Chapter 9
Quarrying and Other Minerals

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Abstract This chapter is an introduction to the significance of quarrying from the point of view of anthropogenic geomorphology. As a consequence of the extraction of mineral raw materials, so-called 'mining landscapes' have emerged since the 19th century. The spatial distribution of quarrying of aggregates, and the characteristics and classification of the resulting features are described at macro-, meso- and microscales. Quarry walls and floors and debris aprons are distinguished at almost every extraction site. The morphological components of accumulated macroforms are plateaux and slopes (accumulated mesoforms). Common excavated microforms of quarrying are rock counterforts, rock benches, out-weathered quarry columns, pinnacles and pillars. Finally, international and Hungarian case studies illustrate some aspects of the opening and after-use of mining sites in order to observe how abandoned quarries can be turned into 'environmental values', and used as possible sites for exhibitions or for regional and tourism development projects.

Keywords Mining landscapes · Stone quarrying · Quarrying landforms · After-use

9.1 Introduction

There is no need to explain in detail *the close relationship between mining activities and geology/geomorphology*. However, it should be mentioned that researchers only became interested in the problems of geomorphic impact at a rather late stage of evolution of these sciences. It is well illustrated by Fig. 9.1 that research on landscape alterations caused by raw material extraction only dates back to the 1960s.

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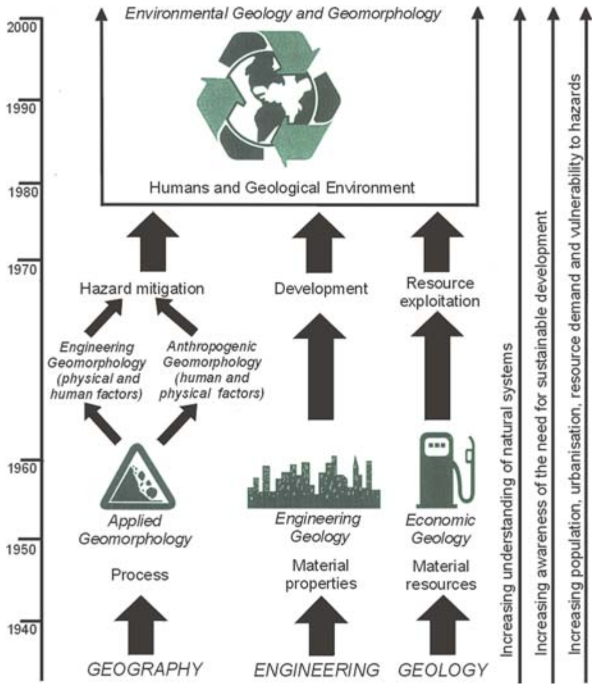

Fig. 9.1 The evolution and differentiation of earth sciences and their relation to environmental issues (after Bennett and Doyle 1999, modified by Dávid and Baros 2006)

Two million years ago, the activity now called mining was just occasional collection of rocks. This early extraction of gravels and stones was later replaced by conscious exploitation of minerals for flint tools, dyes and other purposes. According to the archaeological findings of the oldest flint quarries, this has at least a 100–120 thousand years' history in Hungary. A well-studied quarry of dyestuff at Lovas near Veszprém, as well as the flint quarry discovered in the area of the Tűzköves (Avas, Miskolc) are dated to be several tens of thousand years (40–110 thousand years) old (Simán 1995). Shelters of the primitive man were often carved out of loess. Flint quarries of the Neolithic Age are 6–8 thousand years old in Hungary (Sümeg-Mogyorós Hill, Tata-Kálváriadomb, Miskolc-Avashegy) (Simán 1995). Hollows of the oldest salt mines in the Pannonian Basin can be of similar age. In the 2nd century, the famous mines of the Transylvanian (Dacia) 'Gold Rectangle' (Abrudbánya, Nagyág, Zalatna and Verespatak) were obtained by the Romans and were cultivated through 170 years under imperial rule. The mining of native copper, native gold, tin and antimony gradually displaced the mass use of flint tools. Ore and salt mines, based on their size, were much larger than the former hollows and resulted in caverns and later underground shafts.

