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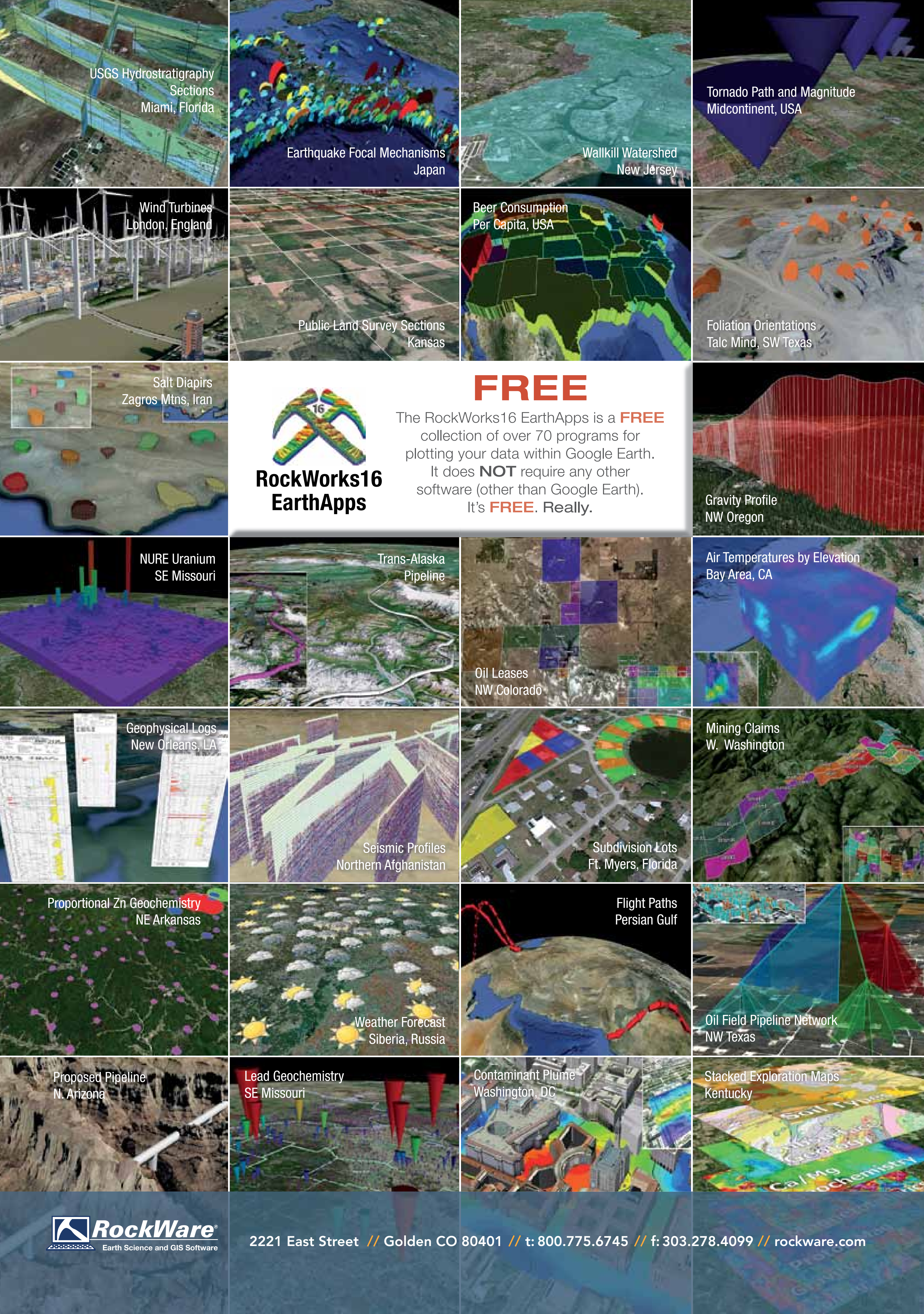
Industrial minerals - materials in our everyday life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Foreword

EurGeol. Vítor Correia, President

This edition of European Geologist is a thematic issue dedicated to industrial minerals. This is opportune since industrial minerals are present in our everyday life and are critical to a wide range of industries, from pharmaceuticals or food processing to isolators or civil construction.

