborate discussion of the risk assessment of AMD [19]. This study concludes that risk assessment of AMD has focused mainly on hazard potential of mine waste and much less work has been carried out for the assessment of the environmental consequences of acid drainage and for integration of these results into formal decision-making process. This study also suggests that the great variety of site settings requires a case-by-case approach [19].

A further example for research development by the industry is given by **ANSTO's (Australian Nuclear Science and Technology Organisation)** Managing Mine Wastes Project (MMW) and the Sulfide Solutions Research Project (SSRP). The main objectives of the MMW project are to develop and apply various measurement and computational tools that can be used in the management of mine wastes. These goals are to be achieved by working closely with the mining industry. ANSTO established its expertise in AMD with work on the Rum Jungle uranium mine in the Northern Territory, Australia [20]. The main objectives of the SSRP project are to (1) provide industry with sustainable cost effective sulfide management technologies, (2) produce and demonstrate cutting edge measurement tools and software that can be readily adopted by the metal mining industry to improve the management of sulfidic waste rock dumps and stockpiles, (3) produce and demonstrate cutting edge measurement tools and software that can be readily adopted by the coal mining industry to improve the management of piles of sulfidic coal waste, and (4) develop expertise, tools and techniques to achieve improvements in the operation and performance of bio-oxidation and bioleaching heaps. ANSTO has developed the Aquarisk [20] ecological risk assessment code to provide a sound scientific basis for decision-making in the management of mine wastes. ANSTO SSRP has developed and applied methods in (1) cover design and assessment, (2) bio-oxidation heap design, (3) field instrumentation, (4) design and implementation of monitoring programs, (5) prediction of pollutant concentrations and loads in effluent, (6) ecological risk assessment [20].

The goal of the Swedish **Mitigation of the Environmental Impact from Mining Waste (MiMi)** programme is to find improved methods to mitigate environmental problems related to disposal of mining wastes. It is organized according to five fields: (1) field studies and characterization, (2) laboratories of key processes, (3) prevention and control, (4) predictive modelling and (5) communication and commercialisation. The project has developed state-of-the-art reports for these areas and numerous studies on various aspects of the key study area of Kristineberg with sulphide-rich tailings deposited in five impoundments along a small valley [21]. It concluded, for example, that wet covers, dry covers and treatment of leachate are the most common methods for prevention and control of AMD, however, substantial uncertainties still remain regarding the proper design of the covers with regard to their long-term performance. In terms of existing conceptual and mathematical methods, MiMi concluded, that none of the existing models extensively account for coupled temporal and spatial variability in the physico-chemical deposit environment [21]. Future model development is required for the quantitative coupling between different processes that may be important for specific field applications. For long-term model predictions, it may also be necessary to develop models that incorporate the kinetics of slow processes and their change in time. For biologically mediated processes, finally, there is a need for both conceptual and mathematical model developments [21].

The **Passive In-situ Remediation of Acidic Mine/Industrial Drainage (PIRAMID)**, a European Commission 5th Framework Programme research project, concluded in the 'Final Report' [22] and the 'Engineering guidelines for the passive remediation of acidic and/or metalliferous mine drainage and similar wastewaters' [22] documents. PIRAMID has sought to harmonise research and practice efforts in Europe to create passive in situ remediation (PIR) methods for acidic drainage treatment. PIRAMID has drawn together into a single database the previously disparate but conceptually identical developments in the creation of (1) artificial wetlands and (2) subsurface reactive barriers for the removal of acidity and toxic metals from mine drainage waters. AMD is a major cause of ground and surface water pollution in the European Union. Because such pollution can persist for a long time after the cessation of industrial activity, PIRAMID suggest PIR as cheap and sustainable remedial methods [22].

The **'Assessing and Monitoring the Environmental Impact of Mining Activities in Europe Using Advanced Earth Observation Techniques' project (MINEO)** funded by the European Commission 5th Framework Programme studied the use of hyperspectral remote sensing techniques for impact assessment of mining [23]. Hyperspectral imaging sensors produce data that can characterise the chemical and/or mineralogical composition of the imaged ground surface. The primary advantages of this future spaceborne imaging technique are the reduction in conventional, time-consuming and expensive field sampling methods and its capability to gather repeat data and so monitor mining pollution. Earth Observation data, when integrated into a Geographic Information System (GIS) and combined with other data relevant to environmental concerns, have been proven valuable in the environmental impact assessment of mining, both at local and regional scales [23]. In particular, these data can be used in the production of pollution-risk maps around mining areas. In this project, hyperspectral techniques were used to study the mine impacts of (1) mineralogy leading to AMD and neutralising it, (2) vegetation stress due to contamination from dust and seepage waters, (3) vegetation stress due to subsidence of ground and rising ground water and (4) revegetation of the mining area. Studies on five test sites led to the compilation of the General Guidelines for image-processing procedures and algorithms for contamination and impact discrimination and mapping from airborne imaging spectroscopy [23]. Good results of airborne imaging spectroscopy have been obtained, despite the problematic abundance of vegetation characterising the European environments. Methods used a combination of maps with other relevant information within a GIS for modelling contamination, pollution risk, and site rehabilitation or change detection [23].

The goal of the **Environmental Regulation of Mine Waters in the European Union (ERMITE)**, a research project of the European Commission 5th Framework Programme, is to provide integrated policy guidelines for developing European legislation and practice in relation to water management in the mining sector, coherent with the catchment management approach [24]. The ERMITE report 'Economic analysis of mine water pollution abatement on a catchment scale' [24] concluded that in the EU in general (1) allocation within a catchment of mine water pollution abatement is commonly not quantified in a catchment perspective, (2) estimated costs for mine water pollution abatement do not commonly include cost components associated with measurement/prediction uncertainties, which imply finite risk/probability of abatement measures not achieving their targeted water quality improvements, and (3) expected long-term temporal changes in different mine water pollution scenarios are not commonly considered in any dynamic long-term analysis of efficient catchment-scale mine water pollution abatement. The ERMITE report 'Mine waters pollution control: the legal situation at BIH and the EU levels' [24] concluded that mine waters are part of the water cycle but are rarely treated as such and this is despite the fact that short and long-term pollution from active and abandoned mines is still one of the most serious threats to the water environment in many European countries.

Environmental assessment of mining: development of methods - some examples

The complex problem of mining impacts requires methods that are (1) **holistic**, i.e. address the problem in its integrated complexity, and are (2) direct **decision support tools**, i.e. environmental decisions can be directly based on their results. Some of the main approaches that meet these criteria and have been tested specifically for mining assessment are briefly described below. Particular tools of sampling, sample analysis, modelling, prediction, treatment and remediation technologies are not detailed here. Indeed, the methods below provide means to integrate these tools and they give a 'holistic' framework for their harmonised use for environmental assessment of mining. Sinding [25] considers environmental impact assessment, environmental management systems, environmental accounting, environmental audits and environmental reports, and life cycle assessment as the most important methods for approaching direct scientific decision support of the complex mining environmental problem. Smith and Huyck [26] mentions material flow analysis (global element cycles) and landscape geochemistry for the holistic approach of environmental geochemistry of mineral deposits. Below we introduce only those methods that meet both the decision support and the 'holistic' criteria as well. These are (1) landscape ecology, (2) industrial ecology, (3) landscape geochemistry, (4) material flow analysis, (5) geo-environmental models, (6) environmental impact assessment, (7) environmental risk assessment, and (8) life cycle assessment. Environmental management systems (EMS), environmental accounting, environmental audit, environmental reports, technology assessment (TA), and other specific decision support and evaluation schemes such as benefit-cost analysis (BCA) and multi-criteria analysis (MCA) are methods for data gathering and evaluation to support and control decisions within the industry and thus these are not dealt with here.

Landscape Ecology (LE) provides the most complex decision-support landscape modelling and mapping techniques available among environmental sciences. LE differs from ecology in that (1) unlike ecology, LE studies the interaction of environmental systems and socio-economic systems and (2) it studies landscapes that are functional units of ecosystems plus abiotic environment and human factors. The largest ecosystem is the total human ecosystem, which includes the biosphere and the human social systems [27]. System processes are described by ecological and mathematical systems analysis methods to study matter, energy and information transport within and between abiotic and biotic natural and social systems. Landscape ecological maps are often produced with GIS technology [28] and show ecosystems, system boundaries and their interactions through barriers, corridors and other control elements [29] [30]. Maps are accompanied by additional information on the functioning of landscape systems such as feedback loops, reservoirs, etc. Since landscape ecological maps show the functioning of systems they are efficient tools of direct decision support for control and management of complex environmental systems. For example, Jordan and Szucs [31] used LE in combination with landscape geochemistry, geochemical modelling and GIS methods to study spatial aspects of mining impact in a small catchment. Based on this work, Jordan et al. [32] used landscape ecological system analysis of AMD impacted natural wetlands to conclude on their instability with respect to sulphide-bound and/or organic-bound heavy metals.

Industrial Ecology (IE) is similar to LE but it limits its scope to the study of industrial activities in relation to ecosystem sustainability. IE is defined as the study of the flows of material and energy in the industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory and social factors on the flow, use and transformation of resources. Industrial ecosystem is defined as the system including all the components that are ensuring the ecological sustainability of the industrial system [33]. IE seeks to optimise the total industrial material cycle from raw material to finished products to ultimate disposal of wastes. IE has two underlying principles [34]. First, the recognition of the similarity of industrial systems and ecosystems. This enables the study of industrial development towards 'self-sustainability', control and regulations. Second, analysis of the 'ecological footprint', i.e. the area and resources necessary to support the industrial system in its complete functionality. An industrial system is more 'eco-efficient' if its ecological footprint is lower than those of others. It follows that the sustainability of a given industrial system by a given area is achieved only if the rate of depletion of renewable resources of the area utilized by the industrial system is lower than or equal to the rate of their renovation [34]. Feoli [34] investigated the use of IE for mining and concluded that this method suggests a theoretical framework that forsees a set of actions to avoid the accumulation and dispersal of waste in the environment and limit pollutant release from industrial plants. He suggested ways for the use of IE for bio-remediation of mine waste sites and abandoned mine sites [34]. He concluded that similar to ecological life cycle studies of ecosystems and materials turnover, life cycle assessment of processed materials (products) and of the industrial system itself is a fundamental tool to assist mine impact assessment.