In the 18th–19th centuries, a new energy source, coal, appeared in history and its mining resulted in landforms larger by orders of magnitude. Parallel to this, the development of mining technologies meant another step in the quarrying of building materials as well. The use of gunpowder and steam machines revolutionised the extraction of minerals and led to the emergence of 'mining landscapes'. In the world, the most commonly excavated raw materials for construction include those for cement and lime industry, building and ornamental stones, sand and gravel, as well as clays for ceramics. An introduction into the anthropogenic geomorphological significance of stone quarrying is followed by case studies on major landscape transformation resulting from the mining of other minerals.

9.2 Stone Quarrying

It can be claimed that the general spatial *distribution* of quarrying is fairly even in a sense that, *geological conditions* provided, there are hardly any mountain settlements without a quarry of some scale opened in their surroundings during their history. When quarrying also aims to reach markets to a greater distance, market regulators (economically exploitable supplies, transportation expenditure and possibility, etc.) become more important, thus in some cases, quarrying can show a rather high spatial concentration. The level of socio-economic development has been decisive for the quantity and quality of the material flow between the user and its environment.

In addition to the geological conditions, the site selection of quarries is also controlled by the *topography* of the area. Longwall face quarrying prevails on mountainous or hilly terrains whereas in flat areas deep mining is applied. However, intermediate types also occur occasionally. Exceptionally, closed work is applied, too, as in the case of Fertőrákos (NW Hungary). As far as longwall face quarrying is concerned, it is the topography that is transformed to a visible extent; face walls of several hundred metres length and of some ten metres height may result, depending on the technology applied (Fig. 9.2).

In cases when the rock material to be exploited is found under a flat or sloping surface, a quarry sunk in the surface has to be established. Such quarries are sometimes created through the lowering of the quarry floor by longwall face quarrying. If cover strata are too thick, extraction takes place from underground shafts or cavities. Apart from this, the characteristics of the quarried (metamorphic, igneous or sedimentary) rocks as well as adherence to various safety regulations are of decisive relevance. All of them may also have an influence on the evolving features.

9.2.1 Characterising and Classifying the Landforms of Quarrying

As a result of quarrying, the landscape undergoes fundamental and visible changes (Table 9.1).

The range of landforms resulting from excavation is classified into three main groups (Dávid and Patrick 1998; Karancsi 2000; Dávid 2000):

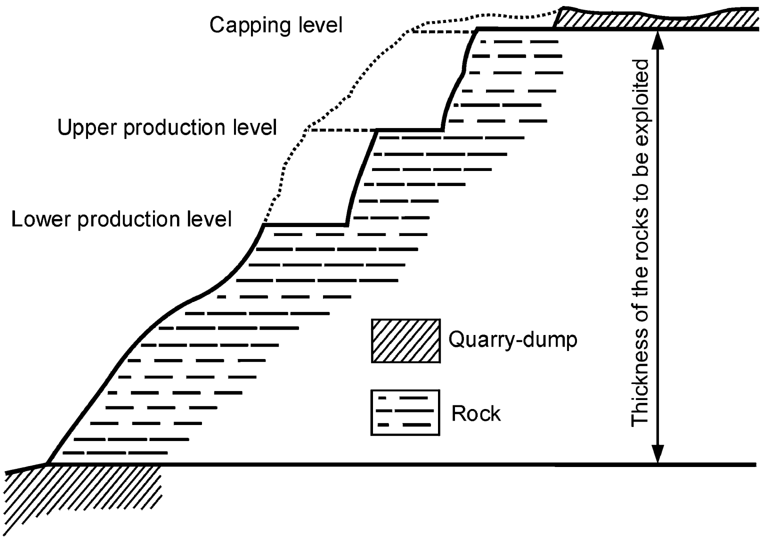

Fig. 9.2 Siting of a quarry of several production levels (Ozorai 1955)

– excavated ('negative') forms,
– accumulated ('positive') forms and
– forms destroyed by quarrying activities, which lead to the levelling of the surface, called planation in geography.