Our society depends on industrial minerals and it is therefore our responsibility, as professional geologists, is to ensure that related exploitation and processing activities are carried out in accordance with the best available practices.

In Europe there are more than 30,000 quarries and mines, producing more than 3 billion tonnes of industrial minerals every year. The number of direct jobs from the European mining industry exceeds 350 000, and the estimate of indirect jobs exceeds 500,000. More than 14% of the jobs in Europe are maintained by industries that use industrial minerals as raw materials.

Quarries and open pit mines may give rise to negative impacts on people and the environment during the exploitation phases. Given this enormous importance, and significant impacts, one might expect huge negative impacts and changes in the landscape disseminated all over Europe. On the contrary; quarries and open pit mines occupy less than 0.1% of the European territory. Furthermore, many of the negative impacts of this activity can be successfully reduced or eliminated during the exploitation phases and most will cease altogether following rehabilitation and closure. The keys to this are proper management, based on integrated environmental impact assessment, and environmental and social monitoring to ensure successful regeneration of the areas affected by exploitation activities.

Considering the importance of industrial minerals and the need to increase the sustainability of their exploitation in Europe, four established activities of the European Federation of Geologists are relevant: 1) setting and promoting best practice and public reporting standards; 2) disseminating best practices and reinforcing the need for sustainability; 3) increasing public awareness of the importance of minerals to our everyday lives; and 4) providing continuing professional development opportunities for geologists to support and improve their technical and scientific skills. This issue of European Geologist highlights all of these themes, and we hope you find the articles enclosed useful.

This is my first foreword as President of the EFG, and I take this opportunity to express my conviction that geoscientists have now a unique opportunity to actively contribute to Europe's short-term development. The instability of global supply chains, the need for solutions to face water scarcity and climate changes and the reinforcement of participative policies in Europe justifies the EFG's focus on the following topics in our interactions with the EU and the public:

1. The EU's future supply of raw materials (including the availability and sustainability of critical minerals, urban mining, recycling, new exploration techniques, mining at increased depths and from the deep sea floor);
2. Water management (droughts and flood control, underground water exploitation and water governance);
3. Natural hazards and urban planning policies;
4. The global professional mobility and recognition of geoscientists (an important aim, considering the role of geoscientists in delivering and adding value to sustainable construction, mining, energy and natural hazard mitigation projects);
5. Public education and awareness about the way geology shapes the landscape, our cities, our houses and our lives.

To conclude, I want to express my gratitude to Ruth Allington, my predecessor, who patiently provided me with the inner knowledge of the EFG projects and responsibilities and who shared with me her wise vision on the need to reinforce professionalism among geoscientists. I must also express my thanks to all the colleagues of the Office and Board who patiently provide me guidance in my first steps as President of the EFG.

Introduction by the EFG Panel of Experts on resources and reserves - Minerals and their sustainable use

Essential but overlooked – the rocks and minerals that shape society

*Ruth Allington**

As the President has rightly highlighted in his Foreword, the production of industrial minerals in Europe is very significant and their extraction takes place in a large number of quarries and pits. The exploitation of these rocks and minerals employs a large number of people both in primary extraction and in downstream industries. He has also introduced the vital roles that these materials, and the products manufactured from them, play in everyday life.

The papers in this issue of European Geologist Magazine emphasise the variety of industrial minerals (including construction materials) produced in Europe and their applications, and provide some valuable insights to support the professional practice of geologists working in this industry.

