3 *Mining & Environment*

Assessment of Open Pit Coal Mining Impacts Using Remote Sensing: A Case Study from Turkey

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ABSTRACT: The environmental impacts of coal mining are many and diverse. However, coal is an essential source of energy in meeting the requirements of the existing and growing industries of a *country*. Damage to the environment is usually seen as an unavoidable consequence of maintaining national development It is also desirable to optimize and minimize environmental impacts by adopting proper mining techniques. Therefore, it is necessary to have quickly accessible, cost-effective, multi-temporal information regarding the area's environmental status. Remote sensing technology affords a viable means of analyzing the changing conditions at mine sites. In this study, multi-temporal Landsat TM data sets from the Soma coal basin were subjected to a number of digital image processing techniques to assist in identifying and monitoring the environmental impacts. The application of digital image processing proved to be an effective means of analyzing the multi-temporal data set

1 INTRODUCTION

The environmental impacts of coal mining are many and diverse. Mining operations cause degradation of the land, loss of forest, topsoil and agricultural land, changes in topography and hydrologie conditions, and the pollution of useable surface and ground water. However, coal is an essential source of energy İn meeting the requirements of the existing and growing industries of a country. Damage to the environment is usually seen as an unavoidable consequence of maintaining national development It is also desirable to optimize and minimize environmental impacts by adopting proper mining techniques, rapidly reclaiming the already damaged parts and identifying the areas vulnerable to environmental damage in the near future. All these need quickly accessible, synoptic, cost-effective, multi-temporal information regarding the research area's environmental status (Chatterjee et al. 1994).

Remote sensing technology affords a viable means of analyzing the changing conditions at mine sites. In addition, the information derived from these data provides a means of assessing environmental compliance and can serve as evidence during litigation.

The Soma coal basin, which has been subject to both open pit and underground mining for more than 60 years, was chosen as the "case study area" for the present study. Multi-temporal Landsat TM data sets from the Soma coal basin were subjected to a number of digital image processing techniques to assist İn identifying and monitoring environmental impacts. Smce it was impossible to find geochemical data for the available satellite images, the research only dealt with the topographic and vegetation changes due to mining operations.

2 RESEARCH AREA

The Soma coal basin lies in the province of Manisa in western Turkey. It is 90 km from Manisa city center and 80 km from Balıkesir city center (Figure 1). The average elevation of the basin from sea level İs around 160 m. The coal basin is composed of three main districts, namely, Soma, Deniş, and Eynez. In this study, southern open pit mines of Aegean Lignite Establishment (ELİ), one of the establishments of the state-owned Turkish Coal Enterprises (TKİ), were studied.
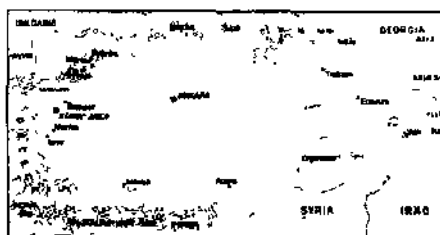

Figure 1. Location of study area

Lignite deposits from the Mesozoic, Tertiary (Miocene and Pliocene) and Quaternary ages are present in the area. Miocene lignite has been mined İn the area since 1939 by ELİ. The total reserve of the area is about 600 million tons, and annually about 10 million tons of lignite is mined from the open pitsofELt.

3 DATA ACQUISITION AND METHODS

3.1 *Preparation of Ancillary Data*

The research area (15.6 km width by 19.8 km length) was determined from six topographic maps of the region (1,000-m Universal Transverse Mercator grid, zone 35, international spheroid, scale 1/25,000, printed in 1978) and then the topographic contour lines of this area were scanned using an A0-sized scanner. Using eight GCPs for each map, six topographic maps were geo-referenced with the projective transformation method that is recommended for scanned materials. To digitize the contour lines, an on-screen digitizing method was used. In this method, a transparent layer is laid over the geo-referenced topographic maps, each topographic contour line is drawn using the mouse, and then the contour value is given. Using this method, 1079 topographic contour lines were digitized with an increment of 10-m contour lines. After the digitizing operation, the minimum contour value of the region was found to be 80 m, whereas the maximum contour value of the region was 1210m.

A digital elevation model (DEM) is a regularly spaced grid covering a surface area, with elevation values associated with each grid location. The DEM, therefore, provides a general model of the earth's surface which becomes more accurate as the distance between grid points decreases. Gridding produces a regularly spaced array of z (e.g., height) values from irregularly spaced xyz data. It does this by extrapolating or interpolating z values at the regularly spaced locations where the data is missing. In this research, using the ERMapper 6.1 software "gridding wizard", me DEM of the region was obtained for 10-m pixel size. To increase the accuracy of the operation, spot heights of the region that are shown on the topographic maps were also digitized and used during the gridding operations.

Any data shown in 2D can also be shown in 3D, provided a suitable height component can be used. A digital terrain model (DTM) of the region was obtained using the ERMapper 6.1 software "3D algorithm". This is shown in Figure 2. In this figure, red is used to indicate high locations, and blue to indicate low locations.

During this research, the drainage network of the region was digitized from the topographic maps. In addition, the geology of the region was obtained from the General Directorate of Turkish Coal Enterprises and scanned using an A4 flatbed scanner. Then the map was geo-referenced and, using the on-screen digitizing method, die geological units and faults of the region were digitized.

Figure 2. DTM (3D view) of the Soma region.

3.2 *Image acquisition and preprocessing*

Landsat Thematic Mapper (TM) images of the area were acquired in the years 1989 and 1999 (path 181, row 33). Atmospheric correction of the Landsat TM images was necessary so that the change detection method employed in this investigation could be used (Singh 1989). During this research, the darkest object subtraction method was used to correct atmospheric effects.

In order to analyze imagery from different dates, the data layers must be spatially co-registered so that the ground measurements and satellite data are in the same spatial reference frame. Image registration was carried out by locating a certain number of ground control points (GCPs) in both images. The latitude and longitude of the GCPs were determined from accurate base maps. The differences between the actual GCP locations and their positions in the image are used to determine the geometric transformations required to restore die image. A nearest-neighbor algorithm was used to resample the corrected images to 30-m pixel size, resulting in a 5.7-m RMS error based on die GCPs.

3.3 *Image enhancement andxlassification*

After preprocessing of the satellite data, several image enhancement methods were applied in order to differentiate die classes. After the visual interpretation of different band combinations, we were able to estimate most of the classes in me region.

RGB32I: This algorithm is a natural color scene comprising Landsat TM bands 3, 2, and 1 (approximately equal to red, green, and blue visible light) imaged in the red, green, and blue computer monitor guns respectively. The composite is not totally natural because the Landsat TM bands do not exactly match the red, green, and blue spectral regions; bands 1 (blue visible) and 3 (red visible) have lower spectral ranges Üran those which the eye recognizes

462

as blue and red. This image looks partly realistic but there is an apparent absence of green vegetation. The "greenness" response of plants is not a very strong one (compare the reflectance of vegetation in the green visible range, 0.56 *p.m.,* Landsat TM band 2), but the human eye is most sensitive to green (it has many more cones sensitive to green) and therefore magnifies the response relative to blue and red. This image combination has lower spatial resolution due to band 1 and has limited spectral diversity since no reflected IR bands are used. Landsat TM RGB321 views of the Soma region (for both 1989 and 1999) are shown in Figure 3.

Figure 3. Landsat TM RGB321 views of the Soma region {1989 on the left, and 1999 on the right).

RGB432: This algorithm is a false color image, usually referred to as standard false color. In this image, Landsat TM band 4 is assigned to the red layer, band 3 (0.66 um, visibİe red) İs in a green layer and band 2 (0.56 um, visible green) in a blue layer. The result of this RGB color composite İs that the high reflectance of vegetation (0.83 u.m, TM band 4) makes vegetation appear red; red features, such as Fe-rich soils appear green, while green features appear blue. This false color image is generally the one used to evaluate a particular image for a variety of resource-based applications. People interested in vegetation can see the location and density of vegetation; people interested in geology can make the same determination - and avoid the over-vegetated images. This algorithm has moderate spatial resolution, whereas it has limited spectral diversity. Landsat TM RGB432 views of the Soma region (for both 1989 and 1999) are shown in Figure 4.

Figure 4. Landsat TM RGB432 views of the Soma region (1989 on the left and 1999 on the right)

RGB74I: This İs a false color image widely used for geological applications. Landsat TM band 7 is assigned to a red layer, band 4 to a green layer and band 1 to a blue layer. The advantage of the RGB741 algorithm is that we achieve better color separation, improving detail and information. A second advantage is that certain mineral groups of interest have distinctive spectral features İn Landsat TM bands 7,4 and 1. In band 1, iron-bearing minerals have low reflectance, whereas phyllosilicates, quartz, and other light-colored minerals have high reflectance. In band 7, phyllosilicates and carbonates have absorption features, whereas hematite and, to a lesser extent, goethite have higher responses. Therefore, the RGB741 composite allows a certain degree of lithological interpretation. Hematite-rich rock and soil is red, quartzites generally appear blue to blue-green because they are light in color and have no iron, while limestones generally appear pale blue or lavender because of the absorption of carbonate in band 7 and their general pale color (high in the blue gun of the computer monitor). Various cements and fracture fillings also add to the spectral responses. Fireburn scars, particularly recent ones, appear red and may be confused with hematite-rich areas. In mis algorithm, coal is generally purple, highly reflective surfaces are white, water is blue, and overburden is gray. Landsat TM RGB741 views of the Soma region (for both 1989 and 1999) are shown İn Figure 5.

Figure 5 Landsat TM RGB74l views of the Soma region (1989 on the left and 1999 on the tight).

RGB view of principal components (PC) 1,2,3: This algorithm generates PCI, PC2, and PC3 and displays them as an RGB image, which is generally used for alteration mapping. The principal component analysis operation is a mathematical method to uncover relationships among many variables and to reduce the amount of data needed to define the relationships. With principal component analysis, each variable (input map) is transformed into a linear combination of orthogonal common components (output maps) with decreasing variation. The linear transformation assumes the components will explain all of the variance in each variable. Hence, each component carries different information that is uncorrelated with other components. Principal compo-

nent analysis results in linear transformation of a set of (satellite) raster maps into a set of output raster maps, each explaining a common component in the input raster maps. The number of output raster maps is taken as identical to the number of input raster maps so as to enable the user to determine the actual amount of reduction. The output raster maps are listed in decreasing order of variance. This enables the reduction of maps because the last transformed maps have little or no variation left (they may be virtually constant maps), do not add significance to the common components, and may hence be discarded. Principal component analysis can be used for several purposes, e.g., data compression, the pre-processing procedure before classification of the data, and finding targets of interest. It is also possible to generate a PCI, PC2, and PC3 image using only Landsat TM bands 7, 4, 1 of the Landsat TM data. Since these bands show mineralogy, this can be a good image for highlighting geology. RGB view of Principal Components of Landsat TM Bands of 741 (1989) is shown in Figure 6.

Figure 6. RGB view ot Principal Components of Landsat TM Bands of 741(1989).

Landsat TM images over DTM: This operation drapes Landsat TM satellite imagery over DEM data to provide a combined view with height from the DEM and color information from the Landsat TM data. Since Landsat TM has a 30-meter ground resolution per pixel, this type of view is only good for large regional overviews. The research area (for both 1989 and 1999) was modeled in 3D using satellite imagery as shown in Figure 7.

Vegetation NDVI: NDVl (normalized difference vegetation index) is a commonly used vegetation index that transforms multi-spectral data into a single image band representing vegetation distribution. The NDVI values indicate the amount of green vegetation present in the pixel, where higher NDVI values indicate more green vegetation. NDVI values range from -1 to 1. Vegetated areas will generally yield high values because of their relatively high near-infrared reflectance and low visible reflectance. In contrast, water, clouds, and snow have larger visible

reflectance than near-infrared reflectance Thus, these features yield negative index values. Rock and bare soil areas have similar reflectance in the two bands and result in vegetation indices near zero.

In this algorithm, red is used to indicate high NDVI values, and blue to indicate low NDVI values. Figure 8 shows die NDVI views of the Soma region (for both 1989 and 1999).

1 igure 7 RÜB542 Landsat TM images of the Soma region over DTM (1989 on the top and 1999 on the bottom)

Figure 8 NDVI views of the Soma region (1989 on ihetopand 1999 on the bottom)

In this figure, it is very easy to see the vegetation changes in the region. The mining area (blue area at the center of the images) changed rapidly over the 10-year period (from 1989 to 1999) and a huge spatial increment occurred in the mining area. In addition to this, an increment was also observed İn regions of high vegetation density (red-colored areas). GPS (Global Positioning System) measurements made during field trips, maps of the Ministry of Forestry and data obtained from the General Directorate of Turkish Coal Enterprises confirmed

464

these changes. During tree plantation works started by the Ministry of Forestry in 1995, approximately 25,000 pine trees were planted in the region, and the General Directorate of Turkish Coal Enterprises planted the landslide and old dumping sites. NDVI maps also showed the increment of the cultivated areas around Bakır Çay. Table 1 shows the classified NDVI values of the Soma region (308.88 km^2).

Table 1 Classified NDVI values of the Soma region.

NDVI		1989	1999	CHANGE
Lower Value	Upper Value	(%)	(%)	(%)
0.8	1.0	0.14	8.62	8 48
06	0.8	7.58	24 30	16 72
04	0.6	21.59	21.31	-0 28
0.2	0.4	26.60	20.75	-5.85
0	02	29 72	17 17	-12 55
•02	0	12 35	7 75	-4 60
-0.4	-0.2	1.62	006	-1.56
-0.6	-04	0 29	0.02	-0 27
-0 8	-0.6	0.06	0.01	-0 05
-10	-0.8	0.05	0 01	-0.04

As can be seen in the table, during the 10-year period (from 1989 to 1999), vegetated areas (having positive NDVI values) increased about 6.52% (approximately 20 km^2), especially highly vegetated areas (NDVI values greater than 0.6) increased about 25.2% (approximately 78 km^2). These values support the increase in vegetation density and tree plantation works in the region.

Detailed investigations conducted in the field showed that the calculated NDVI clearly depicted areas of dense vegetation. However, the applied index was not successful in separating areas with sparse vegetation. Mining areas are characterized by low levels of vegetation cover. Most of the mining sediments vary İn texture,' oxidation crusts, and coaly particle content. The color differs from light gray through mid and dark gray to black depending on the coal content. A low coal content has a strong influence on the color and therefore on the spectral reflectance. The brightness of the mining sediments has an impact on the vegetation index. In this study, we suspect that this is the reason for the unsatisfactory results. The NDVI values were lower in the open pit mining areas than in the already reclaimed areas, even when both areas had the same type of vegetation and the same percentage cover.

Classification: Unsupervised classification is of maximum utility in classifying images where limited field information İs available for accurate location of training sites or where a large number of spectral classes are present. Where numerous scenes are to be classified with few terrain classes of interest and where field information is available to assist training, a supervised classification is most suitable in mined-land applications (Rathore & Wright, 1993).

In this study, the maximum likelihood method was chosen. This method is the most commonly used supervised classification method (Schmidt & Glaesser, 1998). This algorithm provided the most promising results. The maximum likelihood classification assumes mat spectral values of training pixels are statistically distributed according to a 'multivariate normal probability density function'. For each set of spectral input values, the distance is calculated towards each of the classes. If this distance is smaller than the user-defined threshold value, the class name with the shortest distance is assigned; otherwise, the undefined value is assigned.

During this study, firstly, 30 control points for supervised classification were obtained in the field using Garmin 12-type hand GPS. After inspection of the photographs and camera views recorded during the field trips, using vegetation maps of the region obtained from the Ministry of Forestry, five main classes were determined in the area: mining area, forest, cultivated area, bare soil, and urban settlement. Then, training sites that carry the characteristic features of these classes were defined using the software. Each Landsat TM image had its own training sites. This was necessary because of the high temporal variability of the region.

After the maximum likelihood classifier was applied for several band and data combinations, the results were compared with the ancillary data in order to assess the accuracy. Some classes could not be identified from Landsat TM data when using just some of the bands. Because of the spectral heterogeneity of the surface mine areas coupled with their spatial complexity, the spectral resolution achieved by using selected bands was not enough to classify all mine and reclaimed features with satisfactory accuracy. The use of all Landsat TM bands (except band 6, i.e., the thermal band) gave the best results for all classes together. Land cover maps of the region, for both 1989 and 1999, were created (Figure 9 and Figure 10 respectively).

It was found that computer processing of data by itself was inadequate for accurate determinations of active mine boundaries or areas of coverage. This was primarily due to the fact that a number of other features such as road cuts, construction sites, and agricultural fields produced very similar signatures. Many features of small aerial extent (smaller than a Landsat TM pixel) were not extracted by the classification. Table 2 shows the results of the classification of all classes and their temporal and spatial changes.

Figure 9. Land cover map of the Soma region (1989).

Figure 10. Land cover map of the Soma region (1999)-

Table 2. Results of classification.

CLASS	1989		1999		CHANGE	
	Area (km^2)	Ratio 06)	Area (km^{-1})	Ratio (%)	Area (km^1)	Ratio 1%)
Bare Soil	101.35	33.14	90.85	29.76	-10 50	-3.38
Cultivated	55.43	17.86	18.23	5.87	-37.20	-11.99
Forest	103.33	33.29	120.93	38.96	17 60	5.67
Mining Area	14.70	4.74	41.00	13.21	26 30	8.47
Urban Settlement	34.07	10.97	37.87	12.20	3.80	1.23

As can be seen in the table, mining activities in the region increased about three times in the 10-year period (from 1989 to 1999). During this period, bare soil decreased by about 10.5 km, whereas forest increased about 17.6 km due to the tree plantation work conducted by both the General Directorate of Turkish Coal Enterprises and the Ministry of Forestry. Due to the mining activities and industrial developments in the region, urban settlement also increased. Although it seems from the table that cultivated areas decreased dramaticaHy (by about 11.99 km), the figures show that most of the cultivated areas were changed into forestry.

4 CONCLUSIONS

One of the most obvious and major impacts of surface mining is severe land disruption and degradation. Periodic mapping and monitoring of the aerial extent and location of this degradation can be of vital importance in formulating strategies for reclamation once mining has ceased.

A review of the literature indicates that satellite and aerial remote sensing data have been widely and effectively used to monitor the environmental effects of surface mining activities. There is evidence, however, to suggest that increased spatial resolution of Landsat TM does not necessarily ensure increased classification accuracy, as higher spatial resolution leads to increased spectral variability, which in turn may hinder accurate classification.

Landsat TM and other satellite remote sensing data are useful for the investigation and monitoring of lands devastated by open pit mining activities. The results of this work show the cost- and time-effective opportunities of using high-resolution satellite data for monitoring surface mining and reclamation processes in Turkey. In comparison with conventional data acquisition and interpretation methods, satellite images are a good data source with useful temporal resolution. The spatial complexity and the spectral heterogeneity of the surface mine areas made the application of the satellite data more difficult. However, the main surface mine and reclaimed features were detected and monitored by means of Landsat TM data.

In summary, the potential of satellite remote sensing for monitoring lignite open pit mines is much higher than has been recognized thus far. However, remote sensing will not replace conventional methods entirely. The combination of space-borne and air-borne remote sensing and conventional methods will provide a useful and cost effective tool for monitoring devastated lands over a longer period.

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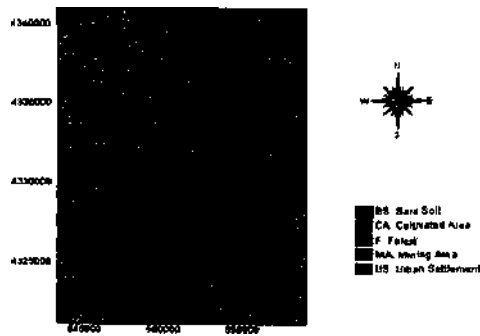
Rational Use and Environmental Impacts of Oil Shale Mining in Estonia

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ABSTRACT: In Estonia, oil shale is produced by underground and surface mining. The excavation methods used cause serious damage in the environment, especially the topography, which hampers further use of mined-out areas. Oil shale mining also has a serious impact on the environment due to the pollution of surface and groundwater by polluted mine drainage waters, lowering of the groundwater level, changing of soil properties and high level of air pollution. Another serious problem relates to high mining losses. The decline in mining activities and the introduction of new technologies together with economic measures have improved the situation, but much needs to be done in the coming years.