The geomorphologic study of quarrying features is undertaken in three categories, distinguished by origin and size (Fig. 9.3). It should be noted, however, that there are several other approaches to *classification* (Erdősi 1966, 1969, 1987; Karancsi 2000). One of them, for instance, is by quarry location relative to geological formations and surface macroforms (Erdősi 1987), whereas size categories taking the characteristics of the given area into account can also be set (Karancsi 2000).

Macroforms are the most obvious traces left behind by quarrying. Excavated macroforms may virtually be regarded as surfaces with material deficit (caverns) and are composed of smaller elements (excavated mesoforms). Quarry walls and floors and debris aprons are distinguished in almost every extraction site. The morphological components of accumulated macroforms are plateaux and slopes (accumulated mesoforms).

The surfaces of *mesoform* components can be divided into smaller and larger excavated depressions (possibly out-weathered sections) or accumulated elevations that are called microforms.

In addition to the influence of quarrying technology and working rate, the properties of features in all three categories are also controlled by the geological

Table 9.1 Landform-shaping role of quarrying activities (Dávid 2000)

Landform-Shaping Role of Quarrying Activities			
A. By the nature of the resulting surface features			
Excavated forms			Accumulated forms
Origin and size			
Excavated macroforms (surfaces with material deficit = caverns)			Accumulated macroforms (mine dumps) Cone-shaped Truncated cone-shaped Terraced
Quarrying technology			
Simple excavated type: excavation pit delph	Complex excavated type: horizon mining	Simple accumulated type: single quarry dump	Complex accumulated type: quarry dumps in groups
Excavated mesoforms Quarry wall Debris apron Quarry floor		Accumulated mesoforms Plateau Slope	
Microforms			
Excavated microforms: rock buttress and pillar pinnacles, rock benches, small shallow ponds	Microforms created as a result of natural processes: mass movements, gully erosion		Accumulated microforms: heap boulder
B. By the type of geotechnic activity			
Planation Abraiding		Filling up	

characteristics of the area (structure, bedding), the nature of the rocks and the natural processes affecting them.

9.2.2 Excavated (negative) Forms

The most common and simple type of excavated forms is an *excavation pit* or a cauldron in the surface. Excavated macroforms of quarrying origin usually appeared before accumulated forms, therefore examples of them can be found in the first period of quarrying history. Mainly in the form of small quarries they are found next to almost every town and village in mountainous areas.

The other type of excavated forms results from multi-levelled horizon mining (complex excavated type). It is increasingly typical in modern times. The technical condition for its occurrence was the increase in the capacity and efficiency of

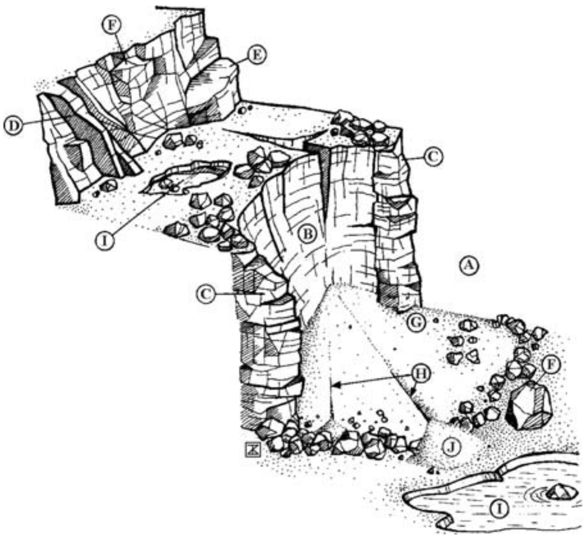

Fig. 9.3 Schematic layout of a stone quarry: (**a**) quarry floor, (**b**) quarry wall, (**c**) pillar, (**d**) rock buttress, (**e**) rock bench, (**f**) out-weathered rock, (**g**) talus slope, (**h**) rainwater groove, (**i**) depression with a small pond, (**j**) debris cone (Dávid and Karancsi 1999)

excavating equipment, while as far as geological conditions are concerned, it was favoured by the presence of thick strata.