The title of the paper by **Regueiro** refers to this group of earth materials as 'our invisible friends'. Similarly, **Goemaere and Declerq** refer to them as 'well hidden but always present in our everyday life'. For anyone with a geology degree, these descriptions are, perhaps, rather surprising – how can rocks and minerals – without which we know modern life would be simply impossible – reasonably be described as invisible or hidden?

As a descriptor of the perspectives of the general public, however, 'hidden' and 'invisible' seem much more appropriate. Many of the readers of this magazine may have challenged friends and family to identify non-fuel items from amongst their possessions or in their houses or offices that originated from a rock or mineral, and received blank looks or a very short list (probably with metals – especially gold – at the top, and possibly also including concreting aggregates and aggregates used in road building but not a lot else). Children can usually provide some more examples – sand to make glass is a favourite in my experience – and I live in an area where the old houses are built from stone, which they may also have noticed. Readers may then have proceeded to point to everyday articles and parts of buildings, naming the rocks or minerals from which they were made.

In short order, it is possible to demonstrate that everything that we use (including some of the things we eat or add to our food) which cannot be grown or fished from the sea has to be mined, and therefore we can say that geological science is as essential as medical science to maintaining human life. People of all ages find this revealing and fascinating and, when thus informed, they generally have little difficulty accepting societal dependence on such a variety of earth materials – and therefore they accept, in principle, the need for mining and quarrying to recover them.

The papers by **Goemaere and Declerq** and **Tyrer** provide fascinating and compelling accounts of the range of uses of limestone and salt, respectively. The paper by **Regueiro** provides an overview of industrial minerals and rocks and reminds us that in a relatively short period, we have become dislocated from the sources of the raw materials we depend on. The paper by **Fulda** celebrates hard rock as a natural resource that makes the construction of modern transport infrastructure possible.

One might think that, if the simple conversation that I described above were arranged in the manner of a chain so that it was passed on around the whole population of Europe, and if this were supported by provision of accessible information (such as that in the papers by **Goemaere and Declerq**, **Tyrer**, **Regueiro** and **Fulda**) this would achieve two things: first to elevate geological careers to an aspirational status alongside, for example, medical or legal careers, and second, to wipe out anti-mining protests and 'NIMBYism' at a stroke – mines and quarries would be welcomed as a public good.

It is, of course, an over-simplistic proposition that public information about the rocks and minerals essential to daily life – however accessible and excellent it may be – will equate to public acceptance of mining and quarrying, or even to an explosion in the status of the professions of geology and other geosciences. It is a part of the human condition that we can accept the need for all kinds of things as for the 'public good' but, when they affect us and our communities and families directly, we can think of many good and compelling reasons why the development in question would be much better placed elsewhere. Effective public engagement and securing acceptance of mining and quarrying by communities (often termed securing a 'social licence to operate') is about more than just providing accurate and accessible information. However, it is very clear that raising public awareness and public education are the foundations for success in this regard. The European Minerals Day described in the paper by **Langedijk** provides a case history of a well-established and highly successful annual public engagement initiative. Members of the public visit operating quarries and, through this experience, understand more about geology and the roles and responsibilities of geologists, and appreciate that a well managed quarry or mine does not give rise to unacceptable environmental impacts, nor do most of them exist in a constant state of conflict with the local population. Events such as this do much to allay the fears that lead to protest groups and antagonism when mines and quarries are at the planning stage.

It is an often quoted truism that minerals can only be worked where they exist and this determines the distribution of mining and quarrying operations. One of the special difficulties that can occur with public acceptance of industrial minerals production relates to the ubiquity of these materials

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– members of the public who feel threatened by plans to establish a mine or quarry argue, not unreasonably, that there is plenty of 'the same' material elsewhere – distant from their community – and seek to persuade planners and mineral companies that they should therefore look anywhere but in their 'back yard'. The other side of this coin is that quarries and mines for the exploitation of industrial minerals tend (with exceptions) to be smaller and shallower than, for example, open pit metal mines. This gives rise to an opportunity for rehabilitation which can make the land suitable for a wide range of beneficial after-uses – in the UK planning system, and in others internationally, quarrying and mining are defined as temporary uses of land.