1 INTRODUCTION

The Estonian oil shale deposit (Fig. 1) is the largest commercially exploited oil shale deposit in the world; its total resources exceed 7 billion tonnes. The resource of the prospective Tapa deposit is about 2.6 billion tonnes. The Baltic Oil Shale Basin, covering ca. 50 000 sq. km, is situated mainly İn northeast Estonia with part of it extending eastward into Russia. Oil shale has been mined in Estonia since 1916, with a maximum annual output of 31.3 million tonnes in 1980 (Fig. 2). During more than eighty years, about 870 million tonnes of oil shale has been mined (together with a lost 1.6 billion tonnes). Currently, oil shale is mined in six underground mines and in three opencast pits with an annual output about of 10 million tonnes. The main oil shale sequence is of Middle Ordovician (Llandeilo - Early Caradoc) age. It contains up to 50 laterally continuous seams alternating with limestone layers. Oil shale layers thin or die out towards the peripheral parts of the deposit This is accompanied by a decrease in the kerogen content. The highest productivity (conditional fuel per sq. m) has occurred in the northern part of the Estonian mining area between Kukruse and Jôhvi (1.5 t/sq. m). Here, the calorific value of oil shale is 10-12 MJ/kg. At the outer boundary of the deposit the calorific value is 1.7 times lower, and the yield about 3 times lower (Bauert and Kattai, 1997). With the southward dip of the layers, the depth of the commercial bed increases to 100 m, which hampers the mining. As a result, the prime cost grows abruptly towards the periphery of the area. Due to the dewatering of oil shale mines, the groundwater level of Quaternary and Ordovician aquifers in the oil shale basin has fallen by 15-65 metres, and several local cones of depression, influencing each other, have formed over an area of 600 sq. km (Vallner, 1997).

2 BRIEF OVERVIEW OF MINING TECHNOLOGIES

The first oil shale mines were located İn areas where it was either exposed on the ground or it occurred relatively close to the surface and therefore mainly opencast mining was used. In earlier times, underground mining was introduced in areas where the thickness of overburden exceeded 5-8 metres; now it starts from several tens of metres. The technologies used exert a substantially different effect on the topography and water regime. The cavities generated by subsurface mining cause deformations that reach up to the surface and hamper further use of the mined-out areas. In Estonian underground mines, oil shale has been produced by pillar and double stall mining, double face longwall stall mining, fully mechanised narrow web underline mining in the longwall stall system and room pillar mining (Toomik, 1999). In all cases, the mining plot is rectangular in shape. Therefore, after mining a new artificial topography is formed on undermined areas, where the small hollows alternate with hillocks. In places where the Quaternary cover

contains loamy deposits, the surface water accumulates in such hollows and the land use is limited

As a result of opencast oil shale mining, the area of quarries covered with waste rocks increases by several hundred hectares annually. Of a total of 10,000 hectares spoiled by mining activities, most has been reclaimed and reforested. Some hundred hectares have been returned to agricultural use, but such areas are far from being of top quality.
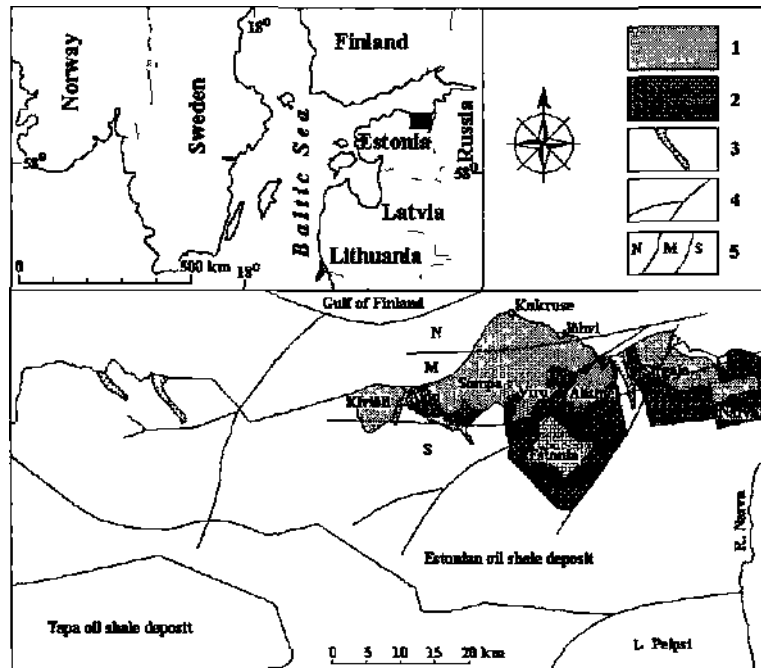

Figure   location map of Estonian and Tapa oil shale deposits
1 - oil shale mines and open pits, 2 - claims and names of mines and open pits, 3 - buned valleys, 4 - tectonic faults, 5 - water regime regions N-northem, M-middle and S-southem
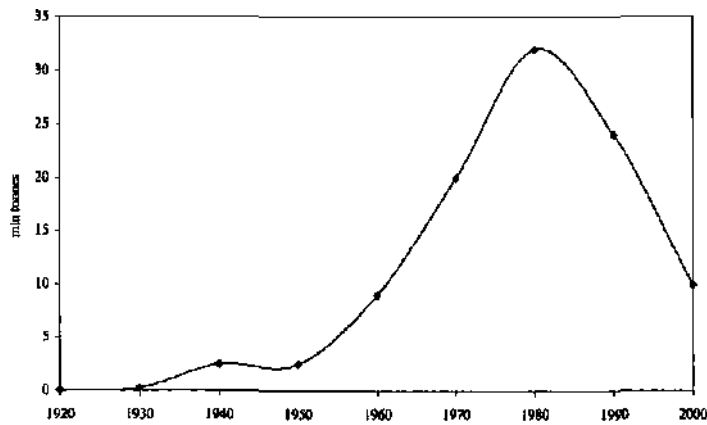

Figure 2 Consumption of oil shale in Estonian oil shale deposit

3 LOSSES AND USAGE OF OIL SHALE

During the last decades, a serious problem has occurred relating to high mining losses. To support the roofs of mining shafts, up to 30% of mineable oil shale has been left intact as pillars. Supplementary losses occur during the hauling and benefaction steps, increasing the net losses to as high as 50%. The vigorous intensification of agriculture and industry during Soviet occupation was accompanied by a sharp increase in the exploitation of mineral resources and mining losses were not the top-priority problems. Over the years 1945-1990, the population of Estonia increased some 1.4 times, the number of workers and employers 3.8 times, industrial output 4.2 times, the production of mineral resources 15 times, and the generation of electric power 100 times. Great losses in mining and concentrating are due to the complicated structure of the productive layer. Some layers remain unmined because of their inconsiderable thickness, or because of thick limestone interlayers or high content (up to 50 per cent) of limestone concretions. The most effective step in minimising production losses would be the application of <u>mining</u> technologies that would enable the excavation of all oil shale layers to their full length. Therefore, in the Estonian National Environmental Strategy (Estonian... 1997), opencast mining is recommended whenever possible. A revision of consumer claims for the quality of oil shale might also contribute to rational utilisation of oil shale reserves. Attention should also be paid to studies concerning the technological possibilities of burning and processing oil shale with low calorific value.

The Baltic Thermal Power Plant (project capacity 1624 MW) and the Estonian Thermal Power Plant (project capacity 1610 MW) are the main oil shale consumers. Together with some smaller local power plants, they use more than 80% of the mined oil shale. About 15% of the mined oil shale is used for crude oil retorting. The number of various products derived from crude oil totals about fifty. The retorting of oil shale and upgrading of shale oil to commercial products also have a severe impact on the surrounding environment.

4 ENVIRONMENTAL CONSEQUENCES

The majority of Estonia's mineral resources, particularly oil shale and phosphorite, are concentrated in the northeast Estonia region. In this densely inhabited agricultural and industrial area the interests of different institutions are in conflict. Unfortunately, in this area, with weak natural protection against pollution, the human impact has already led to undesirable changes. Oil shale mining has exerted great influence, not only on the topography, but it has also polluted surface and groundwater. In waste dumps near benefaction facilities, the residual organic matter is prone to self-ignition, polluting the air. In this paper, we shall concentrate on the problems of water pollution, most dangerous İn the area with thin Quaternary cover.

Due to the excavation of the oil shale, the water regime is upset: the groundwater begins to move concentrically towards the excavation cavities. The irregular spreading on industrial oil shale in the carbonate rocks mainly causes a comparatively big and uneven influx of water into the mines and open pits. The Ordovician aquifer is mainly replenished by infiltrating atmospheric precipitation, by water from water basins and water pumped out of the mines. The process is facilitated by the spatial irregularities in the hydraulic properties of the rocks, the rather thin layer of the Quaternary sediments and the shallow depth of the oil shale deposit.

Different excavation methods cause an increase in "technological" fissures (fissures caused by explosions during excavation) and in the drainage of the Ordovician aquifer, especially the Keila-Kukruse layer (Fig. 3). When forecasting water influx, one must take into account natural as well as mining conditions, especially the development of excavation cavities during the exploitation of the bed. The following equation has been used to calculate the water balance:

$$\sum I - \sum O = \Delta S$$

where the inflow $\sum I$ includes all forms of recharge, such as: seepage from streams, ponds and lakes; subsurface inflows; and infiltrated precipitation. The total outflow $\sum O$ includes every kind of discharge, such as subsurface outflows, évapotranspiration, abstraction of mine water, etc. ΔS represents the change in storage during the period studied.

Research shows that approximately 90-95% of the influx comes from the surface, which includes the atmospheric precipitations, together with infiltration of the water pumped out in the regions of erosion and technological fissures. Only 5-10% of it originates from the industrial oil shale layer. The annual mean water influx amounts to 27 000 m^3 per hour.

A noticeable and regular increase in the amount of infiltrating water occurs all over the bed as the excavation work proceeds. The seasonal irregularity of infiltration depends upon the depth of the excavation, its technology, the lithological composition and cleavage of the rocks and meteorological conditions. Thus two maxima in

spring and autumn and two minima - in winter and in summer - of die yearly water influx can be discerned.

The infiltration of water into excavation cavities is due to natural and mining-induced causes. The natural conditions determine the hydrogeological structure and, accordingly, the groundwater regime (Table I).
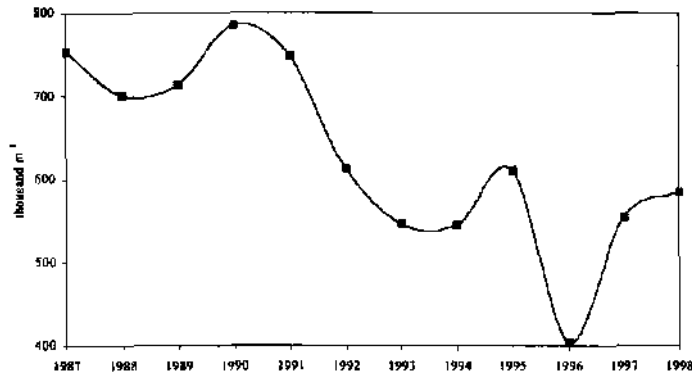

Figure 3. Dewatenng of oil shale mines and open pits.

Table 1. Hydrogeological structure and groundwater regime in natural conditions.

Sub-group	Natural conditions	Influence
geological	rock types, tectonical damage, neo-tectonic movements, cleavage,	permeability of rocks, structural and filtration irregularities
physico-geographical	topography, hydrometrical and hydrological parameters of water basins, atmospheric precipitation	formation of feeding and out-flow areas, regime of surface and groundwater

Table 2. Groundwater regime changes by technological conditions.

Sub-group	Technological conditions	Influence
geometrical	location of mines and quarries, horizontal and vertical parameters	changing of feeding and out-flow areas and of the movement of surface and groundwater
geomechanical	technological cleavage, surface subsidence	change of structural and hydraulic properties of sediments and rocks
technological	inundation of excavation cavities	alteration of geofiltrational conditions on the boundary between closed and active mines and open pits

Exploitation of the mines and quarries brings about changes in the groundwater regime, which İs characterised by alteration in the feeding and outflow conditions (Table 2).

A water level depression occurs around excavabon cavities, its dimension depending on the hydraulic conductivity and storage capacity of the rocks, and the amount of pumped-out water.

According to hydraulic properties, the oil shale bed can be subdivided into three major regions: northern, middle and southern. The northern and middle regions are enclosed by the Keila-Kukruse water layer, with a maximum bedding depth of 45-50 m. There are two separate water layers that coincide with the industrial oil shale layer 25 m deep. In the northern region, the Ordovician aquifer spreads under a thin layer of Quaternary sediments, and is considerably split. According to natural conditions, the infiltration of atmospheric precipitation is biggest in this region in comparison

470

with the rest of the bed. The dissected topography and the thickness of Quaternary sediments regulate infiltration.

The amount of water Q infiltrating into the excavation cavities of the northern region is determined by two important parameters: the surface of the excavated area F and the intensity of filtration, i.e., specific consumption - w_{inf}

$$Q = f(F, w_{inf}).$$

The northern region of the bed is characterised by a surface regime. Buried valleys, bog areas, water basins and closed mines serve as local feeding sources. In the middle regmt wth feeding and outflow conditions change due to the different hydraulic properties of the rocks. Two water layers spread over the excavation area - the Keıla-JÖhvİ and the Idavere-Kukruse - separated by the metabentonid interlayer. Infiltration conditions in the southern region are more complicated than in the two regions described above, because, in addition to the water layers mentioned, the Nabala-Rakvere layer, characterised by very irregular filtering properties, joins the intersection. The structure of the regions described is presented in Table 3.

Table 3. The structure of the regions.

Region	Depth of bedding of industrial layer, m	Water layers	Type of feeding regime of water layer	Mines
northern	25	Keila-Kukruse	infiltration, free-surfaced	closed mines
middle	25-50	Keila-Jöhvi Idavere-Kukruse	infiltration, free-surfaced, pressurised	Sompa, Viru, Ahtme
southern	50-70	Nabala-Rakvere, Keila-Jöhvi, Idavere-Kukruse	infiltration, pressurised	Estonia

In the middle and southern regions, the intensity of the infiltration and the depth of mining determine the amount of water influx into the excavation cavities. When taking into account the influence of the mining depth, the outflow parameters, i.e., the relation K/m, are used, where K is the hydraulic conductivity and m is the thickness of the deposit. The formula used for calculating the amount of filtrating water in the middle region is:

$$Q = f(K/m, w_{inf}).$$

The regime of the drained water complex is locally phreatic or confined. Feeding areas consist of buried valleys, bogs and lakes as well as the Nabala-Rakvere water layer. For calculating the amount of filtering water in the southern region, the following formula has been used:

$$Q = f(K_i/m_i, w_{inf}).$$

The drained aquifer is pressurised and widespread. Local feeding areas consist of bogs and lakes. The chemical composition of the bed water changes in accordance with the amounts of influx into the mines and quarries and the magnitude of filtration.

Drainage of wells causes the depletion of groundwater, which reaches a depth of 20 m in the northern region and 70 m in the southern region of the mining area. Strong depletion of wetls can be observed; the infiltration of contaminants grows and the main aquifers are chemically polluted over a large area. A study of the wells (1980-1998) in the rural areas surrounding some towns showed that of the 173 sampled wells, 95% had a high sulphate concentration, 91% were contaminated with oil products, 60% were contaminated with phenol dérivâtes and 53% did not meet microbiological standards.

5 CONCLUSIONS

Mining processing and utilisation of oil shale in Estonia has produced serious environmental consequences. These consequences exert an influence far beyond the boundaries of the mining area and long after the cessation of mining. Mined-out areas with their disturbed balance of ground and surface water regimes and soft surface layers favouring the infiltration of the surface water are especially sensitive to pollution and other undesirable effects. The decline in mining activities (Fig. 2) and the introduction of new technologies together with economic measures (resource charges, pollution taxes) give us hope that the situation will improve in the very near future.

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472

Soil Fertility in Coal Sterile Dump Assessment in Jiu Valley - Romania

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ABSTRACT: Coal mining results in large quantities of sterile material that are deposited İn dumps. In Jiu Valley, there are over 40 sterile dumps that are mostly not revegetated. These facts represent the main environmental impact in the area. In order to develop other activities, including tourism, simultaneously with mining activity reduction, it is necessary to lessen this soil and visual impact. Revegetation represents the only permissible solution, but this activity must take into account the existing ecological structure. The main issue is the soil regeneration. This process is very complex, and for this reason it İs very difficult to assess fertility increase. Different species of plants grow differently in the same conditions, so it is not possible to evaluate soil fertility by vegetal production. Our systematic studies of sterile dumps allow us to draw the conclusion that chemical parameters like humic acids, nitrites and phosphates do not correlate well with soil fertility. To complete the soil fertility evaluation, we introduce other enzymatic analyses, including ureasis, invertasis and catalysis, which offer us more İnformadon about fertility. These results correlated with the chemical composition, allowing us to better assess the soil fertility and suitability for revegetation.

1 INTRODUCTION

Technogenic soils are soils that are formed after re-cultivation of mining waste dumps. These wastes are also a hazardous source of pollution in the environment.

The evolution of technogenic soils is defined like waste transformation into agricultural or forestry soils. Simultaneously, these processes take place together with the reducing or removing of pollutants. These processes are very important because mining activity results in ever-greater amounts of waste from one year to the next It is estimated that in the world there is over 1600 billion cubic meters of waste in dumps and that that volume increases every year by

40 billion cubic meters. In comparison, land affected by erosion is estimated to amount to 13 billion cubic meters per year. According to some estimations, for every million tonnes of coal mining, in Romania 40-50 hectares of fertile soil is affected.

Technogenic soil evolution is also important also with regard to the landscape.

Technogenic soil evolution reflects revegetation efficiency. Technogenic soil evolution may be assessed by different methods: physical, chemical and biological. In some countries like Russia, the Ukraine and the U.S.A., enzymological methods have been reported. In this study, we consider ten different soils in some mining areas in Jiu Valley, Romania (Table 1).

Table 1. Soil samples considered in this study.

Sample	Place	Characterisation
1	Petnla Mine - natural soil	vegetated poor soil
2	Petrila Mine - dump	un vegetated soil
3	Aninoasa Mine - Tericom Dump	very poor vegetated soil
4	Aninoasa Mine - natural soil close to Tericon	poor vegetated soil
5	Petrila Coal Processing Plant- natural sou	vegetated soil
6	Live2eni Mine - PAj dump	very poor vegetated soil
7	Aninoasa Mine - Piscu dump	well revegetated dump
8	Aninoasa Mine - natural soil	vegetated soil
9	South Aninoasa Mine - natural soil	vegetated soil
10	North Aninoasa Mine - natural soil	vegetated soil

2 SOIL FERTILITY ASSESSMENT

2.1 *Phosphorus*

Although the percentage of phosphorus in plant material is relatively low, it is an essential component of plants. Phosphorus, like nitrogen, must be present in a simple inorganic form before it can be taken up by plants. In the case of phosphorus, the utilisable species is some form of orthophosphate ion. in the pH range that is present in most soils, H_2PO_4'' and $HPO_4^{2'}$ are the predominant orthophosphate species.

Orthophosphate is most available to plants at pH values near neutrality. It is believed that in relatively acidic soils, orthophosphate ions are precipitated or sorbed by species of Al(III) and Fe(in). In alkaline soils, orthophosphate may react with calcium carbonate to form relatively insoluble hydroxyapatite.

Generally, because of sorption and precipitation, lirde phosphorus applied as fertilizer leaches from the soil. This is important from in view of both water pollution and utilisation of phosphate fertilizers.