Excavated mesoforms are composed of the following elements:

– Quarry wall: the steepest component, whose angle of inclination to the floor is determined by quarrying technology (blasting, hand or power excavation) as well as by rock quality. It is normally subvertical. The quarry floor is usually surrounded by walls on three sides.
– Debris cones, debris aprons: components with smaller angles of repose lying at the foot of quarry walls. Their materials partly derive from quarry working and partly from natural processes (rockfalls). They are initially developed by accumulation but their origin is linked to excavation activities. As material accumulates in debris cones, they may coalesce to form a continuous debris apron.
– Quarry floor: an approximately flat ground surface surrounded by walls and debris aprons, including a range of features (accumulations of quarry material, quarry heaps, pillars, etc.).

Common *excavated microforms* of quarrying are rock counterforts, rock benches, out-weathered quarry columns, pinnacles and pillars. The pillars are basically transitional features between excavated and accumulated forms as being the positive remnants of quarrying. They may resist the damaging effects of natural processes and talus slopes of various sizes are found in front of them. Precipitation water may collect in small shallow ponds in the depressions of the quarry floor.

9.2.3 Accumulated (Positive) Forms

Accumulated macroforms are called quarry dumps. They are formed through the accumulation of waste, which is currently of no value from an economic point of view (Fig. 9.4). During open-cast mining, dumps of various origin are heaped. By the removal of burden from above the material to be excavated, a significant amount of so-called sheathing dump is created. This material (interstage and plant dump) can also be a result of the extraction and processing of the material, i.e. during grinding or crushing. The granulometric composition of quarry dumps is rather diverse, being influenced not only by geological conditions but also by the method of processing. There can also be different shapes of dumps, as curve-, fan- and round-shaped dumps created at the end of bankfills are distinguished. In addition, temporary storage of the quarry material also has to be referred to this group. They are found isolated (simple accumulated type) or in groups (complex accumulated type).

The shape of a positive form is determined by several factors: the original ground surface, the mode of accumulation and the physical features of the dumped material. Cone-shaped, truncated cone-shaped and terraced dumps are the most common.

Common components of *accumulated mesoforms* are

– Plateau: the relatively flat ground surface surrounded by the slopes of dumps. Its extent is determined by the type of the dump. The largest plateaux can be found on terraced dumps, while the plateaux of truncated cone-shaped dumps are usually smaller.
– Slope: the sloping ground surface which surrounds the plateau or the peak in the case of a cone-shaped dump. Its inclination varies on a wide range depending on the mode of accumulation, the nature of the dumped material and the shape of the initial ground surface.

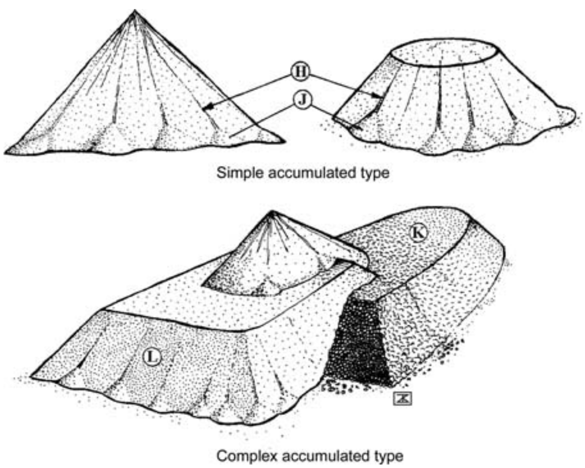

Fig. 9.4 Typical forms of quarry dumps: (**h**) gully, (**j**) debris cone, (**k**) plateau, (**l**) slope (Dávid and Karancsi 1999)

The most obvious *microforms* on dumps, formed by natural processes, are gullies cut into slopes. They are arranged radially on cone-shaped or truncated cone-shaped dumps. The dump material carried by rainwater settles in small alluvial cones at footslopes. Flat-topped plateaux may be dissected by headward eroding gullies.