While landscape ecology has developed complex landscape modelling and mapping methods in an ecological context, **Landscape Geochemistry** (LG) has the complex toolbox for modelling and mapping geochemical systems [35] [31]. Landscape geochemistry is similar to LE but the focus is on material flow analysis and abiotic processes. Applied geochemistry and landscape geochemistry differs in that applied geochemistry studies the distribution of elements and models geochemical processes, whereas landscape geochemistry investigates these as well as the structure and functioning of landscapes and then models complex geochemical systems. The basic geochemical system, elementary landscape, is defined as a landscape volume which is homogeneous with respect to material flow pattern and forms a part of the land surface in which the interactions between rocks, surface- and ground water, organisms, atmospheric constituents and solar energy are maintained constant at any given time [36]. Geochemically related elementary landscapes (landscapes in a watershed, or areas at recharge and discharge regions of the same groundwater system, for example) form a geochemical landscape. LG maps geochemically 'sub-ordinate' landscapes as well where the geochemistry of the area such as a stream segment is influenced by another landscape for example an area with mineralisation or a mine upslope. Classification of elementary landscapes have been extended with the consideration of their spatial relationships through surface and subsurface material flow in a way analogous to the soil catena concept of soil science. The starting point of landscape geochemical modelling is material flow analysis in global geochemical cycles including liberation, transport and deposition of all elements in all environments. Landscape structure (pattern) is described in terms of geochemical abundances and geochemical gradients [32]. Landscape functioning is described in terms of element migration (chemical reactions), geochemical flows (transport processes), landscape geochemical barriers and landscape classification. Landscape evolution is described using historical geochemistry. For example, Bradshow [37] used LG to study and map secondary accumulation of heavy metals in sediments deposited down-slope from mineralisations. He used LG to distinguish between natural background and mine pollution. Szucs et al. [38] used LG and GIS for the spatial analysis of heavy metal distribution in stream water and sediments impacted by metal mining.

The United States Geological Survey (USGS) has developed the **Geo-environmental Model** (GEM) concept in order to analyse and predict environmental impacts of mineral deposits and extraction [39]. The principle is that enough knowledge on the economic characterisation of mineral deposit has accumulated including geological, mineralogical, geochemical information that enables not only the economic but the environmental classification of deposit types. For the geo-environmental characterisation of deposits the most important parameters are deposit and host-rock geology and mineralogy, alteration styles and trace-element chemistry [39]. These parameters are the basis of the well-established economic classification of deposits, as well. Recognising a deposit to belong to a certain deposit class can predict the physico-chemical and spatial characteristics of the deposit, including natural background, acid generating and neutralising potential, hydrochemistry, composition of waste rock and tailings, etc. This is the source or hazard characterisation by geo-environmental models. The various deposit types can be ranked based on nature and extent of alteration, mineral assemblage, metals present in the minerals, presence of acid-generating minerals like pyrite and on the natural acid-consuming capacity of the host rock. In this ranking, for example, deposits rich in pyrite and metals but poor in acid-consuming minerals are ranked as most likely to cause environmental problems, while pyrite-poor deposits being the least dangerous. Often, a unique suite of element concentrations and other physical and chemical properties of water and rocks that come into contact with specific types of mineralised rock in a given region comprise the 'environmental signature' of that rock package. Among the environmental parameters the most important are topography and physiography, hydrology, mining and milling methods, climate, latitude and altitude [39]. The last three parameters may be the primary controlling factors of the weathering of the ore deposit. These parameters define the 'ecoregion' of the deposit, i.e. the physiographic unit it belongs to. The geologic framework, climate, latitude and altitude determine the weathering behaviour of the rocks and mine derived wastes, and their influence on water quality and on soil. In this way, potential impacts of mining can be predicted by geo-environmental models. The purpose of a geo-environmental model is [39]:

- to understand environmental behaviour of mineralised areas, and to anticipate the chemical and mechanical weathering behaviour of rocks within and around a given mineral deposit in a given climatic regime;
- to identify areas with high natural background;
- to determine baseline conditions prior to mining; and
- to anticipate mitigation or remediation requirements for future mines, and mine closing.

An example for GEM application is provided by the joint USGS-MAFI (United States Geological Survey - Geological Institute of Hungary) project results for the Lahoca/Recsk hydrothermal and Gyongyosoroszi polymetallic deposits in the Matra Mts. in Hungary [40]. The Lahoca deposit with quartz-alunite and advanced-argillic alteration was ranked as most likely to cause pollution problems because intensely acidic mineralising/altering fluids consumed whatever natural acid-neutralisation capacity the host rock may have had prior to mineralisation [40]. These waters are characterised by extremely low pH (<3) and high metal concentrations. Geochemical studies by Odor et al. [41] and Jordan et al. [42] on the environmental signatures of these deposits in the Matra Mts. confirmed the predictions of geo-environmental models.

Environmental Impact Assessment (EIA) identifies environmental effects of one economic activity, usually at one specific location, and at one point in time. EIA is used as an aid to public decision making on larger projects, both public and private. EIA is mainly a project management tool in the sense that it allows the decision maker to approve, redesign or reject a project. EIA consists of the screening, scoping [43], report writing [44], report review, decision making and monitoring steps, according to the EU EIA Directive [45] [46]. The Directive prescribes the description of likely significant effects of the project including any direct [47], indirect [48], secondary, cumulative, short, medium and long term, permanent and temporary, positive and negative effects, for the 'extractive industries' as well. All stages of the whole mine project life cycle should be studied for expected impacts which is the subject of asset life cycle assessment as described below. Pre-project baseline studies describing the state of the environment are important to provide a basis for monitoring of impacts of each mining stage. Impact analysis, modelling and prediction results in the environmental impact statement (EIS) report for the mining project describing impact mitigation alternatives as well. Separate impact studies are often carried out for human health impact assessment [49], social impact assessment (SIA) and ecological impact assessment [50]. Norton [51] suggests the use of system analysis methods for ecological impact assessment, similar in principle to the above described LE, LG, IE and GEM methods. Mitigation of mining impacts can mean avoidance (using an alternative action), prevention, reduction (lessening the severity of an impact) or remedy (enhancement or compensation). Mitigation measures themselves can have impacts that also have to be identified. In EIA 'monitoring' is meant for both impacts and implementation of a mining project in accordance with required environmental measures.

Clear difference has to be made between the magnitude and the significance of impacts. Various weighting and ranking systems have been proposed for ranking impact magnitude and significance. The most commonly used methods of ranking apply (1) checklist of potential impacts, (2) the Leopold matrix listing actions and environmental factors, and (3) networks that can identify indirect impacts as well [52] [53] [44]. Weaver and Caldwell [54] discussed in detail the application of these methods for EIA of mining projects and concluded that mining EIA has to consider (1) site-specific features, (2) the whole mining life cycle under the principle of 'design for closure', (3) differences between mining and processing methods (such as underground vs. surface mining, cyanide leaching, etc), and their specific impacts, (4) thorough baseline surveys, (5) alternatives for methods and management practices (alternatives are not valid for location in case of mining and mine waste management), (6) special spatial and temporal scales of mining, and (7) residual impacts for impact mitigation. In addition, mining waste and management facilities may require separate EIA as described by Eduljee [55]. Abundant mining impact assessment case studies are given in the country reports in this volume demonstrating the above aspects [56].

Alternative approaches, cumulative and synergic impacts, ancillary impacts, regional and global impacts and non-project impacts (e.g. impacts resulting from management practices) may all be better assessed initially at policy, plan or programme level, rather than at the project level [46]. This is the subject of strategic environmental assessment (SEA) that is primarily used for sectoral activities such as the extractive industries as a whole. Also, environmental assessment of land use plans can use SEA to study arrangements of juxtaposed land uses, such as mining and agriculture, and to study some significant synergistic and cumulative impacts that cannot be satisfactorily considered in sectoral or project EIA [46]. De Jongh [57] studied uncertainty in EIA and concluded that one of the major problems is that EIA is mainly concerned with expected events, while the problems associated with projects are likely to come from unexpected or low-probability events, such as mine tailings dam accidents. In this context, the scoping process, for example, is essentially a means of reducing uncertainty concerning values. He suggests the application of rigorous decision analysis methods and statistical characterisation in EIA steps. This is in fact the subject of risk assessment.

Risk assessment (RA), defined in its broadest sense, deals with the probability of any adverse effects. Various types of risk to be considered at the mine project life cycle include regulatory risk, engineering risk, facility risk, financial risk, human health risk and ecological risk [19]. Risks posed by regular or accidental emissions to human beings (human health risk assessment, HHRA) or to ecosystems (ecological risk assessment, ERA) are studied by mine RA. While human risk assessment studies the probability of impact on a single individual, ecological risk assessment studies the impact on populations. A difficulty in ERA is the choice of receptors such as fish species in stream water that are indicators of total risk to the ecosystem. Although risk assessment is not directly related to one economic activity, RAs are concerned with the risk involved at a specific site, at a specific time, and due to specific causes. Contamination risk is the combined effect of the probability of contamination and the significance of toxic impacts. This is studied through the pathway from (1) hazard description, through (2) dose/response (toxicity) analysis, (3) contaminant transport, (4) exposure assessment, to (5) risk characterization, and (6) risk management [58]. SENES [19] gives an in-depth overview of risk assessment for AMD. The study concludes that RA of AMD is not different from RA used for any other waste. The study argues that for efficient AMD treatment, practice should move from pure RA to complex risk management. RA is not designed to study risks of indirect impacts of pollution. For example in the frame of ERA, acidification of waters can have direct toxic effect on aquatic biota. However, acidification can lead to the secondary release of heavy metals from sediments thus becoming available for human metal toxicity. Also, hazard of AMD release might be reduced by remediation of waste dumps, for example, but secondary sources of metals remain in lands around the site that were polluted during active mining. This requires a separate RA of contaminated sites [59]. At the exposure assessment part of RA, temporal aspects and stability are also important. While heavy metals in AMD can be efficiently retained in nearby organic-rich wetland sediments for example, climatic change or anthropogenic activity can lead to a drop in groundwater levels that in turn leads to erosion and oxidation of reduced sediments thus exposing metals to human intake. Pre-mining natural pollution can already have local or regional adverse effects on human health for example. Effects of mining can be measured only relative to existing impacts. This makes the study of differences between natural and mine-induced pollution pathways essential both in EIA baseline studies and risk assessment for mining.

Both EIA and RA are concerned with the likely consequences of environmental change. According to Andrews [60], EIA and RA are complementary to each other. Unlike RA, EIA focuses on the environmental fate of contaminants, rather than the effects on health and ecosystems. Integration of quantitative methods of RA into the broad framework of EIA might be a way of further improvement to support environmental planning and assessment.