The need to identify sufficient resources in the public interest underlines the need for soundly based spatial planning for mining and quarrying activities. This must anticipate the way that land will be used after quarrying and mining is complete, as well as identifying deposits of industrial minerals of all kinds which – after exclusion of areas within which there are overriding social and environmental constraints – can be safeguarded to provide 'land banks' of such minerals with a reasonable prospect of being exploited to meet future needs. This is achieved through strategic environmental assessment, often using GIS technology to 'overlay' all relevant spatial information. The essential foundation for this approach is geological mapping and modelling – studies such as the Irish aggregate potential mapping described in the paper by **Stanley and Lally** and the geology of perlite bodies in Hungary in the paper by **Zelenka**.

The results of mapping and modelling to characterise deposits, resources and reserves of industrial rocks and minerals are often used for establishing and keeping up to date regional, national and European inventory for planning purposes. For such inventories to be useful, they should ideally be reported using consistent terminology and within a consistent framework. The United Nations Framework Classification (UNFC) has been developed for this purpose and is under consideration as a pan-European system for harmonising such reporting. Similarly, it is vital, for the protection of the public as investors, regulators and neighbours of mines and quarries, that companies provide transparent and accurate public disclosure of their resources and reserves in a consistent form. The internationally accepted system for company reporting to financial markets is that developed by CRIRSCO. The relationship between the UNFC framework classification and the CRIRSCO codes and standards, and the drivers for and history of their development, are described in the paper by **Henley and Allington**.

At the core of the CRIRSCO codes and standards is the 'competent person concept'. This aims to ensure that those who report on solid mineral reserves, resources and exploration results hold appropriate professional qualifications, have sufficient relevant experience and expertise and take personal responsibility for what they write in the reports they sign. An important pillar of the 'competent person concept' (and a mandatory requirement for holders of the European Geologist qualification and other qualifications with equivalent standing in the CRIRSCO codes and standards) is continuing professional development (CPD). The range and nature of CPD activities carried out by individual geologists is a highly personal matter – the individual should undertake activities that genuinely support and develop their professional practice. However, in all cases, CPD will necessarily include a commitment to keeping up to date with relevant technical literature. The papers by **Xirouchakis** and **Chaminé *et al.*** describe studies that will be of interest to engineering geologists concerned with both the design of hard rock quarry faces and the prediction of aggregate quality from rock mass properties.

Interview with Mr. Mattia Pellegrini, Head of Unit – Raw materials, Metals, Minerals and Forest-based industries, European Commission DG Enterprise and Industry

*Isabel Fernandez Fuentes**

1. The raw material markets are increasingly distorted by protectionist trade policies, and maintaining fair and undistorted access to these materials for EU industry and citizens is increasingly difficult.
To what extent has this been a driver for the Commission's policy in the field of Raw Materials?

Raw materials are fundamental to Europe's economy and recently securing reliable and undistorted access to crucial non-energy raw materials has been of growing concern in economies such as the EU, US, Japan, with several responses. The European Commission launched the Raw Materials Initiative (RMI) in 2008 to manage raw materials issues at an EU level. The RMI has been developed based on three pillars:

1. Ensuring a level playing field in access to resources in third countries;
2. fostering a sustainable supply of raw materials from European sources;
3. boosting resource efficiency and promoting recycling.

In the first pillar of the EU Raw Materials Strategy the EU has committed itself to pursue Raw Materials Diplomacy, reaching out to third countries through strategic partnerships and policy dialogues.

It is essential for the EU that international raw materials markets operate in a free and transparent way. However, many countries are increasingly applying measures – such as export taxes, import duties, price-fixing, and restrictive investment rules -- which distort these markets. The net effect of these distortions is that the manufacturing industry, in developed, emerging and developing countries, suffer when access is distorted in this way.

