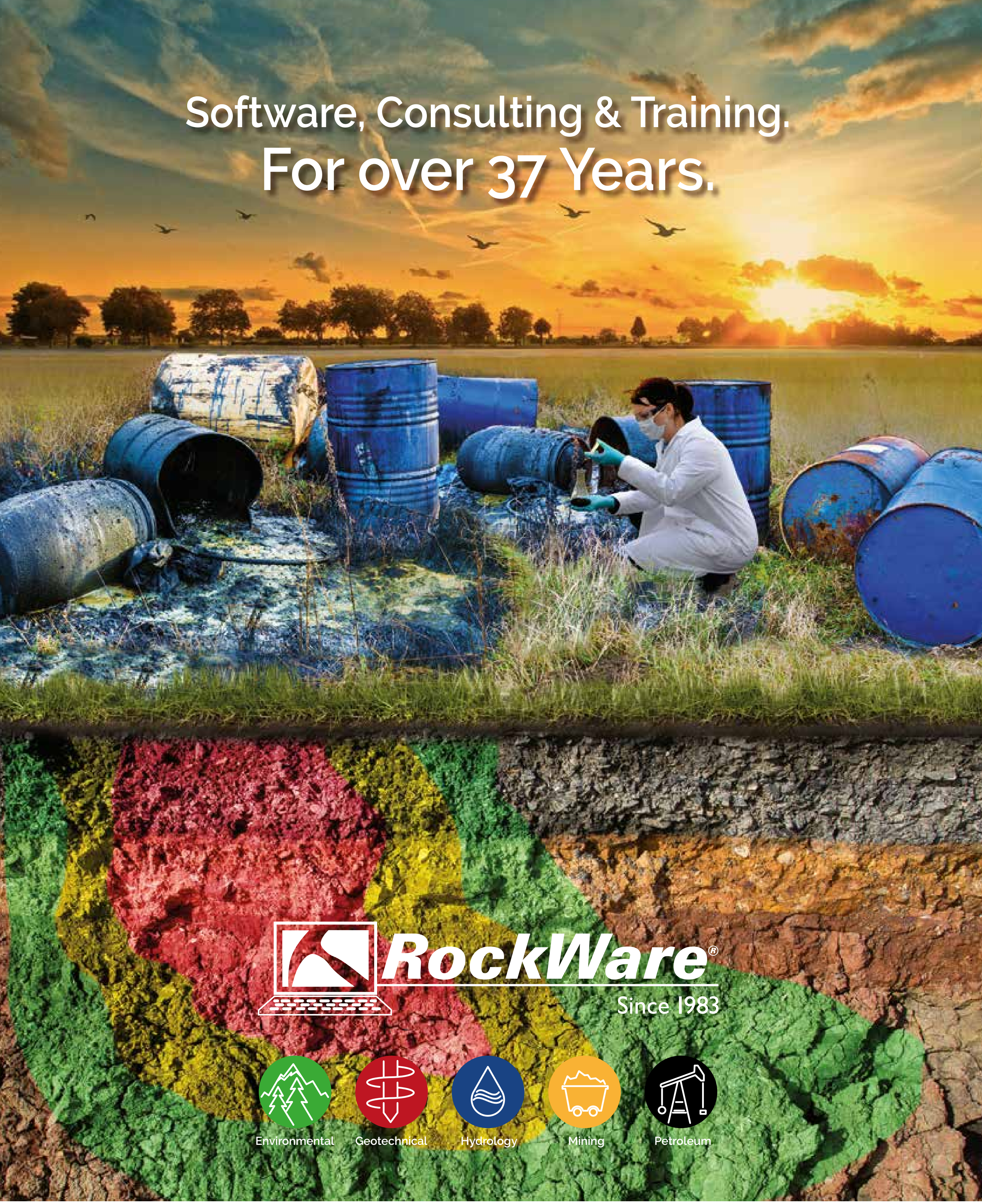
N° 48 November 2019

European Geologist

Journal of the European Federation of Geologists

Geological heritage of Europe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We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist Journal. The content of this issue has been reviewed by John Clifford, Alecos Demetriades, Renata Brezinscak, János Földessy, János Haas, Gareth Jones, Novák Tibor József, Ferenc Kristály, Mate Osvald, Joan Poch and Mónica Sousa.

Advertiser:
Rockware (pages 2 and 72).

Cover photo:
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ISSN: 1028 - 267X

EUROPEAN GEOLOGIST

is published by the
European Federation of Geologists
C/O Service Géologique de Belgique
Rue Jenner 13
B-1000 Bruxelles, Belgium
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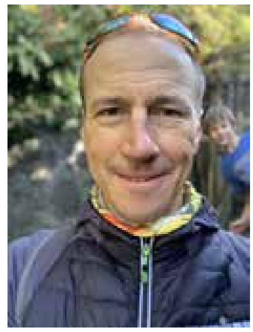
Foreword

EurGeol. Marko Komac, EFG President



Dear Reader,

It is my great pleasure that I can for the first time write the foreword for the *European Geologist* in which we address the topic of the geological heritage of Europe.

The issue of geological heritage, "geoheritage" for short, is probably the most recently addressed domain in geological sciences and has been recognised as one of the best opportunities to promote geology to a wider public. And although the term "geoheritage" seems obvious, it often represents different concepts to different people. Logically, a question arises: what does geological heritage mean? It could mean using the same building material (stones) in restorative architecture as that from which the buildings were originally constructed. It could mean passing geological knowledge to experts through training, students through higher-level teaching or the general public through education, raising interest in geological topics (rocks, fossils, processes). It could mean preserving either geo-sites and materials or the technological heritage related to geology and mining, at a local level or at an internationally recognised level through the UNESCO Global Geopark Network.

To recapitulate all of the above-mentioned areas, geoheritage addresses the conservation of the Earth's related relics and contemporary processes, either by physical protection or by descriptive means, with the aim of their preservation, management and understandable interpretation to both experts and the wider public.

Putting it in simple words, geoheritage is about preserving Earth's treasures for the future. Trying to put it into the frame of trending topics, it also involves tackling the present challenges society is facing, including the climate crisis – all this is a part of our geoheritage. Despite the possibility that I may be understood as being controversial, it is my opinion that not addressing the climate crisis could lead to the disappearance of numerous treasures of the Earth belonging to the geoheritage and as such often even legally protected.

The current issue of the *European Geologist* tries to address various aspects of geoheritage, from different thematic and different cultural perspectives, which gives it additional value in understanding how to approach geological heritage in specific situations with specific topics and at specific scales.

I sincerely hope you'll find the issue interesting to read and I firmly believe you'll also find the information useful in your daily professional work, free-time activities or merely as a casual reader.

I wish you many interesting moments in reading the latest issue of the journal.

Marko Komac

Croatian geological heritage related to historical mining and quarrying

Marta Mileusnić, Ana Maričić, Michaela Hruškova Hasan*

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 nonmetallic; (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 (Tišljar *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 Gjivoje (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 Šoštarić *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 Ibrišević, 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 Zviri (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. Radboa 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 Radboa museum); (right) plant fly – Bibio giganteus (photo from archive of Radboa 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.

Acknowledgment

This contribution is supported by the project “MineHeritage: Historical Mining – Tracing and Learning from Ancient Materials and Mining Technology” funded by the European Institute of Innovation and Technology (EIT), a body of European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation.

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Featuring slate: the German geoheritage initiative "Rock of the Year" in 2019

Christof Ellger[1] and Manuel Lapp[2]*

Since 2007 the geoheritage initiative "Rock of the Year", spearheaded by the Berufsverband Deutscher Geowissenschaftler, BDG *[German Professional Association of Geoscientists], has strived to communicate essential aspects of geology to the general public in Germany. Each year, a specific type of rock is chosen to be featured in publications, media news and events, with the aim to inform the audience about the importance of geosciences, about geology and petrography in Germany, and about the rock industry. In 2019, the choice of slate as a particularly attractive 'rock of the year' prompted a series of media products and events, successfully featuring the rock and its origins, its qualities and its use, both in history and today.*

Depuis 2007, l'initiative "Rock of the Year" concernant l'Héritage géologique, portée en avant-garde par le BDG (Berufsverband Deutscher Geowissenschaftler (Association Allemande des Géologues), s'est fortement développée pour communiquer sur les aspects essentiels de la géologie, auprès de l'ensemble de la population allemande. Chaque année, une roche particulière est choisie pour apparaitre dans les publications, les journaux et faire partie des évènements dans le but d'informer le public sur l'importance des géosciences, la géologie et la pétrographie en Allemagne et sur l'Industrie des carrières. En 2019, le choix de l'ardoise comme "roche de l'année", particulièrement attractive, a déclenché une série de produits médiatiques et d'évènements, rendant compte avec succès des caractéristiques et des origines de la roche, ses qualités et son utilisation, à la fois dans le passé et aujourd'hui.

Desde 2007, la iniciativa de patrimonio geológico "Roca del año", encabezada por, BDG (Asociación Profesional Alemana de Geocientíficos), se ha esforzado por comunicar aspectos esenciales de la geología al público general en Alemania. Cada año, se elige un tipo específico de roca, el cual aparecerá en publicaciones, noticias en diferentes medios y eventos, con el objetivo de informar al público sobre la importancia de las geociencias, sobre la geología y la petrografía en Alemania, y sobre la industria de las rocas. En 2019, la elección de pizarra como una particularmente atractiva "roca del año", desembocó en una serie de productos y eventos digitales; presentando con éxito la roca y sus orígenes, sus cualidades y su uso, tanto históricamente como en la actualidad.

In its 13th Year: the "Rock of the Year" Initiative in Germany

The initiative "Rock of the Year" was started in 2007. Following the model of other "… of the year" activities in Germany, a group of geoscientists with a strong interest in geo-communication and outreach, led by Werner Pälchen and other members of the *Berufsverband Deutscher Geowissenschaftler BDG* [German Professional Association of Geoscientists] proclaimed "rock of the year" as an instrument to communicate aspects of geology, geoheritage and the stone industry into the wider public.

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Year-based communication initiatives in Germany had begun in 1971, when one of the larger conservationists' associations in Germany (*NABU – Naturschutzbund Deutschland* [Association for Nature Conservation Germany], then under the name of *Deutscher Bund für Vogelschutz* [German Association for the Protection of Birds]) made the peregrine falcon (*Falco peregrinus*) "bird of the year", unleashing a tremendous series of annual campaigns for nature objects. A current compilation (***https://de.wikipedia.org/wiki/Natur_des_Jahres***) lists 47 nature elements of the year for Germany, from mushroom of the year to seabird, single-celled organism, potato or mollusc of the year. And it is not just about flora, fauna and, for that matter, mycobiota; there are also larger nature components highlighted year by year: the landscape of the year, the river landscape of the year, the tree-lined allée of the year, and—also in the geosciences and important in the geoscientific community—the soil of the year (*Deutsche Bodenkundliche Gesellschaft* [German Soil Science Society] and *Bundesverband Boden* [Federal Soil Association], since 2005) and the fossil of the year (*Paläontologische Gesellschaft* [Palaeontological Society], since 2008). The idea has also spread beyond nature and wildlife; e.g., there is a public monument of the year (since 2004) or a musical instrument of the year (since 2008). Interestingly, although rather self-evident and convincing in its potential, this idea of the 'year elements' does not seem to have been taken up to much extent outside the German-speaking countries.

For 13 years now, BDG has led the "rock of the year" initiative. It set up a small committee with experts from BDG, from geological survey institutions in Germany, from the stone industry and from geotourism, which decides on the respective annual rock and on the measures to communicate this to the society.

The background for this activity of rock of the year—and also the major reason why it is so important—is the fact that the general knowledge about geological issues in Germany is actually very limited. Apart from a small number of exceptions, geology is virtually not taught in schools, which leaves the existence of geoscientific knowledge to the small group of experts with geological university education and the community of interested amateurs. In this situation the "rock of the year" initiative is one step in the endeavour to get more information about geosciences into people's heads in Germany. In the almost 13 years of its existence, this has been more or less successful. In the media, the rock of the year is well-established by now as one of the elements of nature which are being presented during one year. A series of flyers and booklets have been produced for the rock years, "rock of the year" is published on the internet, by *BDG* and *GeoUnion Alfred-Wegener-Stiftung* (the federation of the geosciences associations and research institutes in Germany) and the Geological Surveys of those federal states which have the annual rock in their geology. A number of major events are staged. Every year, the festivities start in spring with the "baptism" of the rock, usually at a major deposit and mining location of the rock of the year, organised by BDG, the stone industry and the company owning the "baptism" quarry. The rock of the year is ceremoniously baptised, with either wine, champagne or beer, depending on the favourite drink—or even local product—of the region. Other events follow: Geological Surveys of the federal states present the most attractive outcrops of the rock of the year, also proclaiming a "rock of the year geosite", in their territories with public manifestations. Annually in September the Germany-wide held "geosite day" [*Tag des Geotops*]—another initiative of geoscience outreach in Germany (since 2002, every year on the third Sunday in September)—is used for public presentations of the rock of the year in various parts of the country. In addition, natural history museums may take up the idea and present the annual rock in a special showcase. Finally, the rock of the year is also featured in Germany's geoparks, provided of course that there is an outcrop; by autumn 2019 the number of 'national geoparks' reached 16, of which six are also acknowledged as UNESCO Global Geoparks (***http://www.nationaler-geopark.de/startseite.html***).

One fundamental aspect of petrology is already part of the selection procedure for the rock of the year: the classification of rocks into three major groups—igneous, sedimentary, metamorphic—is of course taken into account in the choice of the rock of the year, as the committee tries to cover the three categories equally, ideally taking turns every three years. This has essentially been adhered to as the list of the past "rocks of the year" shows (***https://de.wikipedia.org/wiki/Gestein_des_Jahres***):

Figure 1: Roofing slate at the historic slate mine at Lehesten, Thuringia (Photo: Susen Reuter).

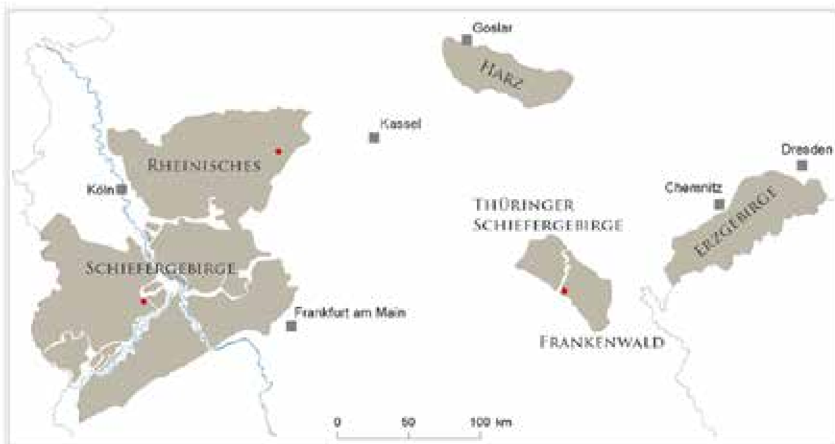

Figure 2: Roofing slate areas and major production regions in Germany (Map design: Angela Ehling, BGR).

2007	*Granite*	*igneous*
2008	*Sandstone*	*sedimentary*
2009	*Basalt*	*metamorphic*
2010	*Limestone*	*sedimentary*
2011	*(Volcanic) Tuff*	*igneous*
2012	*Quartzite*	*metamorphic*
2013	*Kaolin*	*sedimentary*
2014	*Phonolite*	*igneous*
2015	*Gneiss*	*metamorphic*
2016	*Sand*	*sedimentary*
2017	*Diabase*	*igneous*
2018	*Black coal*	*sedimentary*
2019	*(Roofing) Slate*	*metamorphic*

Naturally, there are other criteria and intentions involved. For instance, in order to feature the variegated aspects of sand as a resource, the committee made 'sand' rock of the year in 2016, although sand, of course, in the scientific sense of the work, is not a (solid) rock but rather granular rock material of a specific grain size. On the other hand, sand consists of rock material and therefore the choice was accepted as *cum grano salis* (to mention grain just once again).

There are several motives associated with the annual rock campaigns and their contents: firstly, general geological knowledge and a basic understanding of the key concepts of geology (and petrography, for that matter) are to be communicated into the public: the classifications of rocks, their essential features and also their origins, and

Figure 3: Slate used on roofs and facades; house in Ludwigsstadt, Upper Franconia (Photo: Christof Ellger).

in combination with the latter their distribution (in Germany, in Europe and also worldwide). The rock of the year is also used to enter into the presentation of fundamental elements of Earth History, geological eras and formations, and essential processes in geology like volcanism, weathering, sedimentation and metamorphosis. And there are questions of geomorphology and geoecology: Which landscapes are associated with given rock types? How do rocks influence the ecosystem, including the quality of the soils? Secondly, for BDG and the rock of the year committee there is a strong interest in the use and the economic importance of rocks: What can we do with specific types of rocks? How have they been used in history? How has the use of certain rocks characterised the cultural landscape in European regions, with regard to both the quarrying activities and the built-up areas? And which products of our daily routine (like glass, paint or toothpaste) depend on which rocks (like sand, gypsum and limestone)? And, after all, features in our every-day world have a greater chance to be esteemed and preserved for the future if we are aware of their value. People will support and strive for the conservation of slate as both an architectural element and landscape feature only when they know what roofing slate is, looks like and means in terms of geology, earth history, regional history, tradition and aesthetics and how it differs from, say, asbestos cement elements on roofs and walls.

Rock of the Year 2019: Roofing Slate

Slate: the very special metamorphic rock

For 2019, slate was chosen as "rock of the year"; what is essentially meant here is roofing slate (***Figure 1***). In German, there are some terminology problems due to the fact that the German word for slate, "Schiefer", has a wider connotation than its English counterpart and is also used for certain (high-metamorphic) schists on the one hand and certain shales on the other hand, i.e. sedimentary mudrocks with slate-like properties. Therefore, one of the first tasks of 'teaching' slate to the public is to clarify these terminology issues and distinguish between the different types of "Schiefer". All these slates and slate-like rocks show foliation, the "slaty cleavage" which means that the rock disintegrates in flat sheets. Really fine plane sheets, however, can only be cut from the "real" low-metamorphic slate as a result of its fissility, which the rock owes to the lateral pressure effect on its mineralogical fabric during metamorphism (Wichert, 2017).

More than many other rock types, the attractive slate is certainly an excellent choice for a public outreach initiative, especially in Germany (this would, of course, be similar in e.g. Wales, France, northwestern Spain and northern Portugal). As a rock type and building material slate is very specific, and in a number of areas in Germany slate is common and well known.

Slate in Germany: spatial distribution and (historical) uses

There are several areas in the country where slate used to be mined extensively for centuries, and there are large regions where slate has been used as the dominant building material. Two of the major Central German Uplands mountain ranges were named after slate: *Rheinisches Schiefergebirge* ("Rhenish Slate Mountains", internationally known as the Rhenish Massif), the large Western tract of the Central German Uplands, and *Thüringer Schiefergebirge* ("Thuringian Slate Mountains", Thuringian Highland) as a somewhat smaller part of the Uplands in Thuringia, actually also covering parts of Franconia and Vogtland (Schubert & Schubert, 2015) (***Figure 2***).

The Central German uplands are essen-

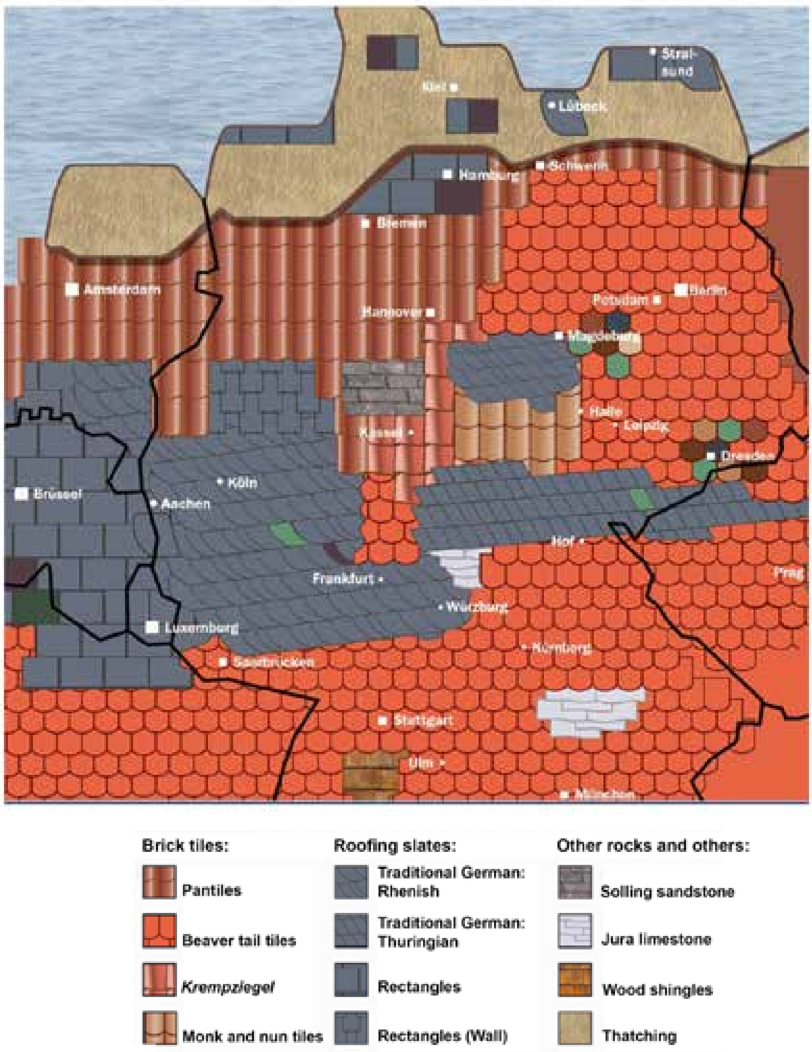

Figure 4: Roof material provinces in Germany (Map design: H.W. Wagner). Source: Wagner 2018, p. 10.

Figure 5: Aachen Cathedral (Photo: CEphoto, Uwe Aranas, Wikimedia Commons).

tially the result of the Variscan (Hercynian) orogeny. And it is here that we find the slate, because it originated from pre-Devonian marine-coastal clay sediments, compacted after sedimentation and subjected to diagenesis and metamorphism in this Variscan (Hercynian) orogeny. It is these remaining areas of the Variscan belt which bear the slate, next to Paleozoic limestones, sandstones (greywacke), but also plutonites, metamorphic and volcanic rocks in the complex uplands geology.

Major historic slate mining areas in the Rhenish Massif are Eifel (south of Cologne and west of Koblenz (Friis, 2018) and, slightly further south, Hunsrück; Sauerland (south of the Ruhr area) in the northeastern part of the Rhenish Massif. Further east, slate mining was important on the northern edge of the Harz Mountains, in the border area between Thuringia and Franconia and on the edge of the Erzgebirge (Ore Mountains) in Saxony.

The major product from slate was—and still is—roofing tiles and, to a lesser extent, façade cladding tiles. In the slate mining regions roofs and also walls were covered with slate, which made these regions specific slate construction provinces (Wagner, 2018) (***Figure 3***). Given the regionally available resource for making tiles, roof material provinces can be distinguished in Central Europe (***Figure 4***). But slate was also exported, transported by ships on rivers and later by railway to major trading centres, territorial capitals or important ecclesiastic centres. From the Middle Ages until the 19th century, roofing slate was appreciated as the optimum material, fine and durable, for roof covering for prestigious buildings all over Germany. A large proportion of the buildings with UNESCO world cultural heritage status, like Aachen Cathedral (***Figure 5***), have a slate roof (Stahr, 2018).

Most of the slate mining in Germany has ended as production was no longer competitive with other European and global slate producers and—more crucially—with other construction materials. Five slate mines have survived. Most roofing and cladding slate is now imported, predominantly from Spain, Portugal, Brazil and China. This means that slate is still available for the refurbishment of old existing slate roofs, even if not necessarily slate from German mines. Helped with interesting product innovations by the slate producers, there is something like a renaissance in slate construction currently, slate being used not only for roofs and the cladding of exterior walls but also for the interior, for floors, walls, stairs and baths.

The other historically relevant slate product was writing slates and blackboards. A century ago, classrooms all over the world were equipped with writing slates and blackboards, often enough from Germany, essentially from the Thuringia-Franconia slate area, where several museums highlight the history of the production of writing slates. An excellent exhibition can be found in the slate museum in Ludwigsstadt, Upper Franconia; slate in schools is focused on nearby in Steinach's local museum.

Celebrating slate in 2019: major events and activities

The year of slate was announced in January with press releases which were issued through various channels. A number of newspapers and internet publishers used text and photos for an article. The main opening event for the year of slate was the inauguration of the rock of the year on 3rd May, with the ceremonial christening of the slate: the event was held in the city of Mayen (Rhineland-Palatinate; on the edge of the Eifel Mountains) at the company headquarter of Rathscheck – Germany's largest slate producer – which itself is a fine architectural masterpiece capable of advertising the use of slate in construction. Before the moment of christening, the slate presentation involved a number of topical speeches by representatives of BDG, the Geological Survey of Rhineland-Palatinate, the mineral resources industry and also by the representatives of Rathscheck, the host company, who gave an overview on slate in geology, mining economics and architecture. In Mayen, the slate was, aptly, baptised with slate Riesling, white wine from the nearby Mosel area, where the wine actually grows on slate soils (***Figure 6***).

An extended fanfold leaflet covering all the essential aspects of the rock's geology, mineralogy, deposits as well as the (historic and present-day) use of slate was produced by the Geoscientists' Initiative in Berlin and Brandenburg (*Geowissenschaftler in Berlin und Brandenburg*), directed by the rock expert Angela Ehling, assisted by Wolfgang Wagner, another slate specialist in Germany. Also as part of the "rock of the year" (and similarly to preceding years), a number of Geological Surveys of the federal states published separate leaflets and internet pages on "their" slate, presenting both slate in general and the slate locations with their products in their territories. A poster for the Rock of the Year 2019 was designed by BDG, again in cooperation with Rathscheck.

In addition, several individual lectures on slate were organised in various cities in Germany. Given the potential to use the topic of slate to convey a larger range of general aspects of geology and the geosciences as a whole into the general public, *GeoUnion Alfred-Wegener-Stiftung* organised a lecture series for town libraries, adult education centres and similar institutions which was

Figure 6: Christening slate as rock of the year 2019, May 3 2019, Mayen (Photo: Rathscheck Schiefer).

Figure 7: Josef A. Kutschera: Landzunge (Promontory), 2018, from the art project 'GREYZONE – a roof becomes art' (Photo: Christof Ellger).

marketed all over the country. As a result, about 25 lectures will take place in towns of very different size throughout Germany during this slate year. Using slate as the key to open up the discussion, the basics of petrographical classification, questions of geological age and stratigraphy, tectonics and the changing configurations of continents and oceans are featured in the lectures. Other topics covered include slate mining then and now and the economy of the slate industry, and there are themes 'beyond geology', like wine-growing on slate (along the rivers Rhine and Mosel) and the use of slate in works of art. With respect to the latter aspect, there are a number of artists in Germany who work with slate. A fine present-day example of a slate art project is "Grauzone" (grey zone): the artist Bernard Misgajski, who lives and works on the Isle of Rügen, found and rescued disused slate tiles (originally from Wales!) from the roof of a railway shed in the Danish harbour of Gedser and distributed them to colleagues of his. As a result, 37 artists from five countries produced twin works, with the Gedser slate tiles on the one hand and an artistic reflection (using any other material) on the other hand, for an exceptional project exhibition (DIE BEGINEN e.V. 2019) (***Figure 7***).

Conclusion

Thirteen years after its start in 2007 the German geology and geoheritage initiative "rock of the year" has become well-established in the geoscience community and well covered by various media. 2019, the year of slate, appears as a special highlight, with a fascinating multifaceted stone. The challenge for the future will be to select rocks that are sufficiently attractive for the media and the public. This encompasses both the attractiveness for the general audience to get them closer to geological issues and the potential for associations and companies to communicate their interests. The initiative itself may improve itself substantially by a range of measures, e.g. with a specific website for the rock of the year and with improved networking between the rocks associations and all the other institutions involved.

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The Geological Wall in Berlin – Over 120 years of teaching geology

Ulrike Hörmann[1], Angela Ehling[2] and Klaus Reinhold[2]*

In 1896 Eduard Zache, a school teacher and geologist in Berlin, planned and built a "Geological Wall" to provide a geological understanding of landscapes and their stones to the people of the growing town of Berlin. He arranged 123 different rocks forming idealized strata sets and tectonic structures in a wall with a length of about 30 m and a height of average 2 m. The arrangements simulate geological formations in former Germany in a very detailed manner and they cover all geological periods. Thus, the strata sets of the Muschelkalk in Rüdersdorf near Berlin are pictured as well as the copper deposit of the Rammelsberg, along with folded Devonian strata in the Harz Mountains, the granite pluton of Lusatia, reef limestones, basaltic columns breaking through older rock strata and much more. The wall does not only show and illustrate features and the genesis of rocks, deposits and geological structures; it reflects the use of stones and raw materials at the end of the 19th century, too. Nowadays this Geological Wall still exists and is in use for teaching.

En 1896, Edouard Zache, professeur des écoles et géologue à Berlin, imagina et construisit un "mur géologique" pour favoriser la compréhension géologique des paysages et des roches qui les constituent, auprès de la population de Berlin, ville en développement. Il disposa 123 roches différentes pour former une série de couches idéales accompagnées de structures tectoniques, sous la forme d'un mur de 30 mètres de long sur 2.5 mètres de hauteur. Cette représentation rappelle les formations géologiques de l'Allemagne d'autrefois, de façon très détaillée et couvre l'ensemble des périodes géologiques. Les niveaux du Muschelkalk à Rüdersdorf, près de Berlin, sont représentés au même titre que le gite cuprifère de Rammelsberg, accompagnés des couches plissées du Dévonien des Montagnes du Harz, du granite plutonique de Lusatia, des calcaires récifaux, des filons de basalte intrusifs dans des couches plus anciennes et beaucoup d'autres choses encore. Le mur ne dévoile ni n'illustre seulement les grands traits et la genèse des roches, les gites et les structures géologiques ; il rend compte également de l'utilisation des roches et des matières premières à la fin du 19ème siècle. Aujourd'hui, ce Mur Géologique existe toujours et représente un outil d'éducation.

En 1896 Eduard Zache, un profesor de geología en Berlín, planeo construir un "Muro Geológico" para proporcionar conocimiento geológico de los paisajes y sus rocas a la gente que había crecido en la ciudad de Berlín. Consiguió 123 tipos de rocas, formando conjuntos de estratos y estructuras tectónicas en una pared de una longitud de 30 metros y una altura media de 2 metros. Los arreglos simulan formaciones geológicas en la antigua Alemania de una manera muy detallada cubriendo todos los periodos geológicos. Por tanto, se muestran los conjuntos de estratos del Muschelkalk in Rüdersdorf, cerca de Berlín; como también los depósitos de cobre del Rammelsberg, los estratos devónicos plegados de las montañas Harz, los plutones graníticos de Lusatia, arrecifes calizos, columnas basálticas y mucho más. El muro no solo muestra e ilustra características y la génesis de rocas, depósitos y estructuras geológicas; también refleja el uso de piedras y materias primas a fines del siglo XIX. En la actualidad este Muro Geológico aun existe y sigue usándose para enseñar.