Material Flow Analysis (MFA) (or Substance Flow Analysis, SFA) limits its scope to the study of industrial activities in relation to matter transport and transition processes between socio-economic systems and the environment. Physical input-output analysis and materials balance methods form a set of related tools for analysis in which flows and accumulations of a substance are studied both within the economic and the environmental systems. Substances cover elements, compounds, group of similar compounds (such as nitrates), and mixture of compounds (such as those contained in wood). The MFA is essentially a book-keeping method, recording the inputs and outputs of a substance to and from processes in economic and environmental systems. Given the law of mass conservation, MFA can detect leaks and accumulations using ratios of different inflows and outflows. Thus, MFA covers the life cycle of a substance in a given geographic unit. A detailed discussion of MFA in the broader context of global biogechemical cycles is given by [3] and [61] where coupled reservoirs, turnover- and residence and response time, coupled cycles, steady-state, and other important aspects of MFA are discussed. Metals are often liberated by mining together with S by the oxidation of reduced metal-sulfide minerals: thus coupling of global S cycle and metal cycles for impact assessment of mining is important [62]. For example, sulfides are oxidised to sulphuric acid that keeps most of the metals in mobile form in AMD and terrestrial aquatic environment. Along the industrial processing pathway of sulfide bearing mineral resources (such as sulfide ore smelting, coal and petroleum combustion) sulfure oxides are emitted to the atmosphere that turn into SO_4 and cause acid rain. Acid rain in turn, increases chemical weathering of metal-bearing rocks and causes general acidification of terrestrial environments that leads to mobilisation of metals from sediments and soils into solutions. This has the effect of increasing bioavailability of metals in toxic concentrations, on one hand, or the depletion of metals in the substrate leading to deficiencies of biota, on the other hand. A geochemical mapping study in Sweden [63] [64] has shown that acidification mobilizes cadmium and results in a regional increase in cadmium in plants and moose in areas most affected by acid rain.

Product life cycle assessment (LCA) focuses on the product itself rather than the production site or process [65]. LCA involves the analysis of all impacts created by a product "from cradle to grave". LCA thus covers the life cycle of a product without reference to any geographic unit. LCA is an iterative process and involves stages of (1) scope definition, (2) inventory analysis (this is the main part including process flow chart construction, data collection, defining system boundaries and data processing), (3) impact assessment (including classification, characterisation and valuation), and (4) improvement assessment. LCA enables a comparison of the impacts of similar products, or an estimation of the total impact of a given product [66]. Site-specific LCA is recommended by Schaltegger [67]. According to Sinding [25] "traditional" LCA, i.e. dealing with a specific product seems unsuitable for use in a mining context because mining is only the first stage of product life cycle and thus it is only a part of the complete cycles.

Asset life cycle analysis of mining includes exploration (discovering natural resources), appraisal (assessing natural resources), development (design and construction of production facilities), production, closure (decommissioning of production and waste facilities) and after-care (sustainable remediation). Today, mining waste management is an integrated part of the lifecycle of a mine. The "cradle to grave" approach is generally applied to the planning of new mine sites. This means that various closure options are considered and evaluated in depth even before the mining activity starts, also called "design for closure". In early phases of asset life cycle, impacts can only be roughly estimated and decisions involve high uncertainty, while in latter phases more accurate estimates can be made [68]. Ritsema [68] concludes that there is a need for a systematic and integrated approach in assessing of impacts throughout the asset life cycle of mining operations. Despite intensive research and some European initiatives towards the development of a comprehensive LCA methodology, there has not been a development of holistic life cycle assessment system for the extractive industries, accounting for all stages of the mining activities, from exploration and development of a mineral deposit, to mining, processing of the ore, production of the concentrate, waste disposal, remediation, environmental monitoring, decommissioning and long term control and monitoring of the impacts [34].

In conclusion it can be said that none of the above methods alone can address and solve all of the environmental problems of mining. Methods of LE, LG, IE and GEM put the emphasis on the study of natural systems while EIA, RA, MFA and LCA study more the inter-

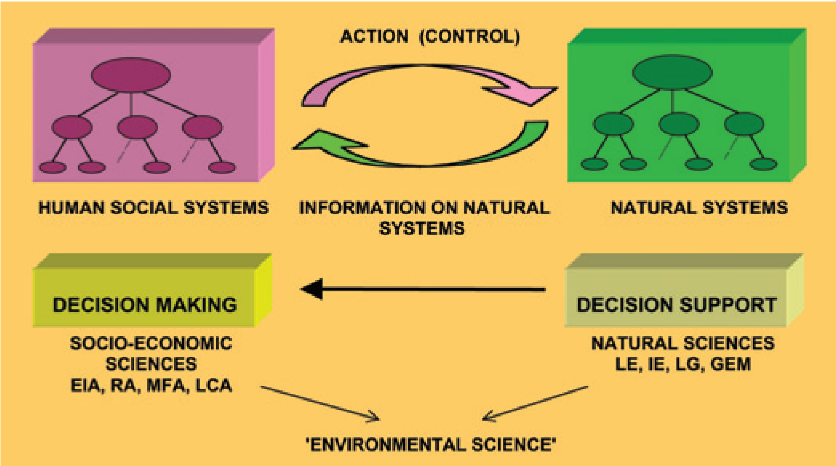

Figure 2. *The environmental decision-making process and the decision support role of sciences (after Jordan and Szucs [70]. Environmental decision support tools discussed in this chapter are also shown. Compare to Figure 1. See text for details.*

nal processes within the human socio-economic systems. The common in all of these methods is that they try to bridge the gap between socio-economic and natural science in order to support decisions on the management of the environment (***Figure 2***). Among natural science techniques an integrated use of the LG with MFA as extended with global cycle analysis seems to be the most efficient for impact studies of mining. Among social-economic techniques, asset LCA may provide the broadest and the most 'holistic' framework to bring together EIA, RA and decision analysis, in general.

Solutions: experiences in the Central and Eastern European Candidate Countries

An expert panel discussion of the Workshop on 'Mine and quarry waste – the burden from the past' [69], organised by DG Environment and DG JRC, concluded with an exchange of views on the three major aspects addressed by the proposed mine waste directive: (1) how to carry out an inventory of closed sites, (2) which procedures should be used for a prioritisation of such sites for remedial action, and (3) who should finance such action. In this section a few examples are given for approaches to the main methodological problems related to the implementation of the proposed Directive: inventory, environmental prioritisation of mine sites and spatial risk assessment. Examples are provided for trans-boundary approaches and on-going international efforts that are relevant to risk assessment of mine sites and related mine-polluted lands in the CC countries.

Inventory

The objective of inventory is to support risk assessment-based classification of mine sites [62]. Regarding the spatial characteristics of mining and needs of risk assessment, the inventory has to be split up into the following parts: (1) inventory of deposits that determines natural background, composition of wastes, location of potential mines and abandoned mines, (2) inventory of active and closed mine waste sites for the classification for safe operation and closure, (3) inventory of abandoned mine waste sites, and (4) inventory of mine-associated impacts, polluted lands and waters.

Since the assessment of mineral potential and natural reserves was politically motivated in the Central and Eastern European Candidate Countries in the past, elaborated and detailed national inventory of mineral deposits exist everywhere. As these programmes were centrally coordinated, data is highly standardised and uniform and they are public. Data includes exploration results, production figures, geological deposit descriptions and detailed geological maps.

One example is the Romanian survey resulting in the 1:1,000,000 scale **'Map of the Mineral Resources, Romania'** that shows 1,289 deposits together with detailed geological descriptions [71]. Geological units related to the most significant zones with mineral resources are represented in 33 more detailed maps (***Figure 3***). Besides mining and mineable deposits, exploited or abandoned deposits, also prospecting targets and small occurrences of special interest have been included. Therefore, all significant occurrences can be found in the map. For each deposit map codes show mineral commodities, genetic type, host rock type and deposit morphology (***Figure 3***). Detailed description gives information on (1) main and secondary constitutents, genetic type and age, (2) geographic location, (3) geological, tectonic and petrogenic units, (4)-(5) host rock formation, (6) orebody morphology, (7) chemical composition, (8) mineralogical composition, and (9) selected references. The structure of the map and explanatory text gives the possibility of easy reor-

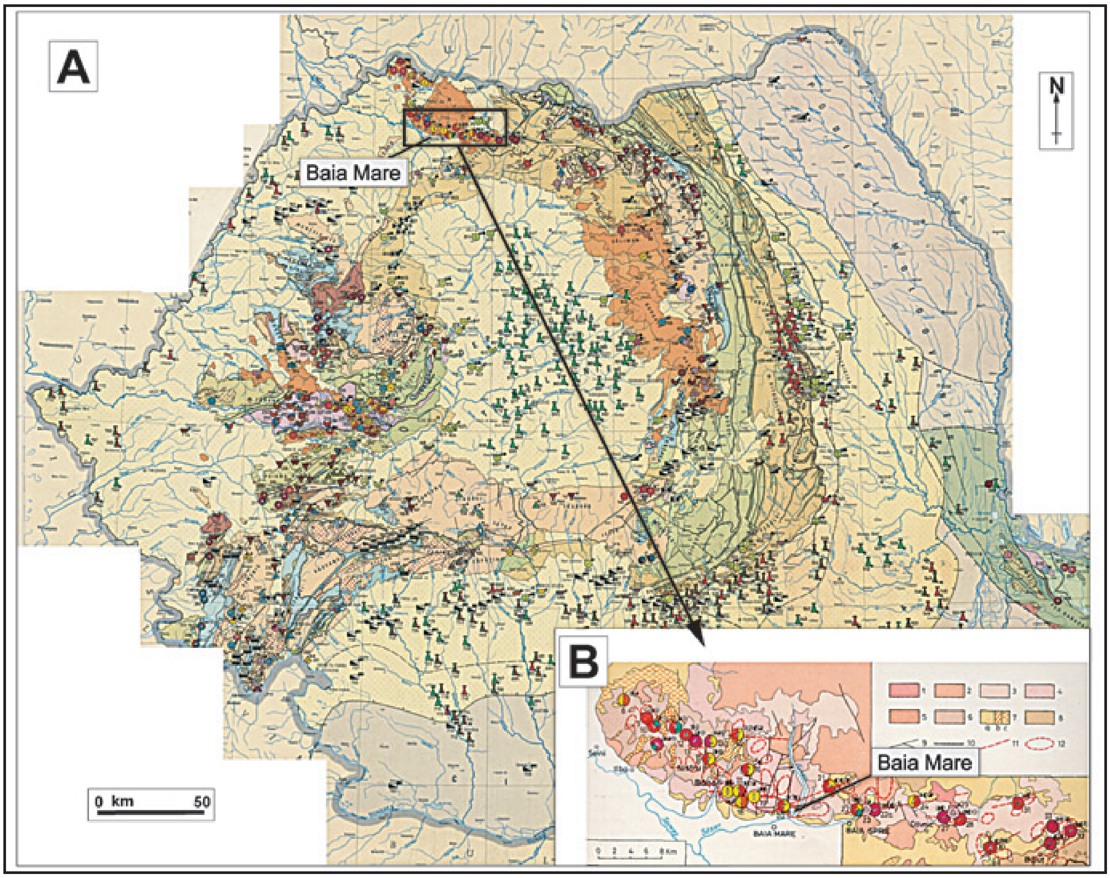

Figure 3*. Mineral deposit map, an example. 'Map of mineral resources in Romania' [71].*

ganisation of information according to the needs of various specialists. From data present in geological maps like in the Romanian example, information on mineral and chemical composition can already tell the physico-chemical composition of (potential) mine wastes.