2.2 *Potassium*

Relatively high levels of potassium are utilized by growing plants. Potassium activates some enzymes and plays a role inthe water balance in plants. It is also essential for some carbohydrate transformations. Crop yields are generally greatly reduced in potassium-deficient soils. The higher the productivity of die crop, the more potassium is removed from soil. When nitrogen fertilizers are added to soil increase productivity, removal of potassium is enhanced. Therefore, potassium may become a limiting nutrient in soils heavily fertilized with other nutrients.

Although potassium is one of the most abundant elements in the Earth's crust, of which İt makes up 2,6%, much of this potassium is not easily available to plants. For example, some silicate minarals such as leucıte, K_2O Aİ20j«4Si02, contain strongly bound potassium. Exchangeable potassium held by clay minerals is relatively more available to plants.

2.3 *Nitrogen*

Nitrogen is an essential component of proteins and other constituents of living matter. Plants and cereals grown on nitrogen-rich soils not only provide higher yields, but are often substantially richer in protein and, therefore, are more nutritious. Nitrogen is most generally available to plants as nitrate ion, NO_3''. Some plants such as rice may utilise ammonium nitrogen; however, this form of nitrogen poisons other plants. When nitrogen is applied to soils in the ammonium form, nitrifying bacteria perform an essential function in converting it to available nitrate ion.

Nitrogen fixation is the process by which atmospheric N_2 is converted to nitrogen compounds available to plants. Human activities are resulting in the fixation of a great deal more nitrogen than would otherwise be the case. Artificial sources now account for 30-40% of all nitrogen fixed. These include chemical fertilizer manufacture; nitrogen fixed during fuel combustion; combustion of nitrogen-containing fuels; and the increased cultivation of m-trogen-frxing legumes. A concern with this increased fixation of nitrogen İs the possible effect upon the atmospheric ozone layer by N_2O released during denitrification of fixed nitrogen.

Prior to the widespread introduction of nitrogen fertilizers, soil nitrogen was provided primarily by legumes. These plants, such as soybeans, alfalfa, and clover, contain in their root structures bacteria capable of fixing atmospheric nitrogen. Leguminous plants have a symbiotic (mutually advantageous) relationship with the bacteria that provide their nitrogen. Legumes may add significant quantities of nitrogen to soil, up to 10 pounds per acre per year, which is comparable to amounts commonly added as synthetic fertilizers. Soil fertility with respect to nitrogen may be maintained by rotating plantmgs of nitrogen-consuming plants with plantings of legumes, a fact recognised by agriculturists as far back as the Roman era.

The nitrogen-fixing bacteria in legumes exist in special structures İn the roots called root nodules. The rod-shaped bacteria that fix nitrogen are members of a special genus called Rhizobium. These bacteria may exist independently, but cannot fix nitrogen except in symbiotic combination with plants. Although all species of Rhizobium appear to be very similar, they exhibit a great deal of specificity in their choice of host plants. Curiously, legume root nodules also contain a form of hemoglobin, which is apparently involved in the nitrogen-fixation process.

In Table 2, the main soil nutrient element content is presented.

2.4 *Soilporosity*

Soil particle size largely determines the physical character of soil. Classified according to size, clays consist of particles smaller than 0.002 mm, while silt particles are 0.002-0.05 mm, sand is 0.05-1 mm, and gravel exceeds 1 mm. Soil texture is classified according to relative amounts of clay, silt, and sand. One of the more productive kinds of soils is loam, which consists of approximately 40 percent silt, 40 percent sand, and 20 percent clay. Even better for agricultural purposes is sandy loam, which is typically 70% sand, 10% clay, and 20% silt.

474

Table 2. The main soil nutrient element content.

Sample	Humus	assimilable N	assimilable P	assimilable K
1	16.5	0.85	16.2	23.6
2	0	0	0.6	5.8
3	2.5	0.10	0.15	2.15
4	13.4	0.69	12.12	8.20
5	14.8	0.51	14.7	12.1
6	0.5	0.12	0	2.35
7	1.8	0.05	0.25	2.25
8	17.5	0.91	13.6	7.9
9	12.3	0.78	15.60	14.35
10	10.5	0.75	16.30	8.9

Normally, because of the small size of soil particles and the presence of small capillaries and pores in the soil, the water phase is not totally independent of soil solid matter. Access of soil water to plants is governed by gradients arising from capillary and gravitational forces. The availability of nutrient solutes in water depends upon concentration gradients and electrical potential gradients. Water present in larger spaces in soil is relatively more available to plants and readily drains away. Water present in smaller pores, or between the unit layers of clay particles is held much more strongly. Soils high in organic matter may hold appreciably more water than other soils,

but it is relatively less available to plants because of physical and chemical sorption of the water by the organic matter.

There is a very strong interaction between clays and water in soil. Water is absorbed on the surfaces of clay particles. Because of the high surface/volume ratio of colloidal clay particles, a great deal of water may be bound in this manner. Water is also held between the unit layers of expanding clays, such as the monhnorillonite clays.

Roughly 35% of the volume of typical soil is composed of air-filled pores. Whereas the normal dry atmosphere at sea level contains 21% Oi and 0.03% CO_2 by volume, these percentages may be quite different in soil air because of the decay of organic matter. This process consumes oxygen and produces $C0_2$. As a result, the oxygen content of air in soil may be as low as 15%, and the carbon dioxide content may be several percent. Thus, the decay of organic matter in soil increases the equilibrium level of dissolved CO2 in ground water. This lowers the pH and contributes to weathering of carbonate minerals, particularly calcium carbonate. The presence of $C0_2$ also shifts the equilibrium of the process by which roots absorb metal ions from soil.

Table 3. Soil granulometry.

Sample	Large sand	Fine sand	Powder 1	Powder II	Clay	Humidity
1	54.39	32.48	9.62	2.36	1.15	5.2
2	56.69	21.58	7.78	1.63	12.32	2.1
3	66.67	20.28	4.21	0.63	8.21	7.85
4	14.48	39.59	21.17	12.38	12.38	5.23
5	42.64	29.25	14.60	4.73	8.78	4.6
6	42.64	29.25	14.60	4.73	8.78	2.4
7	62.64	21.80	5.83	1.75	7.98	7.85
8	46.51	27.47	15.49	4.00	6.53	5.58
9	59.89	17.24	6.93	1.59	14.35	6.3
10	18.23	35.46	21.15	10.69	14.47	4.75

2,5 *Acid-base and ion exchange reactions in soils*

One of the more important chemical functions of soils is the exchange of cations. The ability of sediment or soil to exchange cations is expressed as the cation-exchanged capacity, the quantity of monovalent cations that can be exchanged per 100 g of soil. The cation-exchanged capacity varies with soil conditions such as pE and pH. Both the mineral and organic portion of soil exchange cations. Clay minerals exchange cations because of the presence of negatively-charged sites on the mineral, resulting from the substitution of an atom of lower oxidation number for one of higher number, like magnesium or aluminum. Organic materials exchange cations because of

the presence of the carboxylate group and other basic functional groups. Humus typically has a very high cation-exchange capacity.

Cation exchange in soil is the mechanism by which potassium, calcium, magnesium, and essential trace-level metals are made available to plants. When nutrient metal ions are taken up by plant roots, hydrogen ion is exchanged for the metal ions This process, plus the leaching of calcium, magnesium and other metal ion from the soil by water containing carbonic acid, tends to make the soil acidic. Soil acts as a buffer and resists changes in pH. The buffering capacity depends upon the type of soil.

Acid-base and ion exchange reactions in the soils of the studied samples are shown in Table 4.

Sample	pH	cation-exchanged capacity	hydrogen-exchanged capacity	Total exchanged capacity
1	5.4	4.69	21.63	26.32
2	6.1	0.00	0.00	0.00
3	7 6	3.60	2.55	6.15
4	5 8	20.21	22 57	42.78
5	5 4	5 19	15 82	21.01
6	7 6	0	0.15	0,15
7	7.2	2 75	1.90	4 65
8	5 8	8.47	46.95	55.42
9	5.4	16 78	23.56	40 34
10	6.1	18.60	21.35	39 95

Table 4. Acid-base and ion exchange soil properties.

Tables 2-4 show that the physical and chemical properties are not well correlated with real characteristics, including the vegetation growing stage.

3 ENZYMATIC REACTIONS IN SOIL

3.1 *Nitrogen Organic Compound Decay by Soil Microorganisms*

In the soil there are important amounts of nitrogen organic compounds. They provide 99% of the total nitrogen reserves in tie soil. However, large amounts of nitrogen compounds reach the soil every year from dead plants and animals. If this amount of nitrogen were fixed without any transformation, the nitrogen available for plants would decrease every year, making growth impossible. This does not happen because these compounds are decayed continuously in soil by the forming of simpler nitrogen organic compounds. These processes of nitrogen compound transformation into ammonia are known as ammonification processes. These processes are very important for natural life and agriculture.

Some bacteria produce urea decomposition:

1. Bacillus probatus is a great sporulate bacillus capable of decomposing up to 140 g urea per liter of nutritive solution. It is a widespread bacterium in nature. Similar activities occur in two more bacteria: Urobacillus Leubii and Urobacillus Miquelii, but they exhibit a lower level of activity than Bacillus Probatus.

2. Planoscucina urea are cocci from the mobile charges group that form small cubic heaps of 4-8 spherical cells. These bacteria are less active than the forms above, but they decompose up to 30 g urea per liter of nutritive solution.

3. Micrococcus urea is a spherical bacterium that decomposes urea relatively slowly.

Apart from these bacteria, there are other forms from the same group, very widespread in water basins, İn lagoons, wetlands and other natural substrate. Some of them decompose relatively active urea, e.g. Urobacteria hesmogenes that can hydrolyse a 5% urea solution completely İn 24 hours.

A characteristic feature of these bacteria is their ability to grow in a high alkaline reaction of nutritive substrate. The lowest pH that allows their growth is 7.0 and the optimal value is over 8.0. These characteristics of urobacteria are related to the

fact that they constantly release ammonia into their environment during vital activities, in this way producing a strongly alkaline reaction. During their phylogenetic evolution, these bacteria were adapted to this environment. The same conditions made these bacteria become more resistant to free ammonia. They easily resist ammonia solution of a few percent concentration, while the growth of other bacteria is interrupted even with low free ammonia concentrations in nutritive solution. The bacteria behaviour given by environmental redox potential is also very different. They may grow and reproduce, decomposing urea to rH values between 28 and 0.8, which means both aerobic and anaerobic conditions. For carbon sources, they may use the most different carbon compounds from soil, like organic acid salts, especially citric acid, maleic acid, succinic acid and acetylic acid as well as monosaccharides, disaccharides, dextrin and starch. Urobacteria use mainly organic acid salts that do not contain oxidised carbon (acetic and succinic acids). For nitrogen sources, they most easily use the ammonium salts and free ammonium that are formed as a result of urea hydrolisis. Although urea, in addition to nitrogen, contain carbon, they cannot use it because it is too oxidised, forming by hydrolisis carbon dioxide. For this reason, urea represent just a nitrogen source for bacteria. The urea decay mechanism is simple enough, being one of desammination:

$$(NH_2)_2CO + 2H_2O = (NH_4)_2CO_3$$

The resulting ammonium carbonate is not very stable, and İs decomposed to its component parts;

$$(NH_4)_2CO_3 = 2NH_3 + CO_2 + H_2O$$

The desammination reaction is produced by an enzyme known as ureasis.

According to some authors, this enzyme is placed outside bacteria and the hydrolysis process itself has just an environmental role for bacteria. According to other authors, rapid urea decomposition takes place just in the presence of bacteria and not in the filtrate of their culture. This fact does not exclude the possibility that the urea decomposition process has a physiological role inside the cells.

For the soil samples we determined the ureasis activity and the results correlated very well with the existing situation (Table 5).

Table 5. Ureasis soil activity.

Sample	Ureasis activity mg NH_4^+/24 hours
1	3.383
2	1.264
3	0.800
4	1.678
5	2.203
6	2.308
7	2.439
8	2.91İ
9	2.518
10	4.721

4 CONCLUSIONS

1. Chemical and physical analyses do not always reflect soil fertility characteristics. For different reasons, including microorganism activity, soils rich in nutrients may be poorly vegetated, and poor soils may be well vegetated.
2. Enzymological activity analysis matches better with vegetation development, because it takes into account the microorganism activity.
3. Enzymological analysis technology is very simple and does not require special laboratory equipment.

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Underground Disposal of Hazardous Wastes in German Mines

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ABSTRACT: This paper provides a comprehensive overview of the status and development trends of underground disposal of hazardous wastes in Germany. First, the legal bases for underground waste disposal in Germany are presented. Then, the waste properties and quantities as well as safety concepts recommended for the underground disposal of non-radioactive wastes are explained. The disposal of wastes in underground openings and the utilisation of non-mining wastes as backfill in mines are treated separately. In addition, the most important features of these systems are explained. The final disposal of radioactive wastes in Germany is also discussed. Finally, the future of underground hazardous waste disposal in Germany is considered.

1 INTRODUCTION

Sustainable development is one of the main tasks facing society today. Environmental protection plays a very important part in achieving this goal. Our society should not cause any environmental problems which could jeopardise the bases of life for future generations. The problem of waste ranks highly here. Despite all the efforts and successes in the field of waste reduction and recycling, quantities of waste will still remain, and they have to be disposed of in an environmentally friendly manner. Long-lived, hazardous, chemical-toxic and radioactive wastes in particular represent a serious threat to future generations without proper and safe disposal.

One possibility for the safe, long-term disposal of waste without subsequent treatment is the utilisation or dumping of wastes in suitable underground openings. In Germany, wastes which require monitoring and which can neither be treated by chemical, physical or biological methods nor disposed of through incineration may be stored in surface or underground disposal sites. However, surface disposal sites could become abandoned polluted sites İn the future since the sealing systems used only have a limited service life (Martens et al. 1993). Underground disposal offers the possibility of permanent and safe disposal, particularly for wastes with a high proportion of water-soluble materials and heavy metals. The underground openings produced by mining work represent an important potential for this disposal method for both technical and economic reasons.

Germany has developed into one of the world's leadmg nations in terms of underground disposal and utilisation of non-mining waste, with over 25 years of experience in this field. Three underground disposals (UTD) are already in operation for wastes designated as requiring special monitoring (hazardous wastes), with a total capacity of over 500,000 tons p/a. Two further underground disposals, one of which has already been approved and the other of which İs in the middle of the approval procedure, will ensure an additional annual capacity of around 250,000 tons. Moreover, around 1.9 million tons of non-mining waste is utilised underground (UTV) every year as backfill İn around 20 German mines. Around 850,000 tons p.a. is hazardous waste. This waste is classified as requiring special monitoring in Germany.

Germany is also one of the world's leading nations in the research and development of final waste disposal projects for radioactive wastes. Figure 1 provides an overview of the locations of underground waste disposal sites in Germany, including disposal and utilisation sites for non-radioactive wastes as well as final radioactive waste disposal project sites.

2 LEGAL BASES FOR THE UNDERGROUND DISPOSAL OF WASTES

The legal bases for the underground disposal of wastes İn Germany are shown in Figure 2. According to the principles of the German Cycle Economy and Waste Act (Krw-/AbfG), an act for

479

'promoting closed substance cycle waste management and ensuring environmentally compatible waste disposal' which came into force in 1996, unavoidable wastes should primarily be subjected to substance recycling or used to obtain energy. In the case of substance recycling, the main concern should be the utilisation of the waste properties and not the elimination of the pollutant potential. Wastes which cannot be recycled should be permanently removed from the closed substance cycle and disposed of with no effects on the well-being of the general public.

● Underground disposal sites in operation (3)
◎ Approved underground disposal sites (1)
○ Planned underground disposal sites (1)
▼ Underground utilisation of waste as backfill (20)
■ Final disposal projects for radioactive wastes (4)

Figure 1. Locations of underground waste disposal sites in Germany.

Figure 2. Overview of legal bases for the underground disposal of wastes in Germany.

The construction and operation of underground disposals for non-mining waste require a waste law plan or approval İn accordance with the 'KrW-/AbfG' act. The requirements of the administrative regulation "Technical Instructions on Waste" (TA Abfall) passed by the Federal Government in 1991 must be taken into account. The 'TA Abfall' only allows the construction and operation of underground disposals in salt rock (mines and caverns). These requirements are based on the fact that wastes dumped and sealed in salt rock are permanently kept away from the biosphere and no subsequent treatment is necessary (Schade 2000).

The utilisation of non-mining wastes in mines is allowed if it serves mining technology or safety purposes in accordance with the Federal Mining Act (BBergG), It requires approval by the mining authorities on the basis of a mining law plan of operation. The mining authorities and planning authorities, with the co-operation of all authorities and municipalities affected by the measures, check whemer the project can be approved in consideration of long-term safety. During the approval procedure, the regulations of the Federal Waste Act, Immission Control Act, Water Act, and Labour and Health Protection Act are taken into consideration alongside the Mining Act (Schade 2000). The utilisation and disposal of mining wastes is also the responsibility of the mining authorities in accordance with the Mining Act.

The legal basis for the construction and operation of final waste disposal sites for radioactive wastes is the Atomic Energy Act (AtG). This specifies that the state is responsible for the construction of facilities for final waste disposal. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is responsible for the final waste disposal program.

3 UNDERGROUND DISPOSAL OF NON-RADIOACTIVE HAZARDOUS WASTES

3.1 *Properties-quantities-safety concepts*

Wastes for underground disposal must have special properties. The most important of these are (TA Abfall 1991):

· The wastes must not be explosive or self-igniting.
· The wastes must not be combustible under the storage conditions.
· The wastes must not release gases (may form neither explosive nor other pollutant gases).
· The components of the waste must not be able to react with each other or with the surrounding rock (e.g., salt rock).
· The wastes must not contain pathogens of contagious diseases.
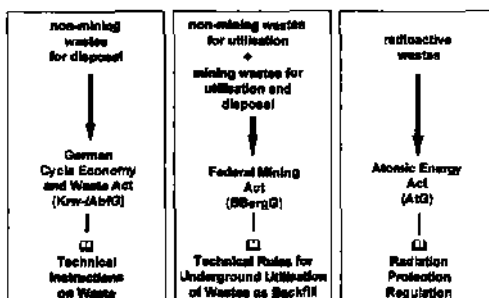· The wastes must not swell.

• The wastes must have sufficient strength or achieve this in their final condition.

Figure 3 shows an overview of the development of the quantities of hazardous wastes requiring special monitoring. Underground disposal is regarded as the safest disposal method for wastes with a high water-soluble share or with toxic pollutant contents (e.g., heavy metals, cyanide). As can be seen in the illustrations (Figs. 3-4), the proportion of wastes disposed of in underground disposals has risen over the past few years despite a drop in the quantities of hazardous wastes which require special monitoring.

million tons p/a
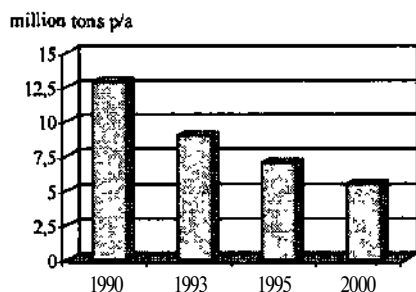
Figure 3. Development of the quantities of hazardous wastes requiring special monitoring.

Some of the wastes disposed of in underground disposals in Germany are from countries which do not have underground disposal systems that can ensure the necessary long-term safety. For example, 17.8 % of the total 2 million tons of hazardous wastes placed in the Herfa-Neurode disposal originated in neighbouring European countries (Wiedemann, 2000). Thus, German facilities perform important disposal functions within Europe.
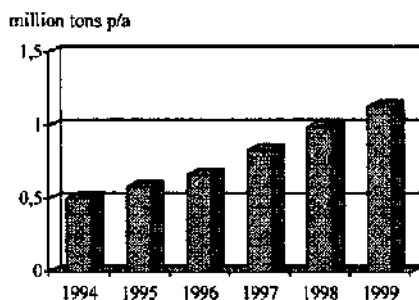

million tons p/a

Figure 4. Development of the quantities of hazardous wastes disposed of in underground disposals.

Apart from the hazardous wastes, large quantities of 'non-mining wastes with a low pollutant content' (e.g., power station ash) are disposed of underground In Germany. A large amount of mining waste produced during the extraction and treatment of mineral resources is also disposed of underground.