Introduction

The hundred-year old history of the Geological Wall does not fit to geological scales but is, nevertheless, an extraordinary geotope. Originally, the geological wall was an object for learning and teaching outdoors (***Figure 1***), or as the builder, Eduard Zache, wrote: "A demonstration model to introduce the theory of

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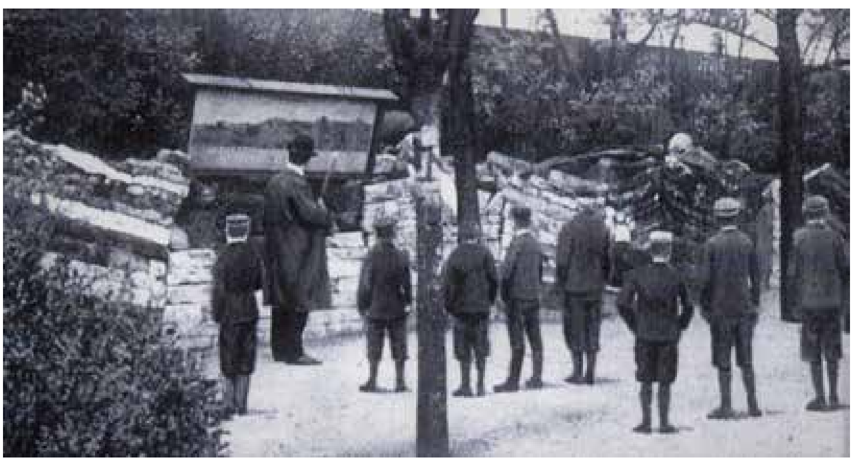

Figure 1: Teaching in front of the Geological Wall at the end of the 19th century (Engel et al.*, 1990).*

Figure 2: A current view of the Geological Wall in the botanical garden in Berlin-Blankenfelde.

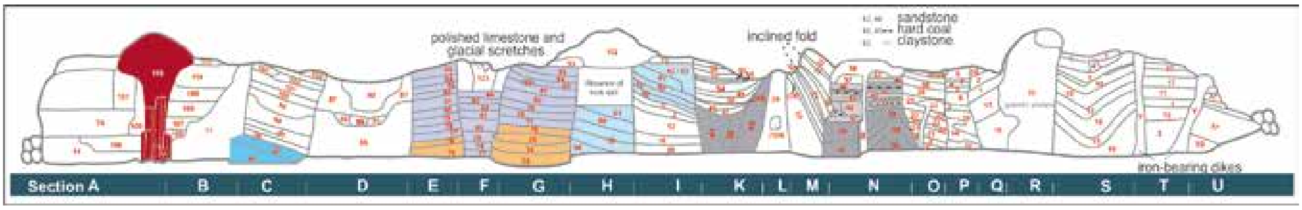

Figure 3: Simplified model of the Geological Wall (extract from the information brochure).

the structure and the treasures of the Earth's crust" (Zache, 1896).

Its original location was in the Humboldthain, a park in Berlin-Wedding directly next to the botanical school garden. Because of the growing city it was moved to the botanical garden in Berlin-Blankenfelde during 1912 to 1914, today the Botanical Park (Wutzke & Liebram, 1999).

Unlike collections of rocks, e.g. in museums or schools, the geological wall has created a combination of rocks and their natural distribution (***Figure 2***). This makes it easier to understand geological structures and earth history. Therefore, geology is the central topic of the geological wall.

The wall is divided into 20 sections (A–U) illustrating geological systems, stratigraphic series, geological structures and tectonic events in the way they really appear in sites located in the former Germany. The ground rock controls the surface shape of the wall, and in its original location this continued into the region behind the wall for a 3-D-effect (today only to some extent).

The geological wall contains even more information from the past and present. The construction of the wall at the end of the 19th century and the rocks used are closely linked to the history of Berlin. Furthermore, it has significance from a geo-historical point of view because it reflects the state of geological knowledge at the end of the 19th century. One example is the absence of Ordovician rocks because this system, although defined in 1879 by Charles Lapworth, was only recognised in the 20th century.

As far as mining is concerned, the wall has serious historic value because the stones often came from the then active mining districts and quarries, e.g. the Mansfeld copper slate district, the closed Pb-Zn-Cu Rammelsberg Mine (now a UNESCO World Heritage site) in the Harz Mountains or hard coal from the Ruhr Region in western Germany. With relation to real geological outcrops of geological and historical significance in many parts of Germany, the Geological Wall promotes knowledge of the natural and local history of our country and arouses interest in further geotopes in Germany.

What do we see?

On average, the wall is about 30 m long and 2 m high. It consists of 123 different kinds of stones coming from several regions in Germany: from the nearby Muschelkalk quarry in Rüdersdorf, the Harz Mountains, Saxony, Thuringia, Bavaria, Rhineland and from Silesia (today Poland).

The geological systems are arranged from the Proterozoic to the Cenozoic system, from right to left (***Figure 3***). The different stones or stone layers are numbered.

Some sections of the wall are presented below.

The oldest rocks of the Proterozoic and Palaeozoic - the crystalline basement - are mainly arranged in Sections P to U. The centre is formed by granitic pluton, the Lusatian pluton in Saxony, which intruded during Cambrian time into Proterozoic rocks, dragging them along – illustrated by sloping older magmatic and metamorphic rocks. On one side, sideritic iron-bearing dikes break through these crystalline rocks. A typical iron cap is found on top. These dikes illustrate the famous iron ore deposits of the Siegerland in western Germany.

Section N shows a typical Permo-Carboniferous evolution in Central Europe. Lower Carboniferous folded and partly eroded slates and greywackes are covered by typical Upper Carboniferous series with sandstones, claystones and hard coal, as developed in several places in Germany. This exemplifies especially the Ruhr Region, where intensive hard coal mining established the basis for the German steel industry at the end of the 19th century. Some Carboniferous plant fossils illustrate the genesis of the hard coal from plants. The

Figure 4: Section K–N with Carboniferous sedimentation (Hard coal – left and right), Devonian series with slates folded, Rammelsberg copper ore (centre), Devonian coral reef (34 inclusive cavern) and Permian volcanism (56) including fault (right).

series is a good example for changing environmental and depositional conditions in a coal basin. The whole series is divided by a fault filled with a rhyolite symbolising the Permian volcanic activity as it developed near the surface in Sachsen-Anhalt, north of the city of Halle (Saale). A displacement of the layers left and right of the fault shows the connection of volcanism and tectonic activities. The red rhyolite, the so-called "Löbejüner Porphyr", was a famous building stone in Berlin.

Section M shows another interesting well-known economic geological situation (***Figure 4***). The section shows an inclined fold of Devonian slates as they occur in the Harz Mountains. This structure is accompanied by copper bearing schists of the world-famous Rammelsberg ore deposit, where copper and other metals were mined for more than 1000 years. Devonian reef limestones with well visible corals flank this series. They also contain a stalactite cavern as known from the caves opened to tourism in the Harz Mountains.

The youngest part of the Palaeozoic is represented by copper slate and evaporites of the Upper Permian – called Zechstein in Germany. The exploitation of copper and other metals from the copper slate along the southern margin of the Harz Mountains in the so-called Mansfelder Revier began already in the Bronze Age and lasted up to 1991. This mining still continues today in Poland near Lubin. The weathering/oxidation of the copper is clearly visible from the green colours at the surface of the copper slate and the underlying sandstone.

The series of evaporites is only partly preserved. The salts are gone; only half of the gypsum and anhydrite remained.

The Mesozoic section shows examples of every geological formation, but main attention is given to the Muschelkalk. It is substantiated by geology around Berlin, which is dominated by young glacial sediments. The only outcrop of solid rocks here is an epirogenetic Muschelkalk formation at the eastern margin of Berlin. Since the Middle Age, the limestone has been quarried mainly for lime but also for building stone. The numerous fossil findings have attracted research in this field in Berlin since the 18th century. The whole sequence of the Rüdersdorf Muschelkalk is presented and well preserved in the sections E to G. However, the basal fibrous gypsum layer has been preserved only partially. It shows a surface as formed by the Ice Age, with a glacier valley and a limestone that has been polished by a glacier and displaying glacial scratches (***Figure 5***). This has been arranged according to the theory of glaciation of northern Europe, which was very modern at that time. The glacial marks found in Rüdersdorf contributed to the confirmation of this theory.

Figure 5: Muschelkalk of the Rüdersdorf quarry with limestone polished by a glacier and with glacial scratches.

Figure 6: Illustration of the geological situation in the south of Saxony with basic granitic rocks, cretaceous sandstones and tertiary basalt volcanism.

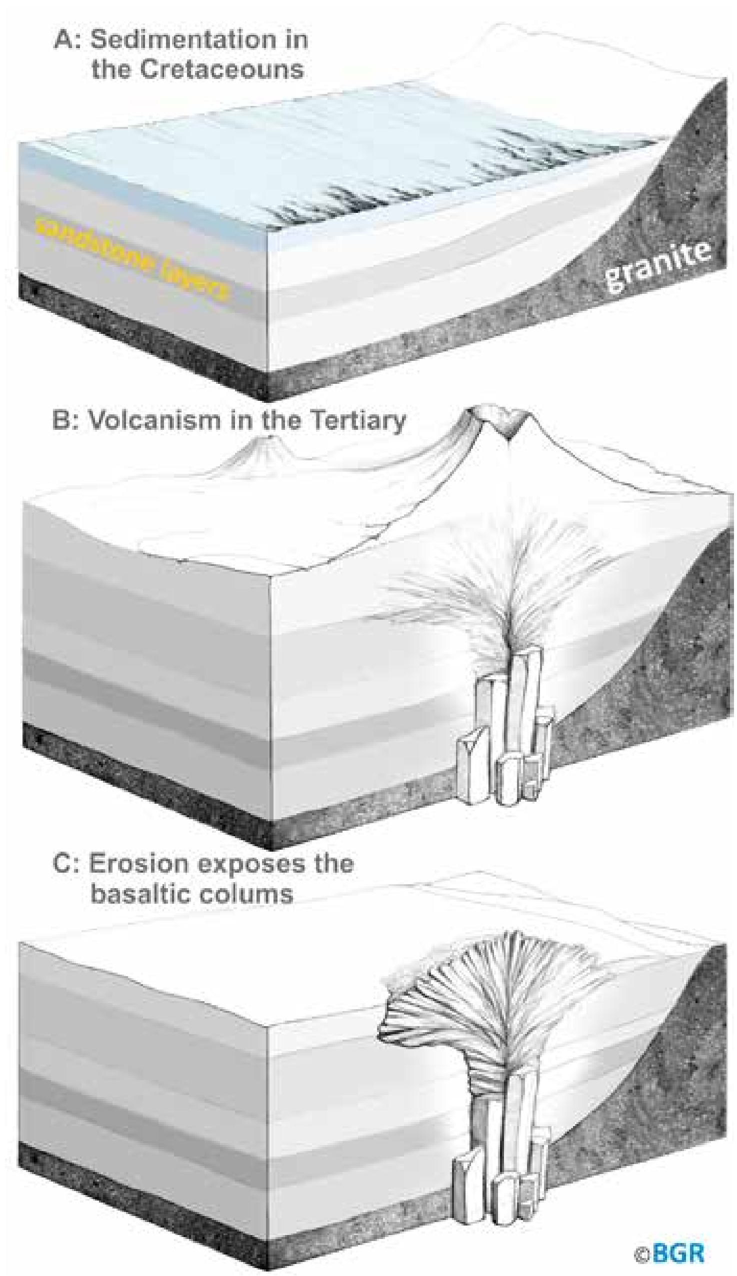

Figure 7: Illustration of the genesis of basaltic columns.

Another significant feature of the Muschelkalk is demonstrated in the Fe-Pb-Zn-deposit in Muschelkalk limestones in Maczeikowitz (now Maciejkowice, Poland).The real geological situation of this deposit has been re-created with Fe-bearing dolomite, galenite and Zn-carbonates. The Zn-Pb-Fe deposit region north of Krakow is among the most important mineral raw material occurrences of Europe (Cerny, 1989).

A typical sedimentary sequence with various alternating sandstones and limestones is presented in Section C, simulating the Jurassic and Lower Cretaceous series of the northwestern margin of the Harz Mountains. The layers are inclined (showing the situation that prevailed in the direction of the uplifting of the Harz Mountains during Cretaceous time). The base of this part is very specifically and descriptively designed. It is one of only two horizontal elements within the wall. Lower Jurassic oolithic iron ores with Ammonites of different sizes are arranged in the same way as they really occurred in Bad Harzburg. The mining of the iron ore was very intensive at the end of the 19th century and ammonites had been found in great quantities. Thus, they were able to build real ammonite fossils into this surface.

Another well-known landscape formed during Cretaceous times is illustrated in Section B: the "Elbsandsteingebirge" in Saxony. It is an easily interpreted image of successive sedimentation of clastic material into the Cretaceous marine basin on the eroded Palaeozoic granitic basement (***Figure 6***).

Section A originally contained the loose sediments (sands, clay, gravel, brown coal) of the Cenozoic – those layers that form the subsurface of the wider Berlin region. Somewhere along the line these materials were lost and temporarily substituted for by Cretaceous sandstones.

Between the last two sections (Cretaceous and former Cenozoic) stands the most attractive part of the wall, illustrating Tertiary volcanism by basaltic columns (coming originally from Unkel (Rhineland) later replaced and extended from Stolpen (Saxony) forming a rosette cupola.

Some erratic boulders of different sizes, found in the countryside around Berlin, are arranged along the flanks of the wall.

Teaching today

Currently the wall is used for education only on a few days per year. On some special dates geologists meet schoolclasses or the public at the wall to explain genesis and features of rock types, structures, problems of sustainability and weathering, to show minerals and fossils, with reference to raw materials and historic mining and the use of rocks in Berlin and to discuss questions connected with the geological underground.

The Geological Wall is situated in an old botanic park with many beautiful and interesting places, and is open to the public every day. Therefore, first of all, the Geological Wall has to be attractive for non-professionals. A modern, well-designed and self-explanatory information board is necessary. One didactic approach for a family with children could be based on riddles, which arouse children's curiosity. For example, a riddle is posed: "Which animals built the biggest stones?", so that the children can find the reef limestones with corals in the wall. Parents could help their children and learn something more about the reef limestones, derived from the Iberg in the Harz Mountains, of Devonian age (385 million years), inviting viewers to visit their beautiful stalactite caverns.

Meanwhile the grandparents could discover the basaltic rosette cupola, which illustrates the geological situation of the Upper Lusatia region in the South of Saxony. An explanation board should tell a story about the genesis of this geological setting beginning with the Proterozoic granodiorite, which was an island surrounded by ocean during the Cretaceous age; the erosion of that granodiorite produced sand, which was deposited along the coast (***Figure 7a***) and later compacted by more overlaying sand, thus becoming sandstone. Volcanic activity in Tertiary times brought the basaltic magma breaking through the fissures of the granodiorite and the sandstone (***Figure 7b***). The development of the basaltic columns near the surface and vertical to the cooling surface and reasons for their form and extent could be explained. Even the basaltic hill in a flat terrain tells a story about the weathering and erosion of older but weaker stones around the basaltic cupola – an example of an inverted relief (***Figure 7c***).

Another story could be told about geoscience history and Alexander von Humboldt: in 1789, when he was a student in Bonn, he visited the "Unkelsteine" in the Rhineland, one of the most prominent basalt occurrences in Germany and source of the basaltic columns originally used in the geological wall. After the visit he took part in the dispute between the "Neptunists" and the "Plutonists" about the origin of the genesis of these columns and took up the position of the Neptunists explaining their genesis by the gradual drying of a marine sediment (***https://de.wikipedia.org/wiki/Unkelstein***).

But not only history could be taught. Geological topics like drinking water, soil, energy and raw materials were part of our daily lives 100 years ago and they are part of it even today. Where and in which form do our raw materials occur? How could we extract them? What do we need for "clean" energy or for electric cars? These issues are not taught – or only randomly taught – at school. The geological wall offers many possibilities to introduce into these subjects. Even if it were for this reason only, it is necessary to make every effort for the protection, renovation and didactical modernisation of the wall.

The Geological Wall through the ages and now

The wall has been altered, partly when it was moved to its current location and also due to the varying people in charge of it through time. Two main parts (salts and Cenozoic strata) are missing, some stones were lost to weathering or vandalism, some stones were substituted or improperly replaced and numbers got lost. From time to time, the surface has been cleaned with varying degrees of professionalism. Associated explanation plates and labels have disappeared.

Nowadays the wall is widely accepted by the authorities and the public. The geological survey of Berlin, the non-profit association of regional geologists (GBB) and the GrünBerlin GmbH association, which is responsible for the whole park, are paying attention to this attraction. Several measures have taken place during the last six years: professional mapping of stones, moss, joint mortar, defects and weathering damages, renovation of the packing, professional surface cleaning, partial replacement of missing stones and revision of the numbering. These measures were carried out by restorers,- restoration students of the University of Applied Sciences Potsdam in accordance with the agreement of monument protectors. The Federal Institute for Geosciences and Natural Resources (BGR) possesses a number of stones and fossils from historical outcrops in its geoscience collection and provided some for replacement. An interactive digital model of the wall with explanations of the stones has been developed (***http://geowand.gruen-berlin.de/***). The work was crowned with first success by the certification of the status of a "German National Geotope" in 2018. This award has outstanding importance because it acknowledges a geotope in a city of nearly four million people. Concepts for further restoration, re-creation of the lacking parts and explanations (both on the spot and digital) have already been developed and will be realised in the next few years, depending on the funding provided.

All involved parties and persons are very committed to a quick and appropriate realisation of the renovation and modernisation concept for the Geological Wall. The teaching of geological knowledge forms the base for understanding complex natural interactions and the attentive use of our natural resources. It should be involved into the school curriculum and could be taught directly in situ at the real natural stones of this fantastic, unique, historical but yet modern Geological Wall.

Location: Botanischen Volkspark Blankenfelde, Blankenfelder Chaussee 5, 13156 Berlin, Germany.

http://geowand.gruen-berlin.de

https://www.berlin.de/senuvk/umwelt/wasser/geologie/

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A field trip enhanced with ARTutor, an augmented reality educational platform

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Field trips constitute a powerful educational tool, providing students with the opportunity to acquire authentic, hands-on experiences by direct contact with the natural environment. Technological advances, especially augmented reality (AR) applications, can add a whole new dimension to field trips. This paper discusses a field trip where secondary school students were asked to locate different rock formations on site from the pictures they had been given. By scanning these pictures with the ARTutor application on their mobile devices, they were given access to educational material (pictures, videos and text) loaded into the ARTutor platform. The instructional design and the application of this enriched field trip were evaluated by the students, who worked in groups combining information collected through ARTutor to complete activities.

Les sorties de terrain constituent un puissant outil d'éducation, donnant aux étudiants l'opportunité d'acquérir une expérience authentique et pratique par un contact direct avec l'environnement naturel. Les avancées technologiques, et, en particulier, les applications concernant la réalité augmentée (RA), peuvent ajouter une nouvelle et totale dimension aux sorties de terrain. Cet article traite d'une sortie où les lycéens ont eu pour tâche la localisation des différentes formations rocheuses sur le terrain, à partir de cartes qu'ils ont reçues. Après le scan de ces cartes en utilisant l'Application ARTutor sur leurs appareils mobiles, ils ont bénéficié d'un accès au matériel d'éducation (cartes, vidéos et textes) chargé sur la plateforme ARTutor. La conception pédagogique et l'apport additionnel de l'Application utilisée, lors de cette sortie, ont été évalués par les élèves, qui ont travaillé en groupes en rassemblant les informations recueillies grâce à ARtutor, pour achever leurs travaux.

Las excursiones geológicas constituyen una poderosa herramienta educativa, que brinda a los estudiantes la oportunidad de adquirir experiencias auténticas mediante el contacto directo con la naturaleza. Los avances tecnológicos, especialmente las aplicaciones de realidad aumentada (AR), pueden añadir una dimensión completamente nueva a estas excursiones. Este documento expone una excursión geológica donde se les pidió a los estudiantes de secundaria que ubicaran in situ diferentes formaciones rocosas con la ayuda de las imágenes que les habían dado. Al escanear estas imágenes con la aplicación ARTutor en sus teléfonos móviles, se les dio acceso a material educativo (imágenes, videos y texto) cargado en la plataforma ARTutor. El diseño instructivo y la aplicación práctica de esta excursión fueron evaluados por los estudiantes, quienes trabajaron en grupos combinando la información recopilada a través de ARTutor para completar las diversas actividades.

Introduction

Geosites are sites of utmost significance for the geological heritage of our planet and attempts to acknowledge and register Geosites are taking place in many countries in order for them to be recognised and preserved. Geoconservation is vital, should people wish to ensure that future generations come into the wealth of diverse sites that have captured and reflect unique moments of the Earth's history. The only way to achieve this is through education. Field trips are the best way to bring students into direct contact with geological treasures in situ and raise the awareness needed so that these are preserved. Technologies such as Augmented Reality applications enrich educational experiences and have the power to capture students' attention, since they employ the use of devices that they are familiar with.

In this paper, we present a field trip that took place at the volcano Sousaki, enriched with AR activities that were created using the educational platform ARTutor. ARTutor was created at the AETMA lab in the Technological Institution of Eastern Macedonia and Thrace. The students that took part in the field trip were asked to locate different rock formations on site from the pictures they had been given. By scanning these pictures with the use of the ARTutor application on their mobile devices they were given access to educational material that had been loaded in the ARTutor platform. The augmentations were pictures, videos and text and provided a great deal of information regarding the rock formations of the volcano. The instructional design and the application of this enriched field trip were evaluated by the students, who worked in groups, combined the information collected through ARTutor and completed all activities. The feedback we received was assessed and will be taken into consideration for future similar endeavours.

This field trip that took place at the Sousaki Volcano site near Athens was the first in Greece to use and evaluate AR activities developed with the use of the ARTutor platform. The results were very promising and technology-enhanced field trips look as if they have a bright future. "The past is the key to the future", as was maintained during the era of Enlightenment, the era of sciences, and what better way to step into the future than by combining real-life and technology-augmented learning experiences.

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Theoretical background

A Geosite is a place of scientific interest due to its geological structures: rock formations, fossil presence, mineral outcrops, sedimentary or volcanic sequences, landforms or any other natural structures that represent an event, process or occurrence which reveal information regarding the evolution of the Earth (Wimbledon, 1996; ProGEO Group, 1998). It is regarded a site of geological heritage (geo-heritage) since its disappearance would result in the loss of information or geological documentation about the specific area.

In an attempt to recognise and record the plethora of Geosites in different European countries, a project called "GEOSITES" was initiated by ProGEO (the European Association for the Conservation of the Geological Heritage) and later joined by IUGS (the International Union of Geological Sciences). This program, which started in 1995, was supported by UNESCO and a number of European countries were involved.

In order to cover the huge diversity of Geosites, the ProGEO group (1998) assigned ten different categories from all areas of Earth Sciences, as follows:

- stratigraphic
- environmental
- volcanic-metamorphic-sedimentary petrology, fabrics and structures, events and provinces
- mineralogical, economic
- structural
- geomorphological structures, erosion-deposition events, landscapes and topography
- events relating to asteroids
- continental and oceanic scale phenomena, plate relations
- under-sea
- historical and cultural Geosites.

Recognising and recording Geosites or places of geological heritage is not enough if nothing is done to preserve them. For this reason, the concept of Geoconservation was introduced. It can be defined as "action taken with the intent of conserving and enhancing geological and geomorphological features, processes, sites and specimens" (Burek & Prosser, 2008, p.2). Geoconservation has been established in different countries across the world and plays an important role in delivering sustainable development in a variety of ways, including the promotion of important sites through education. It is true that sustainable development, a necessity for our planet, is all about learning and the way awareness is raised through gaining knowledge on the interdependence between people and their natural environment. Education for a sustainable future means that educational policy makers need to target teaching our societies to "respect, value, and preserve the achievements of the past" as well as "appreciate the wonders and the peoples of the Earth" (Combes, 2005, p. 215).

This constitutes the main reason why field trips are of immense value when it comes to educating young people. They are given the opportunity to directly interact with the natural environment in the most effective and enjoyable means of teaching and learning. Engaging students in hands-on activities, sharpening all their senses, cultivating a culture of working in groups and underlining the fragility of the environment are some of the benefits for young learners. Outdoor activities within an educational framework can have a positive effect not only on the cognitive but on the affective and psychomotor domains as well, thus promoting a more holistic approach to learning and developing critical thinking.

Augmented Reality Applications and the ARTutor educational platform

Augmented reality applications enrich the environment by embedding interactive digital content. Hence, the user has access to information that would not have been available otherwise (Lytridis & Tsinakos, 2018). It provides the users with the power to view a real-time environment with a digital overlay enhanced with images, videos or sounds (Siegle, 2019). Augmented Reality actually complements and does not replace reality (Tan & El-Bendary, 2013); ideally, the real and the virtual objects co-exist in real time (Azuma, 1997).

Technology has the potential of augmenting traditional teaching in the classroom with exciting out-of-class activities by employing blended learning techniques (Palalas, 2013). The learning procedure is more student-centred and collaborative since it can take place anywhere apart from the actual class itself by using a mobile device (Sharples *et al.*, 2007).

ARTutor was developed at the Research Laboratory AETMA (Advanced Educational Technologies and Mobile Applications Lab) at the Eastern Macedonia and Thrace Institute of Technology and is an educational platform. It consists of two parts: (a) the authoring tool, which is a web-based application used to upload the learning material and the assorted learning objects; and (b) the mobile application, which downloads and displays the learning objects and also allows interaction between the learner and the learning material (Lytridis *et al.*, 2018).

ARTutor allows users to create educational books in PDF with the application of Augmented Reality in a simple and easy way. It has been designed in such a way that digital content can be added to traditional books and other texts. The augmentation can be pictures, videos, text, MP4 files or 3D models. It is available for free and no special equipment is required. What is necessary is to download the application and have Internet access. The instructors do not need to be highly computer-literate since the design of the platform facilitates them in developing activities with the use of Augmented Reality.

Another novelty of this platform is that it allows students with disabilities to interact with the learning material while using it since they can use voice commands to control it.

Sousaki volcano

The volcano called Sousaki lies dormant near the city of Korinthos in Greece. This is a volcano which last exploded 2.7 million years ago but is still exhibiting strong steaming activity, emitting mostly carbon dioxide and hydrogen sulfide. There are a lot of bright yellow sulfur deposits and a device monitoring the geothermal activity of the area has been installed there. It is included in the "Atlas of the Aegean Geological Monuments" (Velitzelos *et al.*, 2002) and has been recognized as an educational geosite. There were three main reasons for the choice of this location, namely, its proximity to Athens, the fact that it is easily accessible, and the clearly visible and distinct geological formations.

Methodology

An educational field trip was planned for twenty (20) sixteen-year-old students to Sousaki. The design of the field trip and educational game using Augmented Reality were based on student-centred and collaborative approaches. Guided discovery learning was applied. The instructors worked on the platform and the augmentations while keeping in mind the specific cognitive objectives, and created augmented reality activities to present the new content and allow students to interact with it. The students worked in small groups and their initial task was to locate a specific spot that had been previously photographed and was included in the PDF given to them. This particular picture worked as the link to give them access to more information by scanning it.

Figure 1: Volcano Sousaki Geosite.

There were no specific requirements on the part of the users of the application. Given the computer literacy that most teenagers possess, all that was required was to have the application installed in their mobiles beforehand and to have internet access.

Upon completion of the activities, students and teachers were given separate questionnaires to answer regarding their experience, including the use of the ARTutor platform. Some of the questions were open-ended and some used the Likert scale.

Objectives and description of the educational outing

The main purposes of this educational outing were to provide the students with an initial experience of what field work is, to point out its role in highlighting the necessity to preserve sites of geological heritage such as Sousaki, to get acquainted with the location of the volcano and to make the most out of the information that was provided by the ARTutor application. The cognitive objectives were recognising the different types of rocks that were present at the site and detecting various volcanic gases. They were also introduced to the way geothermal energy can be used and to its potential. They had to spot the rock formations and various objects from the pictures that were in the PDFs. By scanning these pictures, they were given access to more information and clarifications through the ARTutor application. The students had to work together, exchange opinions and reach a consensus; we hoped this would lead them to appreciate field work as well as group work and to recognise the educational value of this particular Geosite.

In order to achieve these objectives, specific formations and items were chosen. The sequence of sedimentary rocks which formed at the bottom of the lake that used to be present during the two major volcanic effusions is at direct opposition with the structureless lava depositions (***Figure 1***). These were augmented with sketches on how a layer is deposited at the bottom of a sedimentary basin and a video showing underwater lava effusions. The picture of the pump monitoring geothermal activity which was put at the site was augmented using information about countries like Iceland that rely upon geothermal sources in order to cover their energy needs and by videos of geysers (***Figure 2***).

The gypsum crystals of different sizes that all students collected made a great impression on them. Their pictures were augmented using additional information on how the crystals were formed (***Figure 3***). The pictures of caves that were in abundance at the site of the volcano were augmented with pictures of dead birds and insects due to the presence of carbon dioxide and videos of how it can be detected by lighting up a piece of paper that eventually stops burning (***Figure 4***).

After completing all their tasks and interacting with the information that was presented to them, students had to answer questions by choosing among multiple answers. By scanning the correct one they got hold of a picture showing the geomorphological development of the area. Each group of students got a different picture and they all had to work together to put these pictures in the correct order so as to present the geomorphological evolution of the area.

Evaluation

The activity that students mentioned repeatedly was the collection of gypsum crystals as well as studying the different kinds of rocks. They also mentioned the augmented reality application and commented positively on the information and videos that they were given access to. The majority of the students had never heard of this site before and had absolutely no idea that a volcano – even a dormant one – was in the vicinity of their place of residence, so they were really intrigued by this fact. A lot of positive comments were made on the collaboration among the students and the chance to work as a group. Some of the comments made by the students were:

- "We would like more time to spend using this application and even more information."
- "This way we actually understood what we were seeing at this specific site."
- "Working as a group was really positive!"

The instructors were asked to comment on the whole experience from planning this field trip to watching students' reactions and evaluating the level of their engagement and satisfaction. They reported that after setting the learning goals, the design of the augmented reality activities was problem-free. The platform was very helpful when uploading the augmentations chosen and they only had to check the signal reception at the volcano site so that they could confirm that there would be an internet connection during their visit. The quality of the content and the integrity of the materials could not be questioned, since they were uploaded on the educational platform after a great deal of consideration and rigorous screening on the part of the instructors. The students were not lost in the loads of information that self-directed navigation on the Internet might have led them to, nor were they distracted (Fahy, 2004).