A good example for nation-wide mine and mine waste inventory is provided by the **Hungarian national inventory of "Landscape Wounds and Quarries"** [72]. Based on preliminary tests, the inventory did not use remotely sensed images because lot of the abandoned quarries are covered by vegetation or filled by ponds. Instead, the inventory was based on 1:25,000 scale topographic maps that were derived by high-resolution aerial photographs and field observations, thus they show most of 'landscape wounds', i.e. quarries. 5,300 of the total 15,008 inventorised sites have been field-investigated for more than 70 parameters for each site. In the first section of the inventory form, basic data including location is found. Section two includes (1) general data (site status, presence of landfill), (2) mining parameters, (3) mining details, (4) data on mine site, (5) data on excavated pit, (6) waste rock dumps information, (7) spatial data on tailings, (8) data on quarry pond, and (9) further hazards existing on site. The third section gives environmental data as follows: (1) presence, type and activity of landfill on site, (2) information on water, (3) presence and type of air pollution, (4) notes on general environmental conditions. The fourth section gives information on nature and landscape protection: (1) type and percentage of vegetation cover of site, (2) presence of protected plant and animal species, (2) presence of values of geology, landscape, social or industrial history, (3) surface mine is located in protected areas, (4) recultivation status of mine site, (5) significance weights for all these factors (points from 1 to 5). The fifth section gives data on the land use on and around the site: (1) percentage of surrounding land use types, (2) land use on mine site. Finally, the sixth part summarises and evaluates field survey data for each site and gives a proposal for the possible uses of the site. The accompanying GIS database contains 1:25,000 scale topographic data including all road types, streams, lakes and ponds, quarries, and forested areas. It also has the boundaries of protected areas, resort areas, administrative boundaries, and boundaries of authorities such as regional water, geological survey and environmental authorities. All protected areas of high priority have been separately inventorised in detail and 600 quarries were found in them. The objective of the inventory was to develop a ranking system for prioritisation to support tenders for remediation and alternative uses of quarries. This quarry inventory database is perhaps unique in Europe and provides the basis for national spatial planning and waste management for mining areas (***Figure 4***).

An example for inventory focusing on high priority hot spots is provided by Bulgaria. The main **inventory efforts of Bulgaria** are concentrated towards the problems related to uranium production. Based on the PHARE multi-country programme, national programmes have been initiated. The BGP programme is implemented for 74 objects (mines, processing plants, etc.) for which detailed inventory and environmental impact assessment has been carried out and remediation design has been developed. The inventory used specific approach but without national standards in some cases [73]. The on-going BGPE programme aimed at further 34 objects that were not included in BGP. The programme will achieve identification of objects, collection of past data for inventory of liabilities, detailed field measurement and sampling (water, soil, rock), laboratory test of samples, risk assessment (site specific and ranking system), grouping of objects and development of complex programme for remediation.

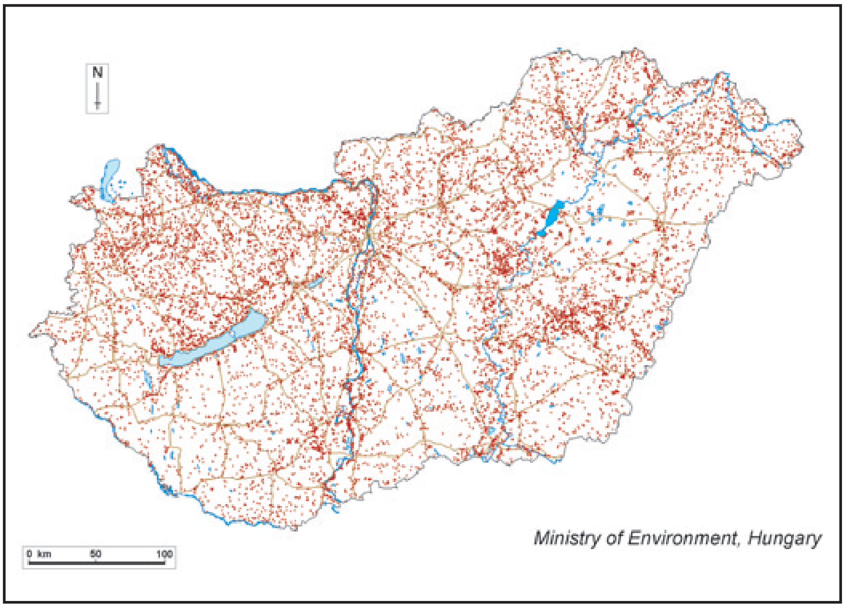

Figure 4. *Quarry national inventory map, Hungary.The map and database contains more than 15,000 sites [72].*

A unique **inventory of abandoned mines in Slovakia** was carried out by the Ministry of the Environment between 1992 and 1997 [74]. It contains an inventory of abandoned mining sites (including galleries, shafts, tailings, mining waste deposits, etc.), a list of abandoned mines proposed for remediation based on hazard and impact prioritisation and proposal for remediation. Altogether 17,260 sites were inventorised, including 10 tailings ponds and 6,418 waste rock or tailings dumps. An on-going effort aims at the remediation of closed and abandoned mines based on risk-based prioritisation, using criteria such as the character of problem, ecological conditions and economic factors. The process includes (1) inventory and evaluation of active mines, (2) inventory of abandoned mines (completed in 1997), (3) inventory and evaluation of impacts, (4) preparation of national monitoring system of the most risky sites, and (5) proposal and realisation of remediation activities.

These examples show that environmental problems of mining waste were recognised long ago in the Candidate Countries and significant efforts resulted in important results despite of the limited funds available. Examples for the interpretation of inventory of mining-associated impacts, polluted lands and waters follow below in the context of impact and risk assessment.

Environmental ranking of mine sites

The objective of mine waste inventory is to facilitate the ranking of mine sites for prioritisation for efficient control and financial resource allocation. Most of the countries have developed their own systems for ranking. All of these efforts are country-specific, so a synoptic picture on multi-country level cannot be made. Some are based on expert judgement, others use various data and criteria for ranking.

A ministerial order in **Romania** establishes **importance categories** of the dams of industrial waste deposits [6]. The category of risk is determined by a ranking system including the following criteria:

- technical characteristics of works, information supplied by the owner;
- the mode in which the dam was designed, built, exploited, repaired, affected during exploitation; if the dam was periodically checked, kept under exploitation, suspended or abandoned;
- the mode in which water/industrial liquid waste is stored in the pond or deposit;
- necessity of inhabitant, property and environment protection against potential consequences in case of giving up these facilities;
- the size of the potential damages that could be brought by an accident to the dam;
- social-economic impacts of a dam brake-down.

Risk assessment of dams uses indexes based on (1) the characteristics of the dam or the deposit (i.e. size, type, dischargers, importance level), location (nature of the foundation and seismicity of the area) and the conditions of the pond or the waste; (2) status of the dam (active or abandoned; conditions of waste and monitoring system, maintenance works, data on their stability); and (3) the consequences of dam or waste deposit failure (possible casualties, effects on the environment, social-economic effects, etc.). Each index is quantified by a system of points based on subcriteria. Total score of a criterion is given by the arithmetic sum of subcriteria points. Depending on the value of **risk index** associated with the dam or waste, these are classified in one of the following categories of importance: (A) dam of exceptional risk, (B) dam of particular risk, (C) dam of average risk, (D) dam of small risk. Provided that the value of the risk index associated to the dam or to the deposit is higher than 1, the risk is unacceptable and the dam cannot be used.

The scope of the **"System of evaluation and monitoring of impacts on environment originating from mining activities"** of the Slovakian Ministry of the Environment are to cover the territory of the whole country, all types of historical and current mining activities, all aspects of environment (engineering-geological, hydrogeological and geochemical aspects) and prioritisation of localities according to their environmental impacts [74]. As a result, localities were classified into 3 categories:

- Category I includes localities and mining sites where remediation is required to prevent acute damages on human health, environment (water, soil, biota), and property. Known impacts have been documented and damages are of large extent;
- Category II includes localities and mining sites of transitional characteristics with partial knowledge on the sites and extent of impacts, but due to specific factors (e.g. type of ore and natural conditions, changes in technology, ceasing of mining) threat of damages is either not so critical or requires supplementary investigation to clarify the situation (with possibility to re-categorise the mining site);
- Category III includes localities and mining sites with apparently low or minor impact on human health, environment and property due to different factors like historical mining, temporarily suspended mines, etc., if there are satisfactory existing national monitoring systems for impact identification or specific conditions exist for management of accidents.

Environmental impact of mining activities is evaluated on the bases of the following criteria: (1) status of mining or ore processing, (2) utilisation of chemicals, (3) size of undermined areas, (4) geodynamic deformation, (5) other negative impacts on relief, (6) hydrogeological and water management conditions, (7) mine waters, (8) hydrogeochemical anomalies, (9) litogeochemical anomalies, (10) biogeochemical anomalies, (11) waste rock stockpiles, (12) tailings, (13) land use type, and (14) monitoring [74]. Ranking system of impact intensity involved 489 localities including 231 with the highest impact category. Based on ranking system, localities of 'Category I' were denoted as "hot spots".

Hazard, impact, and risk mapping

The 1:500,000 'Geological **Hazard** Map of Bulgaria', published together with detailed explanatory text [75] is a good example for regional-scale spatial analysis of hazards. Geological hazard is an integrating definition including all types of destructive process in the lithosphere. This work also defines 'geological risk' as the possibility of arising social, economic and environmental consequences of destructive processes. Hazard investigation and mapping of natural hazard has received increasing attention world-wide. Most of the existing geological hazard maps reveal only one or a few processes of the most important in a region. This map may be unique in that it provides a complete picture of all the destructive processes endangering the country's territory and its population. It is intended to serve for estimation of geological risk in the country for spatial planning. The map produced by the Bulgarian Geological Survey is based on its previous geological, engineering geological, hydro-geological and geophysical maps.

Various models exist for the classification of geological hazards. This approach horizontally identifies natural (endogenic and exogenic) and technogenic (anthropogenic) hazards on a genetic basis. Horizontal classification is based on the duration and presence of risk elements such as processes with sudden or recurrent action (earthquakes, landslides, etc.), processes with permanent action such as soil erosion and weathering, and the third group containing processes with permanent action leading to sudden changes, such as karstic processes, subsidence, loess collapse, etc. The structure of geological hazard is supplemented by some other features like risk categories (disaster, catastrophe, accident, incident), affected area (global, zonal, regional and local), speed of occurrence, degree of prediction, etc. Ranking of hazards is based on degree of the consequences, frequency of occurrence and possibility for prevention or decreasing of impacts. More than 60 types of geological hazards are shown in the map. Background colours show processes of large area distribution like plane erosion or shallow groundwater fluctuations. Overlapping processes are also shown in the map. Point hazards at the scale of the map are shown with point features. Geological risk assessment is facilitated by showing population density, settlements and major infrastructural elements, industrial zones, natural and historic objects in small scheme maps. Hazards associated with **mining** shown in the map are mine collapse, surface subsidence (slow, intensive and sudden collapse), surface subsidence due to intensive water pumping, clay swelling in underground mines, spontaneous coal combustion, explosive gases, water burst into mines, quarries, industrial waste heaps, radioactive waste hazard, and water contamination (surface and subsurface). These mine-related processes exert a considerable geological hazard at the national level in Bulgaria [75]. ***Figure 5*** shows a mining area with various underground mine hazards, quarry landscape wounds, waste rock dumps in a region with earthquake hazard, natural radioactivity hazard and high salt content groundwater. This synthetic picture of destructive processes provides a possibility to determine regional mining environmental management priorities. Simultaneous analysis of various hazards makes possible the assessment of cumulative hazards, such as mining hazard in an area with earthquake risk.