The openings in various underground German mines offer a great potential for the disposal of wastes. Table 1 shows the theoretically usable opening volume for underground disposal in various German mines.

Table !. Usable opening volume for waste disposal In various underground mines (Bieter el ai., 1994).

Underground mines	Available opening volume (x 1000 m V
Potash mines	79 500
Rock salt mines	8 800
Ore mines	8SO0
Coal mines	11 100"*
Other mines***	4 400
Total	112 600

* theoreiically usable opening volume (Status 1994)
** opening volumes produced annually (without shafts and drifts)
*** other mines (e.g., limestone mines, spar mines)

The safety concepts of 'neutral immission' and 'complete enclosure' are applicable for underground disposal in consideration of both legal and technical aspects. In the case of 'neutral immission' disposal (Fig. 5), contact with ground water is possible but the pollutant release from the wastes must be insignificant for the ground water (prohibition of deterioration in quality). Wastes produced in large quantities but with a low water-soluble pollutant potential (e.g., power station ash) can thus be disposed of underground.
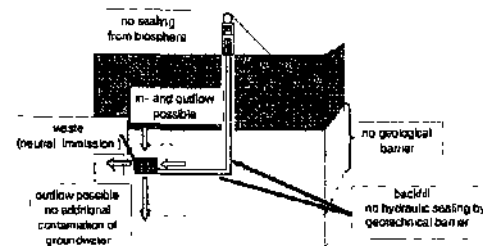

Figure 5. Safety concept of neutral immission.

In the case of 'complete enclosure' (Fig. 6), a multi-barrier system permanently prevents contact between the wastes and the surrounding ground water. Wastes requiring special monitoring can thus be disposed of in accordance with this concept,
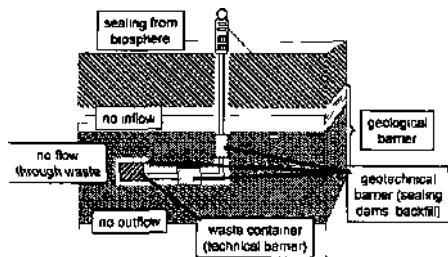
Figure 6 Safety concept of complete enclosure

3.2 Waste disposal in underground disposal sites

The openings in potash and rock salt mines in Germany offer ideal conditions for underground disposal. Waste disposal is only allowed according to the "complete enclosure" concept. These disposals have to fulfil special requirements. The most important requirements are (Kind 1991):

- The mme in which the wastes are to be disposed of must be dry and free of water.
- The openings in which the wastes are to be disposed must be protected against water-bearing layers.
- An abandoned and stopped-out working area must be available for disposal of the wastes.
- The disposal openings and access roads must be stable.
- The disposal operations must be separately ventilated.
- It must be disposal without retrieval.

Around 16 % of all hazardous waste types are disposed of in underground disposals (UTD) in Germany. The majority of wastes which are disposed of in these disposals are wastes 'of a mineral origin and from refinement products' and from 'conversion and synthesis processes'. The most important wastes İn terms of quantity per year are as follows (Prognos 1998):

- Solid reaction products from waste incineration plants (23,000 t/a).
- Mercury and residues containing mercury (11,000 t/a)
- Salts containing cyanide, nitrate and nitrite (11,000 t/a).
- Products and operating material containing PCB (14,000 t/a).
- Mixed waste from waste treatment plants (19,000 t/a).

Underground disposals have had a firm place in the German waste disposal infrastructure since the Herfa-Neurode underground waste disposal site was opened in 1972. They have become an irreplaceable final link in the disposal cham for certain types of waste. The quantities of hazardous waste which are disposed of in underground disposals are shown in Figure 7. The underground disposal site in Herfa-

Neurode is the most famous m the world and is regarded a model plant by international experts. This facility is situated in an abandoned part of a potassium-producing mine in flat-lying strata. The mine workings form a room-and-pillar system and the disposal area is situated at a depth of about 700 m below the surface. In the past 28 years of operation, a total of 2 million tons of mostly drummed hazardous solid wastes have been placed m the abandoned parts of the mine (Wiedemann 2000).
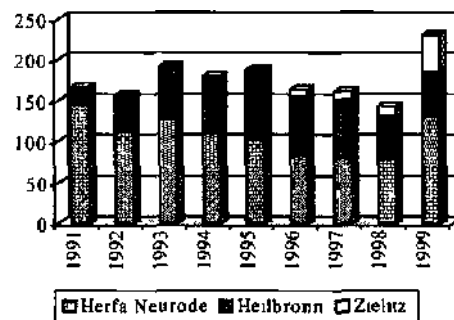
th ou sand tons p/a

Figure 7. Quantities of hazardous waste which are disposed of in underground disposals

The prices for underground disposal in Germany are between EURO 200 and 300 per ton (plus taxes and fees). The prices for surface disposals are between EURO 100 and 350 per ton, depending on the type of waste (Prognos 1998).

3.3 The underground utilisation of wastes as backfill

An increasing volume of non-mming waste can be used as backfill in Germany due to the development of new backfill technologies (Jahn 1998). The backfill should perform the following tasks:

- Protection of the surface.
- Optimum use of the deposit.
- Special safety and operating tasks (e.g., ventilation, fire fighting).

Figure 8 shows that the utilisation of non-mining wastes as backfill has risen steadily over the past few years. In particular, the amount of hazardous waste utilised as backfill has risen, with an upwards trend.

Hazardous waste can only be used in accordance with the 'complete enclosure' concept and with proof of its long-term safety. Other wastes can also be disposed of in accordance with the 'neutral immission' concept - provided they are suitable for this.

thousand tons p/a
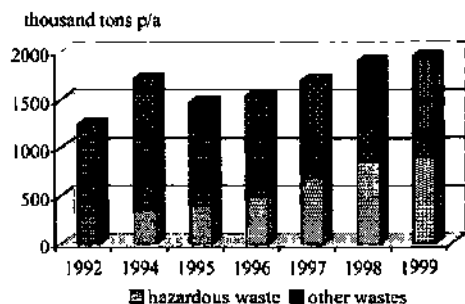
Figure? Quantities of non-mming-wastes which are utilised as backfill m underground mines

Wastes from coal-fired power stations and thermal waste treatment plants are preferably used in these systems. These are ashes which can develop self-hardening properties on their own or in a mixture and thus meet the requirements for the production of a bearing backfill. The most important types of waste in terms of quantity are as follows (Prognos1998):

- Filter dusts and solid reaction products from waste incineration plants (96,000 t/a).
- Slags and filter dusts from hazardous waste incineration plants (43,000 t/a).
- Slags from non-ferrous metal smelters (13,000 t/a).
- Soil, building rubble and excavated earth with noxious pollutants (191,000 t/a).
- Filter dusts and ashes from coal-firing plants.

The disposal pnees in underground backfill systems are around EURO 25-110 per ton (Prognos 1998), and are thus far below those of other disposal methods.

Depending on the type of waste, and its composition and quantity, bulk matenal backfill, stack backfill in 'Big-Bags' or hydraulic backfill are used in underground utilisation plants.

4 FINAL UNDERGROUND DISPOSAL OF RADIOACTrVE WASTES

Even at the beginning of the sixties, there was a preference in Germany for using deep geological formations for the final disposal of long-lived radioactive waste (Lempert 1999).

Final disposal of radioactive wastes commenced in 1967 with the storage of low-level and medium-level wastes in the now non-productive 'Asse' salt mine in Lower Saxony. The disposal of radioactive wastes continued up to 1978, when the licence expired and was not renewed. Around 25000 m³ of waste has been placed in this mine (Wiedemann 2000). The mine is currently open for R&D

purposes. Wastes placed there are accessible and under constant control.

In the former German Democratic Republic (East Germany), disposal of low-level and medium-level radioactive wastes in the non-productive 'Morsleben' salt mine in Saxe-Anhalt started in 1981. During the time of the reunification of Germany, disposal was interrupted for three years, but resumed in 1994 Up to 1998, over 35000 m had been placed in this mine (Wiedemann 2000). As it appears the license will expire, the mine will be closed (Lempert 1999).

At present, no radioactive waste is being placed İn underground mine openings, but is instead stored at special surface plants. However, the federal government is pursuing two projects for the final waste disposal of radioactive wastes. One is the licensing of 'K.onrad\ a non-operational accessible and dry iron ore mine in Lower Saxony, which will offer a disposal capacity of approximately 650000 m³ of low-level and medium-level radioactive wastes at levels between 800 and 1300 m below the surface. The other is the 'Gorleben' project in eastern Lower Saxony, which has been under investigation since 1979. A shaft was excavated and the host rock is being studied for its suitability for the placement of radioactive waste of all categories, including high-level, heat-generating wastes. If the geological structure proves suitable, disposal openings will be mined at a depth of 850 to 1 !00 m

5 THE FUTURE OF UNDERGROUND WASTE DISPOSAL IN GERMANY

Underground waste disposal is an important disposal method in the waste management system in Germany. German underground disposal plants also perform important disposal functions for neighbouring European countries. Despite falling quantities of hazardous waste, the amounts of waste which have been disposed of underground have risen over the past few years. Nevertheless, excess capacities have arisen İn underground waste disposal sites due to an overestimation of the amounts of waste planned for underground disposal.

There have also been legal problems due to imprecisely formulated statutory regulations, which have led to differences of political and social opinions in both Germany and the European Union (EU). Similar problems have also arisen in the final disposal of radioactive wastes. Although underground waste disposal is the best long-term solution for suitably hazardous wastes from a technical point of view, political and social questions still have to be settled. For this reason, the future of underground waste disposal will not be dominated so much by technical progress but by political and social opinions.

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Environmental Impacts of Mineral Resource Exploitation and Use

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ABSTRACT: Human beings are facing a global mineral resource crisis. The earth's finite supply of minerals İs being used by a population that is growing faster than at any time in history. To make matters worse, mineral consumption İs growing even faster man the population. Although we need more minerals to supply society, we are becoming increasingly aware that their production and use pollute the planet. The effects were once local in scale, but have now become truly global, with mineral consumption implicated strongly in global wanning, acid rain and destruction of the ozone layer. There is concern mat the earth is reaching its limit of mineral-related pollution. Human beings cannot ignore this crisis. This paper reviews the environmental impacts of mineral resource exploitation and use.

1 INTRODUCTION

We live İn a time of rapid changes in world population and technological innovations. Techno-logical changes are occurring at unprecedented rates, which are projected to increase İn the years ahead. These forces, combined with the desire of hundreds of millions of people in developing countries to raise their standard of living, are resulting in increasing demands for food, minerals, construction materials and energy. At the same time, there is increased recognition of human influence on the global environment and increased concerns about the long-term consequences of resource exploitation on nature and the ultimate habitability of the world.

2 THE FOUNDATION OF SOCIETY: MINERALS

The world is constantly in a state of change. In order to meet the needs of a growing population, we must employ old and new techniques. The new technologies are more productive, but require the use of greater amounts of resources. All materials (fuels, metals, water, etc.) needed for modern society are derived from the earth's crust, whetiier directly or indirectly. Our civilization is based on mineral resources. These resources are like air - of no great importance until you are not getting any. Most of the machines, appliances and furniture that make life comfortable are made of metals and powered by fossil fuels. World population grew slowly until about 1500 A.D. Increasingly rapid growth from

around 1800 had raised the population to 2 billion by 1930 and 4 billion by 1975; it had exceeded 6 billion by 2000. Exploitation must be carried out m such a way that the environment is not so fouled and irretrievably spoiled that we ruin the planet upon which we live (Craigh et al., 1996).

2.1 Materials we use

Natural resources can be classified into two groups: renewable and non-renewable resources. Renewable natural resources are replenished on short time scales of a few months or years. For example, wind, hydraulic and solar energies. Non-renewable resources are contained in the earth in fixed quantities and are not replenished by natural processes operating on short time scales. Examples are oil, natural gas, coal, metals and mineral products produced from the earth. The formation period of oil, gas, metals and minerals is very long (i.e., over tens of millions of years), vastly slower than the rates at which we mine these materials. The resources we obtain from the earth's crust today are products that have accumulated over the last billions of years. Most non-renewable natural resources are also mineral resources, both organic and inorganic in origin. Resources can also be classified into three major use groups: metallic, energy and non-metallic mineral resources.

Metals can be subdivided into two classes, on the basis of their occurrence in the earth's crust. The geochemically abundant metals are those that individually constitute 0.1% or more of the earth's

crust by weight (such as Fe, Al, Mn, Ti, Si, Mg, etc.). Geochemically scarce metals are less than 0.1% by weight of the earth's crust. These are Cu, Pb, Zn, Mo, Hg, Ag, and Au. Mineable deposits of scarce metals tend to be smaller and less common than mineable deposits of abundant metals. The second major group İn resource classification is energy minerals. Some resources, such as fossil fuels and radioactive minerals (U, Th), are non-renewable resources. Other energy resources, such as running water and solar heat, are renewable. The third group of resources contains all of these material substances, excluding the metals and energy minerals. Such resources include minerals used as sources of chemicals (halite, borax), plus minerals used as raw materials for fertilizers (phosphates, nitrates). This group also contains industrial minerals used as paints, fillers, abrasives, drilling mud, construction and building materials, etc. Water and soil are vital to the production of food.

2.2 Mineral production as apart of GDP

A good indication of the role of mineral production in economic activity in any country can be obtained by comparing the value of mineral production and gross domestic product (GDP) (Keşler, 1994).

Table 1 % GDP obtained from mineral production

% GDP	Countries
35	Kuwait
25-20	S. Arabia, Namibia, Zaire, PNG
20-10	Zambia, Mexico, Zimbabwe, S. Africa
5-2	Brazil, Sweden, USA, Japan
1	Turkey

As can be seen from Table 1, raw material production makes up less than 2% of GDP in the U.S. and Japan, but İs greater than 25% in Kuwait and S. Arabia. In spite of the low percentage in the U.S., America is the world's leading producer of 19 mineral commodities. The impact of minerals on the global economy is enormous. Not including recycled material, world primary fiiel production and metal production are worth about $700 and $500 billion, respectively, and primary industrial mineral production is worth about $150 billion. The value of world raw and processed mineral exports ranges from $400 to $600 billion annually, a quarter of all exports.

3 ADEQUACY OF WORLD RESERVES AND CONSEQUENCES OF THEIR EXPLOITATION

The two systems of forces of the sun's external heat energy and the earth's internal heat energy maintain a geochemical dynamic balance. The formation of the earth's resources is a consequence of these geochemical cyclmg processes. One of the major consequences of our exploitation of natural resources is mat we are interfering with me balance of some natural geochemical cycles (for example, carbon/sulfur cycles).

Geological, engineering, environmental and economic factors control mineral availability. The adequacy of world mineral reserves and resources is strongly affected by consumption, stockpiles and recycling. Figure 1 shows the adequacy of world mineral reserves based on 1992 production data (Keşler, 1994). The reserves of 18 out of 53 minerals will be adequate for more than a century. For example, coal, Fe, bauxite, Ch, V and Pt are in this group. However, another ten minerals, including diamonds, Ag, Pb, Zn and S, have only 10 to 25 years' life remaining. Cu, Mn and oil have a life expectancy of 25-50 years.
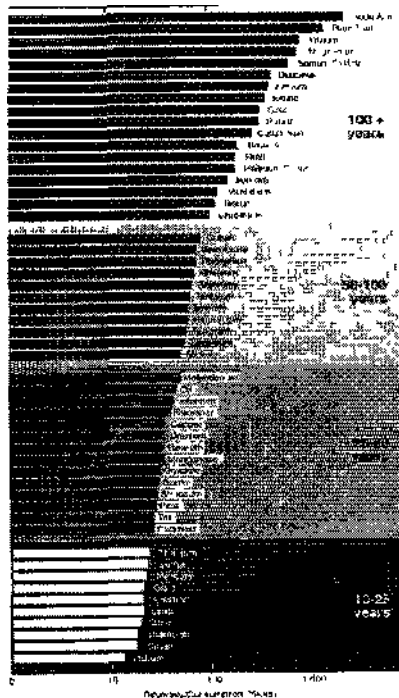

Figure I. Life expectancy of elements/minerals

The chemical elements that we use in modem society number 86. Many of them are used in compounds in which their presence is not evident but is essential. Only three elements (C, N and O) and four noble gases (Ne, Ar, Kr and Xe) can be extracted from the atmosphere. Seven elements (H, K, Ca, C, N, P and I) can be derived from biological

materials. Eighty-one elements can be exploited from mineral resources and derived from the ocean or salt-bearing brines. Thus, it is apparent that most of the chemical elements we use in modem society are derived only from minerals and brines.

The earth's resources have been used by all cultures throughout history. The earliest uses of the earth's resources involved water, salt and simple tools made from rocks. The quantities of various mineral resources used by particular societies vary widely but generally correspond per capita to the nation's degree of development and standard of living. According to the U.S.B.M., each American citizen consumes about 18.8 tons of mineral resources each year. The Umted States total mineral resource consumption is about 5000 million metric tons per year.

The production and use of every natural resource, from the clearing of forests and tilling of fields to the mining of metals and burning of fossil fuels, causes changes that may be large or small, local or global, pleasant or unpleasant. They may be given such names as pollution or environmental degradation or may be called disasters, but they are all consequences of the exploitation of natural resources. The second half of the 20^{Lh} century has seen a rapidly growing awareness in scientists, political leaders and the public of the importance and complexity of environmental problems. In many instances, people have suddenly recognized that the activities we once viewed as beneficial, such as changing waterways, draining wetlands, clearing forests and burning fossil fuels, can damage the environment.

3.1 *How exploiting resources affects the environment*

Mining, quarrying, dredging, drilling and extracting from wells are all activities that have a marked impact on the landscape and environment. Directly linked to these activities are problems concerned with the disposal of water products. Smelting and refining of the ore also causes series environmental problems.

3.2 *Mining and quarrying methods*

The method used to extract minerals depends on the deposit size, shape, depth beneath the surface and grade. A choice is made between surface mining and underground mining. Surface mining, which accounts for about 2/3 of the world's solid mineral production, generally involves open pit mining or strip mining. Open pit mining is an economical method of exploiting large tonnages of reserves and achieving high rates of production. The waste material overlying the deposit (overburden) must be thin enough to be removed.

Surface mining is less expensive, safer and involves fewer complications with air, electricity, water and rock handling. However, surface mining has a greater environmental impact than underground mining. Surface mine production may be as high as 100,000 t/d, while the underground mine production rate may be 10,000 t/d. Thus, surface mining operations disturb the surface more seriously. Quarrying refers to an open pit mine from which building stone or gravel is extracted (Craigh et al., 1996).

In open pit mines, extraction proceeds by drilling, blasting, loading, transporting and dumping the ore out of the pit At the world's largest open pit mine at Bingham Canyon, Utah, every day 400,000 tons of ore plus overburden are removed. In strip mining of coal, clay, bauxite, tar sands, phosphates, iron ores, etc., overburden is removed and dumped to the rear and the ore is scooped up and loaded into trucks.

Deep mines are extracted using underground mining methods. In most mines, ore extraction and mine development involve drilling and blasting, and removal with mechanical diggers onto underground railway cars or dump trucks that reach the surface through a shaft or adit. Groundwater pumping, ventilation, roof support with timbers, waste rock removal, the inherent dangers of rock falls and cave-ins, fires, and the build-up of poisonous or explosive gases are some disturbances to the environment around underground mines.

Hydraulic mining uses high-pressure water jets to wash soft sediments down an incline toward some form of concentration plant, where dense mineral grains (such as gold) and soft mineral grains (such as clay/kaolin) are separated. However, hydraulic placer mining in California in the 1860s yielded large amounts of gold, but dramatically altered the nature of the rivers and the bays into which they flow.

Solution mining (leaching) involves dissolving the ore (Au, Ag, U, S, NaCl, etc.) with a liquid (water, cyanide, etc.). If the ore is extracted on site with solution mining, it is called in-situ leaching. This method is used to recover low-grade Cu, Au, and U ores.