Following the educational outing, the instructors expressed how positive this

Figure 2: Accessing information on Geothermal energy

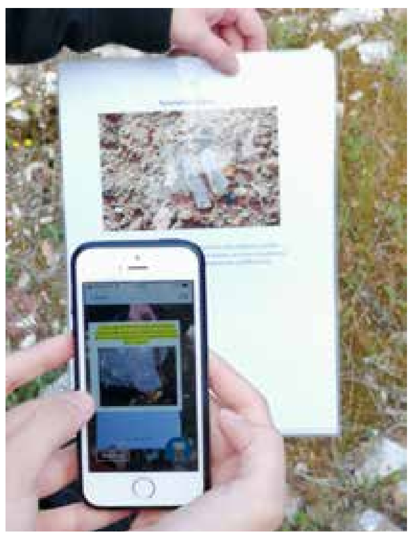

Figure 3: Accessing information on crystal formation

experience had been for the students, who enjoyed working together in groups, had fun locating the spots from the pictures and were amazed by the information provided to them through the AR application. All in all, the true potential of such a field trip was appreciated and taken full advantage of and, as they reported, it was something that they would definitely like to do again. They also pointed out how important such endeavours are for preserving our geological heritage.

Conclusion

Preserving sites of geological significance means recognising, recording them, and raising awareness among people on their invaluable contribution to understanding the way planet Earth functions. Our planet has a lot of stories to relate and they are all connected to Geosites, while literacy in earth sciences is the key to deciphering them. Educational outings such as the one presented in this article are the best way to get students acquainted with the planet's geological heritage and introduce them to the concept of Geoconservation. Earth has endured devastating episodes induced by severe conditions, as has been recorded at different sites, and the past can definitely be a lesson for the future through education.

It is this generation's duty to keep telling these stories to the next generation and if this is to be achieved, then employing Geosites as places of worth-keeping heritage is of utmost importance. The small-scale survey included in this field trip shows in the best possible way how much more efficient and fun at the same time teaching outdoors can be made by the use of AR activities.

Figure 4: Accessing information on caves and carbon dioxide emissions.

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The significance of the Lavrion mines in Greek and European Geoheritage

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The Lavrion mines have had a prominent role in the social, economic and cultural development of Greece since ancient times. The income from the mines was the foundation of Athenian power during the 5th and 4th century BC, but conversely led to significant economic problems for the early modern Greek state. Many mineral specimens from the mines and the slags of the area are unique or were discovered there for the first time. In recent years, due to its significance the area has been proposed as a cultural and natural heritage site, with the mines and the general area being on the Tentative List of the UNESCO World Heritage Centre.

Les mines Lavrion ont joué, depuis les temps anciens, un rôle prépondérant pour le développement de la Grèce aux points de vue social, économique et culturel. Le revenu provenant des mines fut à la base de la puissance d'Athènes pendant les 5ème et 4ème siècles AC, mais, inversement, il a créé des problèmes économiques réels pour le récent et moderne Etat Grec. De nombreux échantillons minéralisés provenant des sites miniers et les scories propres à cette région sont uniques ou furent découverts ici, pour la première fois. Ces dernières années, liée à l'importance de sa signification, la région a fait l'objet d'une proposition de site à valeur d'héritage culturel et naturel, les mines et la zone globale faisant partie de la liste préliminaire d'admission au Centre UNESCO de l'Héritage Mondial.

Las minas de Lavrion han tenido un papel destacado en el desarrollo social, económico y cultural de Grecia desde la antigüedad. Los beneficios de las minas fue la base del poder ateniense durante los siglos V y IV a. C., pero de manera contraria, condujo a problemas económicos significativos para el estado griego moderno. Muchos especímenes minerales de las minas y las escorias del área son únicos o fueron descubiertos allí por primera vez. En los últimos años, debido a su importancia, el área ha sido propuesta como un lugar de patrimonio cultural y natural, con las minas y el área general en la lista provisional del Centro del Patrimonio Mundial de la UNESCO.

Introduction

The Lavrion - also spelled "Laurium" or "Laurion" - mines were of pivotal importance in shaping the socioeconomic framework and ultimately the history of ancient Greece and of the modern Greek state. Also undisputed is the mineralogical wealth of the area; the local ore deposits are the constant focus of research. This article aims to present Lavrion as a part of European geoheritage, both on account of its geological uniqueness and significance and of it being a major factor in the local and national economy and a catalyst for major historical events.

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The Lavrion ore deposits

The area of Lavrion comprises many different ore deposits, including, but not limited to porphyry Mo-W, skarn Fe-Cu-Bi-Te, carbonate-replacement Pb-Zn-Cu-As-Sb-Ag ± Au-Bi, and vein/breccia Pb-Zn-Cu-As-Sb-Ag-Au-Ni-Bi ores (Voudouris *et al.*, 2018). The carbonate-replacement ores of the Kamariza district were mined in ancient and in modern times and are associated with the formation and exhuma-

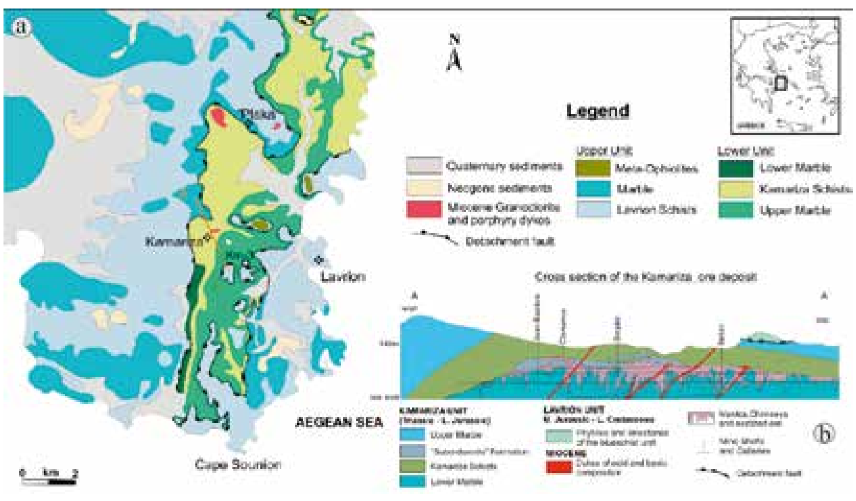

Figure 1: (a) Simplified geological map of the Lavrion ore district; (b) Cross-section A-A' of the Kamariza deposit (after Voudouris et al.*, 2018).*

tion of a metamorphic-core complex, in the Atticocycladic crystalline belt (***Figure 1***). The main minerals of this system are pyrite, arsenopyrite, sphalerite, galena and chalcopyrite. Galena is the principal carrier of Ag, whose maximum enrichment reaches up to 3000 gr/t (Voudouris *et al.*, 2008). Furthermore, Voudouris *et al.* (2018) mention high grades of Au (around 100 gr/t) in the nearby vein-type Clemence deposit, which could have been known and exploited in antiquity.

Mining activities at Lavrion from ancient Greece to the present day

While it is not possible to determine the date when mining activities began at Lavrion, it is commonly held that they began sometime around 3000 BC, during the Minoan Era. The 8th century BC was when organised mining most probably developed and the exploitation of silver must have started a century later, reaching its peak around the 4th and 5th century BC (Economopoulos, 1996).

The ancient galleries (***Figure 2a***) have an aggregate length of many hundreds of kilometres, and comprise six levels, interconnected with a multitude of shafts. The immense and intricate network of the ancient mining galleries is even more impressive considering that they were dug out, a few metres per month, using nothing but hand tools and, occasionally, fire. The mines were worked by slaves, who belonged to wealthy citizens of Athens. Each such citizen was in essence a contractor, to whom a section of the galleries was leased in exchange for a profit percentage. Ancient Athens had very strict mining laws and violators were severely punished (Katerinopoulos, 2010). The entrances of some of these shafts and galleries still dot the countryside of Keratea.

The conspicuous lack of water in Lavrion necessitated the building of a complex drainage system, which was then utilised – apart from the sustenance of the mining camps – in filling the ore washeries (***Figure 2b***) used for ore separation, before the smelting process. This drainage system also ensured that the water of the ore washeries was recycled, thus alleviating the need for constant transport of water from afar. It is truly a marvel of engineering, considering the era in which it was constructed.

The silver extracting procedure itself was a testament to the skill of ancient Greek metallurgists. When the ore came out of the galleries, it was crushed down to fine particles, which were then gravimetrically separated in the ore washeries, based on the fact that argentiferous ore in any mineral form (galena or cerussite) is heavier than the gangue minerals, and as such does not float. The first step in this process was to initially smelt the ore and extract the silver-rich lead. The remaining slag was discarded and subsequently cupellation was carried out, where the lead was ignited and burned within a furnace, aided by a constant influx of air. In the end, only pure silver remained at the bottom of the furnace, while the useless litharge was discarded. This two-stage procedure ensured that around 99 % pure silver was extracted. After 146 BC and the Battle of Corinth, the Romans continued mining activities at Lavrion, using more advanced techniques involving drainage procedures for extending the galleries below the water table (Periferakis & N. Paresoglou, 2019).

After Roman times, the mines of Lavrion were completely abandoned, despite the fact that during the 18th and early 19th century there were reports of the area's economic potential (Periferakis & Paresoglou, 2019). Only in 1860 would the Greek geologist Kordellas notice the ore minerals in the ancient slags, and his memo to the Greek state would incite a second fervent period of mining activity. In 1864 Jean-Baptiste Serpieri founded the Italian-French company Roux-Serpieri-Fressynet, which initially had permission to exploit only the ore deposit itself by expanding the ancient tunnels and creating new ones (***Figure 3***).

Soon, however, the company illegally bought heaps of ancient slag from the Municipality of Keratea, proceeding to extract silver which had been irretrievable using the ancient techniques, in turn leaving massive amounts of modern slag which remain still visible around Lavrion (***Figure 4***). This violated the license issued to the company by the Greek state, and Greek courts issued a condemning verdict, ordering the company to pay significant reparations. This prompted the ambassadors of Italy and France to intervene on behalf of the company and demand that the state drop the legal proceedings.

While initially it refused, eventually the Greek government relented due to the naval blockade imposed by French and Italian warships. In 1873, Andreas Syggros bought the company and renamed it the Lavrion Metallurgy Company. Syggros then tricked the public into buying worthless shares of his company and at the same time blackmailed the Greek state into lowering the annual taxes on his company, and on top of that decreased slag exploitation and silver production. Meanwhile, Serpieri founded the Compagnie Française du Laurium, which managed to obtain the sole right to exploit the underground mineral wealth of the area. The company closed in 1977, while the Lavrion Metallurgy Company

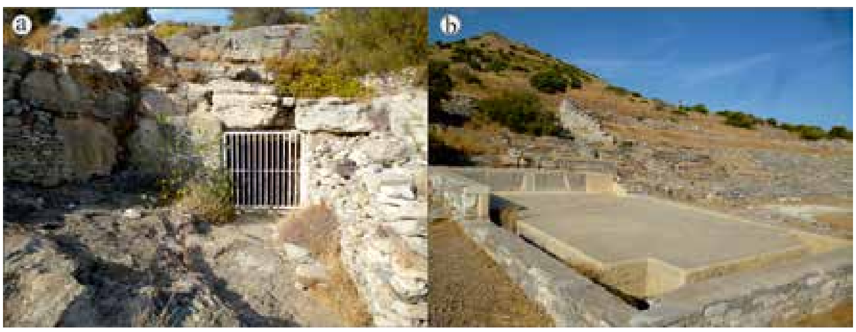

Figure 2: (a) The entrance to an ancient mining gallery in the area of Thorikos; (b) A reconstruction of an ore washery with the ancient theatre of Thorikos in the background.

Figure 3: (a) The interior of the Esperanza tunnel, with the slope increasing rapidly towards greater depths; (b) The entrance of the same tunnel, in the countryside of Lavrion. Many of the most famous mineral samples of Lavrion have been extracted from this tunnel.

Figure 4: (a) Slag from the 19th and early 20th century by the port of Lavrion; (b) Massive heaps of slag from the turn of the previous century still define the contours of the area.

had already shut down in 1917, having exhausted the slag supply (Dermatis, 1994).

The social, cultural and economic consequences of Lavrion exploitation through the ages

The wealth accrued by the mining activities at Lavrion had a profound effect on the course of the ancient Greek civilisation, and by implication, on European cultural heritage. The income generated – directly through the payment of leases and indirectly through taxation and general fiscal growth – enabled the city-state of Athens to build and maintain a vastly disproportionate – disproportionate to the expected financial capabilities of any city-state of the era – fleet of around 200 triremes, which were manned with trained oarsmen and hoplites. In the naval showdown with the Persian fleet in 480 BC the Athenian fleet constituted more than half of the Panhellenic fleet of 380 triremes. This naval power of the Greeks, with Athens at the forefront, checked the Persian advance, which, had it continued, would undoubtedly have altered the history of Europe.

In later years, during peacetime, Athens maintained an expanded fleet of 300 triremes, whose operating cost for the campaigning season - which was about 8 months - amounted to around 1600 talents. This great sum, which was more than twice the annual tribute of the whole Delian League, could not even cover the maintenance of the whole fleet. At all times, around one third of the Athenian triremes were held in reserve. During the Peloponnesian War, Athens fuelled its wartime economy using the silver of Lavrion, and only during the final phase of the war did the Lacedaemonians succeed in disrupting mining activities. So the income from Lavrion partly contributed to Athenian power, creating a precarious balance between the then-dominant city-states of Athens and Sparta. The balance of power could therefore be only tilted via war. Had the mines of Lavrion not been exploited, it is more than probable that Athens would not have achieved its status as one of the leading powers of ancient Greece.

Apart from military matters, the wealth accrued from the mines provided the funds for the construction of the temples at the Acropolis. Colonnaded temples like the Parthenon were probably the most expensive buildings of the Classical Era. The gold and ivory statue of Athena Promachos, the murals and the marble statues of the Acropolis where also paid for in part from the mines' revenue (Periferakis & N. Paresoglou, 2019; and references therein).

When Serpieri founded his company in 1864, during the years of the modern Greek state, Lavrion was an insignificant settlement, but within a year it was transformed into a thriving town of over 10,000 residents. The company built houses for its employees, and public buildings; most notably churches and schools, were also constructed (Dermatis, 1994). Operating under the auspices of the company, pharmacies and local infirmaries took care of the workers. When the company was bought by Syggros it began to use technologies innovative for their time, like electricity and telephones. Between 1882 and 1885 the company paid for and constructed the railway line linking Athens with Lavrion (Katerinopoulos, 2010).

Although there were fiscal and administrative benefits from the companies for the local societies, the bickering over the exploitation rights and the temporising policy of both foreign and Greek investors had detrimental effects on the national economic policy. In fact, the Lavrion crisis was a major factor leading to the financial collapse of the Greek state, which declared public insolvency in 1893.

Lavrion as a unique geological monument

The existence of many different ore deposits at the same area, which are linked temporally and spatially, makes Lavrion an ideal place for research and educational purposes. Indeed, many geologists visit the area to study its regional tectonic setting and the ore genesis processes. In addition, the mineralogical wealth of the area is remarkable, and in fact the mines and the slags of Lavrion are host to hundreds of different minerals, samples of which are on display in the two mineralogical museums of the area, in Kamariza (***Figure 5a***) and in the City of Lavrion (***Figure 5b***).

Around 15 % of the currently known minerals can be found in Lavrion (Katerinopoulos, 2010). A number of minerals, such as laurionite, paralaurionite and thorikosite, were discovered in the area, and in fact some of them cannot be found elsewhere in the world, like the recently discovered voudourisite (Rieck *et al.*, 2019) and others like nealite, georgiadesite, hilarionite, and fiedlerite. Finally, the slags contain crystallised compounds as a direct result of the smelting process and slags found underwater contain crystallised compounds resulting from the chemical reactions between the slag minerals and seawater. As such, Lavreotiki is an ideal place not only for mineralogical research, but also for geochemical and artificial crystallisation studies.

Lavrion as a place of Geoheritage

The mines of Lavrion have directly influenced the culture and history of the Hellenic Nation, both in the Classical Era and in modern history. They are thus tangibly associated with the formation of the sociopolitical and cultural framework of Greece and Europe. In addition, the mines of Lavrion are associated with the creation of the modern town of Lavrion and as such they have a local as well as a national historical value. Mines and quarries represent the way that people in the past lived and the needs of their society, which means they have strong links to the local folklore as well (Prosser, 2019).

The mines themselves provide "windows" onto natural mineral and ore forming processes, and since there are a large number of tunnels that are still structurally safe, they could be made suitable for visitors with relatively cheap structural upgrades. Being near to Athens and easily accessible, Lavrion could thus be made into a large thematic geopark, building upon the existing Lavrion Museum of Mining and Metallurgy and the Archaeological Museum of Lavrion. Some buildings of the French mining company have also been restored, and along with the ancient washeries and the Theatre of Thorikos, constitute interesting tourist sites.

While the administrative area of Lavreotiki has been declared a National Park, the area of Lavrion is also considered as having Outstanding Universal Value and

Figure 5: (a) The Mineralogical Museum of Kamariza, in an old building of the French Company, with the Serpieri Well in the background; (b) The Mineralogical Museum of Lavrion, located in an old office building near the centre of Lavrion.

fits the criteria for inscription on the World Heritage List (Migoń, 2018) of UNESCO. Currently, the mines of Lavrion are on the Tentative List of the UNESCO World Heritage Centre. As mentioned above, the Greek state has made some steps towards maintaining and promoting the rich history and material culture of the area, but further action is required. Ancient galleries are left locked but otherwise unguarded and unmaintained. Most alarmingly, trespassers enter the galleries and illegally extract rare and valuable mineral samples for personal gain. Apart from this, the dockside loading piers of the now closed companies have been left unmaintained, despite the fact that they too could be an interesting attraction if properly restored. Aside from these extensive restoration works, another step should be the complete mapping of the ancient tunnels utilising the most recent advances in exploration geophysics, most notably microgravity measurements. In short, despite some tentative steps taken over the years, there is still a need for extensive geoconservation efforts in the area of Lavrion.

Conclusions

The mines of Lavrion have shaped history on a regional and European level, both in ancient and in modern times. They are proof of the intertwining of history and geology, and also they bear testimony to the way that natural resources influence society, economy and culture. Consequently, Lavrion is a major cultural landscape. Furthermore, the mineralogical wealth, along with the multitude of ore deposits in the area, ranks Lavrion as an important natural landscape.

It must be mentioned that the mines of Lavrion, despite being the best known site of its kind in Greece, are not unique in terms of sociocultural and economic significance. They are part of the rich geoheritage of Greece, which stretches from the emery mines of Naxos Island to the exploitation of Au + Ag ± (Cu, Pb) deposits in Macedonia. To summarise, the mines of Lavrion should be regarded as being a cardinal part of both the Greek and European geoheritage, and, if maintained and exploited properly, can constitute a valuable resource for research, education, training and recreation.

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Pikermi: a classical European fossil mammal geotope in the spotlight

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The renowned Pikermian fauna has long served as a reference for the systematic, biostratigraphic and paleoecological study of Late Miocene Eurasian mammals. The classical locality of Pikermi has been extensively excavated since the mid-19th century, with the latest series of systematic excavations organised by the National and Kapodistrian University of Athens. The preservation and promotion of the locality is of paramount importance, not only for its scientific context, but also for its historical significance and educational value for the paleontological heritage of Greece and Eurasia. In this article we discuss the timeline of fieldwork and research at the locality, as well as the steps currently taken in order to preserve and explore Pikermi as an internationally acclaimed geotope.

La célèbre faune de Pikermi a longtemps servi de référence pour l'étude systématique, bio-stratigraphique et paléontologique des mammifères eurasiens de la fin du Miocène. De façon classique, la localité de Pikermi a fait l'objet d'excavations extensives depuis la moitié du 19ème siècle, les dernières séries de fouilles systématiques étant l'œuvre de l'Université nationale et capodistrienne d'Athènes. La préservation et la promotion de cette localité est d'une importance extrême, pas seulement pour son volet scientifique mais aussi pour sa signification historique et sa valeur éducative pour l'héritage paléontologique grec et eurasien. Dans cet article, nous traitons de la chronologie des travaux de terrain et de recherche en ce lieu ainsi que des décisions prises actuellement pour préserver et explorer le site de Pikermi, en tant que géotope renommé au niveau international.

La renombrada fauna de Pikermi ha servido durante mucho tiempo como referencia para el estudio sistemático, bioestratigráfico y paleoecológico de los mamíferos eurasiáticos del Mioceno tardío. La localidad clásica de Pikermi ha sido ampliamente excavada desde mediados del siglo XIX, con la última serie de excavaciones sistemáticas organizadas por la Universidades Nacional y Kapodistrian de Atenas. La preservación y promoción de la localidad es de suma importancia, no solo por su contexto científico, sino también por su importancia histórica y valor educativo para el patrimonio paleontológico de Grecia y Eurasia. En este artículo, discutimos la línea de tiempo del trabajo de campo y la investigación en la localidad, así como los pasos a seguir actualmente para preservar y explorar Pikermi como un geotopo aclamado internacionalmente.

Introduction:

Pikermi (Attica, Greece) is one of the oldest known and most celebrated fossiliferous localities of the Eurasian Late Miocene. Numerous excavations have been conducted since the mid-19th century, revealing a rich and diverse vertebrate fauna of Turolian age. Pikermi is considered as one of the key reference localities of the European continental Upper Miocene (e.g. Bernor *et al.*, 1996 and references therein) due to the diversity of its faunal composition and the fact that it represents the type locality of several Turolian vertebrate genera and species. The significant paleoecological context of the locality has led to the establishment of the term "Pikermian biome". From both the wealth of the paleontological knowledge accumulated and the historical significance of such a long running excavation locality, it is apparent that the renowned Pikermi geotope must remain a focus of conservation efforts, allowing

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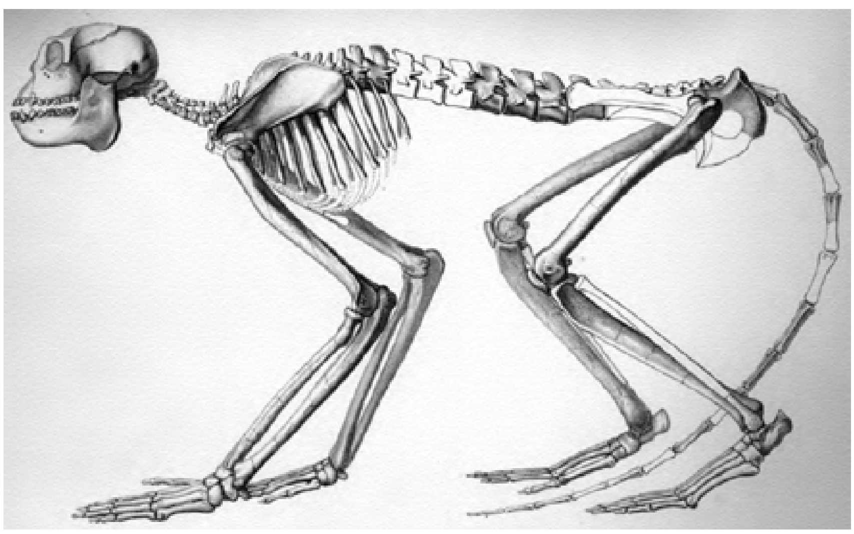

Figure 1: The classical reconstruction of the Late Miocene cercopithecid monkey Mesopithecus pentelicus from Pikermi by Albert Gaudry (1862-67).

Figure 2: On the left, a typical fossiliferous bone assemblage at the PV1 site, with in situ articulated fore- and hind limbs of three-toed hipparionin equids. On the right, excavation of proboscidean limb bones at the PV1 site (NKUA expeditions).

opportunities for the continuation of the fieldwork and its promotion as a prime destination of geotourism.

Geology

The fossiliferous locality of Pikermi is placed within the Mesogea Basin, one of the three major hydrographic basins of Attica, close to the municipality of Pikermi and ca. 20 km east of the city of Athens. The Mesogea Basin is surrounded by Mount Pentelikon to the north and Mount Hymettus to the west, as well as by the Koropi Hills to the south and the Euboic Gulf to the east. The basin's hydrographic system consists of numerous streams originating from Pentelikon and Hymettus Mountains that flow from the higher northern and western altitudes towards the southern lowlands and then to the east. These streams gradually merge into the main Megalo Rema stream, which drains into the Euboic Gulf. One of the main tributaries of the Megalo Rema stream is the Valanaris, and it is along the banks of this tributary that most of the fossiliferous sites have been discovered.

The Mesogea Basin developed during the Late Miocene by activation of a major detachment fault, which separated carbonates of the Internal Hellenides from Mesozoic metamorphic rocks. The Upper Miocene sediments of the Mesogea Basin can be divided into the terrestrial to fluvial Pikermi Formation and the palustrine to lacustrine Rafina Formation (Böhme *et al.*, 2017). The Pikermi Formation represents an up to 30-m-thick sequence of predominantly reddish silts with subordinate clastic channels of conglomerates and sandstones, which has yielded rich terrestrial vertebrate fauna. The Pikermi Formation rests discordantly above a lower limestone unit with palustrine to lacustrine marls and coals, and is concordantly overlain by the Rafina Formation, which is composed of palustrine to lacustrine clay, coal, and platy limestone. The Pikermi Formation can be further subdivided into two members. The lower Red Conglomeratic Member is characterised by an alternation of red silts with a weak pedogenic overprint and debris flow deposits. It is within the lower Red Conglomeratic Member that most historical and recent excavations took place. The stratigraphically younger upper fluvio-alluvial Chomateri Member represents an alternation of reddish to yellowish silts with fluvial channels and channel-fill trains and corresponds to the eponymous excavation site of Chomateri (Böhme *et al.*, 2017).

Timeline of the excavations

The fossiliferous locality of Pikermi was discovered by the renowned Scottish historian and philhellene George Finley in 1836, during a tour he had undertaken in the Mesogea region of Attica with the hope of discovering remains of the temples of the Brauronian Artemis and the Oropian Amphiaraos. While prospecting the area, Finley noticed the unusual accumulation of bones inside a steep bank of red clay that had been washed away by a torrent that descended from Mount Pentelicon and was known to the locals as the stream of Pikermi. The peasants of the neighbourhood, who were acquainted with the spot, called these remains Hellenic bones (κόκκαλα ελληνικά). A few weeks later, Finlay read a note concerning his discovery at the newly established Physiographic Society of Athens, and donated his findings to the collections of the society, which later became part of the University of Athens. The society encouraged Finley to continue the exploration of the site, and he carried on with some additional excavations in collaboration with the distinguished German ornithologist Anton von Lindermayer, a founding member of the society.

Figure 3: Cranium of the Late Miocene cercopithecid monkey Mesopithecus pentelicus from Pikermi in preparation (NKUA expedition 2018).

A Bavarian soldier, who presumably participated in these excavations, collected some specimens, thinking the calcite crystals formed inside the cavities of the fossilised bones as being diamonds. Upon his return to Munich, the soldier presented these specimens to the distinguished professor of zoology Andreas Wagner. Wagner disproved the soldier's hopes about diamonds, but acknowledged the scientific value of the specimens, securing them for the collections of the Bavarian Academy of Sciences by paying a sizeable compensation. Among the scanty material, he instantly recognised the maxilla of a primate, which he subsequently described as a new genus and species, *Mesopithecus pentelicus* (Wagner, 1839). This was one of the first fossilised primate specimens to be ever discovered, thus attracting immediately significant interest from the scientific community. In 1848, Wagner studied some additional material from Pikermi send to him by Anton von Lindermayer. During the winter of 1852-1853 new excavations were organised at Pikermi by the German

Reptilia	**Mammalia**	Bovidae	Carnivora
Chelonia	Primates	*Tragoportax amalthea*	Felidae
Testudinidae	Cercopithecidae	*Miotragocerus gaudryi*	*Metailurus major*
Testudo marmorum	*Mesopithecus pentelicus*	*Palaeoryx pallasi*	*Metailurus parvulus*
Titanochelon sp	Hyracoidea	*Protoryx carolinae*	*Amphimachairodus giganteus*
Squamata	Pliohyracidae	*Prostrepsiceros rotundicornis*	*Paramachairodus orientalis*
Varanidae	*Pliohyrax graecus*	*Pseudotragus parvidens*	*Pristifelis attica*
Varanus	Perissodactyla	*Palaeoreas lindermayeri*	Hyaenidae
marathonensis	Equidae	*Protragelaphus skouzesi*	*Adcrocuta eximia*
	Cremohipparion mediterraneum	*Oioceros rothi*	*Hyaenictis graeca*
Aves	*Hippotherium brachypus*	*Gazella capricornis*	*Lycaena chaeretis*
Struthioniformes	Rhinocerotidae	Suidae	*Ictitherium viverrinum*
Struthio	*Dihoplus pikermiensis*	*Microstonyx major*	*Hyaenictitherium wongii*
karatheodoris	*Diceros neumayri*	Proboscidea	*Plioviverrops orbignyi*
Falconiformes	*Acerorhinus neleus*	*Deinotherium proavum*	Ursidae
Gyps sp.	Chalicotheriidae	*Choerolophodon pentelici*	*Indarctos atticus*
Gruiformes	*Ancylotherium pentelicum*	*Konobelodon atticus*	Mustelidae
Grus pentelici	*Chalicotherium goldfussi*	*Mammut* sp.	*Enhydriodon* (?) *latipes*
Ciconiiformes	Artiodactyla	Rodentia	*Promeles palaeatticus*
Ciconia gaudryi	Giraffidae	Muridae	*Martes woodwardi*
Galliformes	*Bohlinia attica*	*Parapodemus gaudryi*	*Promephitis larteti*
Pavo archiaci	*Helladotherium duvernoyi*	Hystricidae	*Sinictis* (?) *pentelici*
Phoenicopteriformes	*Palaeotragus rouenii*	*Hystrix primigenia*	Ailuridae
Phoenicopterus sp.	Cervidae	Insectivora	*Simocyon primigenius*
	Pliocervus pentelici	Erinaceidae	
	Lucentia sp.	*Schizogalerix moedling*	

Figure 4: Faunal diversity at the Late Miocene locality of Pikermi.

naturalist Johannes Rudolf Roth, and the results were jointly published by Roth and Wagner (1854).

In 1853, Hercules Mitsopoulos, professor of natural sciences at the University of Athens, led the first excavations carried out by a Greek team. In 1854, the physician Aristeides Chairetis undertook a minor excavation and sent some material to the Natural History Museum of Paris, which became the subject of an announcement by renowned zoologist Georges Louis Duvernoy at the French Academy of Sciences.

Duvernoy's announcement, in conjunction with the scientific results presented by Roth & Wager (1854), stimulated the Academy of Sciences of Paris to provide the generous financial means to support a series of extensive excavations at Pikermi under the direction of the geologist and palaeontologist Jean Albert Gaudry during the winter of 1855-56 and the summer of 1860. The scientific results were documented by Gaudry in his monumental monograph "Animaux fossiles et géologie de l'Attique" (Gaudry, 1862-1867). Gaudry described and illustrated in great detail the diverse fossil species of the Pikermian fauna (***Figure 1***). In addition, Gaudry was one of the first paleontologists to apply phylogenetic trees to assess the systematic affinities between fossil forms, taking also their stratigraphical position into account. Even today, Gaudry's monograph remains influential for the comparative study and systematic evaluation of the Late Miocene mammalian faunas in the Old World.