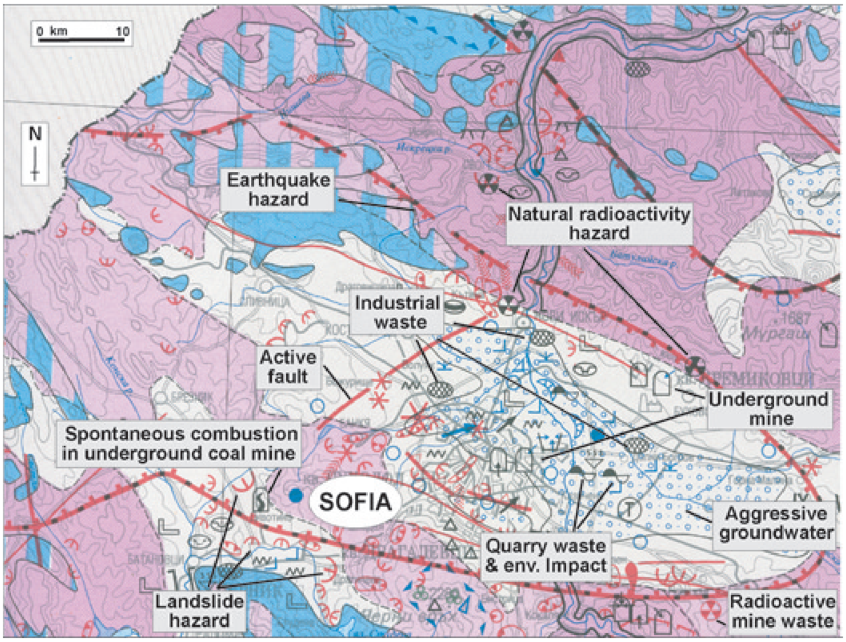

Figure 5.
Environmental hazard map.The 'Geological Hazard Map of Bulgaria' showing mining hazards in relation to other natural hazards [75].

As early as in 1992, The Czech Geological Survey produced the 1:500,000 scale **'Impact** of Mining on the Environment of the Czech Republic' map and explanatory text [76]. The map illustrates the degree of damage inflicted upon the environment in the Czech Republic by past and present mineral exploitation. The accompanying text includes explanatory notes to the map as well as a table which classifies mineral deposits plotted in the map and specifies the negative impacts of their exploitation. Its purpose is to point out the areas and localities in the country where the influence of mining activities is excessive and unbearable in long-term perspective. It is a first attempt to summarise mine impacts in a systematic way based on individual factors. The map tries to present the whole set of factors that operates during the whole mine life cycle from exploration and exploitation, and persists even after the deposit is exhausted or abandoned. The main criteria for the choice of deposits were (1) the extent of mining activities, (2) the material exploited, (3) its chemical composition and (4) dressing methods. In some cases other factors such as proximity to settlements, nature reserves and protected nature monuments were also considered. Type, size and economic significance of deposits were not considered. Only four basic categories such as ore minerals, non-metallic minerals, coal and hydrocarbons were distinguished. In spite of this simplification the map shows how specific is the environmental damage caused by exploitation of individual deposits [76]. Active, closed and abandoned mines are all considered in the survey. The bases of the map are (1) a geological map with deposit boundaries and mining areas, and (2) topography showing major rivers, settlements and infrastructure (***Figure 6***). Altogether, 169 sites and their different risks are presented in the map.

Using the geological map with boundaries of deposits, mining districts and underground mining, a methodology was established for assessing the following 13 factors of individual impacts:

- Risk of surface water contamination by mining waters;
- Risk of surface water contamination by dumps and processing plants;
- Risk of groundwater contamination;
- Risk of groundwater regime changes;
- Risk of impact on mineral water sources;
- Changes in river system;
- Changes of relief by mining and dumping;
- Threat to ecological stability centers;
- Risk to contamination of rocks and soils;
- Dust generation by mining, transport and processing;
- Impact of hazardous noise;
- Anthropogenic seismicity and risk of landslides;
- Anomalous radon risk.

The impact of factors were expressed in 3 categories: high, low and no risk, based on ex-

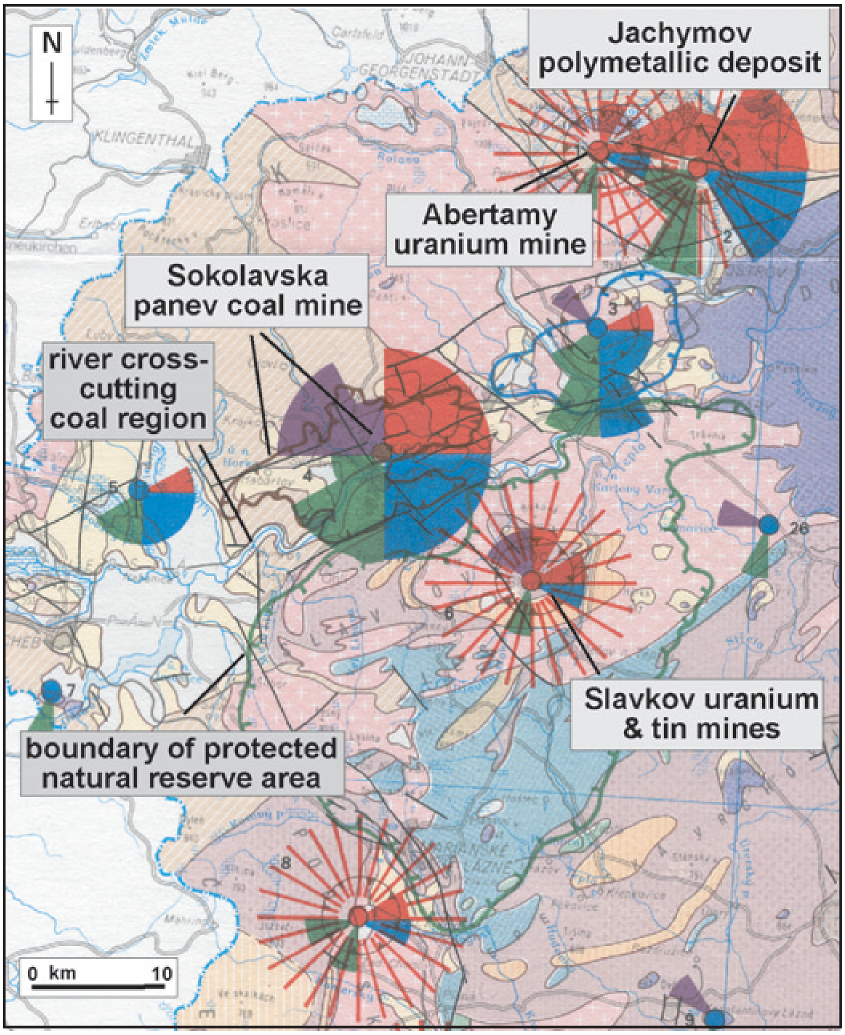

Figure 6. *Environmental impact map.'Impact of Mining on the Environment of the Czech Republic' [76]. Coloured petals show type (angle) and significance (size) of the 13 risk factors.*

pert estimations. ***Figure 6*** shows the Abertamy uranium mine, Jachymov polymetallic deposits, Sokolavska panev coal mines, and Horni Slavkov uranium and tin mines. For the polymetallic and coal mine almost all environmental risks are significant, and the Skalska river just crosscuts the coal mines. The Horni Slavkov uranium mine is situated in the middle of a highly protected natural reserve (green bordered area in the map).

The Polish Geological Institute has developed the high-resolution 1:50,000 scale 'Geological-economical Map of Poland' geo-environmental map series featuring environmental **risks** associated with **mining** [77]. The map series are a cartographic representation of mineral deposit distribution and development against selected elements of mining and mineral processing, engineering geology, nature, landscape and cultural monuments. The aim is the presentation of:

- perspectives and prognosis of deposit occurence,
- classification of mineral deposits and state of their development,
- present and potential natural hazards connected with the mineral deposits, their exploitation and mineral processing,
- selected hydrogeological elements for the groundwater protection purposes,
- objects and areas protected by law,
- conditions of the building subsurface.

They are intended for territorial planning purposes and might be used by the local and regional administration.

The map series consist of (1) the main sheet, (2) comprehensive explanatory text, with tables and complementary maps, (3) physiographic units, geological conditions, major groundwater basins, (4) European nature protection systems, and (5) the mineral deposits computer database. Thematics of the map series is the following: (1) General (administrative borders), (2) Mineral deposits, (3) Environmental classification of mineral deposits, (4) Exploitation, mining and mineral processing, (5) Water, (6) Conditions of building basement, (7) Nature, landscape and historical monument protection, and(8) Sea cost zone.

Based on the detailed pressure, state and impact information, environmental risk assessment is carried out by delineating areas with 'non-conflicted', 'conflicted' and 'very conflicted' resources. This simple scheme enables the identification of areas where mining put the surrounding environment at risk. ***Figure 7*** shows an example where mining is in conflict with agricultural and forest land use.

In spite of the results and approaches presented in the above examples, it seems that inventory, ranking and assessment methods are country specific. The two examples below are given to show that there is a need for experience in the development of harmonised methods for **trans-boundary** environmental assessment between Candidate Countries.