3.3 *Environmental impacts of mining and quarrying*

Much of the impact of mining and quarrying is obvious. The disruption of land otherwise suitable for agricultural, urban or recreational use; the deterioration of the immediate environment through noise and airborne dust; and the creation of ore of the most dangerous environments for workers and potentially hazardous for the public are all environmental problems associated with mining. However, mining is a relatively short-term activity, and much can be done both to limit environmental damage during mining and to restore the land when mining operations are complete. Today, in many countries, legislation has been enacted at nearly all levels to ensure that extreme restrictions could make mining completely uneconomical. Unfortunately, the absence of adequate controls over some mining

activities in the past has left numerous scars on the surface of the earth and led to resistance among many members of the public toward new mining activities in their areas.

Fortunately, many underground mines leave little evidence of their presence, even after mining operations have ceased. They are usually filled by percolating ground water over time, but the rocks are usually strong enough to hold in spite of abandoned mine openings and passageways. Sometimes the old mines can be put to very good use. Old underground mines can be used as storage areas for grains, seeds, burial of nuclear wastes, and truck parking (Craigh et al., 1996).

When an open pit mine closes, a large hole remains with no readily available waste rock to fill it. The pit slopes are often too steep for plantation. If the water table is high enough, the bottom of the pit may flood, creating an artificial lake. Therefore, very large open pit mines are difficult, if not impossible, to reclaim. Smaller open pits may be filled with waste rock. In some places, surface mines can be reclaimed to form small lakes and wetlands mat support fish, birds and other wildlife. Underground mines do not lead to such drastic disruptions of the surface as open pit and strip mining, but a new hazard known as subsidence can be encountered. Subsidence under towns and roads can leave homes uninhabitable and transportation severely disrupted.

In addition to the impact that mining activities may have on the, landscape, the environment may be disrupted over a wider area by changes İn the distribution and chemistry of surface waters or ground water. An example of mis is acid mine drainage, which is the drainage produced when iron sulfide minerals are exposed to oxidation by moist air to form H_2SO_4 plus various other sulfate compounds and iron oxides. Pyrite and marcasite in coals, and pyrrhotite in metallic mineral deposits are me cause of H_2SO_4 when these minerals are exposed to air in underground mines, open pits or the dumps of waste material left by mining operations. Water passing through the mines or dumps becomes acidified, later finding its way into rivers, streams or the local groundwater system. Many streams can be affected by abandoned mine works.

3.4 *Disposal of mining wastes*

Nearly all mining operations generate waste rock, often in very large amounts. Strip mining waste can be used in reclamation, but an alternative method of disposal must be found for underground mining operations and most kinds of open pit mining. Usually, this simply involves dumping the wastes İn piles at the surface next to the mine workings.

Sometimes, die waste rock is put back into me openings created by the mining {backfilling). Piles of waste rock may be dangerous because of the possibility of sliding. Alternatives to the dumping of mining wastes, such as the use of them to fill land, are likely to be expensive and impractical in most cases. Waste dump slopes can be lowered and revegetation can be achieved.

3.5 *Dredging and ocean mining*

Dredging involves removing unconsolidated material from rivers, streams, lakes and shallows seas with machines such as bucket-ladder dredge, dragline dredge or suction dredge. There is no mechanical pollution from dredging, but the process disperses large quantities of fine sands and silt having severe effects on fish and other wild life that require clean water to survive. Ocean mining for Mn nodules involves significant disruption to ocean water and biological system. Currents, sedimentation patterns and erosion patterns are changed by ocean mining operations (Craig et al., 1996).

3.6 *Well drilling and production*

Drilling wells are used to explore and produce oil, gas, brine, geothermal fluids. Blow out and fire hazards can create severe pollution. Oil and brine spillage and seepage must be carefully controlled.

4 PROCESSING AND SMELTING ORES

Ores require processing after removal from the earth. Such processing is usually done at or near the sites of mining. Mined metals constitute 30% in many Al and Fe ores down to as little as 0.000001 % in me case of Au. The amounts of metal extracted from one metric ton of typical ore range from as much as 250 kilograms for iron ores to as little as 1 gram for gold ores. The amounts of waste left for disposal are greater than the quantities of the metals extracted (Fig. 2).

In many operations, size reduction (crushing and milling) for liberation and beneficiation for concentration are performed. Large quantities of waste gangue material, known as tailings, are dumped in the form of fine-grained slurry into ponds or lakes for settling. Clean water may be recirculated.

Prior to smelting, some sulfide ores are roasted and then pure metal can be recovered by smelting. Cu-Ni sulfide ores are directly smelted to a matte, and then conversion with air is applied. Air oxidizes sulfur to sulfur dioxide and changes iron to an oxide.
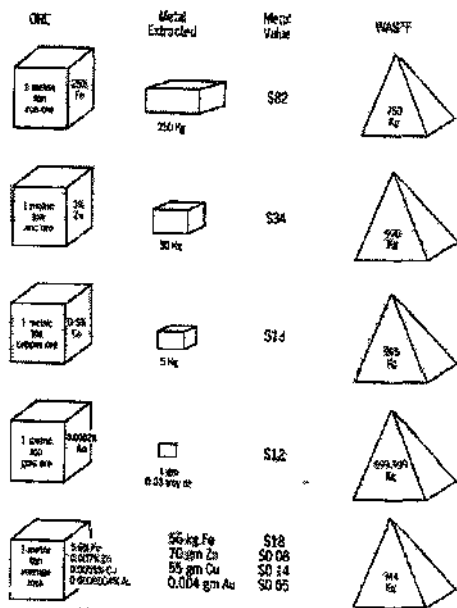
Figure 2. The amounts of metal extracted and waste generated during processing

Smelting and other kinds of pyrometallurgy are very significant sources of air pollution because smelters may emit substantial off-gases, such as SO_2, CO_2 and particular matter (PM). Small quantities of toxic metals, such as As, Pb, Hg, Cd, Ni, Be and V, may be released. Today, Au/Ag is produced by cyanide leaching (hydrometallurgy). Cyanide solutions are highly toxic and their accidental release into the environment can kill many animals and plants.

4.1 How using resources affects the environment

The burning of fossil fuels in power stations, homes and automobile engines results İn gases, particles and excess heat being emitted into the environment. The use of nuclear fuels generates toxic radioactive waste products requiring special disposal. Oil refining and metal/mineral production also generate wastes and pollutants.

4.2 Acid pollution

The most important pollutant of the hydrosphere is acid (H^+} in the form of acid rain and acid mine drainage. Acid mine drainage results from the decomposition of pyrite, usually catalyzed by bacteria (Fe^{*2} to Fe) to produce iron hydroxide, and dissolves H^+ and $SO_4{\sim}$ (Table 2). 95% of the acid mine drainage in the U.S. comes from coal mines or waste piles, which contain small amounts of pyrite.

Acid mine drainage formed by dissolution of pyrite dissolves more pynte, thus accentuating the effects. As the acid water moves downstream, it mixes with less acid water, causing dissolved iron to precipitate as oxides, winch produces further acid. Acid water produced by these reactions can dissolve other metal sulfides and leach metals that are adsorbed on the surfaces of clays and poorly crystallized minerals (see Table 2).

4.3 Burning fossil fitels

The burning of fossil fuels in automobiles, power plants and heating systems creates air pollution. The burning of solid waste and smelting also generates air pollution. Figure 3 shows the effects of the sources of air pollution. Acid rain is die product of reactions between atmospheric water and CO_2, SO_2 and NC\. Possible reactions are shown in Table 2. Acid ram dissolves limestone and lime readily:

$$CaCO_3 + H^+ = Ca^{+2} + HCO_3^- \qquad (D$$

$$CaO + H^+ = Ca^{+2} + OH^- \qquad (2)$$
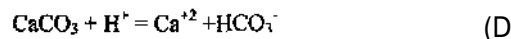
Acid rain speeds up the decay of buildings, sculptures and other structures (Kaya, 1998).
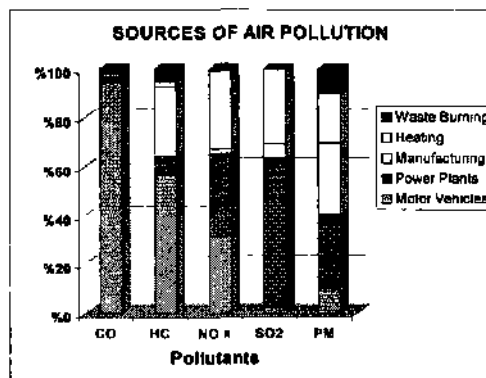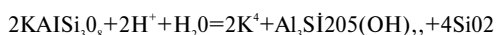

Figure 3. Sources of air pollution

Igneous and metamorphic rocks which consist of largely silicate minerals react slowly with acid:

$$2KAISi_3O_8 + 2H^+ + H_2O = 2K^+ + Al_3Sİ2O5(OH),, + 4SiO2$$

Global temperatures have increased by 0.5 °C since the early 1900s. The increase is related to CO_2, CIL,, H_2O vapor. NO^, CFC and other greenhouse gases, which absorb infrared radiation that would otherwise radiate from the earth into space, thus heating the surface of the planet (Keşler, 1994).

489

Reason for Pollution	Pollution Sources	Pollutants and Reactions	Environmental Effects
Acid Mine Drainage	Coal mines	$2FeS_2+2H_2O+7O_2= 4H^* +SO_4' +2Fe^{'2}$	Pollutes hydrosphere
	Waste piles	$Fe^{*1}+3H_2O \rightarrow Fe(OH)_3i + 3H^+$	
		$ZnS+-3H_2O=Zn^{ri}+SO_4{"}^2$	
		$Clay-Me^{'2}+H^*=Clay-H"+Me"$	Dissolves metals
			Leaches metals
Burning Fossil Fuels	Motor vehicles	$S \rightarrow SO_2 \rightarrow SO_3$	Air Pollution
	Power plants	$SO_3+H_2O \rightarrow H_2SO_4$	⎫
	Heating Systems	$NO+0.5H_2O+0.75O_2 \rightarrow HNO_3$	⎬ Acid rain
	Burning solid wastes		⎭
		$CO_2/CFC/CFCl_3$	
		CO_2	Destruction of ozone layer
			Greenhouse effect
		HC compounds, soot	(atmospheric heating)
		Particulate matter (PM), fly ash	Thermal pollution
		Lead compounds	
		Toxic matter and gases	
Eruptions, Fires, Decay	Volcanoes	SO_2	Acid Rain
	Forest fires	NO_X	Damages vegetation
	Vegetable decay		Damages fish growth
			Leaches nutrients from soil
			Deterioration of metals, lime stones and paints
Disposal of Nuclear Waste Products	Mining and processing of Uranium ores	Radioactive emissions	Radioactive radiation
	Manufacture of nuclear fuels/weapons	Radon gas emission	
	Use of fuels in nuclear power stations	Waste products	

4.4 Disposal of nuclear wastes

The mining and processing of uranium ores, the manufacture of nuclear fuels, the use of fuels in nuclear power stations, and nuclear weapons manufacture all generate waste products requiring disposal. The long-term disposal of radioactive wastes is still an unresolved problem.- Low-level wastes generally have radioactivity less than 1000 times the acceptable level in the environment. Large quantities of this type of waste are produced at uranium mines. In practice, the tails are usually dumped at or near the mine and stabilized by earth cover and vegetation. Large volumes of low-level waste is also produced in nuclear power stations, research laboratories, hospitals or other nuclear industries. These wastes are usually sealed in drums, burned in incinerators and buried beneath a meter of soil. Some low-level wastes have been cast into concrete, put into sealed drums and dumped into deep ocean. Radon, radioactive, odorless and colorless, is gas produced by the decay of uranium and thorium. Radon can escape into the atmosphere as vapor or can be dissolved in ground water. Radon in all forms is harmful to humans. High-level radioactive wastes from the nuclear power industry account for roughly 95% of the radioactivity, but only about 0.1% of the volume of waste generated. High-level nuclear wastes are solidified/vitrified. After being sealed in concrete and stainless-steel canisters, solidified waste can be stored in vaults or reinforced shielded buildings above ground. Solidified wastes can be disposed in the ocean, by burial beneath deep ocean sediments or by deep burial in land. Several countries have already made decisions on the geological environment for long-term high-level waste disposal (e.g., Belgium - clay; Germany - Salt; Sweden and India - granite). (Craigh et al., 1996).

5 CONCLUSIONS

The environmental impact of natural resource exploitation in the United States was estimated by the Environmental Protection Agency (EPA). Recent data for atmospheric pollution in the U.S. show that mineral production accounts for about 30% of Pb, 25% of PM, 18% of SO*, 13% of

volatile organic compounds (VOC), 3% of CO and 2% of NO* emissions. For the three major pollutants to which mineral production makes a major contribution, mining is the most important PM source, smelting is the most important SO* source and crude oil and natural gas processing the most important NO* source. However, the proportion of emissions generated by mineral resource extraction has significantly declined in the last few decades in the U.S. (EPA, 1991)

The total use of land by mining throughout the world between 1976 and 2000 was about 37,000 km^2, or about 0.2% of the earth's land surface. About 60% of disturbed areas are used for excavation and the remaining 40% are used for disposal of overburden and similar wastes. Modern materials such as plastics, polymers, ceramics and composites are introduced to the market. These materials are often in competition with conventional minerals in the form of substitutes. The recycling of some material (such as glass, metals, some industrial minerals, plastic, etc.) also decreases environmental problems. Recycling is the perfect form of mineral reuse.

As a result, miners have to exploit and use minerals in an environmentally friendly way because the globalization of environmental concerns presents complex ethical problems that we have just begun to address. Today, miners cannot ignore the concern that the earth is reaching its limit of mineral-related pollution.

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Monitoring of Damaged Areas Affected by Mining Activity and Possibilities for Reclamation

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ABSTRACT: Environmental transformations, their classification, methods of their monitoring and the prognosis of environmental transformations resulting from mining activity are described. These problems are related with exploited mineral types, prepared and exploited methods, and the characteristics of the area affected by mining activity. Technical suggestions for damaged area reclamation by mining activity are given.

1 INTRODUCTION

Mining activity consists of the exploitation of beneficial ore through three stages: the development of the mine, mineral exploitation and the termination of mining activity. In each stage of mining activity, undesired transformations of the natural and artificial environment are encountered. The range and extent of these transformations are dependent on the deposit type, prepared and exploited methods, the monitoring of damage and the efforts to minimize it. Problems encountered that are related to mining activity may be presented as follows:

Mining

Environmental transformations

Monitoring of mining subsidence

Preventive methods during mining operations

Damage reclamation

The effectiveness of environmental protection against the undesired impact of mining operations depends on proper identification and the ability to forecast negative transformations in the environment, and on the preventive methods applied and measures used to reduce the resulting damage.

In Albania, such a practice is not applied and this has caused a lot of damage, in some cases without possibilities for reclamation. The geographical distribution of mines in Albania is shown in Figure 1.

In about 60 % of these cases, there is significant environmental damage and reclamation is necessary.
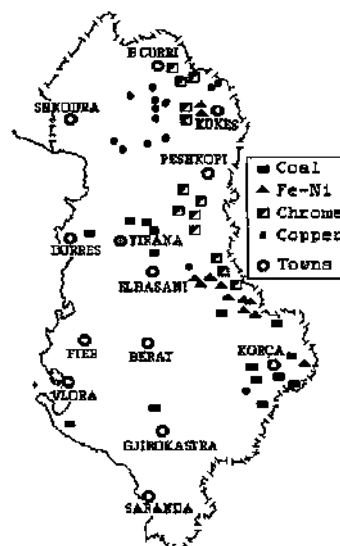

Figure I The localization of the main mining regions in Albania.

2 ENVIRONMENTAL TRANSFORMATIONS CAUSED BY MINING ACTIVITY

The damage caused by mining activity may be divided into different categories, according to the source that causes the environmental changes, or the transformed component of the undermining massive. The environmental transformations occurring in Albanian mining areas may be characterized as given below.

493

2.1 Geomechanical transformations

These transformations are caused by mining- operations performed during the miners construction stage as well as during mineral preparation.

The geomechanical transformations encountered in the mines are:
- open pit excavation (in all mines);
- mine waste dumps during mining and after flotation (Bulqiza, Kalimash, Rehova);
- continuous deformations İn the form of a subsiding trough (Vahas, Memaliaj, Mezes, Alarup);
- slides of mining areas (Rehova, Gjegjan, Pishkash),
- non-continuous deformation in the form of gaps and sink-holes (Rehova, Bulqiza, Spaç, Tue).

Geomechanical transformations constitute a direct threat to the surface and any objects situated on it.

2.2 Hydrological and hydrogeologica! transformations

These transformations consist of the alteration of water in quantity, quality and location both at the surface and underground. Consequently, changes are observed in the hydrographie net, location and dynamics of the underground water, the direction and rate of the surface flows, and contamination of waters by components coming from mining waters.

These transformations occur in the form of:
- alterations of both chemical and physical properties of the water (Valias, Memaliaj, Rehova, Alarup),
- formation of drained areas (Lozhan, Rehova, Klos, etc.),
- formation of depression sink,
- formation of waterlogging areas (Valias, Mezes),

The water alterations mentioned above consequently have a negative effect on other components of the environment.

2.3 Flora transformations

These are alterations in the flora as a result of transformations occurring in particular components of the environment. In the mines a destructive influence is produced mainly by water component changes, flowing from mining openings, as well as by underground and surface water regimen changes. Flora damage caused by polluted water is mainly evident in copper mines.

Natural regimen changes of water flows have caused damage to flora in Valias, Mezez, Memaliaj, Lozhan, and Rehova mines and many others.

Flora in mining areas is also damaged by smoke from industrial operations of mineral processing and metallurgical plants. This phenomenon can be observed especially in the Dumrea and Elbasan areas.

Transformation of woodland areas for mining operations and the deposition of mining dusts in these regions have caused flora degradation and have transformed them in unproductive ones.

2.4 Air transformations

These occur through contamination of the air by dusts and gases These transformations are caused by mining activity as follows:
- mining operations İn open pit mines (open pit mines in Gjegjan. Leten, etc.);
- mechanical and chemical processes during mineral processing (Gjegjan, Rehova, Rubik etc.);
- ventilation of underground mines (Valias. Mezez. Mborje Drenova, Prrenjas etc.);
- fires caused in piles (Memaliaj, Alarup, Lozhan, Pishkash etc.);
- dusts caused by mineral and rock piles;
- gases resulting from fuel combustion needed for mining operations (all mines).

The contamination of the air over a long period may lead to temporary or permanent alterations of the region's microclimate.

Other transformations caused by mining activity may be technical ones: noises and vibrations produced mainly by mining machinery, fans and lifts, transport operations and pre-seismic shocks caused by blasting.

3 MONITORING OF ENVIRONMENTAL TRANSFORMATIONS CAUSED BY MINING ACTIVITY

Environmental protection against the undesired effects of the transformations mentioned above depends first of all on the qualitative and quantitative estimation and prognoses of particular transformations resulting from designed mining activity.

In relation to environmental components and transformation types, the following observations are often made:
- subsidence and displacements of the surface;
- damage and deformations of the objects existing within mining influence zones;
- monitoring of the surface and underground waters;
- monitoring of flora and forests;
- monitoring of ground and soils;
- monitoring of noise and vibrations;

monitoring of places where mining wastes are located as well as the types and contents of the harmful components of mem.

On the basis of observations carried out, it is possible to predict the final effects of mining activity and determine the types and magnitude of anticipated environmental transformations. Prognosis methods for particular transformations are based on theoretical models of the phenomenon causing diese

transformations. The parameters of these models are checked by analysis of monitoring studied results.

A well-prepared prognosis, especially for the influence of planned mineral exploitation, is a precondition for safe mining activity and the minimization of environmental damage during exploitation.

3.1 *Prognosis of the continuous deformation*

Prognosis of the continuous deformation which will occur on the surface as a result of underground mining of a deposit is prepared using the Knothe-Budryk formula. By making calculations with this formula, we can estimate the values of the déforma-tion indicators in the area affected by planned mining exploitation. The deformations are presented either in the form of indicator plots along a selected cross-section, or İn the form of a surface distribution by means of isolines.

