

Croatian geological heritage related to historical mining and quarrying

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Exploitation of geo-resources has played an important role in the development of mankind. Hence, historical mining sites represent valuable industrial heritage. Unfortunately, it is not often recognised that outcrops opened by quarrying and mining, as well as ex situ collections of minerals, rocks or fossils found at such sites, represent precious geo-heritage. Historical mining sites in Croatia are not yet properly protected with the exception of two stone quarries. In this article, we present several mines and quarries recognised by locals as tourist sites which should be brought to the attention of the authorities responsible for geo-heritage protection. Preservation of geo-heritage in the frame of the mining heritage context is fundamental in promoting the proper protection, valorisation and utilisation of former mining sites as geo-tourism destinations.

L'exploitation des ressources géologiques a joué un rôle important dans le développement de l'espèce humaine. C'est pourquoi les sites historiques miniers constituent un héritage industriel de valeur. Malheureusement, il n'est souvent pas fait cas des éléments affleurants mis à jour par les travaux de carrière ou miniers de même que les collections minéralogiques en musée, les roches ou fossiles sur place, qui représentent un précieux héritage géologique. Les sites miniers historiques en Croatie ne sont pas encore protégés, à l'exception de deux carrières de pierre. Dans cet article, nous décrivons plusieurs sites miniers et carrières, reconnus localement comme sites touristiques qui devraient éveiller l'attention des autorités en charge de la protection de l'héritage géologique. La préservation de cet héritage géologique dans le cadre du contexte d'un héritage minier est fondamentale en faisant la promotion d'une protection adaptée, de la valorisation et utilisation des anciens sites miniers en tant que destinations pour les touristes amateurs de géologie.

La explotación de recursos geológicos ha jugado un importante papel en el desarrollo de la humanidad. Por tanto, los emplazamientos mineros históricos representan un valioso patrimonio industrial. Desgraciadamente, los afloramientos mineros y las colecciones de minerales y fósiles encontrados en dichos afloramientos no son normalmente reconocidos, sin embargo, representan un patrimonio geológico muy valioso. Los sitios mineros en Croacia no están adecuadamente protegidos a excepción de dos canteras de piedra. En este artículo, se presentan varias minas y canteras reconocidas por agentes locales como sitio turístico que debería ser tenido en consideración por las autoridades responsables del patrimonio geológico. La preservación del patrimonio geológico en el marco del patrimonio minero es fundamental para promover la protección, valorización y utilización de antiguos yacimientos mineros como destinos geo-turísticos.

Introduction

According to the Register of Protected Areas of the Ministry of Environment and Energy of Croatia (2017), 53 localities are protected exclusively due to their geological value (Figure 1). Those localities have different levels of protection, which include special reserves (paleontological and geographic-botanical special reserves) and natural monuments (geological, paleontological,

geological-paleontological, geomorphological, geological-geographic and hydrological natural monuments). In addition, there is one case of protected minerals. Almost all of these sites are described in Zwicker *et al.* (2008). In addition to mentioned 53 localities, another group of geo-heritage sites in Croatia is located within larger protected areas such as strict reserves, national parks, nature parks, regional parks and significant landscapes.

Croatia is recognised for its extraordinarily long tradition of stone exploitation and application. Many abandoned quarries represent potential geological heritage sites. Only two are classified and protected as geological monuments (in the

subtype of natural monument). The first geological site to be protected (in 1948) is Rupnica near Voćin (Figure 1). Rupnica is an old quarry with well-exposed phenomenon of columnar jointing developed in albite rhyolite (Figure 2 left). Rupnica (together with Trešnjevica Quarry, where a magmatic vein several hundred metres in length breaks through metamorphic rocks that are 300 million years older) is located inside Geopark Papuk. The second protected geological site is Quarry Fantazija (Figure 2 right) near Rovinj (Figure 1). It was proclaimed as a geological monument in 1987 due to numerous structures and textures typical of supratidal dolomitisation (stromatolites, tepee-structures, fenestral

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Figure 1: Locations of protected geo-heritage sites in Croatia (after MZOE, 2019) and mine heritage sites (not legally protected) mentioned in this article.

fabric, load casts and microcasts, desiccation cracks, shrinkage cracks, sand-watch structures, supratidal breccia, tide channels, erosional surfaces, etc.) (Tišljar *et al.*, 1995). Although both sites are protected by law and arranged for visitors, Rupnica is very well maintained thanks to Geopark Papuk, while Fantazija is neglected and even covered with graffiti. The legal basis in Croatia is finally favourable for conservation of our geological heritage, but physical protection is questionable (Marjanac, 2012).

Mineral resources have been traditionally classified as: (1) industrial or non-metallic; (2) ores or metallic; (3) energetic; and (4) rocks and gems. The mining of

non-metallic minerals such as bauxites, gypsum, and sulfur cannot be omitted. Unfortunately, so far none of the historical mining sites of these industrial minerals have been made accessible to wider society. However, some progress can be observed and Radboa Museum in Radoboj (Figure 1) is a good example of how such sites could be presented to the public.