The accumulated microforms of quarry floors, formed as a result of quarrying, are larger heaps and boulders dissecting the approximately flat ground surface.

9.2.4 Planation Activity

Quarrying does not only construct landforms but it can also result in *planation*. With the spreading of dump material over natural or artificial features (slopes, valleys, pits or depressions), they may be filled. Another possibility is the excavation of whole mountains during quarrying activities, resulting in huge landscape scars. Remarkable instances are found in Hungary (the Naszály at Vác, the Bélkő at Bélapátfalva (Plate 9.1), the Esztramos at Tornaszentandrás, the limestone quarries at the Szársomlyó Hills of Nagyharsány, the rhyolite quarry of the Kis Hill at Gyöngyössolymos, the laccolite of the Csódi Hill at Dunabogdány).

Plate 9.1 Excavation of the Bélkő near Bélapátfalva (source: http://www.pihenek.hu/krisztina_apartman/belapatfalvai_szallas/krisztina_apartman18.jpg)

9.3 Other Raw Materials for Construction

The utilisation of one of the most important building materials, i.e. the gravel, also goes back to a thousand years. Gravel was used for building and road constructions,

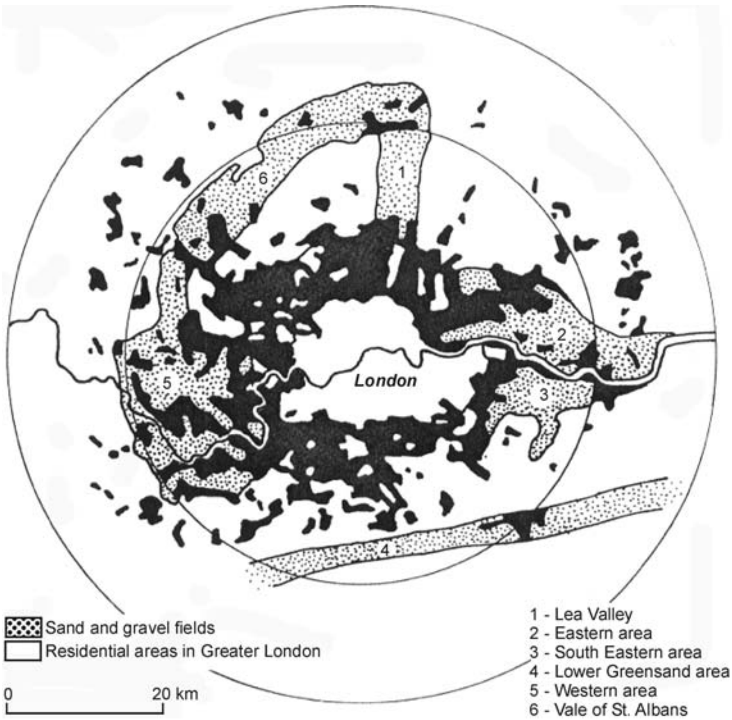

Fig. 9.5 Relevant sand and gravel excavation sites in Greater London (Nir 1983)

and accordingly, excavation sites were placed at the surroundings of settlements (Fig. 9.5).