Moderate fieldwork activity continued during the 1880s and 1890s, with some excavations led by Wilhelm Dames for the Natural History Museum of Berlin in 1882, by Melchior Neumayer and Leopold von Tausch for the Paleontological Institute of the University of Vienna in 1885, by the Prince of Orleans in 1888, and by Michalet from Dijon in 1895. In addition, several occasional minor excavations by amateur naturalists, fossil dealers, and material exchange between museums and institutions distributed fossil specimens from Pikermi throughout the world.

The turn of the century signalled one of the major excavation campaigns in the area, organised by Arthur Smith Woodward for the British Museum of Natural History, and Theodore Skouphos for the University of Athens (Woodward, 1901). During the following years, Skouphos continued the

Figure 5: Cranium and associated mandible of the Late Miocene bone-cracking hyaenid Adcrocuta eximia from Pikermi (NKUA collections).

excavations in Pikermi, further enriching the paleontological collections of the University of Athens. The last of the major historical campaigns was conducted during 1912 by Othenio Abel under the auspices of the Academy of Sciences of Vienna (Abel, 1922).

After a hiatus of over half a century, activity resumed in 1971 with the discovery of a new fossiliferous site in the area named "Chomateri". Several systematic excavations were carried out between 1972 and 1980, led by Nikolaos Symeonidis from the National and Kapodistrian University of Athens (NKUA) in collaboration with Friedrich Bachmayer and Helmut Zapfe from the Natural History Museum of Vienna (Symeonidis *et al.*, 1973).

In 2008, fieldwork began anew in Pikermi, with a series of systematic excavations under the direction of Prof. George Theodorou from the National and Kapodistrian University of Athens (Theodorou *et al.*, 2010). Several new and prolific fossiliferous sites have been revealed, namely Pikermi Valley 1-3 (PV 1-3). The excavations continue to be carried out annually, with more than 2000 new specimens collected during these latest campaigns (***Figures 2 and 3***).

Faunal context and paleoecological remarks

The several hundred studies accompanying the long line of fieldwork activity in the locality have revealed a rich and diverse mammalian fauna with representatives of most macromammalian groups that inhabited Greece during the Late Miocene (Bernor *et al.*, 1996; Theodorou *et al.*, 2010; and references therein). Among the most frequent mammalian representatives are three-toed hipparionini horses, numerous bovid species, as well as three rhinocerotid and four giraffid species. Carnivores exhibit a remarkable diversity of eighteen different species including representatives of the families Felidae, Hyaenidae, Mustelidae, Ursidae and Ailuridae. Proboscideans, primates, hyracoids, suids, cervids, chalicotheriids, hystricids, murids and insectivores are also encountered in various degrees of frequency. Complementing the fauna list of mammalian taxa, there is also a small number of avian and reptilian taxa (***Figures 4–6***).

Recent paleoecological reconstructions, based on a variety of methodologies -including sediment analysis, palynology, isotope analysis, magnetostratigraphy, and evaluation of the potential dietary preferences of the fossil taxa – suggested a savannah habitat for the Pikermian fauna that ranged around the wooded grassland to woodland transition (Böhme *et al.*, 2017).

Figure 6: Cranium of the Late Miocene tandem-horned rhinocerotid Diceros neumayri from Pikermi (NKUA collections).

Current fieldwork activity is focused on the PV1 site, but imminent objectives of the project include the annual continuation of the excavations, with an expansion to other sites including PV3 and Chomateri, as well as the thorough preparation of the material and its scientific evaluation. The detailed study of the newly excavated material is essential for improving the understanding of the taphonomical, biogeographical and paleoecological context of the locality, as well as for the evaluation of the systematic affinities and phylogenetic position of the Pikermian taxa. Of particular interest is the acquisition of high resolution stratigraphical and taphonomical data in order to refine the local stratigraphy by assessing the number of the fossiliferous levels and documenting their exact faunal content (Theodorou and Nicolaides, 1988).

Present and future perspectives

Recent excavations of the National and Kapodistrian University of Athens led to the discovery of a large collection of vertebrate fossil specimens, which is currently housed in the Rafina-Pikermi Municipality's Urban Planning Building. This facility includes a small fossil preparation laboratory, a fossil repository, and an exhibition hall with representative fossil specimens and selected animal reconstructions (***Figure 7***). Since its establishment this exhibition has attracted the public and also media attention, and has been heavily visited by schools, non-profit societies and individual visitors.

Promoting Pikermi as a renowned geotope well outside the limits of the scientific community remains a primary objective. The proposed establishment of a protected geopark in the area, with multidisciplinary and educational context, is considered of paramount importance. The geopark concept has been successfully applied both domestically and internationally, highlighting the geological and paleontological heritage through educational and experiential activities, promoting public environmental awareness, and encouraging the development of a sustainable form of geotourism for the local communities. Some examples of this well-functioning geopark model, which is also supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO, unesco.org) include: the petrified forest on Lesvos Island UGGp (UNESCO Global Geopark), Sitia UGGp, and Psiloritis UGGp in Greece; Swabian Alb UGGp in Germany; Conca de Tremp-Montsec UGGp in Spain; Stonehammer UGGp in Canada; Danxiashan UGGp and Zigong UGGp in China and many more. The renowned Pikermi locality meets UNESCO's criteria and is a suitable candidate for inclusion in the Global Geoparks Network (GGN). Such an important step, if supported by public authorities, local communities, and private sponsors, can lead to the development of sustainable geotourism in Pikermi, taking also into account the short distance from Athens, a city that attracts millions of visitors every year for its unique monuments and cultural heritage.

The discussed scheme involves the transfer of the collected material and existing infrastructure to a larger and more suitable permanent museum facility. The recruitment of specialised scientific staff is also compulsory to facilitate the implementation of the museological arrangement and presentations, as well as the indispensable fossil preparation equipment and laboratory. Furthermore, a notable proposal concerns the restructuring of certain excavation sites

Figure 7: Views of the current paleontological exhibition in Pikermi.

into an area accessible to the public, where visitors may observe the paleontological fieldwork experience and the material itself as it is discovered in situ.

The ultimate goal of this endeavour is to bridge the specialised scientific interest of the locality with the wider appeal of geotourism, combining the ecological implications emerging from the fieldwork research with current environmental issues and diversity conservation efforts. All of these aspects may be achieved through guided tours and excursions, professionally designed educational programs and experiential activities for children and adults, lectures and workshops, as well as continued collaboration with other universities and research institutions.

Acknowledgments

We would like to thank all of the participants of the latest excavations in Pikermi, as well as the personnel of the Municipality of Rafina-Pikermi for their continued assistance. The fieldwork campaigns from 2009 to 2019 were supported by the Municipality of Rafina-Pikermi, several private sponsors, and the NKUA-Special Account Research Grant project no. 70/3/12977.

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The Geological Garden at Tata (Hungary): A geosite of outstanding scientific and geo-educational significance

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The Geological Garden is a nature conservation area located in Tata, about 70 km to the west of Budapest. It has been established as an open-air geological museum where a succession of Mesozoic sedimentary rocks characteristic of the Alpine-Carpathian region is excellently exposed in abandoned quarries and cleaned rock surfaces. Several formations widely distributed in the Transdanubian Range of Hungary were studied here in detail, and type-sections of three of them have been designated on Kálvária Hill. In addition to geological values, the area houses Copper Age chert mines as well as a collection of mountain-building rocks of Hungary. Due to its scientific value and educational potential, the Geological Garden is one of the most important Hungarian geosites.

Le Jardin Géologique est un secteur de conservation de la nature située à Tata, à environ 70 kilomètres à l'Ouest de Budapest. Il a été créé comme un musée géologique à l'air libre où une série de roches sédimentaires du Mésozoïque, caractéristique de la région Alpine et des Carpathes, est exposée de façon parfaite dans des carrières abandonnées et sur des affleurements rocheux aménagés. Plusieurs formations, largement distribuées en Hongrie, au sein de la Chaîne Transdanubienne, ont été étudiées en détail et des sections-types de trois d'entre elles ont été reconnues sur la Colline du Calvaire. En plus des richesses géologiques, le secteur héberge des mines de silex datées de l'Age du Cuivre, en même temps qu'une collection de roches hongroises, typiques des zones de montagne. Lié à sa valeur scientifique et à son potentiel éducatif, le Jardin Géologique est l'un des géosites hongrois les plus importants.

El Jardín Geológico es un área de conservación de la naturaleza ubicada en Tata, a unos 70 km al oeste de Budapest. Se ha establecido como un museo geológico al aire libre donde una sucesión de rocas sedimentarias mesozoicas características de la región alpino-carpática está excelentemente expuesta en canteras abandonadas y superficies de rocas limpias. Varias formaciones ampliamente distribuidas en la Cordillera Trans-Danubiana fueron estudiadas en detalle, además se diseñaron secciones tipo de tres de ellas en la colina de Kálvária. Además de los valores geológicos, el área alberga minas de sílex de la Edad del Cobre, así como una colección de rocas de las montañas de Hungría. Debido a su valor científico y potencial educativo, el Jardín Geológico es uno de los geo-sitios húngaros más importantes

Introduction

Quarries and other man-made exposures are of paramount importance to geological research and geoeducation. This statement applies especially to inland areas of moderate topographic relief, where quarries often provide the only access to geology (Prosser, in press). The territory of Hungary, dominated by lowland areas, is characterised by geologically young, i.e. Neogene and Quaternary, soft surface sediments. Largely due to quarrying, however, the country is relatively rich in scientifi-

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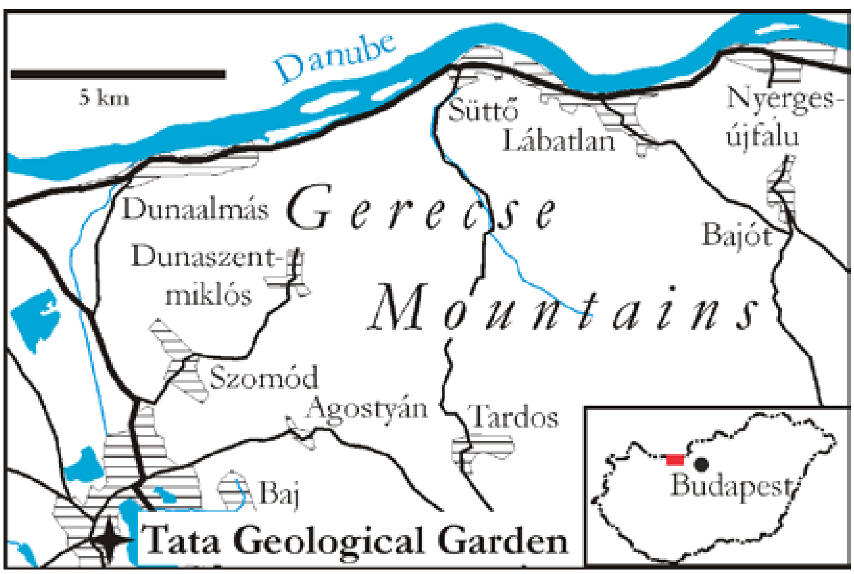

Figure 1: Location of the Tata Geological Garden.

cally significant geosites representing earlier periods of the history of Earth.

The Mesozoic succession of the Transdanubian Range is particularly noteworthy in this respect. It has been built of rocks representing typical sedimentary facies of the Alpine-Carpathian region and as a rule was not affected by considerable post-depositional deformations. Thus, original layering and the stratigraphic successionshave been well preserved. A large number of geosites have become known as a result of quarrying. Exploitation has come to an end at most places and the abandoned quarries, if not refilled, now form spectacular landscapes at some places.

Abandoned quarries usually receive less attention than underground mines in terms of their protection (Storemyr, 2006). In Hungary, on the contrary, they are highly valued and well represented among protected geosites. Most of them are, however, scattered and far from roads and settlements. An exception to this rule is the town of Tata around 70 km to the west of Budapest, where a well exposed succession of Mesozoic sedimentary rocks can be studied in easily accessible and safe abandoned quarries and cleaned rock surfaces of Kálvária Hill (Calvary Hill, if translated), a fault-bounded horst, the area of which is now largely occupied by an open-air museum called Geological Garden and managed by Eötvös Loránd University (*Figure 1*).

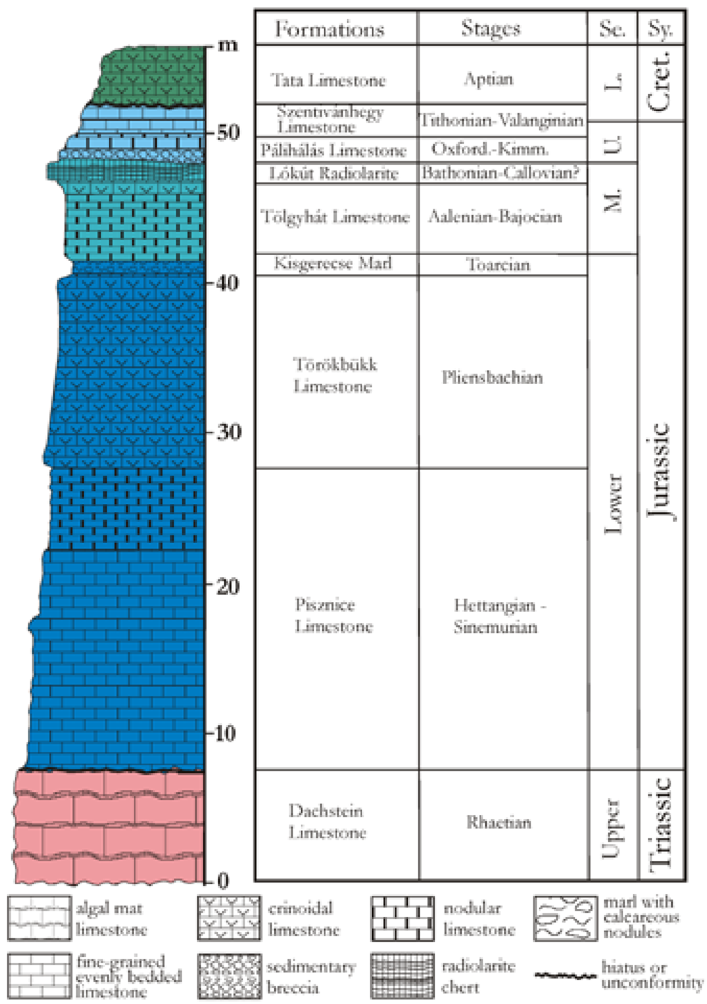

Figure 2: Stratigraphic column of the Mesozoic cropping out at Kálvária Hill. (Abbreviations: Oxford.–Kimm. = Oxfordian–Kimmeridgian; Se. = Series; L. = Lower; M. = Middle; U. = Upper; Sy. = Systems; Cret. = Cretaceous) (after Haas & Hámor, 2001).

A brief history of the Tata Geological Garden

The history of the geological and archaeological research of Kálvária Hill as well as its geology is reviewed in detail in Szente *et al.* (in press). Dominated by soft Cainozoic surface sediments, Tata and its environs are relatively poor in natural building stones. Thus, beds of variegated Triassic, Jurassic and Cretaceous limestones cropping out at Kálvária Hill aroused interest long ago and were extensively quarried for centuries. Robert Townson, an English traveller who visited Tata in 1793, was the first to document the abundant occurrence of red limestone (Townson, 1797). Scientific study of the Mesozoic formations began in the 1850s with the work of Austrian and Hungarian geologists and led to the identification of the Upper Triassic Dachstein Limestone, Lower Jurassic red ammonitic limestone and Lower Cretaceous crinoidal limestone. Observations were made mostly in three quarries, called “Whitestone”, “Redstone” and “Bluestone”, operating at those times.

A new chapter in the study of Kálvária Hill began in the mid-1950s when József Fülöp (1928–1994) started working on it. Fülöp, who played a major role in geology in Hungary for about three decades, had the opportunity to clean large rock surfaces in order to study Middle and Upper Jurassic rocks that had never been quarried, as they were unsuitable for building. Due to the scientific value of these exposures, a section of Kálvária Hill was declared to be a nature conservation area in 1958. Quarrying came to an end in the seventies and since 1976 the area has been developing as an open-air geological museum, founded by the Hungarian Geological Institute.It has been managed since 1994 by Eötvös Loránd University (ELTE). The extent of the protected area, now called at full length “ELTE Tata Geological Garden - Nature Conservation Area and Open-Air Geological Museum”, has increased to 3.5 ha. Due to a grant of EUR 175,300 received by the Eötvös University from the European Union, a large-scale cleaning project was carried out in 2015. As a result of it, the Geological Garden now functions as an appealing place for research, teaching,public outreach and recreation.

Geological values of Kálvária Hill

The favourable exposure conditions made possible a very detailed study of the

Figure 3: “Whitestone Quarry” exposing predominantly lagoonal Dachstein Limestone overlain by deeper-water pink Lower Jurassic Pisznice Limestone Formation.

Figure 4: Lower Jurassic fissure infilling in Upper Triassic Dachstein Limestone.

Figure 5:"Redstone Quarry" exposing an undisturbed Upper Triassic to Lower Jurassic (Pliensbachian) limestone succession. A segment of the wall appearing as an oblique darker band in the photograph was not cleaned in 2015 in order to display the original state of the wall as well as to study the effects of weathering and growth of vegetation.

Mesozoic succession of Kálvária Hill, resulting in the comprehensive monograph by Fülöp (1976). An approximately 50 m thick suite of beds divided into nine formations is exposed at Kálvária Hill (***Figure 2***), displaying intermediate facies characteristics between the successions of the Bakony and Gerecse Mountains.

The oldest rock cropping out is Upper Triassic Dachstein Limestone; it is well exposed in the "Whitestone Quarry" located outside the Geological Garden (***Figure 3***).

The cyclic succession of the Dachstein Limestone, formed in peritidal to shallow-internal platform lagoon environments, is visible in the "Whitestone Quarry" section. Limestone beds of lagoonal origin are prevalent and contain abundant megalodontid bivalves, usually preserved in life position. Other spectacular phenomena include submarine fissure infillings, often called neptunian dykes. The fissures penetrate both Dachstein Limestone and the lowermost Jurassic beds and reach 30 cm in width at some places. They are filled by pink or red mudstone commonly containing clasts of the host rock (***Figure 4***).

The boundary between Triassic and Jurassic beds is a flat surface truncating megalodontid bivalves at some places. The Dachstein Limestone is overlain conformably by pink then red Jurassic limestone beds assigned to the Pisznice and Törökbükk Formations, corresponding to the "red marble" of the older literature. This pure carbonate succession, Hettangian to Pliensbachian in age, is magnificently exposed in the large quarry wall (former "Redstone Quarry") of the Geological Garden (***Figure 5***).

The sharp boundary between the Upper Triassic carbonate platform deposits and the overlying deeper-water Lower Jurassic red limestone is a spectacular example of drowning unconformities and it is a characteristic feature of the Gerecse Jurassic. Fossils extracted from the lowermost beds of the Pisznice Limestone indicate a depositional depth exceeding 200 m (Pálfy *et al.*, 2007). The red limestone succession is more than 30 m thick, while the cumulative thickness of younger Jurassic strata is less than 15 m. The fine-grained Pisznice Limestone is followed by the Törökbükk Limestone Formation, an intensively bioturbated crinoidal limestone (encrinite) of Pliensbachian age (***Figure 6***). Although named after a quarry located in the Gerecse Mountains, this lithostratigraphic unit was introduced by Fülöp (1976) on the basis of the Kálvária Hill quarries.

Due to a normal fault running almost parallel to the "Redstone Quarry" wall, Middle and Upper Jurassic as well as Lower Cretaceous beds are hardly visible in the lower yard of the Geological Garden. Fine exposures can be found, however, on the upper terrace (***Figure 7***).

Figure 6: Bioturbated beds of the Pisznice Limestone Formation.

The older part of the Middle Jurassic series, assigned to the Tölgyhát Limestone Formation, is strikingly diverse in facies: red marly limestone containing Fe-Mn oxide nodules, crinoidal layers and beds formed by small-sized bivalve (*Bositra*) shells occur. The carbonate-dominated succession is followed by brown radiolarian chert beds of the Lókút Radiolarite Formation. This chert was exploited at Kálvária Hill by Copper Age peoples. In addition to the two ancient mining pits discovered in the 1960s and now visible in the exhibition building of the Geological Garden, a third one was discovered in 2015 (Biró-T. *et al.*, 2018)

The basal member of the Upper Jurassic is a peculiar sedimentary breccia bed, known as "Oxfordian Breccia", of 30-80 cm in thickness. Younger beds of the Upper Jurassic as well as the lowermost Cretaceous are developed in a thin succession of pelagic limestones. Ammonite pavements visible on some bedding planes of the Kimmeridgian Pálihálás Limestone are highlights of the

Figure 7: Cleaned rock surface on the upper terrace of the Geological Garden exposing Jurassic–Lower Cretaceous beds dissected by normal faults. The "Oxfordian Breccia" appears in the photo as a near-horizontal light grey band at the foot of the mound covered with grass.

Geological Garden (***Figure 8***).

The Jurassic/Cretaceous boundary can be drawn within the Szentivánhegy Limestone representing Tithonian, Berriasian and partly Valanginian Stages. This latter lithostratigraphic unit was named after a medieval settlement (Szentivánhegy) once located on Kálvária Hill, at the time called Szentiván Hill.

The present-day area of the Transdanubian Range was deformed during an early phase of the Alpine orogeny in the late Early Cretaceous. This resulted in the interruption of the more or less continuous marine sedimentation that began in the Early Triassic and lasted for more than 110 million years. On Kálvária Hill, approximately 20 million years are not recorded in rocks. Sedimentation resumed around 115 million years ago and led to the deposition of the Late Aptian Tata Limestone –another formation whose type locality is Kálvária Hill - that overlies the eroded surface of tilted Upper Jurassic limestone beds (***Figure 9***).

Figure 8: Ammonite in the Upper Jurassic Pálihálás Limestone.

Figure 9: Uneven surface of Upper Jurassic limestone overlain by well bedded Lower Cretaceous Tata Limestone in the former "Bluestone Quarry". Earlier researchers interpreted this exposure as a "fossilised rocky coast".

Tata Limestone is the youngest known example of the vanished facies called "regional encrinite". The term is used to denote crinoidal limestone successions of considerable thickness and lateral extent. This unit is widespread along the Transdanubian Range, from the town of Sümeg (located near the western margin of the range) to Tata, but is completely lacking from the Gerecse Mountains. Cretaceous rocks younger than Tata Limestone are not exposed on Kálvária Hill.

The Geological Garden as a place for geoeducation

As in most European countries, geology does not appear as an independent discipline in secondary school curricula in Hungary and is taught within the subject of geography. The proportion of time allotted to geography has been drastically reduced in the last decades if the total number of lessons is considered. It is therefore of vital importance to utilise the educational opportunity provided by features of geological heritage. Abandoned quarries often serve as valuable resources for education (e.g. Macadam & Shail, 2002).The Geological Garden provides an inspiring environment for teaching. In the last ten years more than 5,000 students have learned geology there. Primary and secondary school students living in Tata or enrolled in schools located in the area, as well as ELTE students and employees, may visit the Geological Garden free of charge.In addition to outdoor geology lessons held on a more or less regular basis, the Geological Garden often serves

Figure 10: Boulders of the Oligocene Csatka Conglomerate in the "Mountain-forming rocks of Hungary" collection exhibited in the lower yard of the Geological Garden.

as a locale for outreach events attended by a wider audience. The "Day of Geotopes", organized jointly each October with the Kuny Domokos Museum of Tata, has proved to be especially popular.

Because it is located in the vicinity of Budapest, the Geological Garden is usually the site of the first full-day field trip of freshman undergraduate geology students of ELTE. Exposures of Kálvária Hill offer a good opportunity to study different rocks and a wide range of geological phenomena. In addition to local rocks, the area houses more than 40 boulders representing the most important mountain-forming rocks of Hungary. The collection, unequalled elsewhere in Hungary, is exhibited in the lower yard and is profited during field trips (***Figure 10***).

Conclusion

According to Brilha (2018), geological heritage is materialised by exceptional elements of geological diversity, and typically elements of high value are considered as exceptional. The Geological Garden at Tata houses a number of geodiversity elements of high scientific value, including type sections of three lithostratigraphic units. Due to the favourable conditions, the area also has a high educational value and provides visitors with an opportunity – unique in Hungary – to study a spectacular succession of Mesozoic marine sedimentary rocks, as well as visit prehistoric chert mines and a collection of mountain-building rocks of Hungary, in easily accessible abandoned quarries and other exposures concentrated in a well-groomed garden environment.

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Geoheritage elements of millstone manufactory, Tokaj Mountains, Hungary

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The changes in the exploitation of natural stones emphasise the continuous changes of cultural landscapes. The widespread Miocene rhyolite tuffs of the Tokaj Mountains usually became intensively silicified, increasing the hardness of the material. The grinding of cereals and ores required high quality, long lasting millstones from the mining industry. The hardest, silicified varieties were carved from the 15th century until the 1970s. The quarries are scattered throughout the mountains; amongst them three sites were selected for detailed assessment. The geoconservation value of the historical quarries is well illustrated by the exposed special geological features and remnants of historical stones. The silicified tuffs demonstrate that anthropogenic landforms could have significant geoconservation roles, and these geodiversity elements might enhance geotourism activities.

Les changements dans l'exploitation des roches naturelles mettent l'accent sur la continuité des changements des paysages culturels. Les tufs rhyolitiques miocène, largement représentés dans les montagnes du Tokay ont subi une silicification intense et classique, augmentant la dureté de cette formation. Les activités de mouture des céréales et de broyage des minerais ont nécessité des meules de haute qualité et de longue durée, de la part de l'industrie minière.

Les variétés silicifiées les plus résistantes furent sculptées à partir du 15ème siècle jusque dans les années 1970. Les carrières sont éparpillées dans les montagnes ; parmi elles, trois sites furent choisis pour une évaluation détaillée. La valeur historique et géologique de ces carrières anciennes est bien illustrée par la description des caractéristiques géologiques particulières et les restes de ces roches historiques. Les tufs silicifiés sont la preuve que les reliefs anthropiques pourraient jouer un rôle important dans la préservation du patrimoine géologique et que ces éléments de géo-diversité pourraient également développer les activités du tourisme géologique.

El cambio en la explotación de rocas naturales enfatiza el continuo cambio de paisajes culturales. Las tobas de riolita altamente esparcidas en el Mioceno en las montañas Tokaj habitualmente se silicifican intensamente, incrementando la dureza del material. La molienda de cereales y minerales requería piedras de molino de alta calidad y duraderas en el tiempo. Los especímenes silicificados más duros fueron tallados desde el siglo XV hasta la década de 1970. Las canteras están dispersas por las montañas; entre ellas, se seleccionaron tres sitios para una evaluación detallada. El valor de la conservación geológica de las canteras históricas está bien ilustrado por las características geológicas especiales y los restos de piedras históricas. Las tobas silicificadas demuestran que los accidentes geográficos antropogénicos podrían haber tenido importantes funciones de geoconservación, y estos elementos de diversidad geológica podrían mejorar las actividades de geo-turismo.

Introduction

Geoheritage is a generic but descriptive term applied to sites or areas of geological features with significant scientific, educational, cultural, or aesthetic value (Brilha, 2016). The anthropogenic landforms of mining (including quarries, underground adits, open pits, etc.) have fundamental importance in geoheritage studies (e.g Kubaliková, 2017; Prosser 2019) providing valuable resources for recreation and geotourism. The Tokaj Mountains are made of Miocene intermediate (andesite) and silicic (dacite, rhyolite) volcaniclastics and volcanic rocks, providing exceptional geodiversity which has attracted earth scientists from the 18th century. The volcanism is associated with continuous circulation of hydrothermal fluids, causing physicochemical changes in volcanic rocks and resulting in different types of alteration (silicification, potassic or argillic alteration, etc.) (Pécskay & Molnár, 2002). The exploitation of primary and altered rocks covers thousands of years of human history. At different levels of social and technical development more and more raw materials became of interest, starting from the early Neolithic obsidians.

The silicified zones of volcaniclastics and subordinate sedimentary deposits were suitable for high quality millstones. After the first mention from the 15th century, the silicified materials were the most popular and important products of this area for more than six centuries (Hála, 2003). Technological and market changes indicated development and evolution in quality and quarrying techniques, from handmills to the grindstones used for precious metal bearing ore grinding at Telkibánya. The silicified deposits are usually associated with clay minerals supporting a famous ceramic industry, which had its golden age in the 1800s. Data on ancient quarries were registered in the early national geological mining inventory of Hungary (1904) and also in recent databases (Atlas of European Millstone Quarries, Historic Quarries) highlighting the continuous national and international interest in this special industry of the cultural landscape. These emphasise that abandoned quarries are important ele-

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ments of geodiversity, but there has been no comprehensive research on their current condition. The present paper describes three quarry sites, in terms of their geological conditions and geography of the cultural landscapes, involving their additional natural and anthropogenic values, which are important from geoconservation and geoeducation points of view.

Site selection, data collection and fieldwork

The inventory and assessment of geodiversity is essential for the preservation of geoheritage. The study of these specific mining landforms follows the steps discussed in various papers (e.g. Kubaliková, 2017; Szepesi *et al.*, 2017). First, the review of the literature includes an overview of geology, mineralogy, historical geography and industrial history papers. After compiling a preliminary inventory (***Figure 1***), three quarry sites were chosen for detailed study with collection of available data and field descriptions.