The atlas of 1:500,000 scale **'Geology for the environmental protection and territorial planning in the Polish-Lithuanian cross-border area'** was prepared by the geological institutes of the two countries [78]. This atlas contains (1) geological, geomorphological and neotectonic maps, (2) partial and total multi-element geochemical maps for soils and water sediments, (3) radioecological maps of gamma radiation dose, uranium, thorioum, porassium content, cesium and radon concentrations, (4) groundwater maps with aquifers and

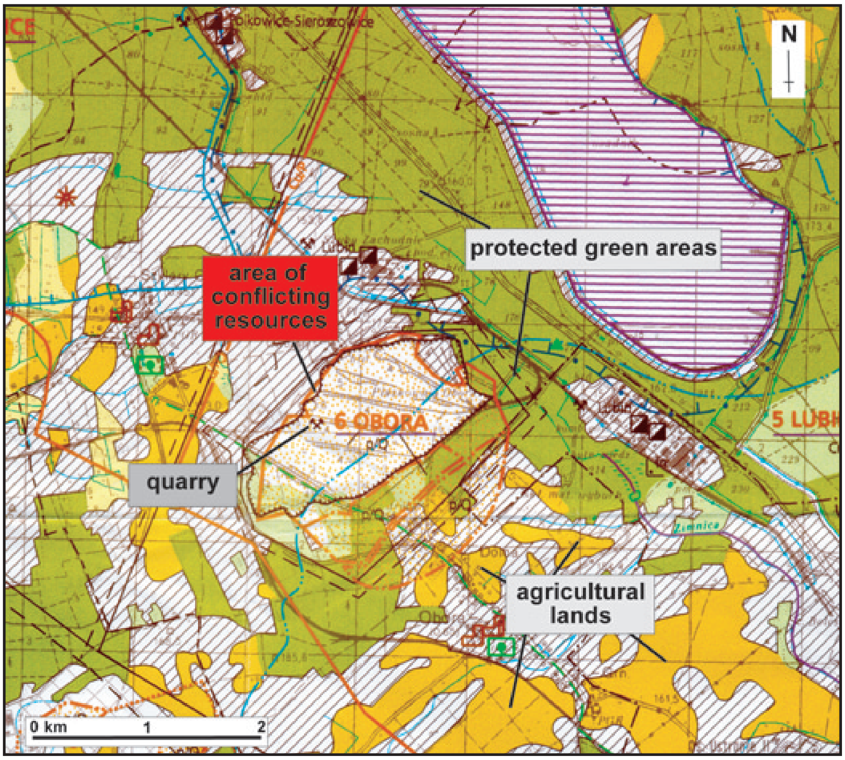

Figure 7.
Environmental risk map.'Geological-economical Map of Poland' [77].

monitoring network, and (5) geo-ecological maps containing mineral deposits and mines, protected areas, land use and environmental hazards. The objective of the atlas is to support spatial management and use of natural resources in an area which is particularly rich in mineral resources and has unique natural value in a still unpolluted environment. The most important are perhaps the concluding eco-geological maps. The 'Map of geo-potential' contains data on mineral and groundwater resources and areas protected by law (***Figure 8***). Also, changes in land use have been interpreted. The 'Map of environmental hazards' (***Figure 8***) illustrates natural threats due to human activity, hazardous object, selected natural hazards, and surface and groundwater pollution. The 'Map of envisaged environmental conflicts' indicates measures to reduce negative human impact.

Another example for environmental map series refers to those produced by the **"Danube Region Environmental Geology Programme" (DANREG)** whose basic aim was to arrange the geological and geophysical data of the border zone of the three partner countries (Austria, Hungary and Slovakia) in a unified framework, in particular along the Danube where the three capitals (Vienna, Bratislava and Budapest) are situated, and to undertake their uniform interpretation to provide assistance to the decision makers dealing with the management and sustainable development of the region [79]. It was its objective to serve as an example for similar international trans-boundary environmental programmes. The project succeeded in providing solutions for the difficult problems of (1) harmonising different projections, (2) harmonising co-ordinate and GIS systems and (3) synthesis of the data that have been produced by survey activities of widely different goals. The map series include a range of various geological thematic maps, neotectonic map, geophysical maps, geothermal potential map, hydrogeological map, engineering geological map and environmental geohazard map.

The 'Map of environmental geohazards' is a complex and multi-purpose map supplemented by a legend and an explanatory text. Coloured planar, linear and point symbols are used to display relevant geological hazards of the Danube region, including (1) natural hazards such as pollution sensitivity, hydrological and hydrogeological phenomena, mass movements, seismicity, erosion and accumulation, and (2) anthropogenic hazards such as deposition (replenishment, waste), **mines**, and subsidence (***Figure 9***). All available information about the selected hazards, in the form of various maps at different scales (ranging from 1:25,000 to 1:200,000) or as databases, aerial and satellite images, together with other DANREG map layers have been used for the geo-hazard map. The sensitivity of the environment (rocks and groundwater) to pollution is pointed out in the map by the five hazard categories:

- very high (permeable rocks on the surface),
- high (permeable rocks on the surface covered by thin aquiclude or less permeable rocks),
- moderate (permeable rocks covered by thick aquiclude or less permeable rocks covered by thin aquiclude or rocks of medium permeability),
- low (rocks of medium permeability covered by thick aquiclude or low permeable rocks covered by thin aquiclude or without cover),
- very low (low permeable rocks covered by thick aquiclude or aquiclude on the surface).

Again, this complex trans-boundary geo-hazard map enables the study of mine hazards in interaction with other hazards such as aquifer pollution sensitivity. The result of the whole programme is a set of thematic maps and their explanatory notes, providing an example of co-operation in a region that is divided into three parts by state borders but is coherent from geological and environmental point of view [79]. One of the main conclusions of the co-operation is that data harmonisation and the systematic use of international standards are essential for efficient support of trans-boundary environmental assessment and resource management in Europe.

Multi-media multi-element environmental assessment at the local, regional, and international scales: methods and results of geochemical mapping in relation to mining

The basis of local and regional risk assessment of mining pollution is the multi-scale, multimedia mapping of pollution baselines in soils, waters, sediments and biota. Geochemical maps have been instrumental in describing spatial risk to human health and ecosystems, as described earlier in this chapter in relation to the state of environmental receptors. Well-documented case studies have proven the need to view geochemical mapping and health issues in global relations (e.g. [9] [12]). Geochemical maps have also been instrumental in the investigation of ecological effects of geochemical background on vegetation [80]. Management of polluted lands around mine sites requires knowledge on the distribution of potentially harmful chemicals, such as radioactive isotopes and heavy metals, as well as the chemical composition of natural environments. Such information is routinely obtained from environmental geochemical maps [81] [82]. Local scale geochemical maps are used primarily for environmental impact assessment of industrial activity and waste disposal on soils, surface and subsurface waters. The trans-boundary nature of receptors of mine pollution emission calls for harmonised international collaboration to support regional risk assessment.

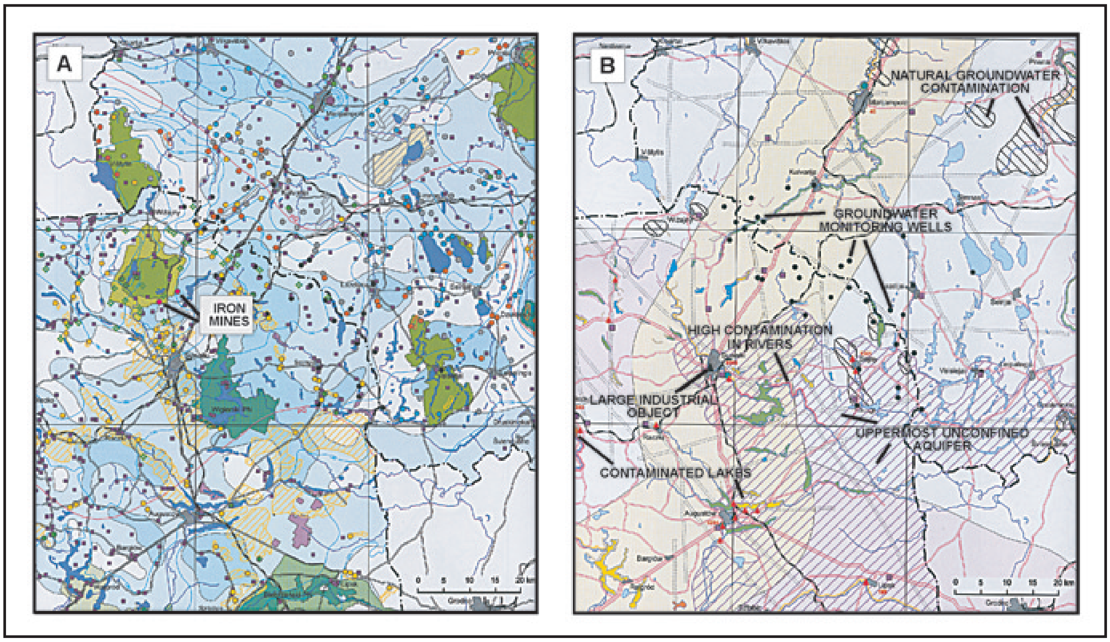

Figure 8. *Trans-boundary geo-environmental maps.'Geology for the environmental protection and territorial planning in the Polish-Lithuanian cross-border area' [78]. A. Map of Geo-potential. Key: coloured circles: mineral resources; hatched areas: mineral (sand, peat, gravel) prospect areas; blue shades: aquifer yields (high, medium, low); purple areas and rectangles: water supply areas; green shade: areas protected by law. B. Map of Environmental Hazards. Key: purple hatch: uppermost unconfined aquifer; coloured river sections: river quality (low, medium, high contamination); Coloured patches: lake quality; other geometric signs: industrial object, water treatment plant, sewage discharge, waste disposal site; thin coloured lines: neotectonic activity, landslides, riverbank erosion, ravine erosion, yellow and pink regions: buffer zones along main roads.*

The **'FOREGS European Environmental Geochemical Baseline Map and Database'** project is the European contribution to the IUGS/IAGC Global Geochemical Baselines Programme [83]. The goal of the Programme is establishing a land-surface global geochemical reference network, providing multi-media, multi-element baseline data for a wide range of environmental and resource applications. The European project groups geological surveys of 26 countries under the auspices of the Forum of European Geological Surveys (FOREGS) to provide the high quality European environmental geochemical baseline maps and database. The main aims of the project are:

- to establish harmonised methods for sampling, analysis and data management,
- the collection and analysis of geochemical materials throughout Europe,
- the preparation of a standardised reference dataset of geochemical baseline data.