Gravel extraction for construction purposes started in Hungary at the end of the 19th century, which was first restricted to the easily accessible gravel in the river beds exploitable by manpower. The first cement mill was established in the 1880s in the area of Lábatlan and Nyergesújfalu; since then the rate of gravel extraction used for constructions had been increasing. The material was obtained mainly by hand power; however, between the 1920s and 1940s, mechanic excavators were already applied. With the development of technical tools, underwater gravel exploitation also became possible. In the period between the two world wars, most of the gravel was extracted by dredging rivers; however, the extraction of other gravel deposits also started. This came to the fore when the use of concrete began to spread. At this time, extraction began in regions where gravel extraction is still typical today (the Alpokalja Region, watercourses of western Hungary, the Rábaköz and along the rivers Rába and Marcal, the Tapolcai Basin, the areas along the River Danube, e.g. Csepel, Délegyháza, the Mura and Dráva regions, the border section of the rivers Körös and Maros, forelands of the North Hungarian mountains, gravel sheets of the rivers Zagyva, Eger, Sajó and Hernád).

Among the surface landforms resulting from mining, the most common and typical ones are mine ponds accumulated from groundwater as well as waste dumps

Plate 9.2 Pond in gravel pit at Sajószöged (source: http://www.sajoszoged.hu/kepek.php?kep=Picture%20060.jpg)

piled up of the waste material (Plate 9.2). Their natural or artificial transformation begins almost immediately following their formation. Natural processes destroying both positive and negative landforms contribute to planation. The other factor is human action adjusting landforms to the purposes of human society. These two impacts can only be distinguished when a mining area is abandoned and natural processes take over its further shaping.

Landforms developed during mining activity are influenced by the same processes as natural landforms. On the sides of both negative and positive forms, various mass movements are present. Waste heaps of loose material and with steep sides, temporarily saturated, undercut bank sections or slopes may provide especially favour such processes. On steep slopes of loose materials (waste heaps, lake shores), rainwater runoff may induce erosion; on waste heaps radial networks of gullies can develop. By this, rainwater can wash (sometimes hazardous) substances from the shores or the heaps into the pond. On barren surfaces deflation can be also significant; however, vegetation on the slopes can decrease its impact.

On the shores of more extensive mine lakes, wave motion can play a relevant role. When steep failures occur, shore sections resulting from mining are abandoned; they are gradually transformed into slopes with stable angle, so-called self-adjusting slopes. In addition to this, wave motions also assort deposits from the lake bottom by depositing larger particles near the shore while carrying fine-grained substances to the central parts of the lake. In the transition of landforms resulting from mining, apart from natural processes, the operator or owner of the mine as well as residents of the surrounding area can also be instrumental. This impact can be diverse including unplanned spontaneous conversions and well-organised landscape architecture.

The aim of the latter is the reclamation of areas with limited utilisation possibilities due to mining activity, making them suitable for re-utilisation and fitting them into their environment. As during gravel excavation, a mine lake is evolved in most cases, by reclamation in a narrow sense, i.e. the total re-establishment of the original conditions cannot be the aim. In such cases, ways of alternative utilisation, for instance, for the purposes of tourism, are often envisaged.

Among building materials, the quarrying of sand, silica sand and clay must also be mentioned. As far as their landscape-forming impacts are concerned, they produce mostly negative landforms. At the outskirts of many settlements in the Great Hungarian Plain, former loam pits are still determinant elements of the landscape (with ponds, which unfortunately usually function as waste disposal sites).

9.4 Other Minerals

Among *other mineral stocks*, the most spectacular surface landforms are produced by the mining of various ores (in Hungary, bauxite, iron, uranium and manganese ores and sulphides), as well as the quarrying of perlite, bentonite and other compound minerals. Some scenic examples are going to be introduced below by the mining of rock salt, some ores and diamond. During their excavation, vast amounts of waste are generated compared to which the quantity of the target material of mining can be often negligible (Table 9.2).

In the case of rock salt, the focus should be on vast underground tunnels and halls (Marosújvár, Torda, Parajd, Aknaszlatina, Wieliczka), which later are used for the purposes of tourism and therapy (Plate 9.3).