The selected sites are situated in the northern and the eastern parts of the mountains and represent current use in geotourism. Megyer Hill, with a lake in the quarry, is the most spectacular anthropogenic object in the mountains. Füzérradvány was the most important site for illite mining. Telkibánya was famous for gold mining for centuries. Due to the mineral stock, there is a history of scientific research at all three locations. Beside the detailed geological and mineralogical studies (e.g. Széky-Fux, 1970; Pécskay & Molnár, 2002; Szepesi & Ésik, 2015) mining and industrial history were also published (Hála, 2003; Benke, 2009). Detailed description of the sites

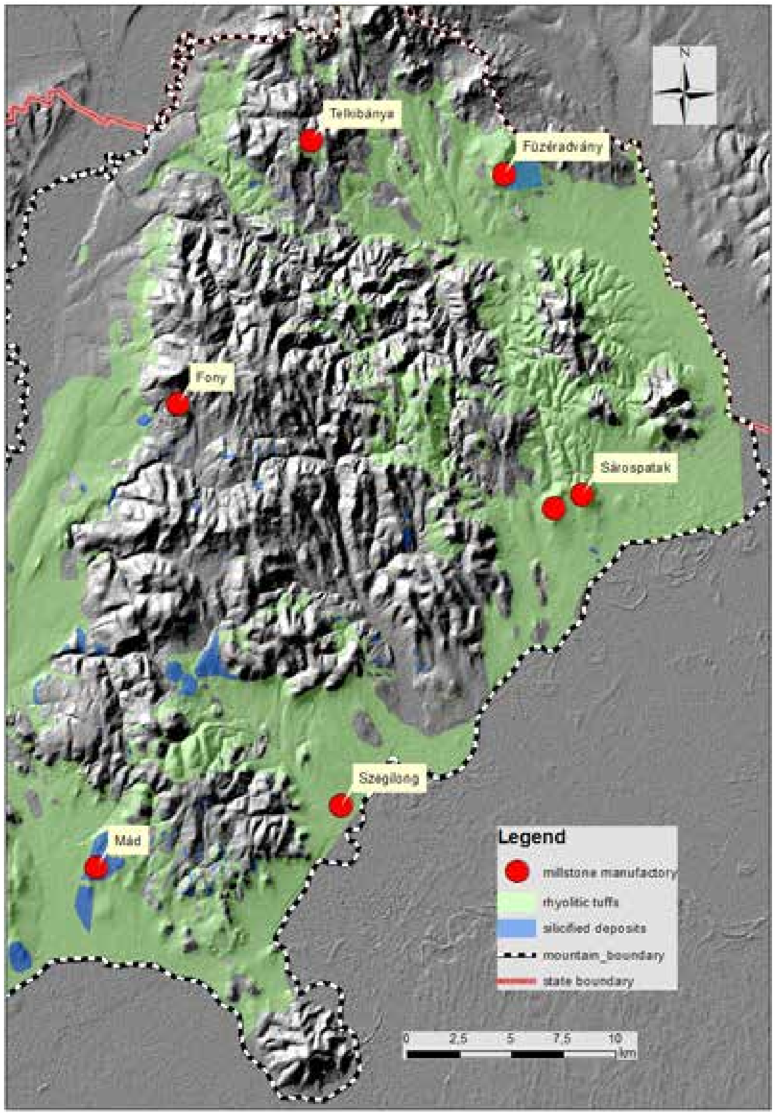

Figure 1: Miocene rhyolitic tuffs in the Tokaj Mountains and inventory of the millstone manufactories. The selected sites are underlined.

Table 1: Inventory and detailed description of the millstone quarry sites: general information, geodiversity and biodiversity features.

	1. Megyer Hill, Sárospatak	***2. Korom Hill, Füzérradvány***	***3. Kánya Hill, Telkibánya***
General information	*280-300 m a.s.l., three-level quarry with picturesque lake (**Fig. 2a, 2b**)*	*398 m a.s.l., single yard quarry (**Fig. 2c**)*	*500 m a.s.l., periglacial block processing only, without surface excavation (**Fig. 2d**)*
Geological settings	*silicified lapilli tuff with variable alteration zones (alunite/kaolinite, illite/montmorillonite, potassic (adularia)*	*silicified lapilli tuff with illite dominated alteration lenses, covering lacustrine clay and silica deposits*	*silicified lapilli tuff sandstone and conglomerate on hydrothermally altered andesite*
Geo-morphology	*semicircular range with basin opening to south, the quarries opened in the silicified cap*	*uplifted morphological unit (200 m above the valleys) surrounded by Hegyköz Basin*	*erosional surface of tuff and conglomerate covered andesite, periglacial block meer on the steep slopes*
Additional geodiversity features	*Király Hill quarry, Zsolnay clay quarry, Botkő quartzite quarry,*	*underground illite excavation in the quarry yard, further mines nearby (Borai, András, Hármas)*	*surface mining objects, Veresvíz open pit field, Lipót shaft, millstone at Telkibánya museum (ex-situ geoheritage)*
Scientific value	*internationally important site, with detailed research on hydrothermal activity*	*regionally important site with detailed research on hydrothermal activity and mining (clay, Au)*	*regionally important site with detailed research on mining (Au,Ag)*
Biodiversity	*Maple-oak woods (Acer tatarico-Quercetum), aquatic plants in the lake (Lemna minor)*	*beech forest (Fagus sylvatica), sessile oak (Quercus petraea), pioneer species in the quarries: birch (Betula pendula), poplar (Populus tremula), protected bat colony*	*hornbeam oak forest (Querco petraea-Carpinetum), rocky slopes, turkey oak (Quercetum petra-cerris) and linden (Mercuriali-Tilietum).*

Figure 2: The three millstone quarry sites: a) Megyer Hill; the first level is under water; b) the canyon-like road cut carved for lake drainage and transportation; c) an unfinished millstone with central hole as first phase of shaping; Telkibánya, Kánya Hill; d) vertical walls of Korom Hill Quarry; the underground hole from where illite was excavated (at the right side of the photo) today is a protected bat habitat.

includes general information with maps and photographs, a brief summary of geological settings, and additional natural and anthropogenic values. The final assessment presents suggestions for site management regarding geoconservation and geotourism development.

Geological setting and mining history

The areal distribution of rhyolitic tuff and hydrothermal materials in the Tokaj Mountains demonstrates the role of explosive volcanism and post-volcanic alterations (***Figure 1***). Variable silicified deposits have been utilised as quality millstone resources for several centuries, as demonstrated by the large number of abandoned quarries (***Figure 1***). The inventory and description of the three quarries are compiled in Tables 1–3.

The three quarry sites (***Figures 2a-d***) are important geoheritage elements that have achieved a very high scientific, historical and cultural value in the region. They represent very similar geological settings: the silicified zones are easily recognised as resistant outcrops at higher elevation, which are surrounded by argillic rocks. The quarries excavated silicified rhyolitic lapilli tuffs. The additional sandstone, conglomerates and rhyolites were also altered in Telkibánya. Depending on hydrothermal zonation, the clays were also mined as raw material (***Table 1***). The largest stocks developed in the Füzérradvány area and were extracted almost to the present day, but important excavation occurred at the other two locations, too. Telkibánya was the predecessor of the famous Hollóháza porcelain factory.

The millstone manufactories were founded in the Middle Ages and the last one was worked until the 1970s. Based on the geological characteristics and quarrying techniques, different styles of stones can be identified. The manufactory started with monolithic stones. The size depended on the type of utilisation (hand or water mills). These one-piece stones could be found recently in the quarry yard of Megyer Hill (***Figure 3a***) and Füzérradvány (***Figure 3b***). Unfinished or broken ones are observable at all three sites (e.g. ***Figure 3c***, Telkibánya). Ore processing required different, mortar-like stones from the harder quartzite exhibited in the courtyard of Telkibánya Museum as ex-situ geoheritage (***Figure 3d***). During the 19th century the milling technique was changed to one with faster rotation (power mills), and long-lasting stones from harder rock were required. The "French-style" millstones were made from cemented pieces (12-16 tiles). Production has become easier and more productive and replaced the monolithic types. The famous Sárospatak millstone won the First-Order Medal of the 1862 World Expo in London, and due to production of this millstone prices were reduced by half compared to the original French market (e.g. La Ferté sous Jouarre Quarry, Atlas of Millstone Quarries). The expansion of steel rolling mills heavily influenced manufacturing in the 20th century. After a continuous decrease in productivity Megyer Hill ceased to operate in 1906. Stones from Király Hill were ordered and delivered even during World War II (Hála, 2003). The last millstone was taken in 1979, when excavation in the Király Hill quarry terminated.

Table 2: Inventory and detailed description of the millstone quarry sites: historical, cultural and aesthetical characteristics.

	1. Megyer Hill, Sárospatak	***2. Korom Hill, Füzérradvány***	***3. Kánya Hill, Telkibánya***
millstones	*Full circle or broken stones in quarry yard*	*Full circle or broken stones in quarry yard*	*unfinished stones at manufactory sites, millstone collection with large mortars at the museum*
geohistorical importance	*old quarry: 15th century-1907* *Király Hill: 1835-1994* *Zsolnay: clay quarry, 1900-1955*	*millstone quarry: 15th-20th century, illite quarries: Borai, Hármas: 1950-1990 András: 1972-2000*	*millstone: n.d.* *open pits: 12-15th century Veresvíz adit, Lipót shaft: 15th-19th century*
other specific features	*miners' house in quarry yard* *French style millstone won "1st order medal" in 1862 World Expo, London*	*small lakes at surface, water accumulates in mining induced surface subsidence*	*Veresvíz (red water) indicates dissolved iron in the drain water; according to legend, this is the blood of miners who died in a collapse in 1443*
aesthetic aspects, view points	*picturesque lake in the quarry yard, high vertical walls (10-30 m) in three levels: Óbánya with lake; 2nd level 5-6 m above lake; 3rd level with mining houses.* *Circular hiking path with several different viewpoints, canyon-like road* ***(Fig. 2.b*** *view at the lake surface)*	*millstones at the entrance, high (10 m) vertical walls with subvertical fractures*	*block meer with large boulders of conglomerate and sandstone, scattered millstones between the boulders*

Figure 3: Millstones from: a) Megyer Hill; b) Korom Hill; c) Kánya Hill; and d) millstones (rhyolite tuff, conglomerate, rhyolite) and quartzite mortars for Au-Ag ore processing in Telkibánya museum, ex-situ geoheritage .

self-guided path (***Figure 4a***) was created in Füzérradvány (Kiss *et al*., 1999) but trail facilities are currently degraded and need renewal. The "Millstone" Nature Trail was established in 2001 by a civil initiative to demonstrate the most important natural and cultural-historical features. The trail was partially renewed in the quarry (2015). The improved information panels (***Figure 4b***) focused on quarrying and mining history. The city of Sárospatak received additional funds for further development of the lake environment in the Megyer Hill area. The via ferrata route around the wall was completed (2019, ***Figure 4c***). The development will be supplemented in the near future with a museum, a lookout tower and a suspension bridge. The development of the Telkibánya area was a complex PHARE cross border activity including Hungarian and Slovakian partners (University of Miskolc, Local Authority of Telkibánya, and Technical University of Košice). A new educational trail ("Gold miners' walk", established in 2011, ***Figure 4b***) connects the mining heritage objects (underground adits, open pit field, buildings, etc.). The establishment of an educational centre was another important area of development supporting field trips for university and high school education.

Geoconservation and geotourism issues

Anthropogenic landforms are attractive landscape features and usually included in natural and cultural heritage (Kubalíková 2017, Prosser 2019). Geoconservation aspects are summarised in ***Table 2***. Megyer Hill is a well-known nature conservation area in Hungary, where the geological, landscape, cultural, and ecological values defined a complex geosite. The amazing 1.1 ha quarry yard with the area of Megyer Hill was listed as a natural reserve in 1977 and became a nature conservation area of national interest in 1997. The quarry is an important cultural landscape element and also part of a UNESCO World Heritage Site (Tokaj Wine Region Historic Cultural Landscape) (Szepesi *et al.* 2017). The other sites are unprotected, but they were surveyed for further geoconservation action in 2018-2019 to establish new natural monuments. The degradation risk of the sites depends on the extent of tourism. Megyer Hill is one of the most visited sites in the Tokaj Mountains, which has caused trail degradation and serious problems with communal waste. The Telkibánya area is famous for mineral collecting activities. The area surrounding the mining site is listed in a national collectors' database as a location of quartz variants and sulfide minerals.

The preliminary assessment of the regional geodiversity summarises the current state of geotourism in the Tokaj Mountains (Szepesi *et al.*, 2017). The importance of geoheritage is recognized by the establishment of geo-educational trails. The first

Conclusions

The manufacturing of natural stones is one good representation of the impact of geology on society and illustrates clearly how culture may influence geoheritage perception and use through the centuries. All quarry sites represent significant scientific, educational, cultural and/or aesthetic values. These criteria determine the perception and exact value of geoheritage and define geosites. Megyer Hill has the widest

Table 3: Inventory and detailed description of the millstone quarry sites: Geotourism and geoconservational aspects.

		1. Megyer Hill, Sárospatak	*2. Korom Hill, Füzérradvány*	*3. Kánya Hill, Telkibánya*
Geoconservation aspects	*protection*	*Natural Reserve (1977)*	*unprotected, conservation survey under Act 55 of 2015*	*unprotected, conservation survey under Act ct 55 of 2015*
	degree of disturbance	*large number of visitors, via ferrata track construction in 2019*	*no human activity induced degradation after abandonment*	*mineral collecting in pit holes*
	degradation risks	*vegetation growth, rock falls, hiking trail degradation*	*vegetation growth, rock falls, hiking trail degradation*	*vegetation growth, hiking trail degradation*
Geotourism aspects	*current use*	*hiking trails, educational trail focused on millstone manufactory, via ferrata trail (2019), suspension bridge over the lake (planned)*	*hiking trails, additional self- guided educational trail focused on geodiversity and mining heritage*	*educational trail focused on mining heritage*
	tourist facilities	*marked pathway, information panels*	*marked pathway, self- guided trail with published booklet*	*marked pathway, information panels*
	number of visitors	*high (over 1,000/year)*	*moderate (under 1,000/year)*	*moderate (under 1,000/year)*

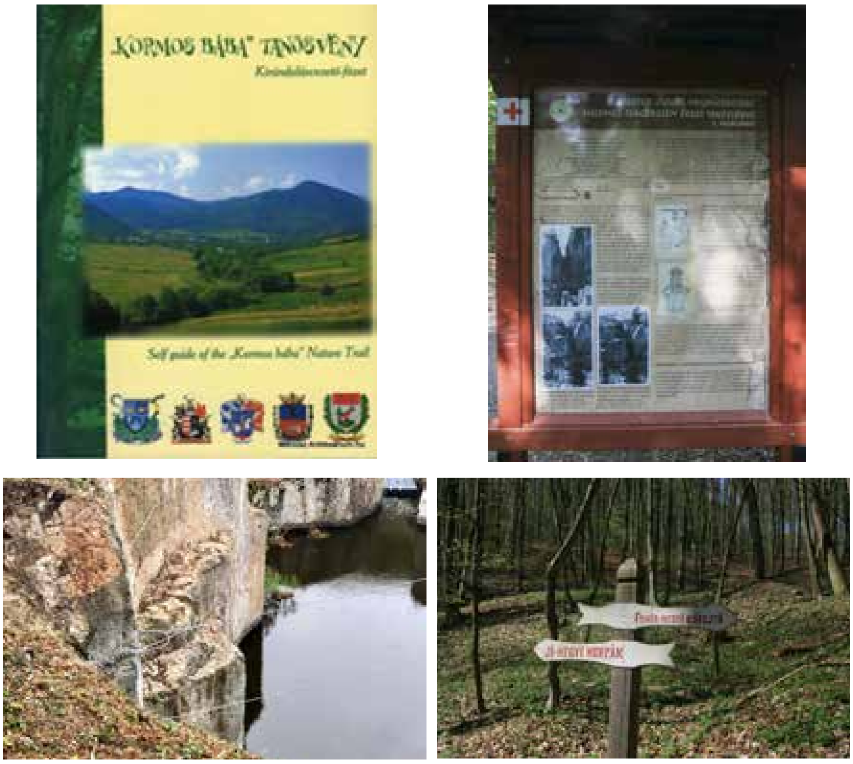

Figure 4: Regional geotourism: a) self-guided nature trail booklet, Korom Hill, Füzérradvány; b) information panel, Megyer Hill; c) Ropes of the new via ferrata trail above the lake (Megyer Hill); d) signpost on the Gold Miners' educational trail, Kánya Hill, Telkibánya.

reputation and is a nationally well-known geosite. The picturesque lake in the abandoned quarry was selected as Hungary's most beautiful natural attraction in 2011. The other sites have regional tourism relevance with moderate tourism flow. Further improvement in site management includes geoconservation and geotourism activities. After the geoconservation survey of Füzérradvány and Telkibánya sites, a declaration of protection would ensure the preservation of the geoheritage. It would be important for organised control over mineral collecting activities. The quarry walls need continuous vegetation removal for better visibility. The new tourism development (Sárospatak) and further involvement of universities can provide seasonal geo-guided walks of public interest. These activities can contribute to maintaining a better image of the sites and more efficient use of their geotouristic and geoeducational potential in a sustainable way.

Acknowledgements

Janos Szepesi's work was supported by the European Union and the State of Hungary, co-financed by the European Regional Development Fund in the project GINOP-2.3.2-15-2016-00009 'ICER'.

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The mining heritage and history of the Silvermines area, County Tipperary, Ireland since the 13th century

Eamonn F. Grennan and Colin J. Andrew*

Recorded mining commenced in the Silvermines area of County Tipperary, Ireland in the 13th century and continued, intermittently, until 1993. Silvermines is different from all of the other mining areas in Ireland in its longevity and in the variety of metals and minerals which have been produced, including, copper, lead, zinc, silver, sulphur, iron, barytes and pyrites. On a number of occasions, it was the focal point for rebellious activities, some of which still resonate in the area. The paper links the variety of lithological and tectonic settings and rock weathering with the various mining enterprises. The use of the terms heritage and legacy is discussed. It concludes by listing the many activities of the post-closure era, including the legacy issues, some of which are negative and many of which are very positive.

L'archivage des activités minières a débuté, au 13ème siècle, dans la région de Silvermines du Comté irlandais de Tipperary et a continué de façon discontinue jusqu'en 1993. Le secteur de Silvermines est différent de tous les autres sites miniers en Irlande par sa longévité d'exploitation associée à la variété des produits métalliques et minéraux créés, incluant le cuivre, le plomb, le zinc, l'argent, le soufre, le fer, la baryte et la pyrite. En maintes occasions, cet environnement fut le lieu de démarrage d'activités rebelles, quelques-unes occupant encore la mémoire locale. L'article fait le lien entre la diversité des formations lithologiques, la tectonique et l'altération des roches, avec les diverses activités minières. L'utilisation des termes héritage et patrimoine est analysée. En conclusion, l'article liste les nombreuses activités de l'ère post fermeture, incluant les questions d'héritage, certaines d'elles apparaissant comme négatives et beaucoup d'autres comme très positives.

Los registros mineros comenzaron en las minas de plata en el área de County Tipperary, Irlanda, en el siglo XIII y continuaron intermitentemente hasta 1993. Esta área es diferente de todas las otras áreas mineras de irlanda por su longevidad y por la variedad de metales y minerales que fueron producidos; incluyendo cobre, plomo, zinc, plata, azufre, hierro, barita y pirita. En varias ocasiones, fue el foco de actividades rebeldes, algunas de las cuales aún resuenan en el área. El documento vincula la variedad de entornos litológicos y tectónicos y la meteorización de rocas con las diversas empresas mineras. Se discute el uso de los términos patrimonio y legado. Concluye enumerando las muchas actividades de la era posterior al cierre, incluidos los temas de herencias, algunos de los cuales son negativos y muchos de los cuales son muy positivos.

1. Introduction

The name Silvermines is unusual in an Irish context, in that it is an English term. The original Irish name for the village/area is Béal Átha an Gabhann, which translates as *"the mouth (of the river) of the ford of the blacksmith"*, which implies iron mining or workings of some sort (***Figure 1***).

Silvermines is not the oldest base-metal mining area in Ireland, but what is unique is the length of time, over 1,000 years, during which the deposits were worked, albeit intermittently, and the wide variety of the metals and minerals which have been exploited.

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2. Geology

The geology of the Silvermines area and regional setting is very well described by Taylor and Andrew (1978), Philcox (1984), Boland *et al.* (1992) and Andrew (2019) (***Figure 2***).

Andrew (2019, p. 13) noted that "…as ideas on "Irish-type" Zn-Pb deposits have swung from exhalative to epigenetic to syndiagenetic, Silvermines has been used to support all of these models. More recently detailed isotopic results and tectono-stratigraphic dating have confirmed the exhalative–syndiagenetic models proposed in the 1970's and debunk replacive models of the 1990's."

So, what is an "Irish-type" Zn-Pb deposit? In simple terms, it is a Zn-Pb rich mineral deposit that formed during or soon after lithification (diagenesis) of the host sediment (normally carbonate) and exhibits most or all of the following characteristics:

- Orebodies have single or multiple stacked, typically stratabound, lenses;
- Structurally controlled - adjacent to normal (generally listric) fault complexes;

- Mineralization: Sphalerite, galena, Fe sulphides and barite;
- Gangue: Calcite, dolomite & silica (and haematite);
- Host rocks: Platformal limestones with or without dolomitization.

At Silvermines the Lower Zone Orebodies (Lower G-, K-, C-, P- and C-Devonian as well as Shallee and Gorteenadiha) show classic epigenetic features and are closely structurally controlled. Equally, the Upper Zone Orebodies (B- and Upper G-Zones) show abundant sedimentary features such as syn-sedimentary slump breccias, graded-bedding, interbedding of pyrite and shale layers, and geopetal structures confirming the sedimentary origin of the stratiform pyrite bodies (***Figure 3***) (Andrew, 2019).

Deep Tertiary-aged weathering resulted in the oxidation of sub-cropping sulphides in the P-Zone. This led to the development of significant deposits consisting of smithsonite and hemimorphite. An evaluation in 1933 determined a resource of 0.5Mt @ 21% Zn, modified to 0.85Mt @ 14.3% Zn, 1.7% Pb by Ennex International in the early 1990s. These deposits were exploited intermittently from the 17th century until 1953.

Tertiary karstic weathering is endemic throughout the area, especially in the valley north of the mine and west of the Magcobar Pit and has created a large volume of cavitated ground. This held a substantial volume of acidified water which almost caused the inundation of the mine in the early 1970s, although fortunately no injuries or fatalities were sustained.

Figure 1: Location map.

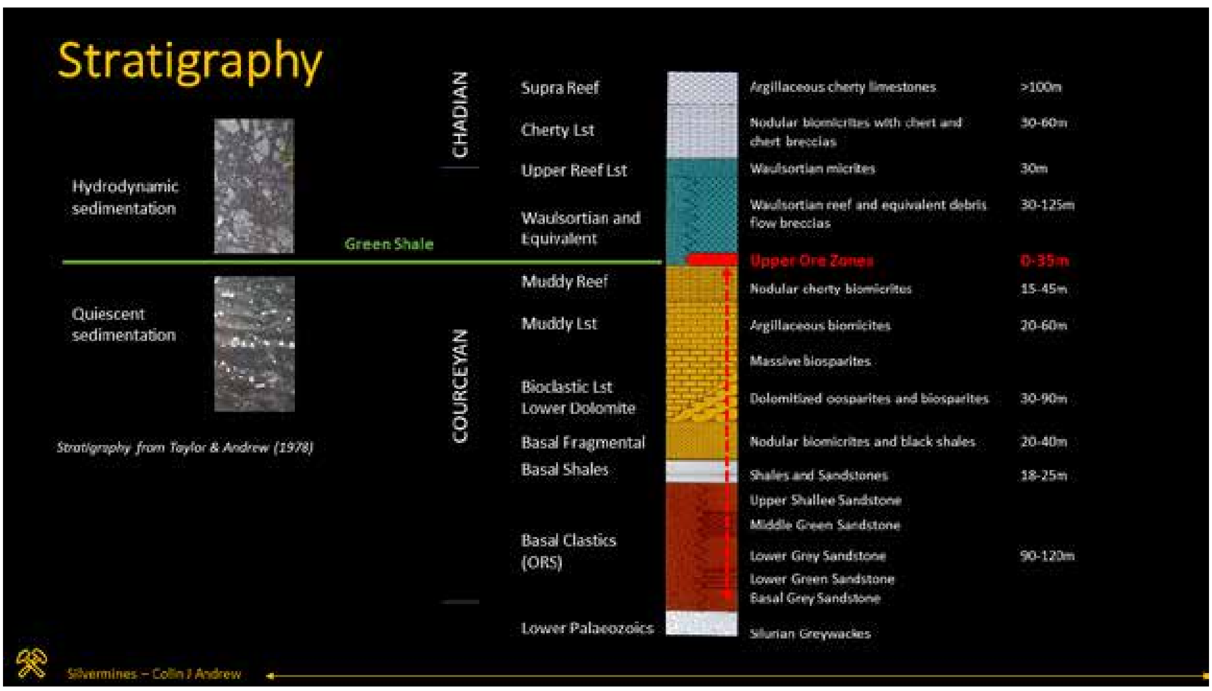

Figure 2: Stratigraphy of Silvermines.

3. Mining History

3.1. 13th Century

Although no written records exist, apocryphal stories in later accounts suggest that silver was exploited in the area by the Danes in the 9th and 10th centuries.

In 1289 Italian miners from Genoa and Florence sponsored by the English Crown came to County Tipperary in search of silver [Gleeson (1937) cited in Cowman (1988)] and opened (re-opened?) a silver mine which they operated until 1303.

3.2. 17th Century

In 1631, all the mines in Munster "were let to Messrs Whitmore and Webb", who concentrated their activities on Silvermines, but "it seems that they found no silver – only lead and copper". Ownership changed hands regularly. An interesting finding of this compilation is that one of those owners was the first Duke of Abercorn, whose direct descendant – the present Duke of Abercorn – was very active in Irish exploration during the fourth quarter of the 20th century. The mines were finally destroyed in the rebellion of 1641 (Cowman, 1988).

At the end of the Cromwellian era in Ireland in 1653, his soldiers were owed a lot of money and, as was the norm at that time, they were paid by "settlement", that is, lands were confiscated from the vanquished and divided amongst the military. Most of the soldiers then sold the land on to established English landlords in the general area.

3.3. 18th Century

Following a series of court cases in England during the late 17th century, the ownership of the mines passed to the Prittie family and this sequence of ownership is well-reflected in today's mineral ownership map (***Figure 4***).

The near surface lead and silver appears to have been worked out, but in 1724 copper was discovered and had some success, at least for a while, because in 1758 the mine was in the hands of Martin O'Connor, who had moved to Silvermines after his copper-mining enterprise at Avoca, Co. Wicklow failed, but Silvermines eventually also failed.

Circa 1770, the lead veins at Shallee were discovered and both lead and copper was produced for a couple of years. Sometime in the 1780s, "a wedge of rich ore" was exploited and a smelter was built "which produced sheet lead and shot" (Cowman, 1988). Pure silver was also produced. This was a very turbulent time in Irish history, with the insurrection in 1798 followed by the Act of Union in 1801. In 1800 Henry Sadlier Prittie was created Lord Dunally, whose lineage and estate persists to the present day.

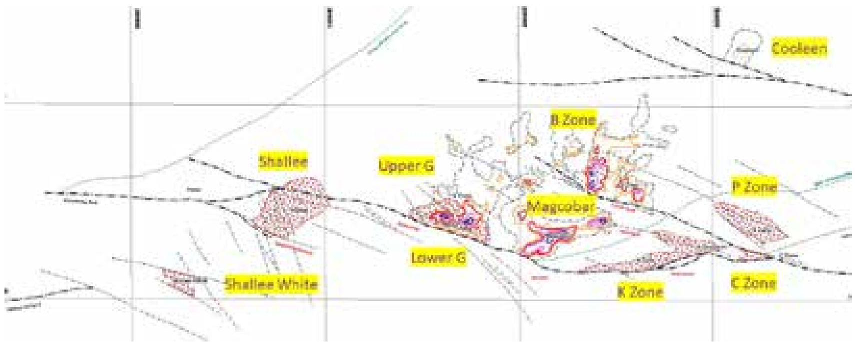

Figure 3: Structure and main orebodies.

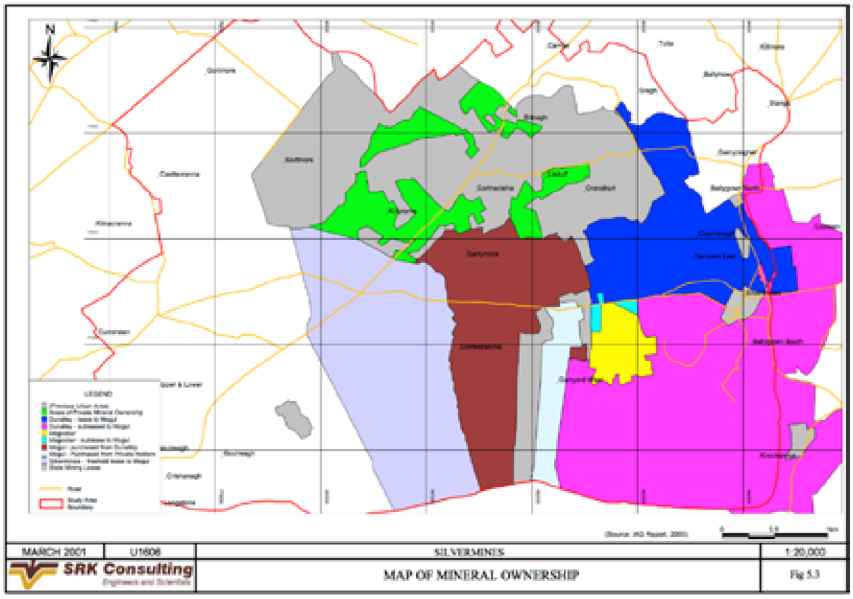

Figure 4: Map of mineral ownership.

3.4. 1802-1875

In 1840, a number of tests were carried-out "at Gorteenadiha and Ballygowan for sulphur as well as checking the lead potential". In 1845 the General Mining Company of Ireland amalgamated all of the workings in the district, and "over the next three decades the mines at Shallee, Gorteenadiha, Garryard and Ballynoe were worked".

Despite the Great Famine (1845–1849) in Ireland, the workings, producing both lead and copper, maintained profitability. However, in July 1853, a combination of low metal prices, near-surface ore being worked out, the failure to maintain investment, poor management and a number of financial irregularities caused major problems leading to a series of strikes because the miners had not been paid their wages. Notwithstanding this, a "new rich vein of silver-lead was reported from Shallee" and was worked (***Figure 5***) (Cowman, 1988).

Figure 5: Shallee area.

3.5. Calamine (Ballygowan)

In 1949, the Silvermines Lead & Zinc Company commenced a project based

Figure 6: Knockanroe and Ballygowan area.

Figure 7: Magcobar (Ballynoe) area flooded pit.

Figure 8: Gorteenadiha & G-Zone (Mogul of Ireland).

on the "calamine zone" (P-Zone), with the first stage being the development of a 'pilot' Waelz Rotating Kiln to treat 40 tonnes per day to produce zinc oxide. The project was unsuccessful and ended in July 1952 (***Figure 6***).

3.6. Shallee Lead

Around this time, the Korean War broke out, during which lead prices rose sharply and mining recommenced at Shallee. Over the next six years to January 1958 there was a series of stop-start efforts at production, which is estimated at 4,677 t of lead and 37,000 ounces of silver from 355,000 tonnes of ore (Andrew, 2019).

3.7. Magcobar

In 1958 the Silvermines Lead & Zinc Company carried out some exploration drilling and identified what became the Magcobar barite deposit in the Ballynoe area. In 1959 they agreed to assign operating rights to Dresser Minerals from Houston, Texas. Whilst production peaked at 329,000 tpa, it generally produced between 200,000 and 300,000 tpa. During its final two years, the company mined 190,000 t by underground methods (***Figure 7***).

4.61 Mt of 85% $BaSO_4$ lump grade barite were sold over the life of the mine to the end of September 1993. To access this ore about 8.5–9 Mt of overburden and waste rock were stripped.