According to the recommendations of IGCP 259 (International Geological Correlation Programme: International Geochemical Mapping), Europe was divided into 160 by 160 km grid cells. Stream water, minerogenic stream sediment, minerogenic top soil and subsoil and soil organic layer samples were collected from five randomly selected 100 km^2 catch-

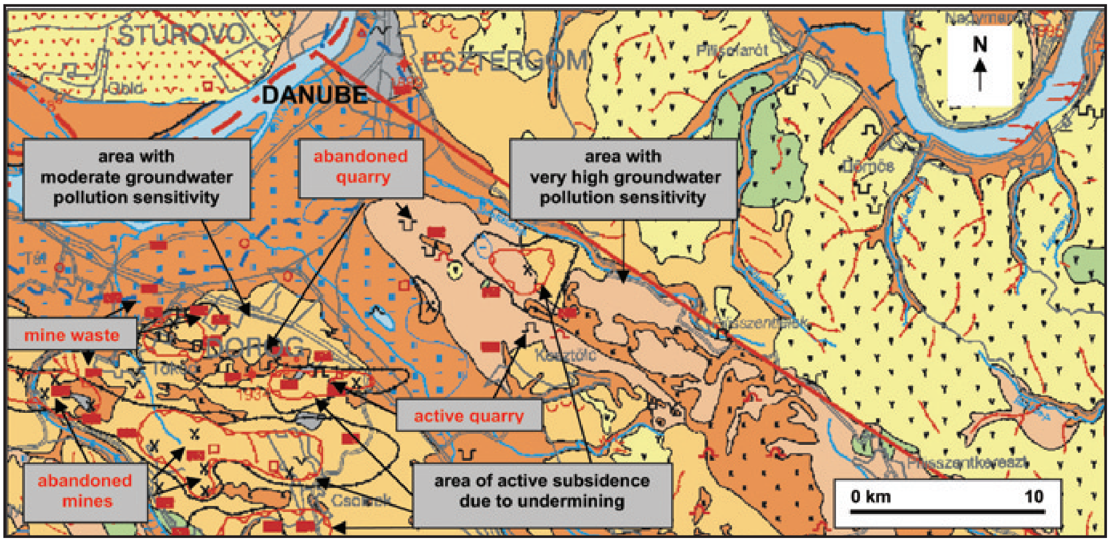

Figure 9. *Trans-boundary geo-environmental maps.'Danube Region Environmental Geology Programme' (DANREG), Map of Environmental Geohazards [79].*

ment areas in each grid cell. Corresponding minerogenic floodplain sediment (the uppermost 25 cm) was sampled from one 1000 km^2 catchment area that includes the 100 km^2 catchment areas. This nested sampling scheme enables the analysis of processes on various scales. Field work was carried out according to the commonly accepted published 'Field Manual' [84]. Samples were analysed for more than 50 elements and other parameters (such as pH and grain size). Both total and aqua regia extractable concentrations were determined from <2mm fraction of minerogenic samples using XRF, ICP-MS and ICP-AES, and total concentrations of organic soil samples were measured after strong acid leach by ICP-MS [85]. Nine laboratories of European geological surveys carried out the analytical work, one sample type was analysed in one laboratory using one method. Altogether some 400 geochemical maps describing the distribution of elements throughout whole Europe are prepared based on the 4,363 samples collected and analysed. All the results and field observations are organised in a common database and the maps will be published as Geochemical Atlas of Europe in 2004. All the sampling sites were photographed and this photo archive, together with detailed field observation database are available, too. Samples are archived for possible future need at the Slovak Geological Survey.

The first results show that the distribution patterns both in surface water and in minerogenic materials are related to large-scale tectonic provinces as shown by calcium, sodium and niobium concentrations of subsoil samples in ***Figure 10*** [86]. The distribution patterns in surface water and floodplain and stream sediment data show large scale pollution, too. Arsenic and heavy metal distribution in organic soil layer samples reveal the most polluted industrialized areas in Europe. In Nordic countries low pH values are due to acid and intermediate rock types in the bedrock where the material of surface deposits were derived during geological processes (***Figure 10***). In Middle and South-Europe carbonaceous sedimentary rocks prevail in large areas giving higher pH values in stream waters, too (***Figure 10***). These multimedia maps indicate the likely regional buffer capacity of rocks, soils and waters against potential mine-induced acidification. This harmonized multi-media multi-element catchment-based approach provides a unique opportunity to develop harmonized water and soil monitoring for European catchments, including mine-impacted areas. Behind the European geochemical maps, the corresponding high-resolution national geochemical maps and databases of FOREGS geological institutes are available as shown by the examples below.

The 1:2,500,000 **Polish National Geochemical Atlas** is based on about 10,000 samples for each media of soil, surface water and water sediments in the country [87] analysed for multi-element content, pH and radiometric properties (***Figure. 11.A***). This survey by the Polish Geological Institute concluded that geochemical composition of each media is determined by underlying rock formations that distinct geochemical patterns between the northern and southern regions of the country. More important is that the mapping identified the regional Pb-Zn-Cd anomaly of the Upper Silesian mining area and the Cu anomaly in soils of the **Glogow-Legnica Copper District** as distinct pollution features (***Figure 11.B***). Based on the national screening survey, a follow-up regional soil geochemistry study for the copper ore mining and smelting area of the Glogow-Legnica Copper District was carried out [88]. The collected 5,677 soil samples along a 1x1 km grid were analysed for multi-element content, pH, particle size, polycyclic aromatic hydrocarbons and radiometric properties. Various soil depths were also analysed around smelters and mines. For data interpretation, geological, land use and land development (mining and other industry) maps were used. This study has shown correlation between heavy metal pollution and grain size and it concluded that elevated contents of some elements (Al, Co, Cr, Mg, Ni, Sc, Sr, Ti and Va) are connected, above all, with the structure of geological substratum. Some elements (such as As, Fe, P, Pb, S, and Va) are concentrated in organic rich sediments due to secondary processes. With respect to mining it is concluded that heavy metal pollution is due to dust emission from smelters as reflected in elevated concentrations in top soils only (***Figure 11. B***). Another follow-up local soil geochemical survey for **Upper Silesian Pb-Zn and Coal Mining Area** was also carried out [89]. The collected 1,279 soil and 318 surface water and sediment samples at the 1:25,00 scale were analysed for multi-element content, pH and particle size. Various soil depth were also analysed around smelters and mines. Here, too, geological, land use and land development maps were used for interpretation. While pollution in the top soil, surface water and water sediment of large rivers was dominated by mining and smelting pollution, lower soil horizons represented natural geochemical background (***Figure 11.C***). Geochemical risk maps constructed for land uses such as arable lands, children's play grounds and sports fields and parks were also derived.

The 1:500,000 scale **Geochemical Atlas of Hungary** shows As anomalies that correspond to natural pollution or industrial pollution in catchments (***Figure 12.A***) [90]. In the Great Hungarian Plain As content in groundwater is higher than the 10 µg/l EU standard due to As-bearing Pleistocene rock formations deep below surface [91], as also reflected by stream sediments in ***Figure 12.A*** Catchments along the eastern border with elevated As in stream sediment are polluted however by upstream **trans-boundary ore mine pollution.** This is also shown in the element association map derived by principal component analysis: the same catchments correspond to typical ore mining heavy metal association (***Figure 12.B***). This geochemical survey also identified polluted lands in catchments due to local and trans-boundary industrial pollution in the north (***Figure 12.B***) [92]. Note that the regional multi-element maps also differentiate between regional geochemical background of siliceous and

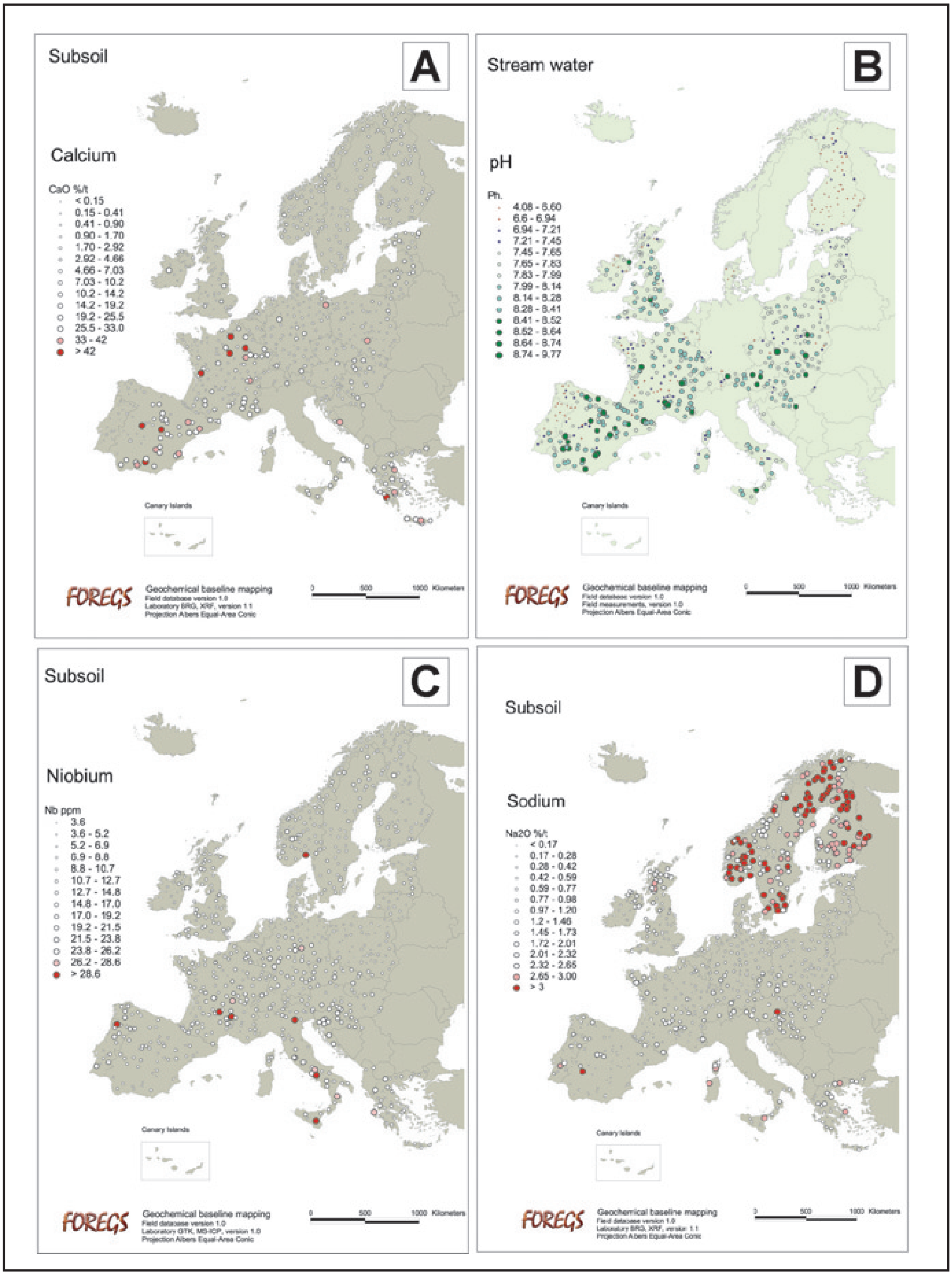

Figure 10. *FOREGS European Environmental Geochemical Baseline Maps [86]. A. Ca concentrations of subsoil samples. B. pH-values of stream water. C. Nb concentrations in subsoil samples. D. Sodium concentrations in subsoil samples.*

carboniferous lithologies. A higher resolution multi-media (surface water, stream sediment and soil) multi-element catchment-based geochemical mapping programme identified natural heavy metal anomalies in the Matra Mts., (***Figure 12.C***) [93]. Results of this study provide the bases for post-closure monitoring and assessment of natural and mine-induced metal pollution in the Matra Mts. historic mining areas. Finally, a high-resolution geochemical survey is shown to demonstrate polluted land assessment in mining regions by geological surveys. Based on the previous larger-scale investigations, the Geological Institute of Hungary carried out detailed geochemical soil survey (upper 15-30 cm layer) along 200x40 m grids