The Bingham Canyon copper mine in Utah (USA) (Plate 9.4 – with an area of 5.4 km^2 and a depth of 695 m), the great vent of Kimberley, the silent witness of the diamond boom in South Africa (Plate 9.5) or the diamond mine near Mirny in Siberia (Plate 9.6 – with a diameter of 1.5 km and a depth of 540 m) are remarkable. One of the iron-ore pits of the Kursk Magnetic Anomaly is 7 km in length, 3 km in width and 90 m in depth (Mihajlovka). Special mining techniques

Table 9.2 Waste generation by the mining of the six raw materials most important in this respect (Nir 1983)

Waste generated by the quarrying of raw materials in the world (1977)	
Material	Material product gained as percentage of the material moved
Iron	50
Bauxite	55
Gold	0.9×10^{-3}
Copper	2
Coal	50
Brown coal	50

Plate 9.3 The great hall of the salt mine in Parajd (Transylvania) (source: http://s021.yatko.com/∼kukullo/imagebank/csillagturak/sovidek/parajd2.jpg)

Plate 9.4 The Bingham Canyon copper mine in Utah, USA (source: http://static.panoramio.com/photos/original/5101732.jpg)

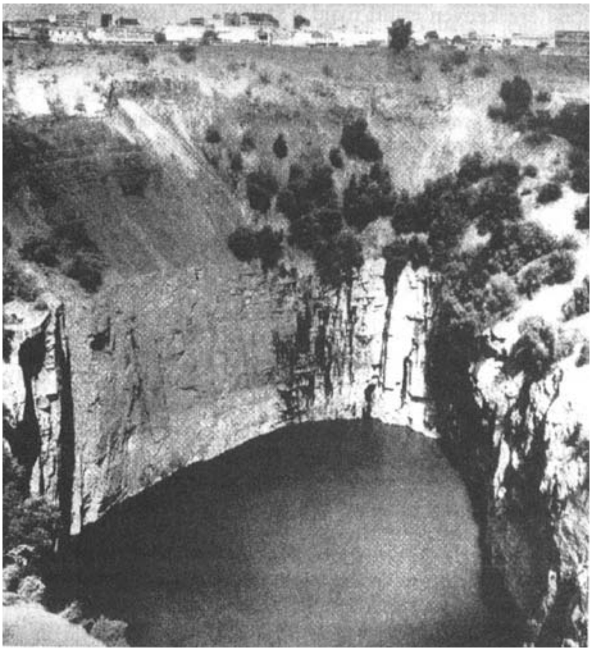

Plate 9.5 Vent of the great diamond mine of Kimberley in South Africa (source: http://www.gps.caltech.edu/news/features/southafrica/pics/d13bighole_mb.jpg)

Plate 9.6 Diamond mine near Mirny in Siberia (source: http://www.acrosstheplanet.net/wp-content/uploads/2008/05/mirny1.jpg)

may result in unique and, from a cultural historical point of view, valuable landforms (Recsk, Gyöngyösoroszi, the mining of veins and placers in Telkibánya (Hungary), or landforms left behind by gold-diggers in Ballarat, Australia, where a thematic park has also been constructed in the derelict mine).

9.5 Some Problems of Mine Opening and After-use

Mine openings and developments are often attended by vociferous opposition. Today's best example is given by the plans of gold mining near Verespatak (Rosia Montana) in Transylvania (Plate 9.7) where, according to estimates, to get gold for a golden ring, 20 tonnes of mining waste would have to be excavated. The mountains around Verespatak contain 300 tonnes of gold and 1600 tonnes of silver, making it one of the richest gold deposits of the world. To have it excavated, 225 millions of tonnes of rocks must be processed and 20 tonnes of dynamite would have to be exploded each day throughout 15 years.