3.8. Mogul

In October 1962 the Canadian International Mogul Mines, who had been active at Avoca, concluded a farm-in agreement with the Silvermines Lead & Zinc Company to explore an 80 km^2 area at Silvermines. Drilling commenced in June 1963, and the company was very close to terminating the exploration programme when the first significant stratiform mineralization was intersected in hole G33. By December 1964 10 Mt of ore were defined. They then ceased exploration to concentrate on developing the mine. Operations commenced in 1968 at a throughput of 1M tpa, which it consistently achieved over its lifetime until closure in July 1982, having milled 10.8 Mt @ 7.36% Zn, 2.70% Pb from the Lower G-, Upper G-, B- and K-Zones (***Figure 8***).

The mine was quite profitable in the early years and this led to a decision in 1970 to re-start exploration. Day-to-day control was handed over to the company's wholly owned exploration arm, of which one of the authors (Eamonn F. Grennan) had just been promoted to Chief Exploration Geologist. Over the next three years the Resource and Reserves were increased to >14 Mt.

3.9. Post Mogul Mine Closure

Heritage

The Mogul tailings pond and, to a lesser extent, the now-flooded Magcobar caused much environmental controversy during the 1980s and 1990s. In 2005, the Government announced the allocation of €10.6M for rehabilitation and as part of the preservation of industrial heritage in the area (Morris, 2011).

Exploration

After the closure of the Mogul mine in 1982, the company was acquired by Ennex International plc in 1983. Ennex decided to evaluate the potential of the area for new ore at depth and shallow primary oxide/sulphide mineralization and, as described above, had some success.

4. Social Matters

4.1. Revolution and Armed Conflict

Italian miners

The first of many known conflicts at the mine took place in 1303. Fourteen years after the arrival of the Italian miners, they were attacked following the killing of a local man and the works were abandoned.

Middle 17th century

A major Irish Rebellion started in 1641, coincident with the Civil War in Britain, that led to the destruction of the mining operations by the Irish under the leadership of Hugh O'Kennedy, brother of John Mac Dermot O'Kennedy, on whose lands the mine was situated (Boate, 1652).

Oliver Cromwell came to Ireland in late 1649 to put down the rebellion and laid siege to the city of Limerick, 30 km south-west of Silvermines. At that time the main route from Dublin to Limerick passed by Silvermines. Indeed, the road leading to the 1970s Explosives Magazine is still known as "Cromwell's Road".

1971

A group from the Irish Republican Army (IRA) took over the mine offices on the evening of July 7 1971. During the incursion, one of its members entered the electrical sub-station and attempted to place explosives close to a transformer but died in the attempt. The occupation was quickly quelled by the authorities.

4.2. Miners and Other Workers

19th Century

In the early 1800s the Dunally Mining Company had the motto, "Employ the people, enrich yourselves", and despite expressing benevolent intentions towards their employees left them unpaid for over a year!! (De Staffort, 2017).

Mid-20th Century

Moving on 100 years, little seemed to have changed, because Griffith (1951), quoted in de Staffort (2017) in relation to the operation of the Waeltz Plant, commented that, "The lack of trained personnel to operate the plant led to many expensive mistakes in the early days and added still further to the general cost. To obtain raw labour from the surrounding farms and outlying villages and to train them as shift bosses and plant operators and to instil into their minds the need for careful temperature control, the accurate sampling of calamine feed, zinc oxide and slag was heart-breaking".

However, by 1968, things had changed radically, because de Staffort (2017) comments on the fact that, "The social impact of the Mogul of Ireland mine at Silvermines had a tremendous effect on the area, extending to neighbouring towns and counties. It was a high-paying mine and created a variety of skilled, semi-skilled and unskilled jobs. There had never been an industry with such an immediate effect on the hinterland. Workers were drawn from near and far".

4.3. Heritage and Legacy

Whilst researching and completing this paper, it became apparent that in regard to mining, the difference – at least in the English language – between heritage and legacy has become very profound. In the past both words were invariably intrinsically linked with each other, especially in regard to wills, legacies and inheritance. By using Silvermines as an example, it is hoped to illustrate the ambivalent and negative comments which should be addressed as a matter of urgency by the European Commission and the European Federation of Geologists.

In the past heritage was taken to mean a property that had been inherited, that is, an inheritance, whilst 'legacy' was taken to mean money bequeathed to someone in a will. In Ireland archaeological studies include buildings, monuments, settlements and also artefacts, a category which includes gold, bronze and iron-based implements. All of these are part of our heritage. More recently the onus has shifted towards post-1700 buildings, especially their preservation. They include large country houses and historic streetscapes and of course include old mine buildings.

It should be noted that when such a building passes from one generation to the next, it is usually by means of a will or legacy. More recently, however, in regard to the mining industry, the term 'heritage' has been used to hinder minerals development in phrases such as 'this is a heritage building and cannot be removed' or 'this area is part of our heritage and cannot be interfered with'. Thus, one can see that the term 'heritage' is always used in a positive sense, that is, heritage equals good. On the other hand, when one also hears of legacy issues in a mining area, it is invariably used in a negative sense, that is, legacy equals bad. As an example, we will review the Silvermines area. In the public mind, what are the post-1965 legacy issues?

- The Mogul tailings pond, also known as the Tailings Management Facility (TMF), which has been partially re-vegetated and is no longer a problem.
- The waste-rock slopes at Magcobar, which now are also partially re-vegetated.
- The collapsed areas of old stopes are now surrounded by two metre-high safety fencing and therefore are no longer a danger.
- The Magcobar open pit, which is filled with water, is being examined for other purposes (VAMOS, 2019).

Are there other legacy issues? Yes there are, BUT they are all positive and thus receive very little public acknowledgement. As examples:

- The training of the miners, electricians and fitters at Silvermines enabled them to take their skills to newer mines such as Tara, Lisheen and Galmoy and to overseas.
- Finally, it should be recorded that most of the geologists and geo-technicians who worked at Silvermines continued to live in Ireland and went on to become senior managers elsewhere in the industry in Ireland, and/

or became well-known and respected consultants around the world. This was not matched by any of the other professions who worked in the mine.

4.4. A last word on geological legacy

The Mogul of Ireland Group, which was an excellent employer, did not however fund many geological or educational projects. This was the background to the very propitious paper by Stuart Taylor and Colin Andrew, both mine geologists with Mogul at that time, who in 1977, against a backdrop of less-than-whole-hearted encouragement, submitted a paper to the Institute of Mining and Metallurgy under the title "Silvermines Orebodies, Co. Tipperary, Ireland". Indeed, it was in this paper that the term "Irish-type" Zn-Pb deposit was used for the first time in the literature. This paper, published in the Transactions in 1978, was deemed to be of such quality and significance that it was awarded the Silver Medal for that year. This in itself is a combination of history, heritage and legacy.

5. Concluding Comments

As more and more emphasis is placed at universities upon so-called productive activities, it is important to maintain other disciplines which may not today be seen as productive, but which in the future will provide valuable data – data that if not recorded now could be lost forever. It will serve to highlight the fact that most of the metals identified in the EC list of critical raw materials have at some time in the past 150 years been produced in Europe and, given the right environment, could be produced again.

6. Acknowledgements

We wish to acknowledge the role of former Mogul employee Dom O'Halloran, who supplied a lot of personal and unpublished data; Des Cowman, mining historian, for his detailed research and many articles; and John Clifford for all of his suggestions. Finally, Eamonn F. Grennan wishes to acknowledge the many publications of his co-author (Colin J. Andrew), which made the compilation of this paper so much easier.

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The cretaceous clays of Baiso, Emilia-Romagna, Italy: A study for their touristic promotion

*Giorgia Campana, Alessandro Ghinoi, Christian Marasmi**

The Baiso area of Italy is characterised by extensive badland formations featuring polychrome clays, thus giving rise to outstanding unique landscapes identified as important geological sites. This geological framework has given rise to the industrial specificity of the area, which has become important for the clay supply for the Sassuolo and Casalgrande ceramic district over the past few decades. A recent multidisciplinary study analysed the strengths and weaknesses of this environment, with the aim of identifying an innovative strategy to transform the areas affected by mining activities into an opportunity for environmental regeneration and an in-depth source of information on geology and geoheritage, incorporating tourist trails past various landscape features and abandoned mining operations.

La région de Baiso en Italie est caractérisée par des formations profondément altérées ou ravinées comportant des argiles polychromes, donc à l'origine de paysages uniques et remarquables, considérés comme des sites géologiques importants. Cet environnement géologique est à la source de la spécificité industrielle de la région, devenue importante ces quelques dernières décades, pour la ressource en argiles destinée à l'industrie de la céramique dans les secteurs de Sassuolo et Casalgrande. Une étude multidisciplinaire récente a analysé les faits positifs et les faiblesses de cet environnement, dans le but d'élaborer une nouvelle stratégie pour transformer les régions affectées par les activités minières en une opportunité de régénération environnementale et de recueil d'informations plus détaillées concernant la géologie et l'héritage géologique, incorporant des sentiers touristiques à côté des diverses caractéristiques du paysage et des sites miniers abandonnés.

El área de Baiso en Italia se caracteriza por extensas formaciones de bad lands con arcillas policromadas, lo que da lugar a paisajes únicos identificados como sitios geológicos importantes. Este marco geológico ha dado lugar a un área industrial específica, que se ha vuelto importante para el suministro de arcilla en las últimas décadas para el distrito cerámico de Sassuolo y Casalgrande. Un reciente estudio multidisciplinario analizó las fortalezas y debilidades de este ambiente, con el objetivo de identificar una estrategia innovadora para transformar las áreas afectadas por las actividades mineras en una oportunidad para la regeneración ambiental y una fuente de información sobre geología y patrimonio geológico; incorporando rutas para turistas a través de paisajes característicos de operaciones mineras abandonadas.

The geological heritage

The flysch complexes (Multi-coloured clays, Argille Varicolori del Casale) are found in a portion of the Baiso territory, in the Northern Province of Reggio Emilia, Italy (***Figure 1***). They date from the Cretaceous period and were formed in a reducing environment of an abyssal plain (Bettelli, 1986; Bettelli *et al.*, 1989; Papani *et al.*, 2002). The tectonic events that led to the development of the Apennines disrupted the original sedimentary structure, at the same time creating the outstanding shape that marks the local landscape (***Figure 2***).

Beside regularly folded elements, a few complex folded units can be found, also featuring variously oriented disharmonious folds at the points where the original thin variously coloured, initially regularly alternating pelitic layers become discontinuous, lenticular, fraying, turning into various shades ranging from light grey to red, with absent, uneven geometries turning into parallel ordered geometries, known

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Figure 1: Baiso area, northern Italy. Emilia-Romagna Region (Source: maps.google.com).

Figure 2: Landscape featuring gullies in the Baiso territory.

Figure 3: Varicoloured clay outcrops.

Figure 4: Badlands featuring varicoloured clays (argille varicolori).

Figure 5: Local site of geological interest, Casale.

as foliations, with colours ranging from brick red to black, alternating with light grey spots (***Figure 3***).

Runoff has led to linear and widespread erosion, continuously changing the landscape morphology, further enhancing the beauty of spectacular clay outcrops, with spires, pinnacles, ravines and deep furrows (***Figure 4***).

Vast municipal areas are characterised by extensive badland formations featuring polychrome clays, thus giving rise to outstanding unique landscapes with large multi-coloured ravines: some of them have been identified as important geological sites, given their great scientific relevance.

A few remarkable and spectacular gullies located in the Baiso territory have been classified as sites of geological interest by Emilia Romagna: the ***Casale*** (***Figure 5***) and ***Mélange di Baiso*** geological sites (named Geosites of the Emilia-Romagna Region, see ***https://geo.regione.emilia-romagna.it/schede/geositi/***).

The varicoloured clays are also interesting from the mineralogical point of view: the formation and development of minerals such as pyrite, marcasite, barite, calcite and pyrolusite occurred in very deep basins below the carbonate compensation limit, in a reducing environment featuring the presence of organic material.

The Apennine diagenetic mineral genesis is closely linked to the Apennine orogenesis. Ion-rich fluids, such as iron and barium, were first adsorbed by clays during the diagenetic processes, thus giving rise to gemination nuclei, in a completely buried environment, at the interface between permeable lithologies (sandstones) and waterproof (clays) when the sedimented, not completely lithified material was subjected to severe tectonic stress.

Iron sulphide minerals are found in the Baiso territory, featuring both polymorphic pyrite and marcasite phases, although pyrite formations are more prevalent. Pyrite is often found in aggregates on the surface of lithic fragments of sedimentary nature (such as sandstone or limestone) present in the clay formation. More recent pyrite features more or less clear shades of a bright brass yellow color; much more frequently, pyrite turns reddish, brown or almost black. In the most frequent cases cube-octahedron shaped pyrite formations can be observed, featuring often curved, saddle-shaped faces, with the presence of geminates and aggregates. Marcasite (***Figure 6***) features a slightly lighter shade of yellow than pyrite; if freshly fractured, it can be found in small-sized pinacoidal prismatic polygeminate aggregates (up to 3–4 mm). Spherical nodules covered with rhombic-pyramidal or cubic and octahedral terminations occur in the Helminthoid flysch (Scachetti *et al.*, 2015).

The so-called Liguride and Epiliguride paleontological outcrops can be found in the territory, with a broader and more relevant presence of Liguride outcrops: these are the direct testimony of a vanished ocean during the Cretaceous era (145 to 66 million years ago), spread over an area roughly corresponding to the current Liguria region and the Ligurian Sea.

The paleontological study of these sediments is made difficult by the complex and troubled history of the Apennine orogenesis, as previously described, and by the deposition paleoenvironment, which was presumably buried for a long time at an extreme depth, below the carbonate compensation limit, i.e. the depth beyond which first aragonite and then calcite tend to dissolve. Under these conditions, the preservation capacity of tiny marine organism shells, which are normally used for biostratigraphic dating of rocks (planktonic foraminifera and calcareous nanoplankton) is extremely low: it is in fact almost impossible to find microfossils useful for dating purposes, except in limited cases.

Hence, the discovery of a Pliosaurus tooth (***Figure 7***) in the Baiso territory should be considered of great scientific relevance, especially if combined with the discovery of calcareous nanofossils, which made it possible to determine with good accuracy the age of the artefact: Turonian (dating from 93.9 to 89.8 Ma), consistent with the finding in the Scabiazza sandstones (*Papazzoni CA, 2003*).

The "Ceramicland"

This geological framework has given rise to the industrial specificity of the area within the Municipality of Baiso, which over the past few decades has become a very important area for the clay supply for the Sassuolo and Casalgrande ceramic district (Reggio Emilia Province mining plan). The importance and evolution over the centuries of the ceramic clay pits within

Figure 6: Marcasite found near Cava Il Monte.

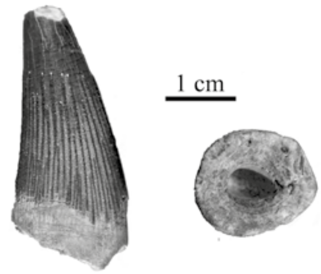

Figure 7: The Pliosaurus tooth.

Figure 8: Tower House at Colombaia.

the Reggio Apennines territory led to the economic boom of the district during the 1960s, when raw material for the ceramic tile production began to be sourced locally, mainly within the Carpineti, Baiso and Castellarano municipal areas. The mining industry, which produced locally relevant morphological changes still visible today, also led to the economic and social development of the so-called "Ceramicland", i.e. a key international benchmark for ceramic tile manufacturing.

A further highlight of the local economy of Baiso that results in an anthropic landscape is tied to mixed-grass fodder meadows surrounded by linear hedges. The localised presence of rural farming settlements, sometimes characterised by buildings of historical and cultural interest, marks the landscape, as in the case of tower houses (Figure 8) found in the hamlets of Colombaia and Fontanella (*Cervi, 1982,2009*).

Vegetation of the area

The vegetation structure that characterizes the study area lies within the framework of sub-mountainous oak forests, typical of the median Emilian Apennine belt. The presence of vast clay-rich surfaces belonging to the geological Mesozoic Clays series of the Northern Po Valley Apennine has led to considerable specific grassland variations as opposed to the usual flora characterising sub-mountainous oak forests.

With the exclusion of ravines, which due to their strong dynamics do not allow any grass formation, the other clayey soils have allowed the growth of a suitable layer of topsoil, resulting in the formation of the oak forests, which, according to their edaphic characters and exposure slopes, are characterised as either mesophile or acidophile oak forests. The oak forest formation prevalent in the area is mainly constituted by groupings of downy oak (*Quercus pubescens*) associated with flowering ash (*Fraxinus ornus*), juniper, blackthorn, hawthorn and firethorn.

The vegetation of the study area is also locally characterised by the presence of extensive populations of Scots pine (*Pinus Sylvestris*), which shows good vegetative vigour and tends to concentrate mainly at lower altitudes along the valleys, sometimes giving rise to almost pure Scots pine forests. Scots pines are also present, although to a much lesser extent, in very localised nuclei within sub-mountainous oak forests.

The mining paths of Baiso clays

The multidisciplinary study "The mining paths of Baiso clays" (Cervi *et al.*, 2018) was carried out in this environmental context. It aims to identify an innovative strategy to transform the areas affected by mining activities into an opportunity for environmental regeneration and in-depth geological and geoheritage knowledge. It begins by analysing and describing the strengths and weaknesses of this environment. In fact, the study has shown that on one hand all of the abandoned mining areas can be a weakness of this territory, being considered unattractive by tourists. However, from a landscape point of view, they are often well contextualised and sometimes no longer identifiable: the presence of slopes reshaped by runoff gives rise to the outstanding gullies now typical of the Apennine landscape.

The great natural and scenic interest of this area within the municipality of Baiso were confirmed by the classification of Argille Varicolori del Casale (the Multicoloured Clays of Casale) and ravines within the sites of geological interest of the Emilia-Romagna region and within the UNESCO MAB (Man and the Biosphere) area. This led to the drafting of a social and environmental enhancement proposal, i.e. a landscape project intended as a tourism-nature-education development project of the territory under question, based on its geological, geomorphological, paleontological, botanical and historical features.

The European network of minor routes (i.e. local paths and existing trails) crossing all the territory under study is the main

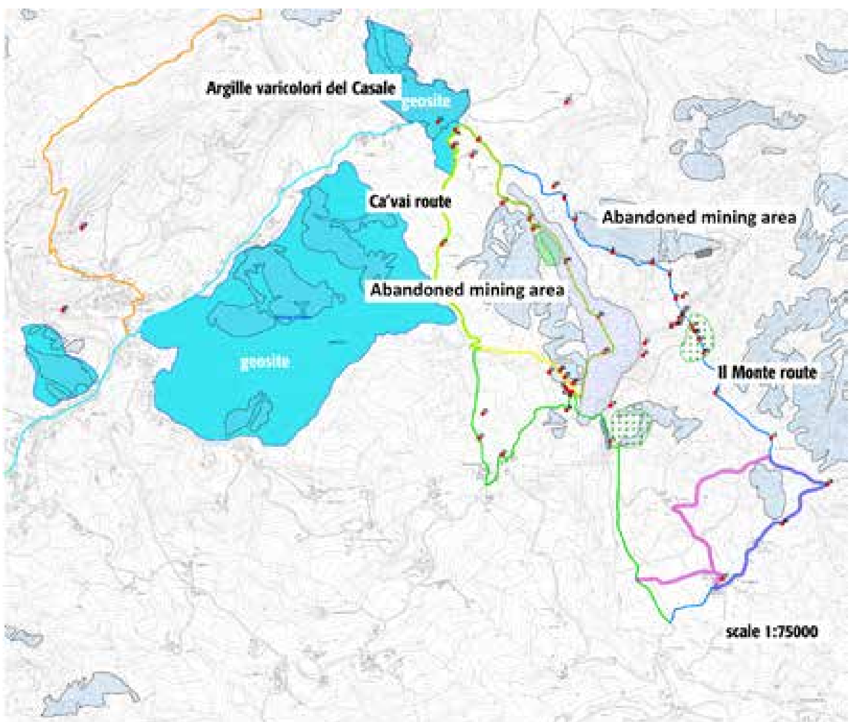

Figure 9: Topographic map of proposed trail routes in the area. Red dots indicate points of interest, light blue shows abandoned mining areas featured along the Ca' vai route (yellow, 4.1 km) and Il Monte route (blue, 4.4 km). (Cervi et al.*, 2018).*

tool enabling the enhancement of environmental peculiarities related even to derelict mining areas. To this end, six main routes have been identified, easily accessible to everyone, leading to the main geological, geomorphological, landscape and natural highlights, described in special cards providing information on the natural and man-made history of the sites.

The Ca' Vai Route (***Figure 9***, yellow) is the most significant path from the geological point of view: it allows visitors to fully appreciate the geological characteristics of the Giorgella River Basin, with reference also to the quarries that were located there. The 4.1 km trail starts from the hamlet of Casale and by following the local northbound path visitors will soon reach the watershed that overlooks the breathtaking scenery of the Baiso geological site of polychrome clays, among the most significant geological sites nationwide. This stretch offers several interesting botanical and geological landscape highlights, including the stunning view of the Giorgella River gully, featuring its characteristic outstanding sequence of erosive forms of grey and polychrome clays. The unmistakable sandstone spire of Mount Valestra, a true landmark, stands out in the background.

Immediately downstream of the southbound dirt road, previously mined clay heaps form quarry squares surrounded by big boulders. The path leads to stunning gully ridges close to polychrome outcrops of clays, which are characterised by particularly bright colours (ranging from dark brown to purple and brick pink). The route, built on clay soil, often features calcareous outcrops covered by a manganese layer, or more occasionally a few typical minerals, including Marcasite, fibrous calcite nodules, rocky sandstone blocks embedded in clay and rarely baryte (barium sulphate).

A further relevant trail is the 4.4 km il Monte route (***Figure 9***, blue) connecting the two decommissioned mining sites known as Il Monte and Castagneto (see Province mining plan, ***https://www.provincia.re.it/page.asp?IDCategoria=701&IDSezione=4329&ID=86218***), featuring two quarries:

- **The former Monte Quarry** is configured as an exceptional open-air classroom for understanding the specific characteristics of the mining sites of clay used in the ceramic tile district. It also offers a natural environment, great scenic attraction and a unique opportunity for better understanding the complex reality of Emilian Mesozoic clays.
- **The former Castagneto Quarry**, given its characteristics and easy accessibility, is an ideal place to host the planned information and tourist centre of the mining sites included in the Mining Park of Baiso clays. The centre could offer a wide range of educational activities linked to the theme of clay and highlights of natural and cultural tourism. Finally, the presence of large flat surfaces makes it suitable for tourist and sports events.

The two sites are connected by secondary roads (***Figure 9***), thus making the various spatial contexts accessible also by means of shuttle buses. These routes are also valuable for local development and tourism purposes. They will be equipped with tourist signs providing a description of the highlights of the places to be visited, characterised by a stunning view, allowing visitors to fully grasp the key aspects of the Baiso mining, cultural and historical landscape.

In conclusion, the study allowed us to describe and map the key landscape, environmental and geological futures of the territory of Baiso, identifying a network of paths enhancing the landmarks of the area. The study thus provides the basis for the creation of a new Mining Park of Baiso clays, which is under consideration for inclusion in the UNESCO MAB area and in Protected Landscape of the hills of Reggio Emilia and the Lands of Matilde di Canossa.

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Evaporite dissolution sinkholes in the Dwejra Depression, Malta

*Peter Gatt**

The well-stratified Oligo-Miocene carbonates along the western coast of Gozo Island include four exceptionally large sinkholes (300 to 400 m diameter), smaller sinkholes and natural arches, clustered within the 1 km-wide Dwejra Depression. The dipping limestone along the rims of the sinkholes, dissected by faults, shows cyclic sedimentation reflecting palaeoclimatic changes. Joints have been eroded to produce natural sea arches, including the iconic Azure Window (which collapsed in 2017). The structural depression and sinkholes are linked to dissolution of subsurface evaporites. The dramatic landscape comprising exceptional carbonate outcrops along cliffs, natural arches and circular pools and coves formed by the flooded sinkholes in western Gozo are a testament to past climatic change and catastrophic events pertaining to the Earth's geological heritage.

Les carbonates bien stratifiés de l'Oligo-Miocène, le long de la côte ouest de l'île de Gozo comportent quatre gouffres de largeur exceptionnelle (300 à 400 mètres de diamètre), des gouffres de plus petite taille et des arches naturelles, groupés à l'intérieur de la Dépression de Dweira, d'un kilomètre de large. Les calcaires plongeant en bordure de gouffres, morcelés par des failles, montrent une sédimentation cyclique en rapport avec les variations paléoclimatiques. Les joints stratigraphiques ont été érodés pour créer des arches marines naturelles, incluant l'emblématique Fenêtre d'Azur maltaise (engloutie en 2017). Les formes structurales, dépression et gouffres sont liées à la dissolution d'évaporites de subsurface. Le paysage spectaculaire incluant des affleurements carbonatés d'exception le long de falaises, arches naturelles, piscines circulaires et criques, formées par les gouffres noyés dans la partie ouest de l'ile Gozo atteste des changements climatiques passés et des événements catastrophiques se rapportant à l'héritage géologique terrestre.

Los carbonatos bien estratificados del oligo-mioceno a lo largo de la costa occidental de la isla de Gozo incluyen cuatro sumideros excepcionalmente grandes (300 a 400 m de diámetro), sumideros más pequeños y arcos naturales, agrupados dentro de la depresión Dwejra de 1 km de ancho. La piedra caliza que yace a lo largo de los bordes de los sumideros, seccionada por fallas, muestra sedimentación cíclica que refleja cambios paleoclimáticos. Las articulaciones se han erosionado para producir arcos marinos naturales, incluida la icónica Azure Window (que se derrumbó en 2017). La depresión estructural y los sumideros están vinculados a la disolución de evaporitas subsuperficiales. El espectacular paisaje que comprende afloramientos excepcionales de carbonatos a lo largo de acantilados, arcos naturales, calas y piscinas circulares formadas por sumideros inundados en el oeste de Gozo son un testimonio del cambio climático y de los eventos catastróficos relacionados con el patrimonio geológico de la Tierra.

Introduction

Sinkholes are widely distributed on the Earth's surface, especially where subsurface voids are prone to develop. Giant sinkholes measuring hundreds of metres in diameter are less common and form enigmatic features. Over 50 sinkholes with a diameter >40 m are recorded in the Maltese Islands in the Central Mediterranean Sea (***Figure 1A***). An exceptional cluster of large sinkholes are located along Western Gozo Island where they form a spectacular landscape. The area is a Natura 2000 site and is tentatively being considered as a candidate UNESCO World Heritage Site. Four giant sinkholes dominate the landscape and coastline (sinkhole diameter in brackets): Dwejra (400 m) and Berwin (300 m) sinkholes, which have their base entirely flooded by the sea, Qawra Sinkhole

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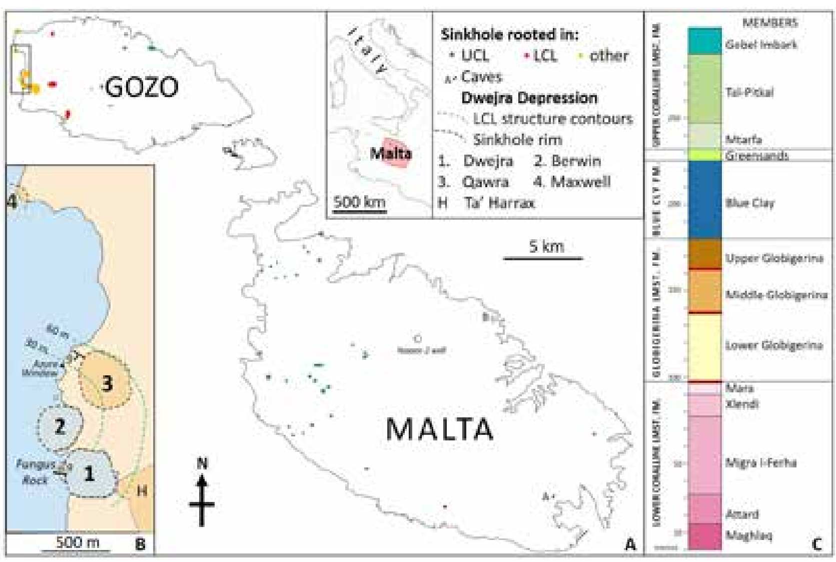

Figure 1: A. Location of the Malta Carbonate Platform (red shading) in Central Mediterranean and map of Maltese Islands showing location of sinkholes with diameter >40 m; B. Map of the four main sinkholes in western Gozo Dwejra Depression; C. Stratigraphic column of the Maltese Islands showing average thicknesses of members and formations.

Figure 2: (a) Dwejra Sinkhole (marked 1), flooded by the sea and Fungus Rock, a stack along the sinkhole rim; (b) Berwin Sinkhole (2) and lowest part of structural low; (c) Qawra Sinkhole (marked 3). Thick black lines are normal faults along sinkhole rim, oblique to the regional east-west trending normal and strike-dip faults. Location of now collapsed Azure Window; (d) Maxwell sinkhole (4); (e) Scutella subrotunda pavement exposed near Berwin Sinkhole; (f) Cross-bedded limestone of the Xlendi Member (location of e and f shown in photograph 2c).

(300 m), infilled with Blue Clay and Quaternary sediments and partly flooded, and a remnant of the here named, Maxwell Sinkhole (150 m) (***Figure 1B***). The sinkholes are nested in a larger structural depression, here named the Dwejra Depression. Although the base of the sinkholes is <100 m, which is less than that of deeper sinkholes (>240 m deep) in the European continent, e.g., Hranice Abyss (Czechia), Red Lake (Croatia), and Pozzo del Merro (Italy), their size, and their clustering within about 1 km^2, makes the sinkholes in western Gozo exceptional at the European level.

Discontinuities and differential marine erosion of the carbonate stratigraphy produced natural arches in Dwejra and Qawra sinkholes. A stack called Fungus Rock is what remains of collapsed arches. The most recent arch collapse was that of the spectacular Azure Window in March 2017, which was a background to epic fantasy films.

Stratigraphy

The Maltese Islands are the emergent parts of the >200 km-wide isolated Malta Carbonate Platform (***Figure 1A***) that aggraded >8 km of mostly carbonates since the early Mesozoic over the subsiding North African passive margin (Gatt & Gluyas, 2012). The Islands consist of five Oligo-Miocene formations (***Figure 1C***); the topmost Upper Coralline Limestone Formation (UCL) and the basal Lower Coralline Limestone Formation (LCL) consist of shallow marine carbonate sediments, with the latter extending to below sea-level, reaching a formation thickness that ranges from 200 to <400 m (Gatt, 2012). The range in thickness reflects the shallowing of the carbonate platform towards western Gozo (Pedley & Bennett, 1985), which is the result of antecedent Eocene bathymetry.