On the basis of graphics compiled for each mme, it is possible to:
- determine deformations of the ground surface and estimate the zone which will undergo maximal subsidence and displacements;
- estimate the resistance of the buildings and other infrastructure constructions located in the area affected by mining operations.
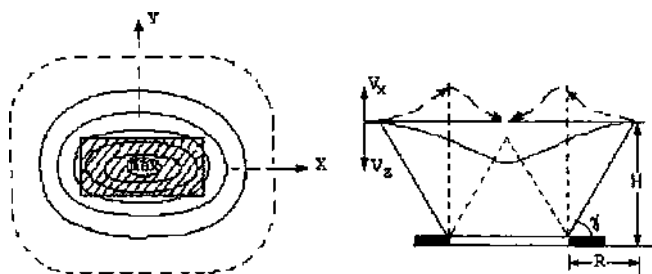

Figure 2 Prognosis of continuous deformations.

3.2 *Prognosis of the non-continuous deformations*

Prognosis of non-continuous deformations is carried out for the case of shallow deposits mined with fall of roof. As a result of the prognosis, we can estimate the possibilities of non-continuous deformations occurring and the types of these transformations throughout the planned exploitation. The accuracy of the obtained prognosis results depends on the information obtained about the geological structure and deformation mechanism of the rock mass in the mining regions under consideration.

4 PREVENTIVE METHODS AND REPAIR OF DAMAGE IN MINING AREAS

The methods for counteraction and regeneration of the undesired transformations of the environment, as well as minimization of these transformations, depend on the type and range of the forecasted effects of the mining activity. If we have information about the type and range of expected transformations, we may prepare measures and a preventive plan before and during mining activity. These measures can be classified as static or dynamic.

Static measures include the determining the working position in relation to the structures that need protection, limiting the panel in the protective zones and choosing the methods of mining works. The dynamic measures affect interim ground movements and concern the direction and rate of the advancing face, as well as the chronological sequence of the workings.

Reclamation, on the other hand, is carried out in two main phases: technical and biological rehabilitation. The target of the first phase is to re-establish on the despoiled land the conditions required for plant life and restoring the fertility of the soil, or for using it as building ground. The surface of the spoilbank is leveled and, if necessary, covered with a layer of arable land.

In the biological phase of reclamation, the soil is prepared for agriculture or forestry. Re-cultivation for agriculture presupposes that sufficient quantities of arable land are available to be spread as cover on the sterile sub-soil of the spoil heaps, and that the new farmland will yield a profit.

Reclamation of land for forestry does not call for soils of such high quality, and therefore it is practised more frequently than rehabilitation for agriculture.

495

Reclamation of land for forestry does not call for soils of such high quality, and therefore it is practised more frequently than rehabilitation for agriculture.

At present, especially İn Albania, the tendency is to try and solve these problems by imposing the duty of environmental protection and control on industnes which disturb the environment.

The first step is the creation of realistic laws and directives that impose the same standards. Once environmental protection has been assigned its proper place in the structure of the economy, it will become one of the decisive factors in further economic development.

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Possible Ecological Consequences of Liquidation of Mines of Mirgalimsai Deposit

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ABSTRACT: the hydro-geological conditions of the mirgalimsai deposit region were analyzed, a description is presented of potential sources of environmental pollution and possible ecological consequences of full flooding of mines, ways of decreasing costs are suggested in preventing ecological catastrophe in the conditions of non-operating mines of the deposit.

1 INTRODUCTION

Mining operations İn the Mirgalimsai deposit were stopped in 1995 because of the low profitability of <u>mining</u> the remaining reserves. This deposit is filled with more water man any other in the mining industry İn CIS countries, with an average mine inflow of 12,000 m^3/h over many years. Such substantial mine inflow is caused by the fact that the Mirgalimsai deposit is situated in the center of a depression cone asymmetrical in form with a radius of influence 25-30 km in the southeast direction and 9-13 km in the northwest direction. Its appearance and development is a result of mine working driving. The development of the system of mine workings and the opening-up of deeper levels were the cause of the increase in mine inflows. The depression cone also developed, Water enters the mine workings through fractures in the riverbeds of the rivers Bayaldyr, Biresek and Kantagi.

2 ANALYSIS AND CONSEQUENCES OF WATER DISCHARGE

Today at mmes of the Mirgalimsai deposit, only a mine pumping complex is operated, sustaining water at the mark of level 13. The annual costs for the maintenance of this complex are about 1 billion tenge, including costs for electrical energy of 641.3 million tenge.

In relation to the high expenses for the maintenance of die mine pumping complex, a decision was made concerning wet conservation involving full flooding of the mines. However, with the liquidation of mine pumping and flooding of mine workings above level 13, a catastrophe could occur in terms of movement of the surface of industrial zones and residential areas of the city of Kentau and disturbance of the ecological conditions in the region. This problem was discussed by the Kazakhstan government and the special state municipal enterprise "Kentaulikvidrudnik" was founded. Its mission is solely to pump large volumes of water from "closed down" underground mines at the expense of budget financing, and no ore mining takes place. The necessity of continuous pumping of water from non-operated mines is due to the fact that large volumes of toxic materials were buned in the worked-out space. This is because a chamber-and-pillar system with goaf stowing was employed during underground ore mining at "Atchpolimetar mining and processing integrated works. As a filler, in order to save cement, solid wastes from the preparation process were used - ore tailings. During processing of polymetal ores by the flotation method, toxic reagents were used at some technological lines of the preparation plants, including extreme poison - sodium cyanide. Two ore tailings piles were formed, - Bayaldyrskoye and Kantaginskoye, which are located near Kentau. As a result of technical-in-genesis activity, as joint investigations of the VNIMI, "Atchpolimetar' JSC and SME "Kentaulikvidrudnik" institutes show, the ore tailings used for filling worked-out space include 183,00 kg of cyanides. In addition, they include other toxic materials: 7,486 tons of sodium sulphide, 876 tons of xanthate, 342 tons of oleic acid, 47 tons of shale resin, and 472 tons of phenol.

There is a common water-bearing regime in the Turkestan region, located in an area of a large depression cone, with a wide mouth at the surface, and under it the Mirgalimsai deposit is situated. Water from water-bearing seams moves through the

cone walls up to level 13, where 22 pumps operate twenty-four hours a day, pumping water up to level 9. From level 9, where pumps are placed, the volume of water of a river is pumped up to the surface. In the case of the pumps stopping, because of the electricity being cut off, lack of money or other factors (breaking of pumps), non-planned flooding of levels may take place. Thus, in 1997, because of a shortage of electricity supplies, non-planned flooding of level 19 took place. Water flooding from overlying levels would dissolve toxic materials, and even if the pumping station at level 9 were saved, on the surface in the cities of Kentau and Turkestan, springs would be contaminated with toxic water, as Turkestan is situated 212.0 m above sea level, and level 9 is 261.8 m above sea level. If the pumping station of level 9 were to be disabled, then the region (the largest part of the southern Kazakhstan region) would lose its water reserves. Failure of the pumping stations of the closed down mines of the Mirgalimsai deposit would cause catastrophic pollution of underground waters with highly toxic materials and create an ecological disaster area in a densely populated region of Kazakhstan. The negative consequences of cessation of the operation of the pumping complex and full flooding of the mine workings and extracting area would be to wash out rocks non-stable to water (limestone), placing in layers of chamber, block and barrier pillars, and it would cause their destruction and caving of the surface. Most of die residential and industrial areas in the city are in the proposed zone of caving, and moving them requires serious investigation.

However, the existing economic situation of the country requires tfiat the project of conservation of the mines of the Mirgalimsai deposit be carried out at lower cost, while still taking into account the danger of disturbance of the ecological conditions in the region.

A feasibility study carried out jointly by the institutes VNIMI (Saint Petersburg, Russia), "Kazgiprotsvetmef* (Ust-Kamenogorsk, Kazakhstan), and SME "Kentaulikvidrudnik" (Kentau, Kazakhstan) showed that wet conservation of mines above level 13 is not appropriate with relation to the causes given above.

In order to reduce the cost of the conservation of mines with savings from a reduced form of mine pumping, recommendations have boen made on decreasing costs for mine pumping maintenance and holding the water level at the mark of level 13. They include water-pumping adit driving from level 4 up to the surface, and small hydraulic-electric stations constructed for additional production of electrical energy.

Water-pumping adit driving will ensure savings in the electrical energy consumed by the pumps of up to 20-25% at the expense of decreasing the height of water pumping up to 81 m.

In order to use the energy of the underground waters, the construction of a small hydraulic electricity station has been proposed at the mouth of a water-transferring mine working, and this will allow the partial supply of mine pumping by electrical energy. Obviously, full use of the potential energy of the water would be realized with the placing of a hydro-generating device at level 13 with a water head of 110 m. With an average annual water inflow $0=12,000$ m^3/h and water column height $H=110$ m, the calculated capacity of the small underground hydraulic electricity station would be 2,000 kw.

For additional refunding of expenses for electrical energy in mine pumping, it has also been proposed that small hydraulic electricity stations be constructed at the surface on the riverbeds of the Bayaldyr, Biresek and Kantagi rivers. If the average annual water consumption were 15.0-16.0 m^3/h, the total capacity of the surface hydraulic electricity stations would be 4,000 kw.

As preliminary calculations show that these measures (water-pumping adit driving and construction of small hydraulic electricity stations) would ensure up to 45-50% of the electric energy for die pumps, there would be a saving in electricity equivalent to 300 million tenge a year,

In addition, relief in the up-river areas of these rivers would allow the construction of a series of small hydraulic electricity stations, which would increase electricity production and lead to a saving in the budget which is provided by the state to maintain pumping of the mines of the Mirgalimsai deposit.

3 CONCLUSION

For the prevention of possible flooding of the top levels of the Mirgalimsai deposit with catastrophic consequences, because of problems with electricity supplies, it is necessary to construct independent sources of electricity in order to decrease the costs of maintaining the mine pumping complex. An alternative of full flooding of mines is proposed, fixing the water at the mark of level 13 with constant mine pumping in more favourable conditions than are present today, so that part of the energy consumed (up to 50%) will come from independent sources. Such a system of supply for the pump motors, with automatic blocking for sudden drops in voltage or full cut-off from the city supply, would exclude the possibility of sudden cessation in the operation of the mine pumping complex, flooding of the top levels and the catastrophe that could follow these events.

Acid Mine Drainage at Sarcheshmeh Copper Open Pit Mine

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ABSTRACT: Acid Mine Drainage (AMD) problems are predominantly chemical, and are of great complexity. Any deposit containing sulphide minerals, particularly pyrite, is a potential source of AMD. Acid mine drainage is a serious environmental and economic concern. Pyrite oxidizes when it comes into contact with air and water, and sulphuric acid is produced. This lowers the pH of the water and increases the solubility of many metals. The planning of a mine and design of pit walls can be affected by environmental factors. By making environmental assessments, quantitative estimates of the effects of the mine on its surroundings can be considered during design. This research was directed toward evaluation of alternative procedures to minimize the drainage of poor quality water from the mine.

1 INTRODUCTION

The Sarcheshmeh porphyry copper-molybdenum deposit is located in southern Iran. A large-scale open pit mine was started up by the National Iranian Copper Industries Co. (NICICO) in 1974. It is currently the largest open pit mine in Iran. The Sarcheshmeh pit is oval shaped, about 3000m long by 1800m wide. The ore body contains 1200 Mt. of ore. The average sulphide is 0.7% copper and approximately 0.03% molybdenum. The mine produces 100,000 tons of copper and 2200 tons of molybdenum concentrate per year.

The planning of a mine and design of pit walls can be affected by environmental factors. By making environmental assessments, quantitative estimates of the effects of the mine on its surroundings can be considered during design. Engineering alternatives have to be compared on criteria that include specific environmental requirements. It is important to make an early identification of potential problems in order to devise practical solutions. After an environmental plan is adopted, monitoring of key criteria throughout die operating stage is required to identify and correct deviations from the plan. This study focused on pyrite weathering during the productive life of a mine.

Various water types within the Sarcheshmeh mine workings can be identified on the basis of quality differences. These water quality differences exist because of differences in rock types, mineral-ogy, flow path length and travel time. In many instances these water types have been discharged directly into Sarcheshmeh River. To remove the dissolved metals or suspended solids a settling pond and liming facilities have been installed. The current activity in this regard involves minimizing the production of mine drainage, thereby eliminating or at least minimizing the mine drainage.

2 GEOLOGICAL SETTING

The Sarcheshmeh Copper Open Pit Mine is in southern Iran, at an average elevation of 2600m. It is located İn the central part of an elongated NW-SE mountain belt, which is principally composed of folded volcano-sedimentary complex. The geology of Sarcheshmeh porphyry copper-molybdenum deposit is complex, with widely varying rock types. Mineralization in the Sarcheshmeh porphyry copper-molybdenum deposit İs associated with a Late Tertiary granodiorite porphyry stock. The whole complex is criss-crossed by a series of inter-mineral and postmineral dikes. The original sub-circular Sarcheshmeh porphyry stock exhibits an east-west elongation due to dilation by the dike swarm, whose strike is predominantly NNW (Fig. 1). The highest-grade hypogen zone occurs as an annular ring in altered andésite around the periphery of the Sarcheshmeh stock (Waterman et al. 1975).
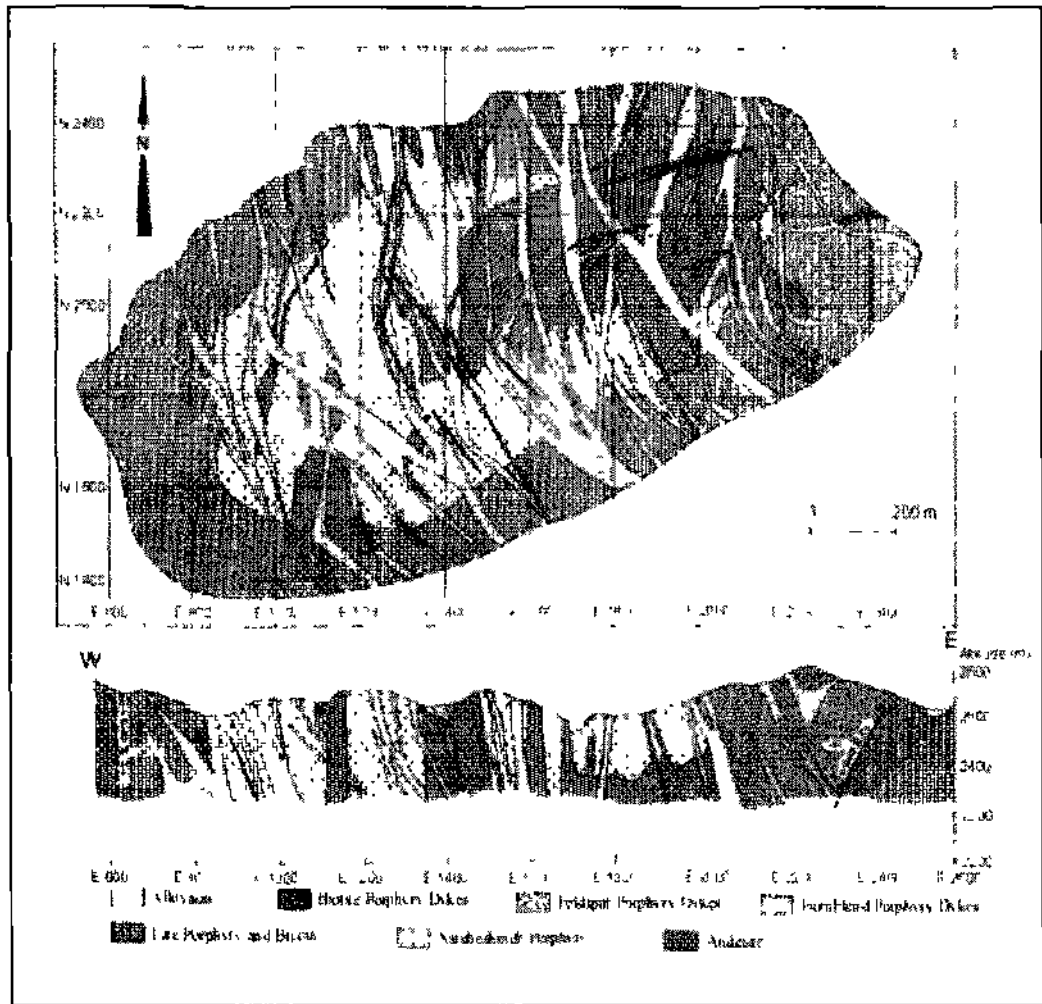
Figure ! Distribution of the rock types at 2400m elevation within outer 0 40% copper line Sarcheshmeh deposit with geological section (Etminan, 1977).

3 HYDROGEOLOGY

The Sarcheshmeh mine has a catchment area of about 21 km and average annual precipitation of about 440 mm, showing the direction and quantity of surface flow to the pit. Hydrogeological studies around the Sarcheshmeh area show that there are definite relationships between geologic, topographic, hydrogeologic and climate factors and existing ground water flow systems.

At Sarcheshmeh, structural features control to a large extent *the* location of groundwater entering a geologic formation. Hydraulic conductivity is fracture-controlled. Water enters the mine by two mechanisms:

a) Downward movement of water under saturated or unsaturated conditions within the cone of depression created by the mine

b) Lateral ground water movement to the margins of the mine

Water samples were collected at Sarcheshmeh, on a monthly basis over a one-year period. The results of this initial hydrologie investigation showed that the acid drainage is controlled structurally. Considering the structural information, the Sarcheshmeh pit was initially divided into 4 pit sectors in terms of the anticipated hydrogeological conditions as follows (Karimi Nasab 1997):

- West pit wall: the crests are parallel to the general strike of the dikes with a dip angle of 70° to 85°

500

towards the east. Considering the general hydraulic gradient from south to north, the dikes act as a barrier to acid water flow.

- South pit wall: the crests are approximately perpendicular to tiie strike of the dikes, which do not appear to act as structural barriers to acid water flow.

- East pit wall: hydrogeologically, this sector İs similar to the west wall, but the dips of the dikes are against the bench slope.

- North pit wall: this is similar to the south wall.

An estimated 66,000 meters of surface exploratory diamond drilling has been completed in the mining area. This type of drilling is designed to reach ore bodies, which are usually more permeable than the surrounding rock. This type of exploration increases recharge to the groundwater flow systems by providing more interconnections between the surface and subsurface.

Hydrogeological problems from mining activities are related to the modification of the existing ground water flow system or the creation of a new flow system. Thus, future mining activities should incorporate hydrological variables in mine planning and surface-waste site selection procedures. Preventing acid mine drainage is much less difficult than curing acid mine drainage.

4 BASIC PROCESS OF AMD

AMD problems are predominantly chemical, and of great complexity. Originally considered to be a problem associated only with coal mining, and particularly with abandoned mines, AMD is now known to occur as a result of the working of many other minerals. Any deposit containing sulphide minerals, particularly pyrite, is a potential source of AMD.

AMD is produced when a sulphide reacts with air and water to form sulphuric acid. The basic process occurs in three stages:

1) The oxidation of the sulphide, usually $FeS2$- If the reaction takes place in a dry environment, water-soluble ferrous sulphate and sulfur dioxide are formed (Williams et al. 1979):

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2 \qquad (1)$$
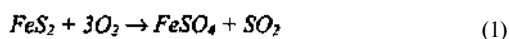
More commonly, the reaction occurs in the presence of water, with the direct formation of sulphuric acid:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \qquad (2)$$
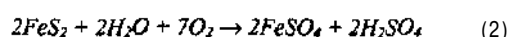
2) Ferrous sulphate, in the presence of sulphuric acid and oxygen, can oxide to produce ferric sulphate. This transformation İs not controlled by the presence of water, but it appears that a bacterium

(Thiobacillus ferro-oxidans) is an essential mediator, and if it is not actually responsible for the oxidation, at the very least it greatly accelerates it. The reaction is:

$$4FeSO_4 + 2H_2SO_4 + O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2 \qquad (3)$$
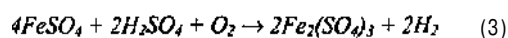
3) The ferne iron so produced combines with the hydroxyl (OH) ion of water to form ferric hydroxide. This is insoluble in acid, and precipitates:

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2O \qquad (4)$$

An alternative to this reaction occurs because the ferric iron may also enter the reaction with iron sulphide and "back-trigger" further oxidation, thus accelerating acid formation.

$$Fe_2(SO_4)_3 + FeS_2 \rightarrow 3\ FeSO_4 + 2S \qquad (5)$$

$$S + 3O + H_2O \rightarrow H_2SO_4 \qquad (6)$$

The sulphuric acid generated tends not to be found as high concentrations of free acid due to further reactions with other minerals.