There are no potential ore deposits in Croatia nowadays, but there were times in the past when metal production was significant. Although not protected as geological heritage, two sites have been revitalised for geo-tourism (the copper mine Rude and the silver mine Zrinski). Concerning

energetic resources, coal and bitumen were mined in Croatia as well in the past and there are attempts to restore mining sites for geo-tourism purposes (e.g. the bitumen mine Škrip on the island of Brač and the coal mine Raša in Istria).

The goal of this article is to present several historical mining localities and/or excavated content in Croatia that are recognised as mine heritage sites in the framework of the EIT KIC Raw Material Wider Society Learning Project “MineHeritage: Historical Mining – Tracing and Learning from Ancient Materials and Mining Technology”, funded by the European Institute of Innovation and Technology (EIT). This article considers existing and potential tourist sites that have value in multiple roles, as mining, industrial, cultural and geological heritage, in order to encourage their proper protection as geo-heritage.

Natural building stone quarries

Since prehistory, throughout antiquity and Middle Ages, a great number of small quarries were active and used for exploitation of a high-quality sedimentary rock; most are abandoned today. However, there are few old quarries in Croatia that are prepared for visitors with an emphasis on presentation of natural and cultural heritage, even if they are not officially protected as natural geological monuments.

A rare example of such good practice is Vinkuran (Figure 1), the oldest quarry in Istria (Figure 3 left), known as “Cava Romana”. Vinkuran stone is an upper Cretaceous rudist limestone used for the construction of the Arena in Pula in the 1st century CE (Figure 3 right). Massive bioclastic limestone with a 40 m thick deposit, it is comprised of three different varieties known under the commercial names *unito*, *statuario* and *fiorito* and represents a typical coarsening and shallowing-upward



Figure 2: Quarries declared natural geological monuments: (left) Rupnica (courtesy of Geopark Papuk); (right) Fantazija.



Figure 3: (left) Vinkuran, the oldest quarry in Istria; (right) the Arena in Pula.

sequence (Tišljarić *et al.*, 1995). Today the quarry is used as a venue for concerts and other performances and as an open-air monument of mining activity. Industrial heritage from the Roman period is presented by visible chisel marks.

Interesting unprotected sites that combine natural and cultural heritage values are the quarries on Korčula Island (Figure 1) and on neighbouring islets (Vrnik, Planjak, Majsan, Sutvara, Gubavac and Planjak) (Figure 4 left). This small region contains numerous quarries which were active during different periods in history. During antiquity, according to Gjirović (1970), stone was exploited solely by the underground mining method (Figure 4 right). The top surface layer of poor-quality stone was left intact because it reached a thickness up to 3 m. A very high-quality decorative building stone, a white upper Cretaceous rudist limestone, was used for the construction and decoration of buildings and summer houses in the old town of Korčula and exported to Dalmatia, especially to Dubrovnik, Italy and even to the Ottoman Empire.

Many other quarries comprising renowned different varieties of natural stone excavated in the coastal areas of Croatia deserve to be acknowledged and

protected as geological and cultural heritage sites. For example, natural stones like Kirmenjak, Giallo d'Istria, Adria grigio, Veselje unito and Benkovac stone were used for the construction of many monuments and old towns of cities such as Venice, Dubrovnik, Korčula, Split, Solin, Trogir, Šibenik, Zadar and Pula. All of these old mining sites represent outcrops where different geological features of rocks are visible. These features are added values from an educational point of view. Evidence of formation of different types of sedimentary rocks can evoke and add to knowledge about geology.

Underground mines

Underground mining in Croatia has ceased (except for one active underground quarry of natural stone in Istria), but there are several old mines that are significant in terms of mining heritage. Preservation of such monuments is difficult and requires a significant amount of money. Fortunately, there are two mines partly restored for visitors and some others in such a condition that there is a possibility of their restoration. The local community is engaged in an effort to preserve them from oblivion.

Croatia is very poor in metallic ores.

However, ore mining was significant in Croatian history. The old mining settlement Rude (Figure 1), situated about 30 km southwest of the capital city of Zagreb (Figure 1), represents an excellent example of local community efforts for restoration of mine heritage and preservation of mining tradition. In 16th century its copper production was twice the amount of the total copper production in England and four times that of Norway, reaching one third of the production of the famous Swedish mine in Falun (Budak, 1994). The first miners mainly came from Saxony. Beside copper, iron was mined, as well as gypsum from the early 19th century till the 1950s. The network of mining trenches spreads under the settlement. Nowadays 350 meters of trenches are accessible to visitors (Figure 5 left). According to Borojević Šošarić *et al.* (2010), Rude deposits in the Samoborska Gora Mts. may be declared a prototype of the Permian siderite-polysulphide-barite deposits (products of rifting along the passive Gondwana margin) in the Inner Dinarides and their equivalents extending north-eastward and south-eastward. It is hosted by Permian siliciclastic sediments below gypsum and anhydrite strata. Hence, this site – besides its mining heritage – has



Figure 4: (left) Vrnik islet with old abandoned quarries; (right) underground natural stone quarry at Sutvara islet.