The sinkholes rims above sea level expose up to 80 m of cyclic shallow marine sedimentation of the Lower Coralline Limestone Formation (Oligocene), capped with <10 m of the pelagic Globigerina Limestone Formation (Miocene) that draped the drowned carbonate platform (***Figure 2***). Gatt (2012) sub-divides the Lower Coralline Limestone Formation into 7 depositional sequences that generally coincide with the 7 lithostratigraphic members (***Figure 3***), whereas the Globigerina Limestone is subdivided into 3 depositional sequences corresponding to the lower, middle and upper members. Each depositional sequence ends with a sequence boundary (Sb) that represents extensive shallowing marked by a distinct shift to negative (δ^{18} O = -3‰) stable isotopes (Gatt *et al.*, 2010). In the case of carbonate platforms, this represents subaerial exposure that produces sharp bedding planes and significant changes in carbonate lithology. Three Rupelian (SbRu1 to SbRu3) and five Chattian (SbCh1 to SbCh5) sequence boundaries are identified as sharp and distinct bedding planes in western Gozo (Gatt, 2012). In the pelagic Globigerina Limestone Formation, the depositional sequences end with a phosphorite bed produced during marine shallowing.

The geology of the sub-surface base of the Lower Coralline Limestone Formation can be deduced from data of two oil wells: (1) the Naxxar-2 dry well in Malta reports loss of well circulation at the base of the Lower Coralline Limestone Formation at a depth between 150 to 200 m below sea level. Further down the well, fluid loss is associated with cavernous and brecciated limestone; (2) the Aqualta Well in eastern offshore Malta records brecciated limestone along the base of the LCL and anhydrite at depths of 156 and 212 m, respectively, measured from the base of the Globigerina Limestone.

The nearly vertical wall of the Qawra Sinkhole exposes depositional sequences 4 to 7 of the Lower Coralline Limestone Formation (***Figure 4***). The early Chattian (depositional sequences 4 and 5) carbonate succession comprises abundant micrite, imperforate foraminifera and coral. The overlying circa 30 m-thick depositional sequence 6 (Migra l-Ferha Member) is entirely exposed and marks a dramatic change to coralline red algae deposition, characterised by thick beds of rhodoliths in coarse algal sand. The lower part of depositional sequence 7 includes large cross-bedding (***Figure 2f***) dominated by large benthic foraminifera, especially Lepidocyclina, corresponding to the Xlendi Member. Further up the succession, Mara Member sediments become more micritic where the echinoid

Depositional Sequence	Sequence boundaries	Lithostratigraphy Gatt (2012)	Thickness range (metres)	Dominant biota at Dwejra
8	SbCH5	Lower Globigerina Limestone Member	1 - >100	Planktonic foraminifera
7		Mara Mbr.	4 - 30	Echinoids
	SbCH4	Xlendi Mbr.	2 - 40	Large benthic foraminifera
6	SbCH3	Miġra l-Ferħa Member	30 - 60	Crustose coralline red algae and rhodoliths
5	SbCH2	Attard Member	20 - 30	Imperforate benthic foraminifera, coral and geniculate coralline algae
4	SbCH1	Magħlaq Member	25 - 50	Imperforate benthic foraminifera
3	SbRU3	Ghar Lapsi Member	50 - 80	
2	SbRU2	Żabbar Member	50? - 200	
1	SbRU1			

Figure 3: Depositional sequences and stratigraphic members of the Lower Coralline Limestone Formation and the eight sequence boundaries (Sb) spanning the Rupelian (Ru) and Chattian (Ch) stages. Grey shading indicates depositional sequences exposed in the Dwejra Depression.

Figure 4: Dipping beds and faults along the Qawra Sinkhole western rim and natural arch that allowed partial flooding of the sinkhole. Red lines mark sequence boundaries between sequences 6 to 8. Inset shows Azure Window prior to its collapse in March 2017.

scutella subrotunda forms dense pavements exposed in the area between the Berwin and Qawra sinkholes (*Figure 2e*).

Structural geology

Bedding is generally horizontal along the cliffed coastline of Gozo, except along the rim of the sinkholes in western Gozo. Structure contours of the top Lower Coralline Limestone confirm that a structural low is centred over Berwin Sinkhole (***Figure 1B and 2b***). Faults in the structural low are oblique to the regional normal and strike-dip faults which trend east-west. Normal faults along the rim of the Qawra Sinkhole step down into the structural low (***Figure 2c***), with antithetic faults developing in response to surficial extension (***Figure 3c***). The bedding dips 9° towards the southwest (***Figure 4***), whereas the bedding at Fungus Rock, a remnant of the western rim of the Dwejra Sinkhole, dips 9° north.

The structural low, here named the Dwejra Depression, developed by subsidence that produced surface extension. The depression is 1 km wide, although its axial length is mostly submerged and may extend to Maxwell Sinkhole and to ta' Harrax, east of Dwejra Sinkhole. The Dwejra Depression suggests the development of a large subsurface chamber with a roof span of hundreds of metres. The gradual subsidence of the cavern roof produced the structural depression with concomitant concentric faulting preserved along the rim of the Qawra Sinkhole (***Figure 2c***). At a later stage, large parts of the cavern roof collapsed, producing the large vertical sinkholes that cut into the dipping limestone of the structural depression. The upward void migration produced a considerable volume of breccia. Volume increase by bulking as well as the surface subsidence of tens of metres had to be compensated by the spread of breccia into the intact part of the subsurface cavern.

The faults and vertical joints along the coast were susceptible to differential marine erosion, creating several natural arches in the Dwejra Depression, e.g., Azure Window and arches in Fungus Rock and Qawra Sinkhole. The growth and eventual collapse of these arches became the main process of the erosion of the rim of the sinkholes, sometimes leaving stacks behind, as in the case of Fungus Rock in the Dwejra Sinkhole, or complete collapse, as in the case of the Azure Window.

Discussion

Circular collapse structures related to carbonate or evaporite dissolution have been widely reported in the Mediterranean. Most of the sinkholes in the Maltese Islands are karst features created by carbonate dissolution along major joints, rooted in the horizontally-bedded Upper and Lower Coralline Limestone formations. The two limestone formations have enough compressive and tensile strength to support large caverns. The accessible, larger intact cave systems in Malta (***Figure 1A***) are also found in these two formations and are characterised by narrow (<30 m) and long (<150 m) geometry controlled by jointing. When the caverns reach a critical size between 40 to <250 m-wide as a result of carbonate dissolution, the cavern roof collapses, forming a sinkhole.

The sinkholes in the Dwejra Depression differ from the other sinkholes in the Maltese Islands for three reasons: 1) the large sinkholes are clustered together, 2) the rock between the sinkholes is dipping, and 3) the size of the depression is indicative of the development of a much larger cavern size, over 1 km wide. These factors suggest a mechanism responsible for the Dwejra Depression that differed from that for other sinkholes in the Maltese Islands, formed by the post-Miocene dissolution of limestone. The clustering and large-sized sinkholes in the Dwejra Depression of Gozo resemble those found in the offshore Eastern Mediterranean formed by the dissolution of Messinian evaporites which can be >1 km wide (Bertoni & Cartwright, 2005). However, Messinian evaporites are absent over the Maltese Islands and their shelf area (Gatt, 2007). A deeper, underlying mechanism for sinkhole formation linked to the Cenozoic geometry of the Malta Carbonate Platform is proposed.

Western Gozo was a bathymetric high of the Malta Carbonate Platform during the Miocene, when it was subject to erosion by strong currents (Pedley & Bennett, 1985). During the Palaeogene, the same area experienced episodes of subaerial exposure. The base of the LCL coincides with the Oligocene-Eocene boundary which correlates to evaporites that were widespread in North Africa and produced during regional arid climatic conditions (Gerdes *et al.*, 2010). The Maltese well data supports deposition of extensive evaporites at this level as evidenced by brecciated limestone from collapsed caverns and anhydrite in Naxxar and Aqualta wells. Western Gozo may have experienced sabkha-type of environments during Late Eocene subaerial episodes which could have produced several tens of metres of evaporites.

The density and size of the sinkholes in western Gozo suggest the dissolution of top Eocene evaporites underlying the *circa* 200 m-thick Lower Coralline Limestone Formation, as the single underlying process for the formation of the Dwejra Depression. Evaporite salt beds are prone to dissolution by infiltration of undersaturated water, especially during prolonged sea-level drawdowns, as happened during the Messinian salinity crisis.

The cavern roof collapses when it reaches a critical thickness (t) and the cavern reaches a critical width (w). Studies on sinkholes found that the stability of caverns generally followed the relationship t = 0.7 w (Waltham *et al.*, 2005). Based on this relationship, the 300-metre-wide Qawra Sinkhole would have collapsed when the cavern roof thickness beneath it diminished to *circa* <200 m, which is the entire thickness of the Lower Coralline Limestone Formation.

A three-stage development of the Dwejra Depression through time is proposed (***Figure 5***):

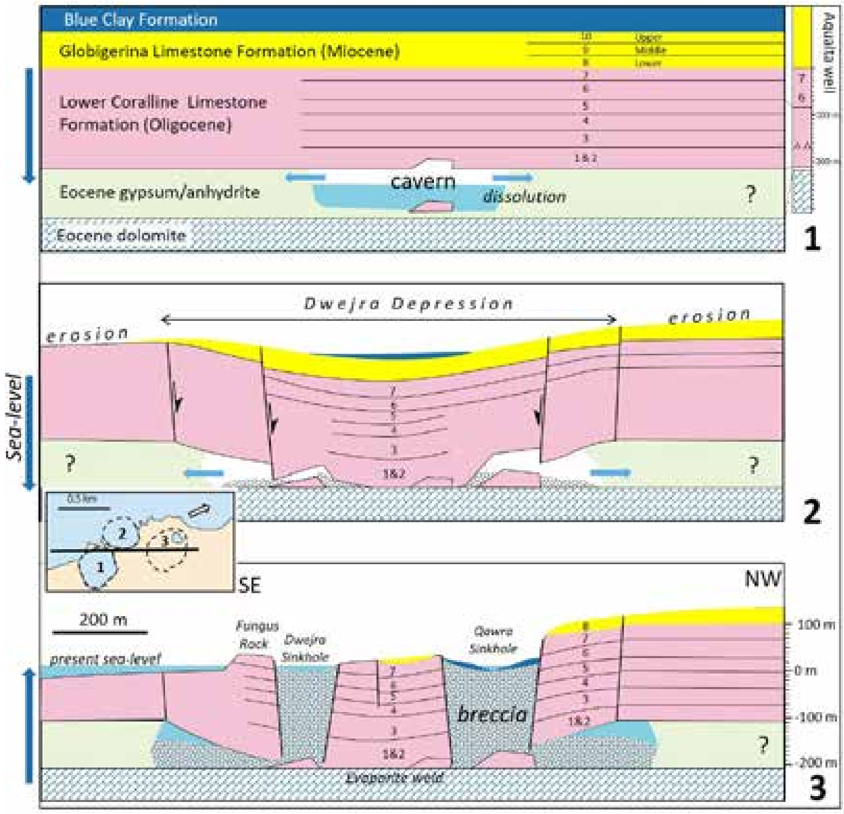

Figure 5: Proposed development of the Dwejra Depression and sinkholes based on a NW-SE cross section. Sedimentary succession at the Dwejra Depression is correlated to the Aqualta Well offshore Malta.

1. During the Pleistocene glacial period, sea level was 120 m below present, which would have exposed evaporites along the Eocene-Oligocene boundary to freshwater dissolution. The dissolution of gypsum/anhydrite formed an incipient cavern beneath the horizontally bedded Lower Coralline Limestone Formation.
2. The subsidence of the limestone over the cavern created concentric faults and dipping forming the structural low. The load was diminished by erosion, especially of the softer Blue Clay and Globigerina Limestone formations.
3. Continued subsidence and evaporite dissolution welded the Lower Coralline Limestone with the top Eocene carbonates. Holocene sea-level rise flooded the cavern and saturated the limestone, causing a reduction in its strength, already weakened by faulting and jointing. Parts of the cavern roof collapsed to form the four large sinkholes in the Dwejra Depression. The breccia produced spread into the intact parts of the subsurface cavern. The rim of the sinkholes preserves the dipping bedding of the Dwejra Depression. Most of the Globigerina Limestone has been eroded from the Dwejra Depression, and an outlier of transported Blue Clay is preserved in the Qawra Sinkhole.

The seven depositional sequences of the Lower Coralline Limestone Formation are interpreted as having formed during third-order sea-level cycles of circa 1.2 Ma duration, controlled by the waning and waxing of the Antarctic ice sheet, when the Earth had a unipolar ice-sheet. The changes in biota and level of micrite up the succession are interpreted as suggesting shallow marine to restricted conditions during depositional sequences 4 and 5, when oligotrophic sea conditions stimulated high carbonate production. Depositional sequence 6 suggests deeper, moderate energy, open marine and mesotrophic conditions. The sequence abruptly changes along SbCH4 to shallow, high energy, open marine deposits in the lower part of depositional sequence 7. Further up, sea-level deepened. The lithological changes are interpreted as resulting from meridional climatic shifts in North Africa which was relatively dry during depositional sequences 4, 5 and 7, but became more humid during the depositional sequences 6 and 8, resulting in greater continental fluvial discharge of nutrients into the Neotethys, creating a mesotrophic sea where coralline red algae (Migra l-Ferha Member) could thrive (Gatt & Gluyas, 2012). Eventually, the carbonate platform was drowned during eutrophic marine conditions that deposited sporadic phosphates, and later draped with pelagic sediment of the Globigerina Limestone Formation (Gatt *et al.*, 2009).

Conclusions

- The size of the sinkholes in western Gozo exceeds 300 m diameter. The sinkholes are clustered within the 1 km-wide structural depression, here named the Dwejra Depression.
- The limestone depositional sequences exposed along the sinkhole walls show cyclic sea-level changes that throw light on the Oligocene palaeoclimate.
- The mode of formation of the sinkholes in limestone is related to subsurface evaporite dissolution unlike the other sinkholes in the Maltese Islands which are the result of limestone dissolution.
- The dissolution of evaporites could have occurred by infiltration of meteoric water during the Messinian sea-level drawdown.
- The concentration of sinkholes nested in the Dwejra Depression makes this area an of exceptional geological heritage at the European level.

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Unearthing Europe's Bronze Age mining heritage with tin isotopes: a case study from Central Europe

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Being exclusively placer-based, evidence of prehistoric tin mining in Europe was erased rapidly in the fluvial environment. Circumstantial evidence has suggested that the tin ores of the Erzgebirge along the German-Czech border were exploited in the Bronze Age. To investigate this further, tin ores from the three Erzgebirge plutons, as well as Cornwall, were isotopically characterized and compared with the Sn isotopic composition of Bronze Age tin-bearing artifacts from the region. After accounting for isotopic fractionation associated with the smelting process, a probabilistic approach indicates that at the transition to the Middle Bronze Age, the predominant mining center was the Central Pluton, but mining activity shifted to the Western Pluton for the remainder of the Bronze Age.

Etant exclusivement d'origine alluvionnaire, l'évidence d'exploitation minière d'étain en Europe fut rapidement effacée dans un contexte environnemental fluvial. Une preuve circonstancielle a suggéré que les mines d'étain de l'Erzgebirge, le long de la frontière germano-tchèque, furent exploitées pendant l'Age de Bronze. Une investigation plus poussée dévoile que les mines d'étain des trois massifs plutoniques de l'Erzgebirge, de même que celles de Cornouailles furent caractérisées du point de vue isotopique et comparées – composition isotopique de l'étain - avec les artefacts à étain de l'Age de Bronze de la région. D'après les données de la fracturation isotopique associée à un processus de fusion, une approche à l'aide de probabilités indique qu'au moment de la transition vers l'Age de Bronze, le cœur de l'exploitation minière correspondait au massif plutonique central mais les activités minières se déplacèrent ensuite pour occuper le Massif ouest, durant la période restante de l'Age de Bronze.

Al estar exclusivamente basado en sitios puntuales, la evidencia de la minería prehistórica de estaño en Europa se borró rápidamente en el entorno fluvial. La evidencia circunstancial ha sugerido que los minerales de estaño del Erzgebirge a lo largo de la frontera germano-checa fueron explotados en la Edad de Bronce. Para investigar esto más a fondo, los minerales de estaño de los tres plutones Erzgebirge, así como Cornwall, fueron caracterizados y comparados isotópicamente con la composición isotópica del estaño de los artefactos de la región en la Edad del Bronce. Después de considerar el fraccionamiento isotópico asociado con el proceso de fundición, un enfoque probabilístico indica que, en la transición a la Edad del Bronce Media, el centro minero predominante era en el Plutón Central, pero la actividad minera se trasladó al Plutón Occidental durante el resto de la Edad del Bronce.

Introduction

The discovery and characterization of mineral resources remains a cornerstone of applied Earth Science.

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Since the invention of extractive metallurgy in the Balkans 7,000 years ago, human technological and social development has been inextricably tied to the availability of mineral resources, as is evident in the fundamental three-age system of European prehistory: Stone Age, Bronze Age, and Iron Age. However, much of Europe's ancient mining heritage remains to be discovered.

Extensive bedrock mining of European copper, dating as far back as the Eneolithic (ca. 5000 BC), has been documented in Serbia and Bulgaria. Although extensive subsurface and open pit tin mines dating to the Bronze Age have been documented in arid regions of Iran, Central Asia, and Central Turkey, such mines are absent in Europe. This is due to the contrasting climatic conditions. Weathering and fluvial processes associated with Europe's temperate to Alpine climate produced placer tin deposits from the natural breakdown of bedrock ores. Being easier to work and requiring fewer resources, placer deposits were exploited rather than the nearby bedrock ores from which they were derived. Unfortunately, the wooden tools associated with sluicing and panning are unlikely to be preserved, and the mining process itself leaves only ephemeral scars (Tolksdorf *et al.*, 2019). Consequently, the archaeological record of early tin mining in Europe has been largely erased in dynamic fluvial environments.

Lead isotopes have been used in archaeological studies of copper ore provenance for decades, given that Pb isotope compositions can indicate potential ore sources based on the age of the ore from which the metal was smelted. Although this approach has been used successfully to link Late Bronze Age tin ingots from the eastern Mediterranean with Variscan ores (Berger *et al.*, 2019), Pb isotopes cannot be applied to tin provenance studies for bronze, for which the signature is derived from the volumetrically predominant copper ore. The recent development of analytical techniques for the measurement of tin isotope composition has been considered a promising means for approaching tin ore provenance and thereby determining mining practices associated with the prehistoric production of tin bronze.

Recent studies of tin ores and tin-bearing artifacts from Central Europe and the Mediterranean suggest that multiple tin sources were in use across Europe in the Late Bronze Age, including those of Cornwall and the Erzgebirge (Berger *et al.*, 2019; Nessel *et al.*, 2019). However, confidently assigning ore provenance has been considered problematic due to the extensive compositional overlap between metalliferous regions, with the geological processes that produced this extensive fractionation being undocumented.

Although there are 29 radioactive isotopes of tin, none have half-lives long enough for geological time frames; 126Sn has the longest half-life of 100,000 years. So, unlike Pb, there is no age dependence in the Sn system. A given mining region is likely to have similar bulk average Sn isotopic compositions inherited from the source rocks from which the tin granites were derived, and the partitioning of Sn between the magma and the residual rock during anatexis. However, isotopic variation between deposits or ore zones may result from fractionation during ore genesis.

Precipitation of cassiterite requires the oxidation of tin from Sn^{2+} to Sn^{4+}, and the stronger bonding environment associated with oxidized tin favors the heavier isotopes (Yao *et al.*, 2018; Wang *et al.*, 2019). Thus, redox-related Raleigh fractionation results in the progressive enrichment of lighter isotopes over time (Yao *et al.*, 2018). Thus, small, rapidly formed ores would be expected to have more homogenous isotopic compositions, whereas larger deposits in which the reaction front had advanced significantly over time would likely exhibit a more heterogeneous and zoned isotopic signature. Evolution of a vapor during ore formation also induces fractionation of tin isotopes, resulting in enrichment of heavier isotopes in the vapor, leaving the residual fluids with lower $\delta^{124}Sn$ values (Wang *et al.*, 2019). Thus, ores formed at shallower depths at which boiling is possible will exhibit greater degrees of Sn fractionation (Wang *et al.*, 2019). These processes may lead to isotopic fingerprints of related ore bodies that would match that of their derived metals.

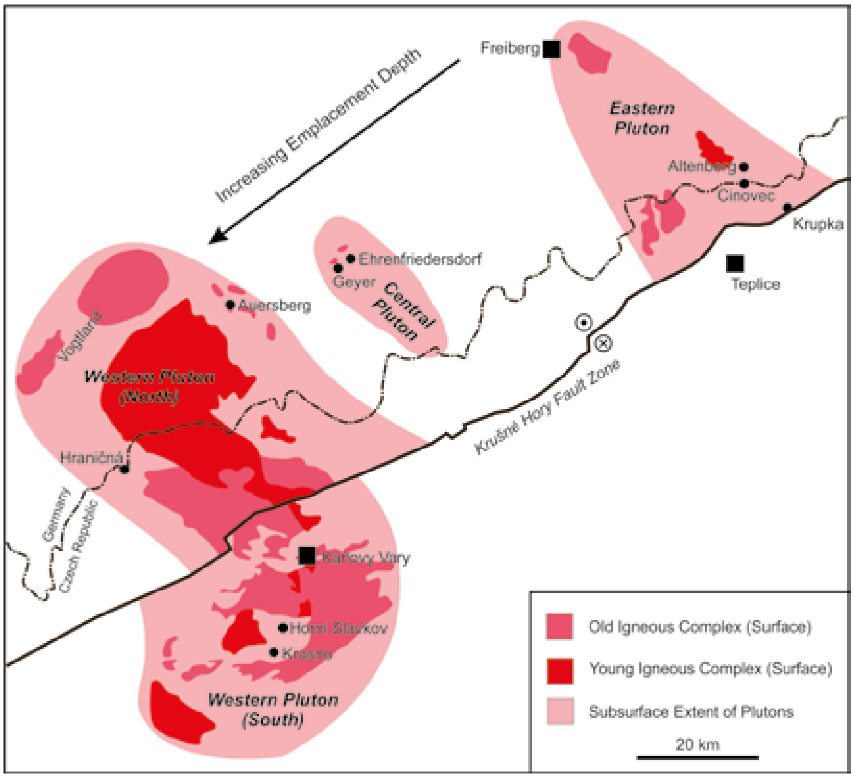

Figure 1: Granitic plutons of the Erzgebirge region. Named sites on this map refer to sites from which cassiterite samples were obtained.

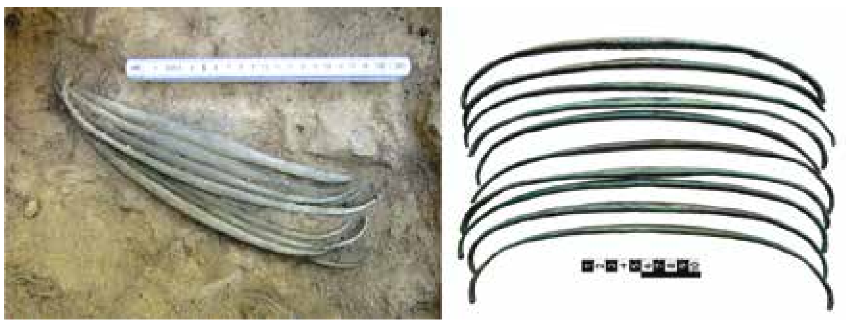

Figure 2: Rib ingots from the hoard at Habří, South Bohemia.

A case study in Central Europe

The Erzgebirge (Ore Mountains) of Saxony and Bohemia is a classic ore locality that hosts both copper and tin mineralization. In this region, tin mining (both bedrock and placer) has been documented as far back as the 12th century at Ehrenfriedersdorf and Altenberg, and Agricola's *De Re Metallica* (1556) includes references to the mining of Erzgebirge placers. Archaeological evidence of prehistoric mining of these ores has been mostly circumstantial, based on the spatial association of placer tin sources with clusters of Early Bronze Age Únětice culture and Late Bronze Age Lausitz culture settlement sites. However, a recent geoarchaeological study documented direct evidence of placer mining near Altenberg in the early second millennium BC (Tolksdorf *et al.*, 2019).

The Carboniferous granites (330-295 Ma) that are associated with tin mineralization in the Erzgebirge include the fault-dissected Western pluton, the poorly exposed Central pluton, and the Eastern pluton (***Figure 1***). The granitic magmas were produced from the late syn-collisional melting of Sn-enriched sedimentary rocks derived

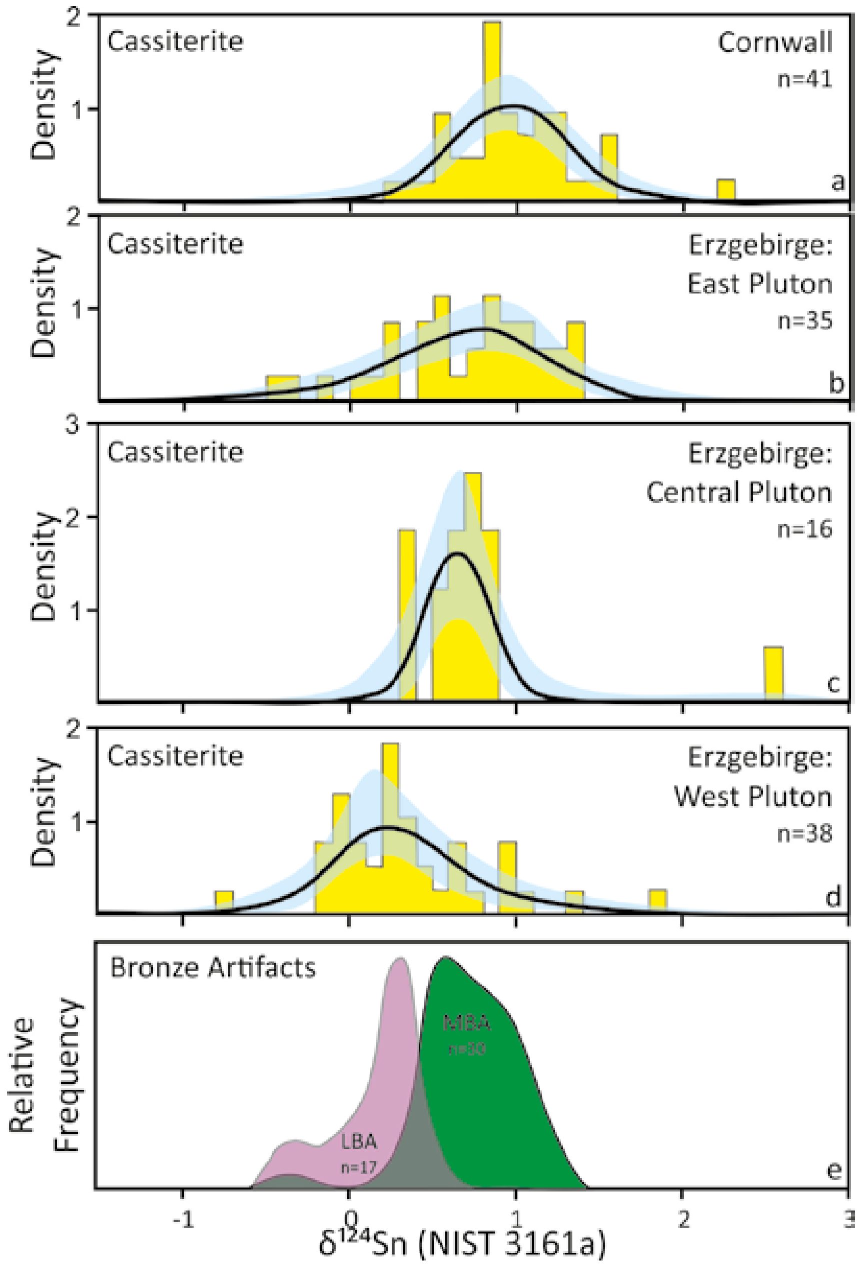

Figure 3: Histograms of δ^{124}Sn values for cassiterite and bronze samples. (a through d) Histograms in yellow, and model curves for the cassiterite data the black curve is the 50% quantile density for each δ^{124}Sn value across posterior samples, blue bands mark the ±2.5% quantile density. (e) Histograms of bronzes from two time periods of the Bronze Age. MBA=Middle Bronze Age; LBA=Late Bronze Age; n=number of samples.

from the erosion of Gondwana (Romer & Kroner, 2016). Mineralization is predominantly associated with greisens and, to a lesser extent, vein systems. Tectonic tilting of the section resulted in larger, more deeply eroded, predominantly S-type plutons being exposed in the southwest, and smaller, A-type, volcanic-associated plutons to the northeast (Breiter, 2012). Such variation in geological setting would be expected to be associated with variation in Sn isotopic composition between the plutons.

Here we focus on the Erzgebirge and its potential exploitation at two points in prehistory: the later phase of the Early Bronze Age and at the beginning of the Middle Bronze Age (Reinecke BrA2 to BrB1, c. 1900–1500 BC); the latter Late Bronze Age (Reinecke BrB2 to HaA, c. 1500-1000 BC). Given their proximity and size, deposits of the Erzgebirge and Cornwall are the most likely sources of tin at this time.

To characterize the ores, the isotopic composition of 43 new cassiterite samples (predominantly single crystals from the collection of the American Museum of Natural History) from the Erzgebirge and 14 from Cornwall were added to the dataset of Haustein *et al.* (2010) for a total of 89 samples from the Erzgebirge (38 from the West Pluton; 16 from the Central Pluton; 35 from the East Pluton), and 41 from Cornwall. Cassiterite samples were digested following the procedure of Mathur *et al.* (2017).

Bronze Age copper ingots in the shape of ribs (***Figure 2***) are widespread mainly in southern Germany, Upper Austria and South Bohemia. Specifically, more than 40 hoards of these ingots are known in the South Bohemian region. Copper ribs are found almost exclusively in hoards, which usually contain tens, but sometimes hundreds of ribs. The largest hoard so far was found in Oberding in Upper Bavaria in 2014 and contained 796 ingots.

The precise chronological definition of rib ingots occurrence is difficult, as hoards generally do not contain any types of chronologically sensitive artifacts. In general, their occurrence can be expected in the later phase of the Early Bronze Age and at the beginning of the Middle Bronze Age, according to the Central European chronology A2 and B1 periods. The weight of the rib bars has a relatively large dispersion, but on average it is around 100 grams. The rib ingots have a relatively varied elemental composition, sometimes including tin (up to 3%) and, in rare cases, large amounts of lead (up to 38%).

In this study, 30 rib ingots from five Bohemian hoards (Habří, Kroclov, Kučeř, Slavč, Veselíčko) with a range of 0.4 to 3.5 wt% Sn were analyzed. In addition, 17 later bronze items (BrB to HaA) including pins, wires, bracelets, and axes from museum collections in České Budějovice, Prague, and Salzburg were analyzed. Samples were obtained either by drilling with cobalt-tipped bits or cutting with cubic boron nitride cutting wheels, after the patina was removed. Approximately 0.02-0.1g of each bronze sample was digested in ultrapure aqua regia (3ml HCl, 1ml HNO_3) to which 0.02ml HF was added. Samples were heated at 90°C for 6 hours in enclosed Teflon containers.