At pH 3.5 or less, bacteria such as Ferrobacillus ferrooxidans, F. Sulfooxidans and Thiobacillus ferrooxidans accelerate the rate of conversion of Fe' to Fe^{i+}. Singer & Strumm (1970), noted that such bacteria may accelerate the reaction in equation 3 by a factor of 10^6 or more. The organism, which requires oxygen for growth, can also transform nickel, copper, zinc, molybdenum and other metallic sulphides (Hawley et al. 1971).

In addition to the formation of water with low pH and high iron, acid produced from the oxidation of pynte may also dissolve other minerals which by themselves do not contribute to the formation of acid waters. The dissolution of the sulphide copper mineral chalcopyrite is an example.

$$CuFeS_2 + 2Fe_2(SO_4) + 2H_2O + 3O_2 \leftrightarrow CuSO_4 + 5FeSO_4 + 2H_2SO_4 \qquad (7)$$
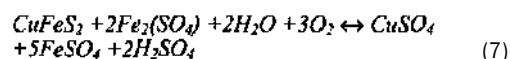
Increased flow through mine workings during spring runoff flushes oxidation products from areas not normally in contact with water. Numerous pools of acid water also collect in mines during low flow periods. The influx of water during spring runoff flushes out these pools, with the addition of poor quality water to the system.

5 SURFACE WASTE FEATURES

Acid production from surface waste features is governed by the following variables:
a) oxygen
b) availability of pyrite and other heavy metals
c) moisture in the waste material

d) availability of water to transport oxidation products

e) physical location of the waste features

Surface waste features are vulnerable to flushing of oxidation products from within the waste material. Erosion of the waste material by surface water is also a problem.

6 AMD ASSOCIATED WITH MINING ACTIVITIES

Waste dumps that progress over or fill up drainage routes must also have special design considerations. If run-of-mine rock is end-dumped from the tip head, then given sufficient dump height, gravity will segregate the larger and smaller fragments. The larger material will roll to the bottom of the dump and will normally from a very permeable base. The finer material gathering in the upper portions of the dump will tend to form an almost impermeable surface. Waste dumps built with this natural segregation have free drainage and offer little chance of saturation unless the base material weathers rapidly. They will also have decreasing permeabilities through time. The high base permeability will allow the dumps to progress over small drainage routes and not block the flow.

Water quality problems associated with mining activities can be minimized by considering the following points:

- Hydro-geological site selection factors should be considered for the location of tailings disposal areas, waste rock storage areas, and low-grade ore storage areas planned for future mining activities. Disposal areas for tailings and waste rock are limited by the physical characteristics at Sarcheshmeh mine.

- Diversion of discharge to central flow points within the mine workings would help to eliminate the flushing of accumulated oxidation products or contamination of good-quality discharge sources.

7 ANALYSIS OF WATER QUALITY DATA

Water discharging from the pumping tests can be further subdivided based on whether or not the drill hole has encountered the ore body. The change in quality of water with time under at the constant pumping rate for 4 pumping stations are shown in Table 1. The water quality differences for each pumping station exist because of differences in rock types, mineralogy, flow path length and travel time. The quality of water after 99 hours (5 days) pumping was better than the first day of pumping test owing to limitation of available oxygen. Over a period of 19 months water flowing from streams or springs were sampled at 7 stations (Fig. 2). The water source was

thought to be from ground water originating from faults and fractures. Stream and spring water quality around the Sarcheshmeh pit is good. Figures 3-9 show quality variations for these sources. The quality of water from Sarcheshmeh River and dump No. 11 is lower than the other stations. Acid production from dumps near stream channels is a significant source of acid water and heavy metals in the Sarcheshmeh River. In waste rock leach the rate and amount of acidity and metals produced under saturated conditions are different compared to similar materials under unsaturated conditions (Keith. & Runnells 1995).

8 CONCLUSIONS

Preventing acid mine drainage is much less difficult than curing acid mine drainage. However, the following points are worth noting:

a) Sulphide, water and oxygen are necessary.

b) An excess of any one component can produce more acid.

c) The reaction is auto-catalyzed by the presence of acid.

d) Biological catalysis via Thiobacillus and Ferrobacillus can occur.

e) The pyrite reactions control the presence of such toxic heavy metals as *Pb. Zn, Cd, Cu* in solution through pH.

f) Acid production can be prevented by excluding oxygen, water or sulphide.

- Surface exploratory diamond drilling is designed to reach ore bodies, which are usually more permeable than the surrounding rock. This type of exploration increases recharge to the groundwater flow systems by providing more interconnections between the surface and subsurface.

- The results of pumping tests at the Sarcheshmeh mine have shown the significant role of rock types, mineralogy, flow path length, travel time and oxygen availability in acidic water production.

- Analysis of water quality data for different sources around the Sarcheshmeh pit has shown that dumps play an important role in acidic water and heavy metals production.

- Hydrogeological site selection factors should be considered for the location of tailings disposal areas, waste rock storage areas, and low-grade ore storage areas planned for future mining activities.

- It may be possible to divert surface water or reroute the shallow groundwater flow systems, recharging localized acid-producing areas in the upper workings in order to reduce the flushing of acid reaction products into the mine drainage system.

- Finally, the results of this research have strong implications for mine planning.
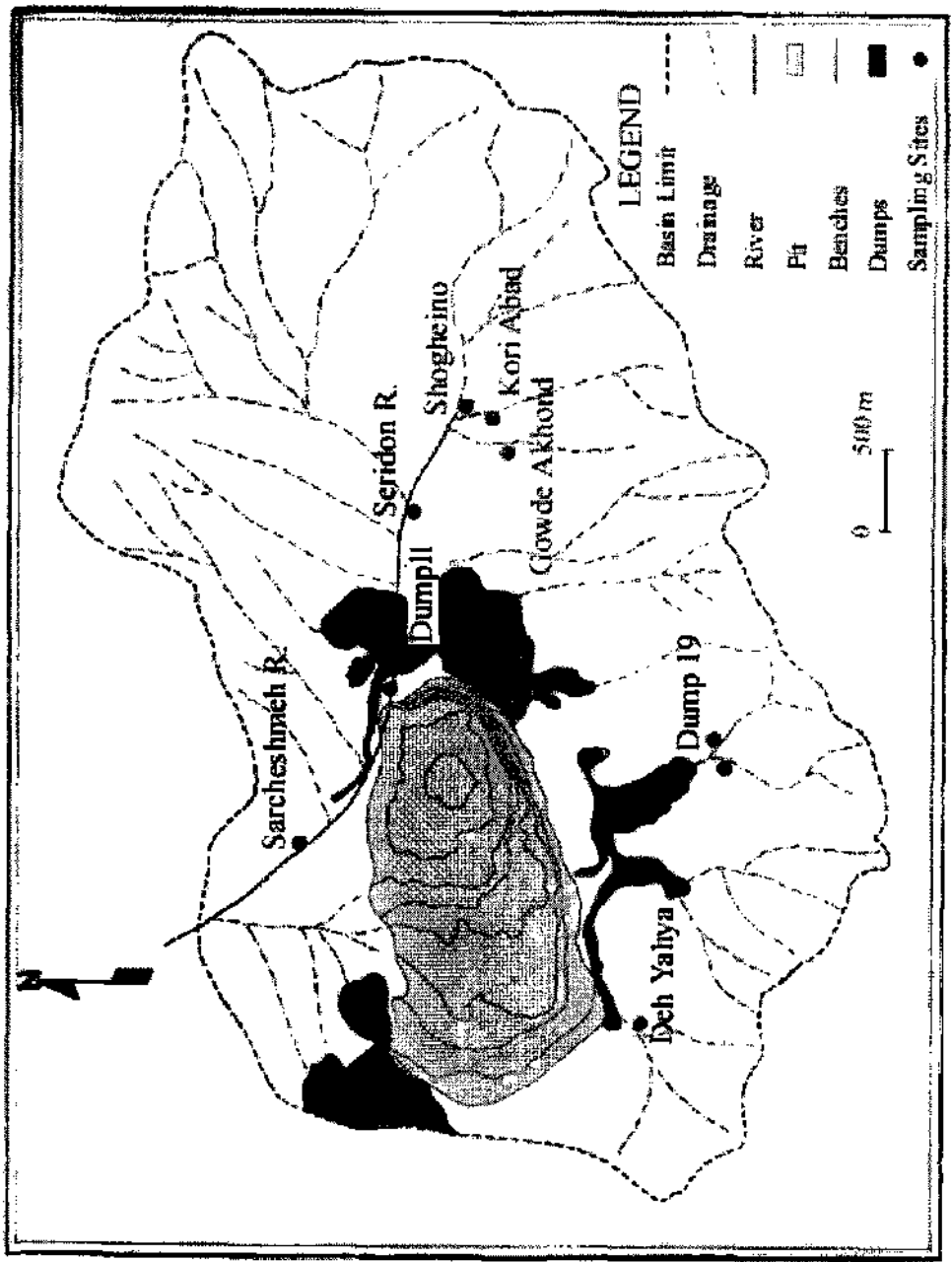
Figure 2. Sarcheshmeh basin and location of water sampling stations.

Table 1. Water quality data for different pumping stations, during 99 hours of pumping test

Pumping station	Date	Sample	pH*	Ec	SO4	HCO3	Ca	Mg
PTW1	21/09/99	S₁	5.9	3591	2400	20	560	230
	22/09/99	S₂	4.3	2473	1900	0	416	160
	23/09/99	S₃	6.3	2234	1900	5	460	130
	24/09/99	S₄	6.3	1990	1700	11	408	120
	25/09/99	S₅	6.4	1990	1640	54	350	120
PTW2	20/12/99	S₁	7.6	280	59	98	41	8
	21/12/99	S₂	7.3	280	59	100	42	8.8
	22/12/99	S₃	7.2	290	64	100	42.8	8.6
	23/12/99	S₄	7.1	319	65	100	43.2	8.6
PTW3	01/01/00	S₁	6.7	1197	750	50	245	46
	05/01/00	S₂	6.9	1117	690	65	220	45
	06/01/00	S₃	6.6	1070	700	58	235	43
	07/01/00	S₄	6.8	1077	700	82	240	43
	08/01/00	S₅	6.8	1037	700	78	235	43
PTW4	29/02/00	S₁	7.2	710	320	125	100	34
	01/03/00	S₂	6.8	910	360	110	112	34
	02/03/00	S₃	7.1	758	360	115	105	34
	03/03/00	S₄	7.1	718	360	115	104	34
	04/03/00	S₅	7	790	360	112	100	36

*pH in standard units, Ec: specific electrical conductance is reported as μmoh/cm at 25°C, and other parameters are reported in ppm.
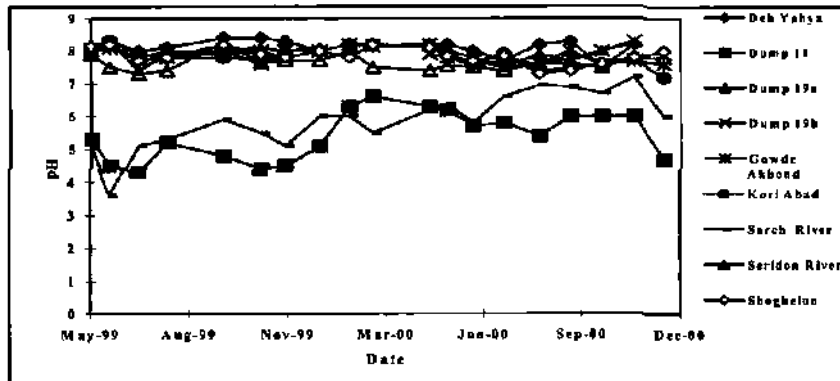

Figure 3. Variation of pH value for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000.
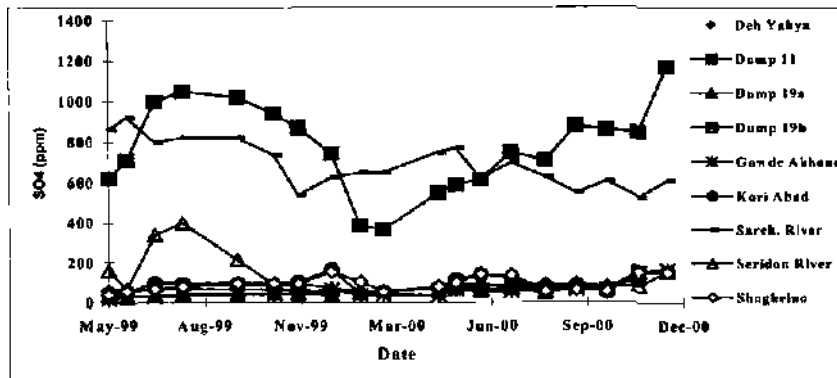

Figure 4. Variation of SO₄ ion for different sources of water around the Sarcheshmeh pit for May 1999 to December 2000
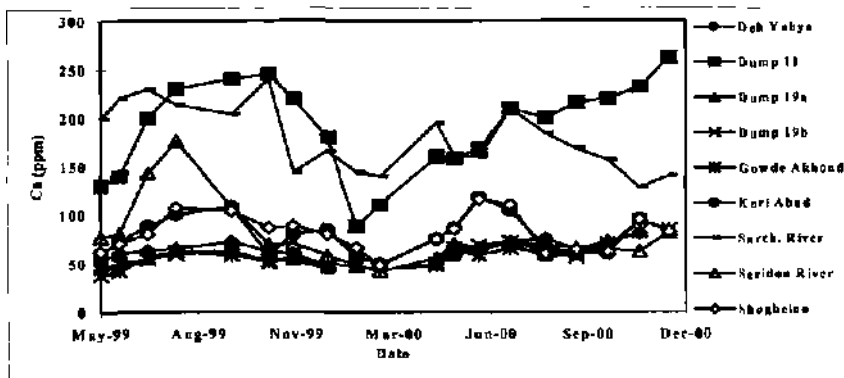
Figure 5. Variation of Ca ion for different sources of water around the Sarcheshmeh pit for May 1999 lo December 2000.
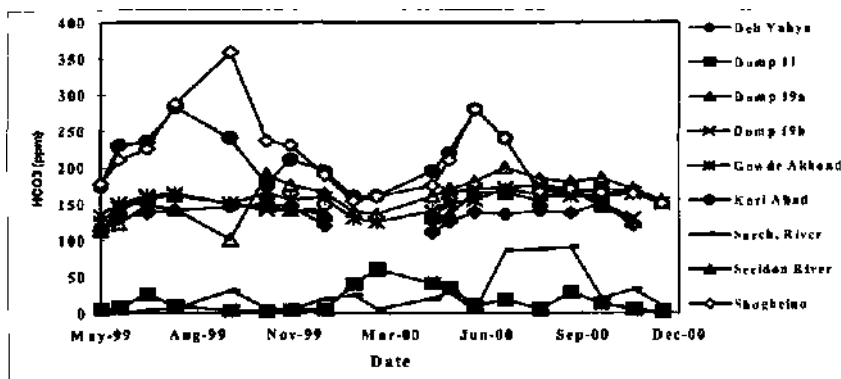

Figure 6. Variation of HCOj ion for different sources ofwaterarouiid (he Sarcheshmehpii for May 1999 lo Decern bei'2000.

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505

Waste Management Practices at Çayeli Bakır İşletmeleri A.Ş.

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ABSTRACT: Industrial processes generate a number of industrial wastes in many forms (solid, liquid and gaseous states). Such waste may be harmful to the environment, either because of the volume produced or the damage it could cause if not disposed of properly. ÇBI, as an environment-conscious company, is committed to protecting the local environment in which it operates and has adopted a waste management program which is designed to eliminate any negative impact on the natural environment because of the operation.

1 INTRODUCTION

Çayeli Bakır İşletmeleri A.Ş. (ÇBÎ) is a copper-zinc mine located in the northeast part of Turkey. It started producing copper and zinc concentrates in late 1994 (Fig. 1). The mine is a joint venture of Inmet Mining of Canada, Eti Holding, and Gama Endüstri ve Pazarlama A.S. There are 386 employees and operation continues seven days a week and 24 hours a day. The size of the facility and acreage of the property are 16,700 m^2 and 584,605 m^2 respectively. In the year 2000, 860,763 tonnes of ore were milled, from which 148,366 tonnes of copper concentrate and 51,370 tonnes of zinc concentrate were extracted.
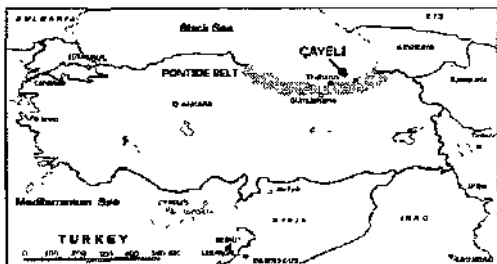

Figure 1. Location of Çayeli Mine.

Çayeli Bakır İşletmeleri recognizes that industrial waste can be harmful to the natural environment, and understands *its* role as a leading mining company in Turkey with respect to protection of the environment. For this reason, ÇBÎ developed a Waste Management Program in order to:

(i) establish protection of the local and global environment;

(ii) implement strategies to:

a) refuse products that because of their volume, excessive packaging, or toxicity may harm the environment,

b) reduce the amount of waste, either by using lesser quantities or reducing the size of the waste generated,

c) recycle waste, either within ÇBÎ's operations, community programs or through private enterprises,

d) reuse waste materials in any phase of its operations;

(Hi) establish and maintain consistent work practices that would reduce or eliminate the generation of waste;

(iv) comply with legislation and company policies and procedures.

In this paper, waste management practices at CBI are briefly described.

2 WASTE IDENTIFICATION AND CLASSIFICATION

2.1 *Waste Identification*

For the identification of wastes, the following four basic questions need to be answered:

1. Can it be used somewhere else in the process?
2. Can it be recycled internally or externally?
3. Does it have a potential to contaminate the air, the land or the waterways?
4. Does it need special treatment prior to disposai?

507

2.2 Waste Classification

Wastes are basically divided into two major groups at CBI:
- hazardous,
- non-hazardous.

2.2.1 Hazardous Waste

Hazardous wastes are those which are toxic, infectious, flammable, eco-toxic, corrosive, etc., which have the potential to cause harm to human or animal life or to the environment, producing either short- or long-term effects.

The Turkish Environmental Regulation (TER) mandates that hazardous wastes are to have separate collection, packaging and storage before disposal. The list of hazardous wastes commonly found at CBI is given in Table I.

Table 1. List of hazardous wastes at CBI.

TYPE OF WASTE*	REGULATORY WASTE CODES	TOTAL AMOUNT-	HAZARDS	DISPOSAL METHODS OF CBI	METHOD OF REGULATED DISPOSAL
MEDICAL WASTES*	Y1	10 Kg/mo	Infectious Pathological Toxic	D10	D10, D5, R1
LUBRICANTS*	Y9	1350 Kg/mo	Flammable-Combustible Eco-toxic	D10	D9, D10, R1, R9
CHEMICALS*	Y14	850 Kg/mo	Toxic, eco-toxic Corrosive, oxidant Flammable, explosive	D10	D5, D9, D10
BATTERIES*	Y31	250 Kg/mo	Toxic Eco-toxic	R4	D9, R4
TAILINGS	Y22 Y23	370 m³/hr	Eco-toxic Corrosive Toxic	Deep Sea Discharge, R4	D10, D5, D9, R4

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D5-Storage on land by special treatment R1-Use as fuel or use for production of energy R9-Refiningofused oils or
D9- Physical-chemical treatment   R4- Improvement/recycling of metals and metallic other uses of previously
D10-Burning   compounds   utilized oils

2.2.2 Non-Hazardous Wastes

Non-hazardous wastes are those that are not harmful to human or animal life or to the environment.