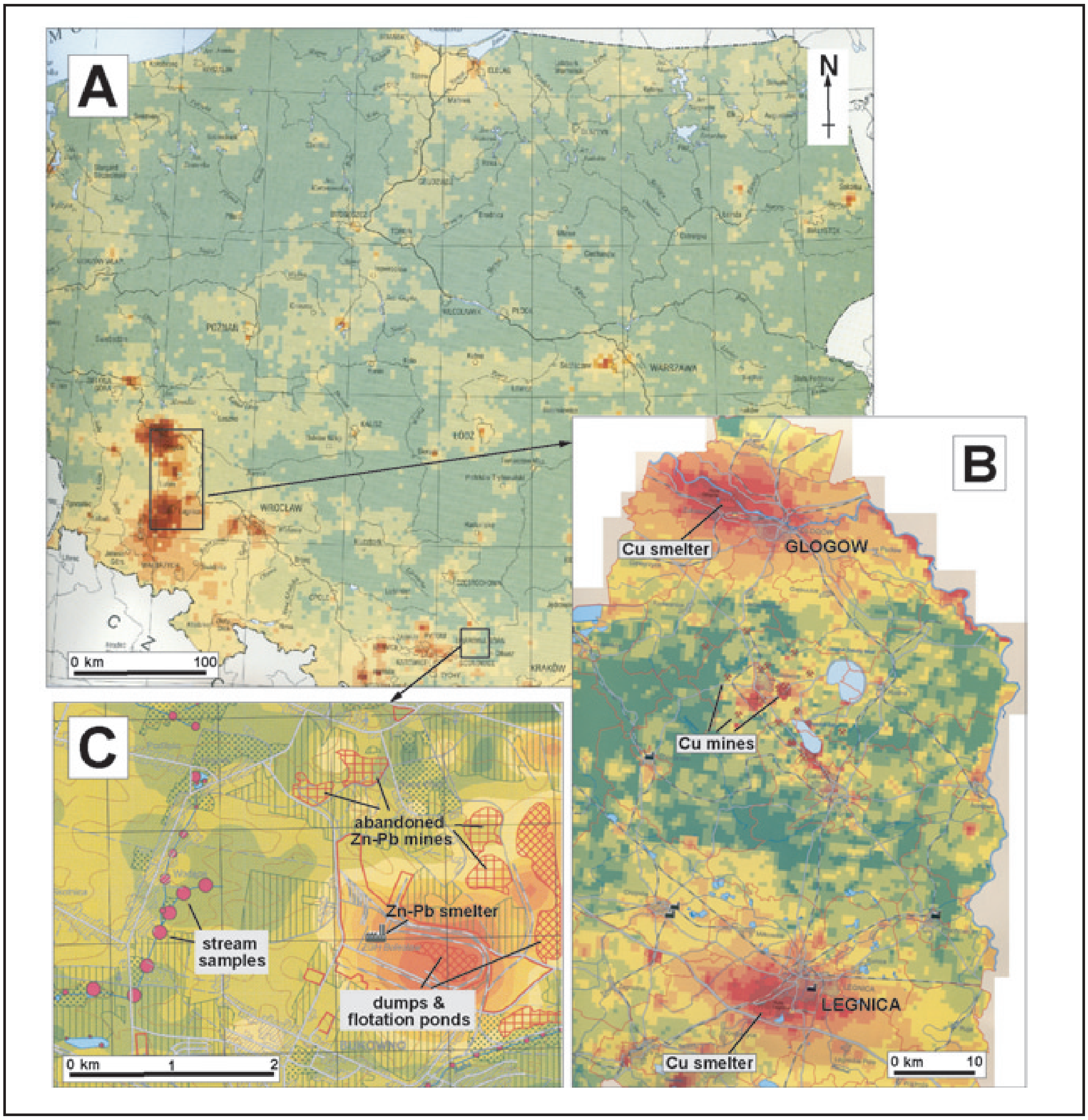

Figure 11. *Multi-scale environmental geochemical survey (Cu) for mining impact assessment, Poland.A. National survey: geochemical map of Poland [87]. B. Regional survey: Legnica-Glogow Copper District [88]. C. Local study: Upper Silesia [89].*

because some metal anomalies could not be interpreted at the larger scales. ***Figure 12.D*** shows an area with As anomaly. Based on this investigation the Institute suggested the area for Au exploration; the area now is in concession for Au mining. More important is the environmental interpretation of the survey. Despite the occasional 2810 g/t As content in the soil vegetation is thriving in the area because As is not available for plant uptake here [94].

Conclusions

The first conclusion drawn from the discussion, together with the introductory chapter [62] and the country reports [56] in this volume, is that environmental assessment of **mining waste must be studied in the context of the whole extractive industry**, including complete material flow cycles and project and product life cycles. Second, there are a number of **features specific to the extractive industries** that must be explicitly addressed by the inventory, impact and risk assessment of mining and mining wastes. This requires a 'holistic' approach to the problem. Although there have been many national and international programmes, most of them focused on one or a few particular problems such as AMD. Non of them has developed tools that would have considered all of the mining-specific problems which is indeed a requisite for risk assessment-based ranking of mine sites. There are a number of 'holistic' approaches available such as LG, LE, IE, GEM, EIA and LCA and there are numerous examples for their application to mining and mining waste assessment. However, non of these approaches has been used for the systematic inventory or ranking of mine sites.

Examples from the **Candidate Countries and trans-boundary programmes for inventory, ranking and environmental assessment of mining** shows that there have been significant efforts and results of complex approaches to the mining problem. Common in all of them is that they **study mining in the broad context of environmental hazards, impacts and risks** and they integrate mining and environmental data in a consistent way. They analyse mine waste in the context of the extractive industries as a whole and study mine waste in the complete mine life cycle. There are examples for the consideration of data and knowledge uncertainty in risk-based ranking, and for the consideration of potential impacts of prospective deposits. They all agree in that mines have to be studied together with deposits and the spatial aspect of hazards and impacts is one of the most important aspects of environmental assessment of mines. Together with trans-boundary programmes and the FOREGS European Environmental Geochemical Mapping activities, these examples show that European **geological institutes** have a long experience in harmonisation of environmental data collection, interpretation and evaluation for mining and associated contaminated land assessment.

It can be concluded that the comparison of trans-boundary and country specific efforts shows the basic differences in approaches. The countries have established the problem-oriented methodologies for inventories and ranking, based on their specific problems and research traditions. **The approach used in one country cannot be easily converted into another**. Systems of ranking have been established in some of the countries. These ranking systems have been developed for certain type of objects or mined commodity (for example dams in Romania, old metal mines in Slovakia, uranium mines in Bulgaria). Also, definition of hazard, impact and risk, and their mapping and evaluation are country specific. For the inventory, risk assessment and ranking of mine waste sites there are several ap-

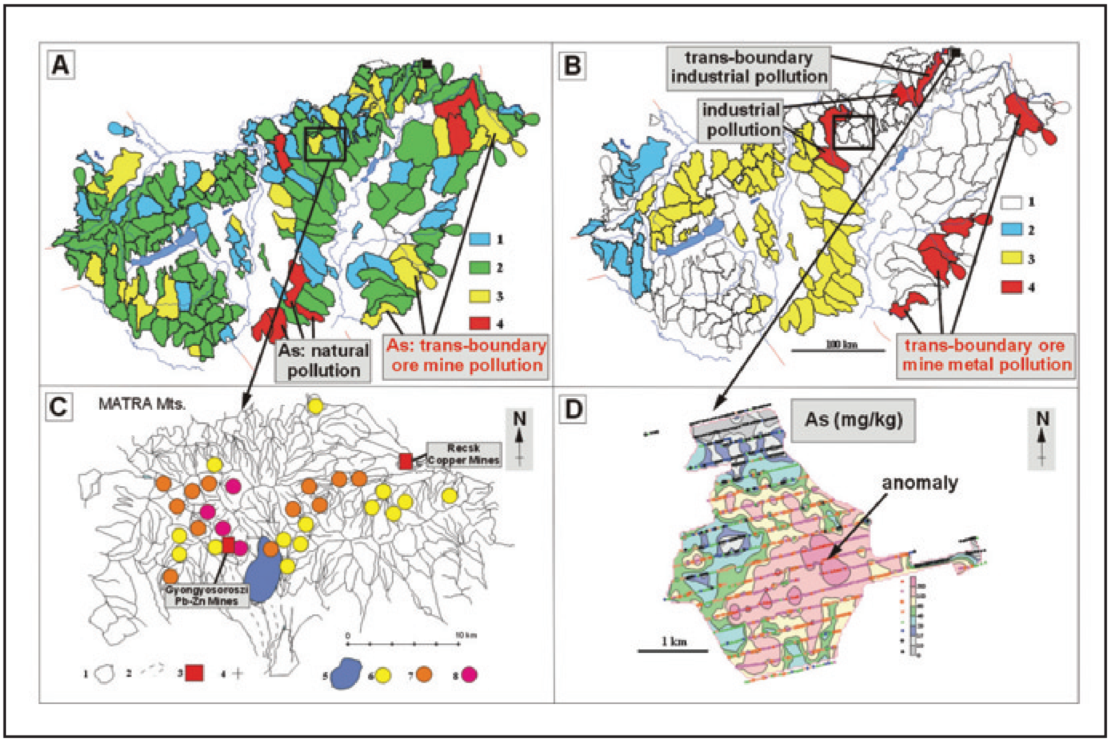

Figure 12. *Multi-scale environmental geochemical survey, an example in Hungary. A. Regional survey: geochemical atlas of Hungary, As content in stream sediments [90]. B. Geochemical atlas of Hungary, regional element associations in stream sediment [90]. 1: no association; 2: Co, Cr, Ni; 3: Ca, Mg, Sr, (and SO_4); 4: Ag, As, Au, Cu, Pb and Zn. C. Combined anomaly map of the stream sediment survey based on Pb, Zn, As, Cu and Cd at mineralisations in the Matra Mts., Hungary. 1: drainage basins; 2: location of the detailed investigations; 3: abandoned ore mines; 4: Asztagko Hill; 5: low-temperature hydrothermal mineralization zone; 6: poorly prospective; 7: prospective; 8: with proven ore mineralization or strongly prospective [93]. D. High-resolution geochemical survey at mineralizations. Natural As anomaly at the Korom Hill, Hungary [94]. Sample locations along transects are shown. See text for details.*

proaches available but none of them alone can satisfy the needs of mine waste assessment. It is therefore **necessary to harmonize results** of international programmes, general methodologies and national approaches in a uniform approach that can address the problem of standardized inventory and risk-based assessment and ranking of mine waste sites, including the assessment of old abandoned mines and impacts of accidents.

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