A small aliquot of each sample solution was dried and the redigested solutions were purified using the ion exchange chromatography described in Balliana *et al.* (2013). Samples were measured on the Isoprobe MC-ICPMS at the University of Arizona and the Neptune MC-ICPMS at Rutgers University within 24 hours of digestion. Solutions were measured and corrected

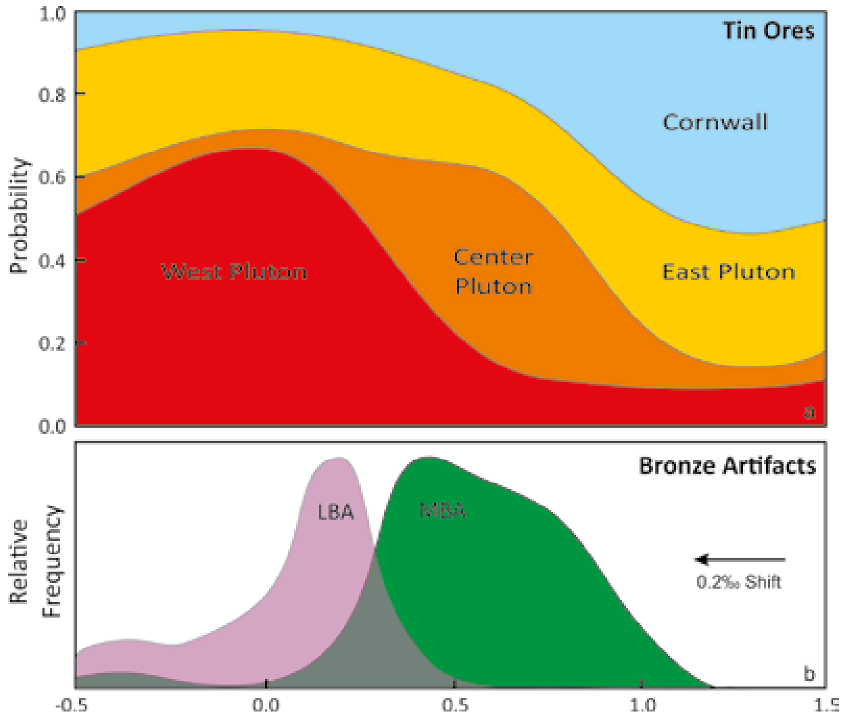

Figure 4: (a) Posterior probability bands as a function of δ¹²⁴Sn value assuming the prior probability of all four sources is equal. (b) Isotopic composition of bronze artifacts corrected for smelt-associated fractionation (-0.2‰).

Table 1. Probability of derivation of tin from groups of artifacts from a single ore source.

Artifact Assemblage	*Smelt Fractionation*	*Provenance Probability*			
		West Pluton	*Central Pluton*	*East Pluton*	*Cornwall*
EBA-MBA	*0.0*	*0.0%*	*0.6%*	*0.7%*	*98.7%*
EBA-MBA	*0.2*	*0.0%*	*99.8%*	*0.2%*	*0.0%*
MBA-LBA	*0.0*	*87.4%*	*11.0%*	*1.6%*	*0.0%*
MBA-LBA	*0.2*	*99.9%*	*0.0%*	*0.0%*	*0.0%*

for mass bias as described in Mathur *et al.* (2017). Data are presented relative to the NIST 3161A Sn standard (Lot# 07033) in per mil notation defined as:

$$\delta^{124}Sn‰ = \left(\frac{\left(\frac{^{124}Sn}{^{116}Sn}\right)sample}{\left(\frac{^{124}Sn}{^{116}Sn}\right)NIST\ 3161} - 1 \right) * 1000$$

Whole procedural 1σ errors for analysis are $\delta^{124}Sn$= 0.08‰.

Histograms of the Sn isotopic compositions of cassiterite from these four sites are illustrated in ***Figure 3*** as bar graphs. Model curves for the cassiterite data were calculated using a Bayesian framework by sampling for the parameters of a three-component Gaussian mixture density using the Stan programming language (***https://mc-stan.org/users/citations/***) called with the rstan R package, a platform for statistical modeling and statistical computation (***https://www.R-project.org/***). In ***Figure 3***, the black curve is the 50% quantile density for each $\delta^{124}Sn$ value across posterior samples and the blue bands mark the +/-2.5% quantile density. Although there is substantial overlap between sites, variations in mean and range are evident. As was predicted based on the geological setting of the three plutons of the Erzgebirge, the deeper level ores of the West Pluton exhibit the lowest degree of fractionation (***Figure 3d***), and the East Pluton tends to higher values of $\delta^{124}Sn$ (***Figure 3b***). The isotopic composition of Cornwall and the East Pluton are similar (***Figure 3a and b***), although Cornwall tends toward slightly higher values.

The two groups of bronze artifacts from Central Europe exhibit distinct isotopic distributions. The older rib ingots have a modal peak of $\delta^{124}Sn$ 0.65‰ and a positively skewed distribution, whereas the group of younger artifacts have a $\delta^{124}Sn$ mode of 0.4‰ and are negatively skewed (***Figure 3e***). This indicates a change in tin ore source from the Early-Middle Bronze Age transition to the Middle and Late Bronze Age.

Given that there is a compositional overlap between the four localities, a probabilistic approach was adopted. ***Figure 4*** plots posterior probability bands as a function of $\delta^{124}Sn$ value assuming the prior probability of all four sources are equal (0.25). The probability bands in ***Figure 4*** apply to single observations. In order to assign provenance probabilities to assemblages of artifacts, which consist of multiple observations with differing $\delta^{124}Sn$ values, we implemented a model in which all artifacts were assumed to originate from the same source. The likelihood that each source gave rise to the assemblage was calculated, averaged across Bayesian samples of the cassiterite densities. Assuming, as before, that each source has the same prior likelihood, the posterior likelihood is proportional to these averaged likelihoods, normalized such that the posterior likelihood sums to one.

Kazenas *et al.* (1996) noted that SnO_2 evaporates at a noticeable rate above 1225°C, a process likely to induce fractionation. Furnace-based casting experiments at 1100–1200°C documented a 0.5‰ per amu shift in composition along the surface due to selective evaporation of lighter isotopes of tin (Yamazaki *et al.*, 2014). Based on cassiterite smelting experiments, Berger *et al.* (2019) concluded that a negative shift of 0.25 ‰ per amu in the composition of tin-bearing artifacts is required before comparisons are made with isotopic compositions of ores in order to compensate for smelting induced fractionation. Accordingly, the provenance probability model was run using the measured $\delta^{124}Sn$ isotopic values of artifacts, as well as measured $\delta^{124}S$ minus 0.2‰ (124/116, 8 amu). The results are shown in ***Table 1***.

Assuming that the tin for the Middle to Late Bronze Age artifacts from the Czech Republic and Austria was derived from one of the four tin sources studied here, there is a high probability that the ore was associated with the West Pluton of the Erzgebirge (99.9% with -0.2‰ correction; 87.4% without correction). The Sn isotopic composition of the older rib ingots indicate that the associated tin was sourced from a different site. If one includes the correction for evaporative loss during smelting, then the model indicates that there is a 99.8% probability that the tin ore was derived from the Erzgebirge Central Pluton. If, however, the uncorrected value is used, the model indicates a 98.7% probability that the tin was of British origin. Given that there is no archaeological evidence for a strong trading connection between Britain and Bohemia in the late Early Bronze Age, the Central Pluton provenance associated with the 0.25‰ per amu correction factor for smelting induced fractionation is considered more likely. This would provide empirical evidence to support the experiment-based conclusion of Berger *et al.* (2019), and that this correction factor should be used in future Sn provenance studies.

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EFG Strategic Plan 2018-2022

Towards a sustainable future

1. EFG Members

Developing and maintaining a strong EFG Member network

- To network for sharing knowledge, good practices and experience
- To disseminate policymaker agendas to National Associations (NAs)
- To facilitate information flow between Members and policymakers
- To represent geologists

2. EFG Network

Participation in the global community and maintaining international networks

- To participate in initiatives contributing to European policies on geosciences issues
- To enhance cooperation with international geoscience organisations
- To promote the global mobility of professional geologists

3. Professional expertise

Promotion of geoscience professional excellence

- To promote the EurGeol title and uphold the status of professional titles
- To support the development and expansion of the Competent Person concept
- To promote Continuing Professional Development, supporting geoscientific education and high-quality training
- To promote professional specialisation and public access to registers of geoscience experts
- To support early career geoscientists
- To ensure monitoring of and strict disciplinary control over professional practice

4. EFG Projects

Participation in EU and international funded projects

- To participate in funded projects to expand the network and EFG's capacity to influence policymakers
- To diversify income streams

5. EFG Communication

Accessible communication of geosciences and outreach

- To create public awareness of the importance of geoscience to society by promoting public outreach and understanding of geosciences
- To communicate transparently to National Associations and other audiences

6. Panels of Experts

Provision of independent, reliable information on geoscientific issues

- To provide information to policymakers that is authoritative and objective
- To become the European organisation of reference on the professional practice of geoscience

European Federation of Geologists
The voice of European Geologists
www.eurogeologists.eu

News corner:
Compiled by Anita Stein, EFG Office

EFG welcomes Glen Burridge as its new Executive Director

On 1st October 2019 Glen Burridge took up the role of the Executive Director of the European Federation of Geologists (EFG), succeeding Isabel Fernández Fuentes.

"As someone passionate about gaining greater recognition for the importance of earth science – and the role of the geologist in telling that story – I'm delighted to have the rare opportunity to join an organisation at the heart of shaping that message in Europe both through its professional and project activities. I look forward to working with our national association members and EFG's incredibly dynamic Board to play our part in responding to the critical themes of energy transition, climate change, societal engagement and raw materials supply firmly on Europe's agenda." Glen Burridge, new Executive Director, EFG

Glen brings to this multi-national organisation more than 20 years of global experience as a geologist and management advisor on subsurface energy projects, where he developed a reputation as a trusted voice on technical excellence, project governance and capability development.

In recent years, he has driven several cross-industry efforts concerning risk and the use of geological models, including three recent pioneering conferences for the Geological Society of London: Sharing an Uncertain World: Lessons in Managing Risk, Managing Risks across the Mining and O&G Lifecyle and 4D Subsurface Modelling: Predicting the Future.

He has a diverse background, having worked across the spectrum of geosciences for a number of international oil & gas operators as well as specialist consultancies and research institutes. His keynote talks at international conferences have tackled topics as wide-ranging as novel ways of viewing resource exploration risk and the future of geomechanics as a discipline to the human factor in geomodelling and the importance of intercultural competence.

Glen is a Platinum member of the European Association of Geoscientists & Engineers (EAGE) and co-founded the Geomechanics Technical Section of the Society of Petroleum Engineers (SPE).

He has a Bachelors of Science in Geophysics from the University of Edinburgh in Scotland and a Masters of Science and Diplôme d'ingénieur in Petroleum Geoscience from IFP's Ecole du Pétrole et des Moteurs in Paris. He has lived and worked in multiple locations across Europe, North Africa, Middle East, India and Australia.

Federation thanks Isabel Fernández Fuentes for outstanding contribution

To embark on new professional adventures, Isabel Fernández Fuentes has moved back to Seville in Spain at the end of September after managing EFG's Brussels office for more than 17 years.

Isabel began her professional career with a decade in applied research, implementing geophysical technologies for the Spanish ministry of public construction. She set up the EFG office in Brussels in the early 2000s, establishing its credentials at the heart of Europe and developing crucial links with the EU institutions.

In the next instalment of her career, she intends to unite these two elements, focusing on coordinating projects which contribute to the energy transition and sustainable development in Europe. With this target in mind, she has recently taken up the role of Project coordinator of the CROWDTHERMAL project on behalf of EFG, which kicked off during September, and so she will firmly remain part of the EFG network.

Isabel is excited about this new career step and looks back on her longstanding role as the EFG Executive Director:

"It has been a real privilege managing the EFG office over these years. EFG is a continuous source of learning, which has helped me to understand the European project with its challenges, but also opportunities, to share experiences and understand what unites us across Europe and beyond."

EFG took the opportunity to thank Isabel for her outstanding contribution to the organisation during a festive reception on 25 September attended by dozens of her European and Belgian colleagues, an event which also enabled Glen Burridge to be officially introduced to EFG's Brussels network.

On this occasion of change of Executive Director, the EFG Board and staff wish the greatest of success to both Isabel and Glen in their new endeavours!

EFG releases position paper on the energy transition

On 20 June 2019 the European Federation of Geologists (EFG) released its position paper on the energy transition. As Europe is accelerating the transition from fossil fuels to renewable energy to meet the goals set by the ratified Paris Agreement on climate, the EU will need to develop the means to achieve those ambitious targets. Based on the expertise that professional geologists provide, EFG believes geothermal energy (both shallow and deep geothermal), CO_2 capture, and mineral extraction are part of the answer to the challenges set out by the climate crisis. All three geological activity areas are developed in EFG's position paper that can be downloaded here: ***http://bit.ly/2XVOQip***

Bill Gaskarth receives EFG Medal of Merit

In recognition of his major contribution to the development and wide recognition of the status of professional geologists both nationally and internationally, the Geological Society of London (the Society or GSL) proposed Dr JW (Bill) Gaskarth for award of the EFG Medal of Merit in 2018. The official award ceremony took place during the recent EFG Council meeting in Delft, the Netherlands.

Bill, as he is universally known, was appointed as GSL's first Chartership Officer in 2009 and was pivotal to the development and strengthening of the Chartership process within the Geological Society. In the light of his long-term commitment, exemplified by his exceptional and distinguished contribution to the geological profession, EFG considers Dr Gaskarth to be a very worthy recipient of the EFG Medal of Merit.

Read more: ***https://eurogeologists.eu/bill-gaskarth/***

EAGE/EFG photo contest 2019

EFG and EAGE are pleased to announce the winners of the 2019 edition of the "Legends of geoscience" photo contest. We have received many amazing photos depicting the categories Geosciences for society, Women geoscientists, and Landscape and environment. Thank you to all who have participated in the contest and in the public voting that allowed us to determine the winners of this edition.

Congratulations to the winners and thanks for sharing your passion for geosciences with the public!

More information: ***https://eage.eventsair.com/photocontest***

First prize: "The Himalayas – A Folded and Faulted Beauty Undergoing Weathering" by Soumya Chandan Panda

"This photo was taken in the North of India. The Himalayas were born from extreme conditions as two continental plates collided. These majestic mountains are a geoscientist's paradise with their folded and faulted structures and so many secrets unexplored. The weathering induced by ice water and wind can be clearly seen in the picture. One is simply awestruck standing in front of these legendary mountains."

Second prize: "The Vinicunca Legend" by Dario Chisari

"In 2016 I travelled all the way to Peru just to take one single photo. This one. I think this peak fully deserves to be considered as a legend of geoscience. It used to be a much harder (6 days) hike to get all the way up to the Vinicunca (also known as the Rainbow Mountain). I got discouraged many times due to difficult meteorological conditions and a thin layer of snow which wouldn't have given such a crisp image. Nowadays a new road opened up and it's much easier to get to the top (about 3 hours). Needless to say that meteorological conditions can change here at any moment….I think that was even more than I could possibly have dreamed of for my 32nd birthday."

Third prize: "The Solution of the Student Hammer in the 21st Century" by Camille Thomasset

"This photo shows students of Savoie Mont Blanc University during an end-license trip in Morocco. We can see here the size of the mine truck behind those brave looking students. I have chosen this picture because we worked hard to organise this trip and mining is essential nowadays for society."

Horizon 2020 projects

Horizon 2020 is the biggest EU research and innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in five active Horizon 2020 projects: INFACT, INTERMIN, MINLAND, ROBOMINERS, and CROWDTHERMAL. The projects CHPM2030 and UNEXMIN recently closed, but new projects have already been granted and will start soon. Below you will find descriptions of the topics and aims of these projects.

CHPM2030

654100 - CHPM
Combined Heat, Power and Metal extraction from ultra-deep ore bodies
START DATE: 1 January 2016
DURATION: 42 MONTHS
http://chpm2030.eu

Objectives:

The CHPM2030 project aimed to develop a novel pilot-level technology which combines geothermal resource development, minerals extraction and electro-metallurgy in a single interlinked process. In order to improve the economics of geothermal energy production the project investigated possible technologies of manipulating metal-bearing geological formations with high geothermal potential at a depth of 3-4 km in a way that the co-production of energy and metals will be possible and may be optimised according to the market demands in the future. Led by the University of Miskolc, the project was implemented in the cooperation of 12 partners from 10 European countries.

UNEXMIN

690008 - UNEXMIN
Autonomous Underwater Explorer for Flooded Mines
START DATE: 1 February 2016
DURATION: 45 MONTHS
www.unexmin.eu

Objectives:

UNEXMIN was an EU-funded project that develops a novel robotic system for the autonomous exploration and mapping of Europe's flooded mines. The Robotic Explorer (UX-1) was designed to use non-invasive methods for autonomous 3D mine mapping for gathering valuable geological and mineralogical information. This will open new exploration scenarios so that strategic decisions on the re-opening of Europe's abandoned mines can be supported by actualised data that cannot be obtained by other ways.

The Multi-robot Platform represents a new technology line that is made possible by recent developments in autonomy research that allows the development of a completely new class of mine explorer service robots capable of operating without remote control. UX-1 was the first robot of its kind. Research challenges were related to miniaturisation and adaptation of deep-sea robotic technology to this new application environment and to the interpretation of geoscientific data.

Work included component validation and simulations to understand the behaviour of technology components and instruments to the application environment, construction of the first prototype, development of post-processing and data analysis tools and pre-operational trials in real-life conditions. The final, most ambitious demonstration took place in the UK with the resurveying of the entire flooded section of the Ecton underground mine (UK), which nobody had seen for over 150 years.

MINLAND

776679 – MINLAND
Mineral resources in sustainable land-use planning
START DATE: 1 December 2017
DURATION: 24 MONTHS
http://minland.eu/

Objectives:

Access to mineral resources in Europe is one of the pillars of the Raw Materials Initiative (RMI). Yet competing societal interests, such as expanding cities, infrastructure development, agriculture and nature conservation, have had negative effects on the available area for exploration and mining of mineral resources. Consequently, the supply of mineral raw materials within the EU is at risk. Therefore, the integration of mineral resources policies into land-use planning at different scales and levels is a key factor for achieving the goals of the RMI.

The MinLand project is designed for addressing this challenge: to facilitate minerals and land-use policy making and to strengthen transparent land use practice. MinLand is composed around the acknowledgement that the call requires a broad and competent consortium with strong links to related projects and activities, a comprehensive and structured data repository, an efficient work flow and strong and broad stakeholder involvement.

INFACT

776487 – INFACT
Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT)
START DATE: 1 November 2017
DURATION: 36 MONTHS
www.infactproject.eu

Objectives:

Exploration discovery of raw material resources requires innovations that either change the geological targets of exploration, the physical places that are reached, or the manner in which they are explored. Despite its rich history of mining and residual mineral wealth, current conditions within the EU present a number of social, political, legislative, cost, technical and physical obstacles to raw material exploration: obstacles to be overcome by innovation, dialogue and reform.

The Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT) project unites stakeholders of Europe's future raw materials security in its consortium and activities. Via effective engagement of civil society, state, research and industry, the project focuses on each of these obstacles. It will co-develop improved systems and innovative technologies that are more acceptable to society and invigorate and equip the exploration industry, unlocking unrealised potential in new and mature areas.

The project is developing innovative geophysical and remote sensing technologies (less invasive than classical exploration methods) that promise to penetrate new depths, reach new sensitivities and resolve new parameters.

The project will also set the EU as a leader on the world stage by establishing permanent infrastructure to drive innovation in the next generation of exploration tools: tools that are cost-effective, designed for EU conditions and its raw materials strategy, and high-performing in terms of environmental impact, social acceptability, and technical performance.

INFACT is comprised of the following main components:

- Development and testing of innovative, non-invasive exploration technologies.
- Foundation of 3 test sites for exploration technology in the south, centre and north of Europe.
- Stakeholder engagement, education and policy reform.

These actions combine to reach each of the main areas in which the EU has the power to influence change in its raw materials security.

INTERMIN

776642 – INTERMIN
INTERNATIONAL NETWORK OF RAW MATERIALS TRAINING CENTRES
START DATE: 1 February 2018
DURATION: 36 months
http://interminproject.org

Objectives:

INTERMIN is intended to create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials professionals. Specific objectives:

- Develop common metrics and reference points for quality assurance and recognition of training;
- Develop a comprehensive competency model for employment across the primary and secondary raw materials sectors;
- Introduce an international qualification framework for technical and vocational training programmes;
- Create a conceptual framework for the development of joint educational training programmes based on present and future requirements by employers;
- Create and launch a joint international training programme by a merger of competences and scope of existing training programmes.

CROWDTHERMAL

857830 – CROWDTHERMAL
Community-based development schemes for geothermal energy
START DATE: 1 September 2019
DURATION: 36 months
http://crowdthermalproject.eu

Objectives:

CROWDTHERMAL aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project will first increase the transparency of geothermal projects and technologies by creating one-to-one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. This will be done by assessing the nature of public concerns for the different types of geothermal technologies, considering deep and shallow geothermal installations separately, as well as various hybrid and emerging technology solutions. CROWDTHERMAL will create a social acceptance model for geothermal energy that will be used as baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project will work out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings. The models will be developed and validated with the help of three Case Studies in Iceland, Hungary and Spain and with the help of a Trans-European survey conducted by EFG Third Parties. Based on this feedback, a developers' toolbox will be created with the aim of promoting new geothermal projects in Europe supported by new forms of financing and investment risk mitigation schemes that will be designed to work hand in hand with current engineering and microeconomic best practices and conventional financial instruments.

ROBOMINERS

ROBOMINERS

820971 – ROBOMINERS
Resilient Bio-inspired Modular Robotic Miners
START DATE: 1 June 2019
DURATION: 48 months
http://robominers.eu

Objectives:

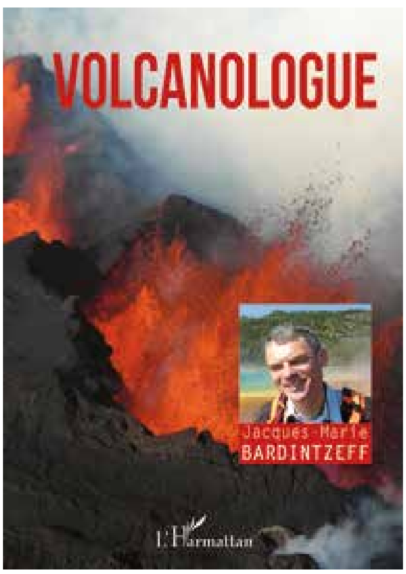
ROBOMINERS will develop a bio-inspired, modular and reconfigurable robot-miner for small and difficult to access deposits. The aim is to create a prototype robot that is capable of mining underground, underwater or above water, and can be delivered in modules to the deposit via a large diameter borehole. In the envisioned ROBOMINERS technology line, mining will take place underground, underwater in a flooded environment. A large diameter borehole is drilled from the surface to the mineral deposit. A modular mining machine is delivered in modules via the borehole. This will then self-assemble and begin its operation. Powered by a water hydraulic drivetrain and artificial muscles, the robot will have high power density and environmentally safe operation. Situational awareness and sensing is provided by novel body sensors, including artificial whiskers that will merge data in real-time with production sensors, optimising the rate of production and selection between different production methods. The produced high-grade mineral slurry is pumped to the surface, where it will be processed. The waste slurry could then be returned to the mine where it will backfill mined-out areas.

ROBOMINERS will deliver proof of concept (TRL-4) of the feasibility of this technology line that can enable the EU have access to mineral raw materials from otherwise inaccessible or uneconomic domestic sources. This proof of concept will be delivered in the format of a new amphibious robot Miner Prototype that will be designed and constructed as a result of merging technologies from advanced robotics, mechatronics and mining engineering. Laboratory experiments will confirm the Miner's key functions, such as modularity, configurability, selective mining ability and resilience under a range of operating scenarios. The Prototype Miner will then be used to study and advance future research challenges concerning scalability, swarming behaviour and operation in harsh environments.

Book review by Antoine Bouvier

Volcanologue

by Jacques-Marie Bardintzeff
Published by: Harmattan Editions, France, 180 pp, 2017 (in French)
ISBN: 978-2-343-12326-4



Volcanologue, the latest book from Jacques-Marie Bardintzeff, answers the question asked by many high school pupils and university students wishing to avoid a professional career confined to a permanent office: what is the key for becoming a volcanologist?

Looking at Jacques-Marie's experience, the right answer is:

- to be first of all passionately curious about science and then to work obstinately to become deeply versed in physics, chemistry and geology as taught at university colleges or engineering schools specialising in these areas (in his case, *Ecole Normale Supérieure* in Saint-Cloud, France);
- to participate in field discoveries and scientific analysis resulting in a higher degree in Natural Sciences, then getting a scientific research position at the Paris-Sud Orsay University while earning a Doctorate in Volcanology;
- to travel around the volcano world to meet famed volcanologists and then, as a Professor of Petrography, Volcanology and Planetary Science, to share major theoretical and practical findings with students.

Moreover, like for any unconventional profession, you need some luck during your study years:

- to be born at the foot of the Alps and close to mineral sites, having a mountain dweller and a botanist as a grandfather along with a first-rate skier for a grandmother; to be physically fit and to maintain this fitness through cycling, athletics and parachuting;
- to meet remarkable teachers – both by scholarly and human standards: Henri Vaissière (secondary school), Jean Gourc and Robert Brousse (Paris-Sud Orsay University).

The biographical elements mentioned in the book provide allot space also for information on data sampling and measurement near craters and on volcano slopes, documented through amazing photos accompanied by clear and comparative descriptions. Of course, the security risks close to an erupting volcano are obvious and the right decision needs discernment and experience.

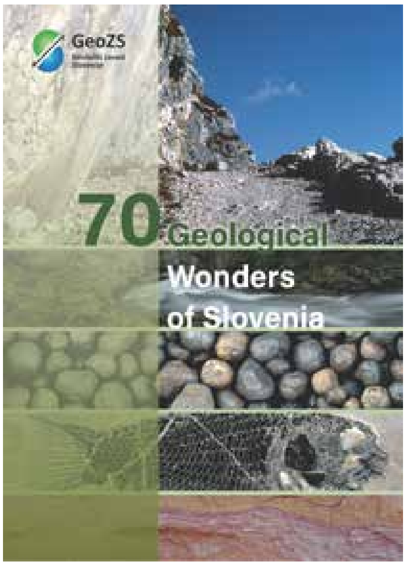
Jacques-Marie Bardintzeff has written several books targeted at both specialists and the curious public, well as giving conference presentations in many countries with active volcanoes. These nearly always inspire a trip up to the edge of these great structures.

Easy to read for 7 to 107-year-olds, the book rivals Jules Verne's written works in excitement.

Book review by Marko Komac and Nina Zupančič

70 Geological Wonders of Slovenia

Edited by Nina Rman & Matevž Novak
Published by: Geological Survey of Slovenia (GeoZS), Ljubljana, 204 pp, 2016
ISBN: 978-961-6498-46-3



The guidebook *70 Geological Wonders of Slovenia* was published by the Geological Survey of Slovenia to celebrate its 70 years of existence. The first 500 print-runs in the English language have been made available since the beginning of September 2016. About 27 authors and several other experienced colleagues from three main Slovenian geological institutions contributed to the volume, from the Geological Survey of Slovenia, the Department of Geology of the Faculty of Natural Sciences and Engineering of the University of Ljubljana, and the Slovenian Museum of Natural History. Colleagues at UNESCO Geopark Idrija and Geopark Karavanke and the Institute of the Republic of Slovenia for Nature Conservation also supported its content. In addition, more than 40 collaborators and 15 organisations provided the photographs. The content was reviewed by two professors of geology from the University of Ljubljana, prof. dr. Jože Čar and prof. dr. Jernej Pavšič, while two designers made it very attractive.

The book consists of 204 pages, where the 70 outdoor sites – covering the three billion years of geological history in the Slovenian area - are listed according to their position in 12 statistical regions. An additional six appendices highlight the most exquisite features of rare minerals and fossils in Slovenia which remain strictly protected and so whose sites are not open to public, or unique samples such as a meteorite that are no longer placed at their original location but are stored in geological collections. The list of 84 geological collections in Slovenia offers the most comprehensive overview of private and public collections in this country at present and is regularly updated on the website accompanying this publication, *http://www.geo-zs.si/index.php/en/?option=com_content&view=article&id=180*. At the end of the book, you can find 164 professional references in English that supplement the popular science description of the phenomena. For every location a general description and further reference are provided, there is a detailed map indication, an accompanying photo of the site, the description of the access, its coordinates and a QR code that leads the reader to the online map with further descriptions and web links.

The book is designed as a tourist guide and is useful to a wide audience, from schools to individuals, from families to solo hikers, and although it is mainly focused on outdoor enthusiasts, it also includes museums that host interesting geological examples found on Slovenian soil. The aim of the book is to advocate for geology, its use in society and in everyday life.

Readership: all those that like geology (including geologists, students and teachers ;)

EurGeol App at a glance

>> An increased user-friendliness and many additional functions:

> Easily **accessible** on all electronic devices: PC, mobile phone, tablet, etc.

Login

> Electronic CV can be updated using data from **LinkedIn** profile

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My messages

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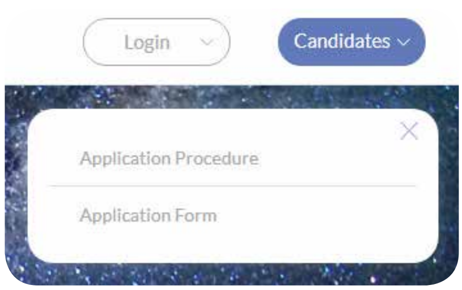
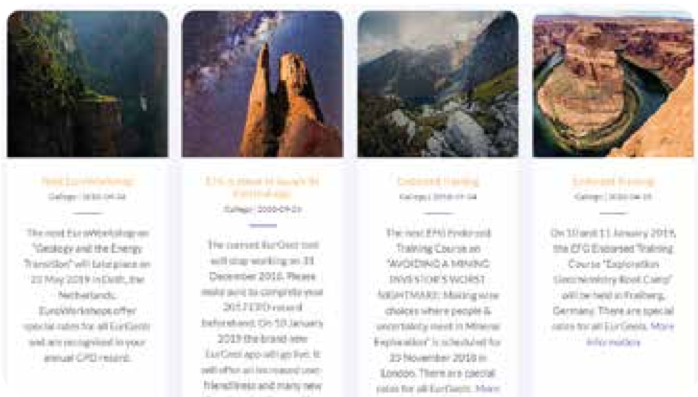
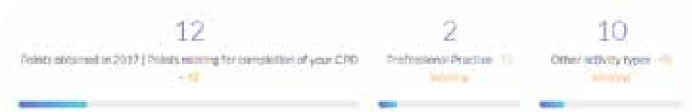


> **News feed** with special offers and information for all EurGeols



> EurGeols can easily monitor their renewal status and update their **CPD** directly via their mobile phones (including the scan of QR codes for certain CPD training courses)



Check the EurGeol App at www.eurgeoltitle.eu

European Federation of Geologists
www.eurogeologists.eu

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout
- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract
- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text
- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
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- Figure captions should be sent in a separate doc or docx file.

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- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
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- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations
- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
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Our different communication tools are the:
- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

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