However, because of their volume or low degradable rate, they must be disposed of in a manner that will minimise the negative long-term effect on the environment.

Non-hazardous waste can be recycled, reused, reduced in volume, etc. The list of non-hazardous wastes commonly found at CBI is given in Table 2.

Table 2. List of non-hazardous wastes at CBI.

TYPE OF WASTE	TOTAL AMOUNT	DISPOSAL '*' METHODS OF CBI	METHOD OF REGULATED DISPOSAL
Scrap metal	17800 kg/mo	Recycle, reuse	Recycle, landfill
Scrap wood	1700 kg/mo	Reuse	Reuse, landfill
Scrap plastic and nylon	500 kg/mo	Recycle, landfill	Reuse, recycle, landfill
Scrap rubber and tires	1000 kg/mo	Reuse, recycle	Reuse, recycle, landfill
Domestic wastes	15 ton/mo	Landfill	Landfill
Electrical cables	100 kg/mo	Reuse, Recycle	Reuse, recycle, landfill

(*) Through the use of contractors

508

3 WASTE SEGREGATION

Segregation refers to the physical separation of waste according to classification, compatibility and hazards to employees, the premises or surrounding properties.

Wastes can be segregated in the simplest form: hazardous (to humans or to the environment) and non-hazardous. Furthermore, each of these basic groups can be divided into subgroups by considering their chemical compatibility, degree of toxicity, degree of corrosion, whether they are solid, liquid or compressed gases, their shipping requirements, etc.

3.1 Hazardous waste

Hazardous wastes are segregated according to the requirements of the Turkish Environmental Regulation. The main groups are given below.

a) Medical Waste

The medical wastes of the health unit located on the site are collected and treated as separate from the others. Medical wastes are put in red plastic bags with a thickness of 150 microns. Each bag İs then put in a secondary plastic bag with an international biohazard sign on both sides. The bags are kept in a closed hazardous waste container until transportation for disposal. Medical wastes are sent to an incineration plant at regular intervals for disposal.

b) Lubricants

Used oil, oil filters, gᵀeases and anti-freeze, etc. are collected in steel barrels and the barrels are labeled with a proper label which shows the content. Oil- or grease-contaminated hoses, rags, gloves, sawdust, clothing, etc. are collected in durable plastic bags at the work areas, and then they are transferred to plastİc-Hned İm bags with proper labels. The bags are transported to a temporary storage area on the site and stored until they are transported from the site for disposa],

c) Chemicals

Chemical wastes (expired, out of standard, contaminated, etc.) are collected in steel or plastic barrels with proper labels. Chemical-contaminated bags, rags, etc. are also collected in labeled plastic-lined lm bags.

d) Copper- and Zinc-Contaminated Wastes

Because of the nature of the operation, CB1 generates copper and zinc concentrate- or ore-contaminated wastes at the site such as mill filter cloths, rags, filter plates, etc. These wastes are also classified as hazardous waste at CBI and they are collected in the labeled 1m³ bags for disposal.

e) Others

Wastes which do not fit into the above groups are separated and packaged according to their properties and according to the TER.

3.2 Non Hazardous waste

Non-hazardous wastes are segregated into the following groups:

a) Scrap Metal

CBPs main non-hazardous waste is scrap metal. Most of the scrap metal is generated by the mine and maintenance departments. Scrap metal is collected at the scrap metal bin on site.

b) Scrap Wood

Another large amount of non-hazardous waste is scrap wood. The main source of the wood is the packaging of goods received on the site (chemicals, spare parts, etc.). Scrap wood is collected at the scrap wood storage bin on site.

c) Scrap Plastics

Reagent bags and drums are the main sources of the scrap plastic. All plastic drums and bags are washed and rinsed three times by the operating departments before they are transported to the serai ' plastic storage area.

d) Scrap tires and rubber

Damaged or used tires and scrap rubber are collected separately and stored at their designated location.

e) Other Waste Materials

Non-hazardous wastes which do not fit into the above groups are segregated as others.

3.3 Packaging

a) Hazardous Wastes

i) Liquid Waste

Liquid hazardous wastes are collected m plastic or metal barrels. The barrels used for this purpose are fitted with covers. After filling, the covers of the barrels are closed tight to prevent spillage. The

509

barrels that are used for the collection of waste in the departments are labeled properly to show content before transport to the temporary hazardous waste storage area. Before the transportation of the barrels to the temporary waste storage area, the departments follow these steps:

- each barrel is labelled properly,
- barrels are placed on pallets (four drums per pallet),
- the drums on the pallets are tied to each other,
- the drums have a cover and there İs no leakage from the drums,
- waste drums are not damaged; if they are damaged at a later stage, the waste is moved to another drum immediately.

ii) Solid wastes

Hazardous solid wastes are collected by the departments which produce them, and they are placed in labeled collection drums which have a plastic bag liner. Once full, the waste collected in the barrels is transferred to labeled and plastic-lined $1m^3$ bags and the bags are transported to the temporary storage area.

b) Non-Hazardous Wastes

Non-hazardous wastes are physically segregated and stored in designated collection bins.

c) Labelling

Proper labelling of the wastes İs an important element of the waste management program of CBI. A color-code labeling system was developed for the hazardous wastes. There İs a color code for each main group mat generates waste on the site. Those groups are the mine, mill, surface workshop, and underground workshop.

The labels are in both Turkish and English and the name of the waste, the transportation date to the hazardous waste storage area and the person who transported the waste is recorded on the labels and posted on the waste container before the transportation takes place.

Groups are not allowed to use any other label then their own and two labels are posted on the containers (one on top of the container and the other one on me side). $1m^3$ bags are also labeled along the same principles.

4 TEMPORARY STORAGE

CBI constructed a waste storage area as part of its waste management program. The waste storage

area is intended to accomplish the following main purposes:

- to collect hazardous and non-hazardous wastes in the dedicated place only;
- to allow easy access to the wastes for waste segregation, salvaging and disposal;
- to allow efficient, concentrated control in the case of emergencies;
- to minimize support installations (eyewash stations, emergency showers, spill response equipment, etc.).

4.1 Hazardous waste storage area

The hazardous waste storage area has the following features:

- the storage area has a concrete floor with secondary containing walls to prevent spills from leaking from the storage area;
- the storage area has a roof to prevent the wastes from becoming exposed to direct sunlight, rain or snow;
- initial fire response equipment is available at the storage area;
- spill control equipment is readily available;
- emergency showers and eyewash stations are available and operational, to be used in the case of personal exposure to me wastes;
- the storage area is locked at all times and only authorized employees are allowed to enter the storage area;
- the storage area has enough capacity to hold wastes generated on the site over a period of three months.

4.2 Non-hazardous waste storage area

This area has five bins for different types of waste. The floor of die storage area is concrete and concrete walls separate the bins. There are bins for scrap metal, scrap wood, scrap plastic, used tires and rubber and other wastes. Before any scrap material is dumped in the bins, the departments fill out a "Waste Declaration Form" and send a copy ofthat form to the Safety, Health and Environment Department.

5 TRANSPORTATION

Hazardous wastes of CBI are transported to an incineration plant with a licensed hazardous waste transportation company. The transportation company employees are trained and certified to handle hazardous wastes, including the loading and unloading of the truck. CBI is responsible for packaging and labeling of the wastes before they are loaded onto the truck.

Waste loading is performed by CBI employees under the supervision of the transportation company. Hazardous wastes are transported to the incineration plant at quarterly intervals. During that process, three copies of the waste transportation form are filled out, which is a requirement of the TER.

Non-hazardous wastes are collected by the local contractor and transported from the site

6 DISPOSAL

CBI fulfils the requirements of the Turkish Environmental Regulation for the disposal of hazardous wastes. All hazardous wastes of CBI are transported to the incineration plant for disposal. The disposal method is decided by the incineration company according to me nature of the wastes.

Non-hazardous wastes are sold to local contractors for recycling.

7 CONCLUSIONS

A waste management program is an important element of mining operations and should be established by considering legislation or, in the absence of legislation, internationally accepted best management practices. There are many benefits of a sound waste management program for the operators. Those benefits can be summarized as cost saving, risk elimination, improved process control, improved community relations and an enhanced corporate image.

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Turkish Environmental Regulation

Design Considerations of Heap Leaching at Sarcheshmeh Open Pit Copper Mine

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ABSTRACT: Copper heap leaching uses a diluted sulfuric acid solution. Copper leaching solutions vary in chemical composition, including sulfuric acid concentration and organic constituent composition. Leach pad sites are generally selected for a combination of geotechnical and economic considerations. Slope failures on geomembrane liners are far less frequent, but have occurred on landfills, leach pads and liner caps. The three main conditions of instability before or during heap leaching are: sliding along the slope due to a low value of the interface friction of the granular veneer with the geomembrane, tensile tearing of the geomembrane, normally at the crest of the slope where the force is at a maximum, and failure of the anchorage of the geomembrane when its maximum pull-out strength is achieved. The purpose of this paper is to present the design considerations of the steepest heap leaching at Sarcheshmeh Open Pit Copper Mine.

1 INTRODUCTION

The second site of Sarcheshmeh heap leaching area extends over 300,000 m" on a steep valley which is situated on the western side of the mine.

The leaching process has literally made many mines by taking low grade geological resources and transforming them into the proven ore category.

The leach pad supports the ore heaps, collects solution flowing through the heaps, and transports the solution laterally to drainage pipes or ditches. The leach pad site and its topography should be selected so that it is free of flooding or other hazards. The foundation must be stable to prevent movement or cracking of the pad liner under the weight of ore heaps, which may eventually reach heights of nearly 80 meters.

This paper outlines some of the selection and design considerations for geomembrane-lined heap leaching.

2 HEAP LEACHING CONSTRUCTION AT SARCHESHMEH

Before installation of the liners, the subgrade was prepared by clearing, grubbing, stripping, rough grading and compacting. All the fill materials should be free of excessive vegetation, debns, organic matter and other deleterious materials. Random fill may be obtained from excavation of areas of the leach pad, solution channels, pond excavation or other borrow areas. It can be placed at the base of the deeper fills. Random fill should contain no particles larger than 200 mm in nominal diameter and have a plasticity index of no more than 15. Perforated high-density polyethylene (HDPE) pipe 355 mm in diameter was placed within collection ditches with sized gravel of 13 to 76 mm surrounding the pipe as an underground water drainage system.

The bottom lining system of the heap is composed of 2 sections: one section constructed over the rock, which consists of a 0.3-m compacted impermeable clay layer that acts as a "second liner", and another section constructed over the second liner which comprises a 0.2-m-thick fine-grained protective "cushion layer".

The 1.5-mm HDPE geomembrane liner is laid on the cushion layer with a minimum slope of 1 % and a maximum average slope of 30%. Another cushion layer is constructed over the HDPE liner, comprising a 0.2-m-thick fine-grained protective layer

Over the second cushion layer, perforated HDPE pipe was placed within collection ditches with sized gravel surrounding the pipe to prevent pluggmg by fines. Finally, the liner was covered with 350 mm of select granular material.

Oxide ore is hauled to heap leaching pads located outside the pit, north of the oxide dump. Heap construction practices have progressed to one of the steepest valleys, with a heap lift height of 7 m and maximum average slope of 30%. Heaps are built on top of one another with a final overall height expected to exceed 80 m H2SO4 solution is applied

through the heap pipe network to saturate the ore before leaching.

Low-grade copper ores are often processed by heap leach technology, where the ore is hauled to heap leaching pads, to top sizes of about one or two centimeters and sometimes only to top sizes of about 10 centimeters, stacked in heaps. For periods ranging up to several months, a sulfuric acid solution is sprayed on top of the ore, leaches through it, reacting with the copper, and carries the solution to the drainage system, where it is collected.

With standard heap leach technology, metal recoveries are generally only in the range of 70 percent, since the copper minerals may be locked İnside the large ore particles and may be inaccessible to the leaching agent, or because diffusion of the leaching agent into the large ore particles may be extremely slow.

Separation of the ore from the leachate occurs in an on-site processing plant. The leaching solution is renewed and the process is repeated until it is no longer economical.

3 DESIGN CRITERIA

The design criteria can be outlined as given below.

- The leach pad must form a suitable foundation and a low permeability liner for the heap, as well as facilitate solution collection and heap construction. The collection ponds must provide adequate storage capacity for operation, storm runoff, and winter shutdown, as well as have a low-permeability liner.

- The major criteria affecting the design of heap leach facilities is the optimization of recovery. Meeting these criteria means that seepage losses through pad and pond liners must be minimized, liner permeabilities should be as low as possible, and the zone of saturation on top of the liners should be minimized.

- Site conditions have an important effect on the design. The major site condition is topography. It is desirable for leach pads to have a slope of 1 to 4 percent to accommodate drainage and to direct solution flow toward the collection ponds.

- The collection system consists of a series of components to collect solutions in the heap and convey them to the pregnant solution pond. The collection system within the heap is designed to maintain zones of saturation above the liner at levels as low possible so as to provide adequate stability and minimize seepage.

- Good drainage minimizes the head on the leach pad liner, reduces the detail of collection facilities in the heap and enhances the slope stability of the heap.

- The slope of the pad and associated liners is very often controlled by the existing topography. The slope of the pad *must be steep* enough to allow efficient drainage of the leachate but not so steep that the stability of the heap is jeopardized or that erosion of the liner occurs.

- One or several lifts are used in constructing the heaps. The height of the heaps depends on the condition of the foundation, the strength of the leach pad and liner, and the topography as well as the physical and leach chemistry conditions of the ore. The outer slopes of the heap depend on the shear strength and durability of the ore, and the extent of saturation in the heap.

- When cut-and-fill techniques are used to prepare the pad foundation, careful attention must be paid to compaction of the fill so that a stable, high-density base is obtained to minimize differential settlements beneath the heap. The most sensitive location for differential settlement is at the interface of the cut-and-fill.

3.1 *Clay liners*

Soil liners consist of selected materials placed in lifts and compacted to a prescribed moisture content and density specifications in order to produce a liner with a permeability below a predetermined value. This maximum value is commonly 10^{-6} or 10^{-7} cm/sec. Geotechnical index tests, such as grain-size distributions and Atterberg limit tests, give an inexpensive but indirect indication of the suitability of a potential liner material. The values of maximum dry unit weight and optimum moisture content are mostly dependent on the soil type and the compaction energy. There is a significant change in soil permeability with change in compaction water content, and therefore dry unit weight.

3.2 *Geomembrane*

The material widely used in the first heap leach facilities was polyvinyl chloride (PVC). The use of PVC in new application diminished with the development of hypalon. Currently, the most widely used material is high density polyethylene (HDPE).

The method of liner installation must suit the construction schedule and climate conditions. Most membrane liners are manufactured panels that are spread out and seamed on site. Techniques for field-seaming the panels vary with the liner material, from solvent welding for hypalon to heat-fusion welding for HDPE.

HDPE liners are flexible, nonstructural elements and therefore are not intended to provide structural support. The liner's tensile strength and ability to resist puncture, deformation, abrasion and tear should be examined in order to determine the liner's ability to withstand the stresses, strains and environmental conditions within the unit without suffering damage. Another property that should be reviewed is elongation due to temperature changes,

which can cause wrinkles with an increase İn temperature or bridging with a decrease in temperature (Koerner 1997).

3.3 *Site selection*

The selection of sites for leach pads, collection ponds and the extraction plant is often a very obvious choice for many operations in order to stay on patented claims or to be near the mine. Site selection can be outlined as given below.

- The first step in the site selection process is the delineation of an area of interest where sites can be defined and selected. Because sites a long distance from the mine may be uneconomic, this distance is dictated by hauling costs and other operational factors.

- Within the area of interest, there may be areas where facilities should not be used. The reasons for this include ownership, topography, potential flooding, subsoil conditions and mineralization. Therefore, regions within the area of interest where sites should not be located are screened out.

- The remaining sites are then logically compared to determine the best site. Comparisons should be made according to some fair or unbiased technique.

4 POTENTIAL MODES OF FAILURE

At Sarcheshmeh mine, geomembrane will be applied to an inclined surface. This will lead to a component of gravitational force acting in the plane of the geomembrane, which can cause it to slide down the inclined surface. Consequently, it is important to be able to assess the bond properties of the interface between the geomembrane and inclined surface. The bond strength which can be made available may be frictional, cohesive or a combination of the two.

The critical failure surface and factor of safety depend upon the shear strength of the weakest material in the heap, liner and subsoil system. For synthetic materials, the critical failure surface and factor of safety may depend upon the frictional resistance between the ore and geomembrane or between a sand blanket and the geomembrane.

On the other hand, the mechanical behaviour of a geogeomembrane İs quite different from that of a mineral liner and, consequently, a new geomechanical approach is necessary.

There are far fewer slope failures on geomembrane liner. The three main conditions of instability before or during heap leaching are:

- sliding along the slope due to a low value of the interface friction of the granular veneer with the geomembrane;

- tensile tearing of the geomembrane, normally at the crest of the slope where the force is maximum;

- failure of the anchorage of the geomembrane when its maximum pull-out strength is achieved.

The shear strength developed at a geosynthetic interface is dependent on both the normal stress applied to the interface and the displacement at the interface. Several authors (e.g., Seed et al., 1988, Byrne 1994, etc.) have shown that most geosynthetic interfaces are strain softening.

At Sarcheshmeh, HDPE geomembrane in heap leaching is placed in direct contact with clay liners. Very little is known about the interface friction of polypropylene geomembrane against soil due to its relatively new use. It is known that a heap leaching liner system must not only provide a barrier, but must also be structurally stable. The failure of a liner system can be catastrophic in terms of the harm it can do to the environment and the financial cost to the community. The sudden slope failure of Kettleman Hills waste landfill in California, U.S.A. (Mitchell et al., 1990, Seed et al., 1990, Byrne et al., 1992) is a perfect reminder to our profession of how important it is to evaluate the strength of liner system components and interfaces.

The potential failure modes against which the pad system must be designed are given below.

- Settling of the underlying foundation may lead to disruption of the leach pad system. Differential settling is usually of bigger concern than overall and even settling.

- When a pad is constructed on fill of low shear strength or on fill of significant height, slope failure through the fill or subsoil is a concern. In a number of cases, instability has been due to the build-up of a high water level in the heap resulting from poor heap drainage or high rates of infiltration due to high rates of leachate application or rainfall. Instability has also been due to low frictional resistance between the geofabric and liner materials.

- Deterioration of liners may occur due to exposure to the elements.

Failure of a clay liner occurs when the permeability increases considerably above the design value, either locally or over a larger area. A clay liner can fail for a number of reasons. The major causes are:

- differential settling of the foundation leading to localized cracking of the clay liner,

- drying out of the clay liner leading to the development of microcracks,

- alteration of the permeability of the liner due to geochemical reactions between the liner and the leach solution.

5 ENVIRONMENTAL CONTROL

The key to effective environmental control of leaching solutions is nearly always contaminate of solutions under a worst case scenario of possible

emergencies so that environmental contamination is prevented. The cleaning up of solution spills and leaks İs usually only partially accomplished, is often not feasible, and nearly always proves to be much more expensive than prevention. The key to contaminate is proper design and construction of the leaching system, coupled with an adequate monitoring system to give early warning of any failures so that small leaks and problems can be corrected before they become big leaks and disasters.

5 CONCLUSIONS

A review of different parameters was presented here in design considerations of geomembrane-lined heap leaching. Risk analyses, quality assurance, and regulation environmental geotechnics refer not only to the sitting, design, construction, operation, aftercare, monitoring, etc., of heap leaching but also to contaminated land evaluation and remediation. The risk of environmental impact from heap leaching can be minimised by proper site supervision and control in the long term.

The selection of an appropriate liner should be based upon performance requirement. The liner must be compatible with the leaching conditions and also be resistant to stresses, strains and environmental conditions to which it will be exposed during installation and operation. It must adequately retain its design properties and characteristics throughout its intended life.

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