Figure 5: (left) Copper mine Rude (photo: Romeo Ibršević, courtesy Mine St. Barbara); (right) underground mine of pyritised bauxites Minjera.

geo-heritage value. Proper protection of outcrops inside the mine and on the surface is very important. Other metallic ore mines not to be omitted are Zrinski (partly restored and maintained by Nature Park Medvednica), Kraševi Zvirni (a zinc mine suitable for restoration and with a local community interested in preservation), and Trgovska gora (a mining area highly significant in Croatian history).

The most significant mine heritage site of a non-metallic resource is Minjera (from the Italian *miniera* – mine) in Mirna valley in Istria (Figure 1). This combined open pit and underground mine (Figure 5 right) of pyritised bauxites was opened in the 16th century in order to obtain vitriol and alum. Hence, Minjera is the first bauxite mine in the world. The first scientific description (chemical-mineralogical study) of the bauxite ore in the world is the 67-page book “Della preparazione dell’allume nella miniera di S. Pietro nel dipartimento dell’Istria” by Pietro Turini in 1808, addressing the bauxite from Minjera (Marušić *et al.*, 1993). Especially detailed is the technology of the ore beneficiation process with some technological innovations. The raw material is pyritised bauxite of Lower Paleogene which contains both pyrite and marcasite. There are two phases of pyritisation of bauxite: sulfur from the first phase originated from

organic matter of hanging wall sediments, while the second phase retrieved sulfur mainly from the sea water. Pyritisation is in some places accompanied by diasporisation (Šinkovec *et al.*, 1994). Although there have already been several attempts to protect this site as a natural geological-paleontological monument, so far all efforts have been unsuccessful. There are many other bauxite mines in Croatia, including Kalun, which at the time of its closure in 1963 was the deepest bauxite mine in Europe and probably in the world.

Ex situ geological heritage

There are many mining sites, especially underground, which are no longer available for restoration. One of them is a sulfur mine in Radoboj (Figure 1), founded in 1811. Sulfur from Radoboj was free of arsenic and therefore appreciated and used in medicine and industry without limitation. Moreover, the process of purification was invented and developed on site, leading to the world famous Radoboj machine construction. Marl, which was the body carrying sulfur material (Figure 6 left), contained abundant fossilised fauna and flora that is 12–14 million years old (middle Miocene to Sarmatian). The variety of fauna captured in marl is rich, ranging from shells

to fishes and whales. Flora are presented by imprints of leaves (e.g. the oldest found leaf of a vine in Europe, Figure 6 middle), seeds or flowers, revealing a mild climate. Especially notable are the well-preserved insect fossils (Figure 6 right) that were described by the Swiss palaeontologist Oswald Heer in his work “Die Insektenfauna der Tertiärgebilde von Oeningen und von Radoboj in Croatien” in 1847. Due to all of these features, Radoboj represents an important mining site with technological, industrial and geological-paleontological heritage. Although the original site was flooded and is not accessible, local authorities recognised its importance. Radboja museum is a highly valuable tool for ex-situ presentation and dissemination of heritage. Unfortunately, most of the exhibits are replicas, as most of the valuable paleontological material is kept in Landesmuseum Joanneum, Graz. There is also considerable material from Radoboj housed in the Natural History Museum in Zagreb.

Conclusion

Geo-heritage encompasses natural geological or geomorphological features possessing aesthetic, intrinsic, scientific and educational value, that provide unique insight into geological processes affecting the formation or evolution of the Earth. Often only by human activity do these features come to light. In that case, we can talk at the same time of natural (geological) and also cultural (historical, industrial, mine) heritage. Although there are 53 localities already protected as geo-heritage sites in Croatia, there are still many potential sites – especially those related to mining – that could be classified as geo-heritage sites. They provide a fascinating geological, historical, scientific and mining record, valuable not only as natural heritage but also as a part of our cultural heritage. If properly preserved and presented, mines and quarries, as well as ex situ geo-heritage (e.g. minerals, ores, rocks or fossils collec-



Figure 6: Geological samples from Radoboj: (left) sulphur in marl – finding of König Friedrich August II von Sachsen in 1845 (Min 20650 Sy, Senckenberg Naturhistorische Sammlungen, Museum für Mineralogie und Geologie, Photo: Jana Wazeck); (middle) vine leaf – *Vitis teutonica* (photo from archive of Radboja museum); (right) plant fly – *Bibio giganteus* (photo from archive of Radboja museum).

tions) are interesting not only to scientists but also to the wider society, local community and tourists.

There is plenty of room for work on the promotion of geological heritage related to mining in Croatia. Preservation of geological heritage within the mining heritage context is fundamental to promote proper protection, valorisation and utilisation as geo-tourism destinations. The currently running European wider society learning

project “MineHeritage: Historical Mining – Tracing and Learning from Ancient Materials and Mining Technology” is a good basis for longer-term planning of geo-conservation of such sites.

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