Until recently, *abandoned quarries* both in Hungary and abroad have raised negative, unpleasant associations as 'scars in the landscape' (Plate 9.8). However, according to a new assessment, abandoned quarries and mines are regarded as 'environmental values', appreciated as possible sites for various uses (Bauer 1970; Dávid and Patrick 1999), i.e. exhibition sites or scenes for regional and tourism development projects (e.g. Fertőrákos, Ság Hill, the Kálvária Hill of Tata). The case studies below intend to provide a brief overview.

Plate 9.7 The mine of Verespatak (source: http://storage0.dms.mpinteractiv.ro/media/1/186/6450/2378245/1/rosia-montana-vt.jpg)

Plate 9.8 Scar of the Sás-tó andesite quarry near Gyöngyös made visible by a clear-cut in the Mátra Mountains, with the peak Kékes-tető (1014 m) in the background (Dávid 2004)

9.5.1 Case Studies

9.5.1.1 Rehabilitation of Abandoned Mining Grounds in Cornwall (England)

Cornwall, located at the south western part of England, is a region formed by settlements traditionally involved in the mining of noble ores. It was a centre of copper and tin mining from the 16th century until the end of the last century. Copper and tin exploration has also left significant environmental damage behind in the region. During the time of this project, more than ten mining grounds were reclaimed and a further five are at the stage of planning. At these grounds, 31 buildings were secured and further 20 are expected to be rescued. The historical scenery and unique atmosphere provided by old mine tunnels, dressing-rooms and engine-houses is intended to be preserved as well.

Along the track of the railway connecting the mines, tourist paths and nature trails were established. The path network will total 100 km and, in addition to providing ideal possibilities for tracking, cycling and horse-riding, it will also connect the settlements for the benefit of local residents. Wandering along these routes, several mining sites, machine-houses and other buildings converted into museums can be seen. This mining landscape represents such a special and unique value that an application was prepared (Fekete 2001) and in 2007 it was declared to be a World Cultural Heritage Site.

9.5.1.2 Bluewater Shopping Centre

In recent years, many precedents, mainly from Great Britain show that commercial centres (hyper- and supermarkets) are constructed in old quarries outside cities and next to them facilities for entertainment (parks, multiplex cinemas, gaming-rooms,

Plate 9.9 The Bluewater shopping centre near London with the wall of the blue circle chalk quarry in the background (source: http://upload.wikimedia.org/wikipedia/commons/7/7e/Bluewater_Shopping_Centre,_Kent,_England_Crop_-_April_2009.jpg)

concert halls, discos, galleries, art centres, etc.) are also developed (Bennett and Doyle 1999). The most outstanding example for this is the Blue Water Shopping Centre located in Dartford at Junction No. 2 of the London Ring Road M25, marketed as the largest entertainment centre of this kind in Europe. This investment, compelling both in its outside and inside appearance, has been built between 1995 and 1999, in the area of the abandoned Blue Circle Chalk Quarry (Plate 9.9).

9.5.1.3 Tokaj–Patkó Quarry

The former quarry hosted a large-scale cultural event on 30th June 2002, functioning as a 'festival cauldron'. The event took place on the occasion that the Tokaj-Hegyalja Region was awarded the UNESCO World Heritage status in the category

Plate 9.10 Concert and festival in the Patkó Quarry at Tokaj (30th June 2002) (source: http://www.tokaj.hu/galeria_eletkepek)

Plate 9.11 Sculpture park in the Hársas Hill of Nagyharsány (source: http://upload.wikimedia.org/wikipedia/commons/a/a8/Nagyharsanyi_szoborpark.jpg)

of cultural landscapes. Cultural programs were organised in the quarry to celebrate it (Plate 9.10). Since then it has been regularly used as a site for similar events.

9.5.1.4 Sculpture Park in the Hársas Hill of Nagyharsány

This quarry is a good example of after-use for the purposes of fine-arts. The excavation of limestone for cement industry had already begun at the Eastern side of the hill in the early 20th century (Lóczy et al. 2007); a sculpture park can be found in the former quarry floor (Plate 9.11).

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