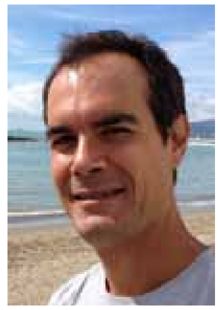
« The dependency of EU industry on mineral raw materials that are exploited in regions where geopolitical risks are high is often indicated as the main trigger for recent EU support for increasing mining exploration activities in Europe. »

As a response to these priority trade policy issues, the EU's trade strategy has been threefold:

1. Propose trade disciplines on export restrictions in bilateral and multilateral negotiations,
2. Tackle trade barriers through dialogue but also other tools including WTO dispute settlements and the Market Access Partnerships, and
3. Raise awareness and support awareness-raising in international fora such as the G8, G20, OECD and UNCTAD.

Regarding the critical raw materials, which are those displaying a particularly high risk of supply shortage in the next 10 years and with a great importance for the value chain at EU level, a report "Raw Materials: Study on Critical Raw materials" dated 2010 was prompted by the highlighted concerns over securing reliable and undistorted access to non-energy raw materials, and the detrimental impact on the wider European economy to which supply issues may lead. In total 41 raw materials were assessed on their criticality and 14 are considered to be critical. It was agreed that the Commission would undertake a study at least every three years. A review of the study on Critical Raw materials" is now been carried out by the European Commission and will be published in 2014.

A growing concern in the critical raw materials markets relates to measures imposed by certain countries to ensure privileged access to raw materials for their domestic industry including through export restrictions. These measures create distortions in the global markets and uncertainties in the regular flows of commodities. Such measures may affect developed and developing countries alike, as virtually no economy is self-reliant for all raw materials".



The dependency of EU industry on mineral raw materials that are exploited in regions where geopolitical risks are high is often indicated as the main trigger for recent EU support for increasing mining exploration activities in Europe.

2. Long- term strategic planning for sustainable raw materials supply is an essential part of policy in individual Member States – and this can lead to protectionism, either politically or because the collection and presentation of data and statistics are not harmonised.
Do you think the European Strategic Implementation Plan arising from the work of the European Innovation Partnership will reach a pan European long term strategy on Critical Raw Materials and, if yes, how will the necessary harmonization and high level co-operation be achieved?

The study on critical Raw materials which is being carried out is part of the Raw Materials initiative. The original RMI communication has now been followed up by further communications on "tackling the challenges in commodity markets and on raw materials" in 2011, and reporting on the progress of the RMI in 2013.

The Strategic Implementation plan, which was adopted on 25 September 2013, is part of the European Innovation Partnership which is embedded in the wider strategy of the Europe 2020 strategy. The work is structured under three pillars, reflecting the nature of 97 actions:

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- Technology Pillar
- Non-Technology Pillar
- International Cooperation Pillar

As a whole this work aims to ensure smart, sustainable and inclusive growth and is closely linked to the flagship initiative for a resource efficient Europe. We are very encouraged by the high spirit of co-operation that we have seen so far in the European Innovation Partnership, from industry as well as from governments and other stakeholders. This augurs well for the implementation phase of the Partnership (2014-20).

3. Decision making related to strategic planning for raw materials in Member States is closely linked to scientific knowledge of existing resources and the levels of development and quality and availability of fundamental geological and exploration data varies widely.
If a pan-European raw materials supply strategy is a real possibility, how will scientific knowledge will be taken into account in decision making?

Through the Strategic Implementation Plan which details actions necessary to achieve the European Innovation Partnership through research, raw materials knowledge, exchange of best practices, revision of selected legislations, licensing steps, standardisation, and policy dialogues. It targets innovation in both technology-focused and non-technology policy areas, as well as international cooperation. In this framework, scientific knowledge will be essential and one of the actions areas is to strengthen the EU knowledge base on raw materials. In this regard, a Knowledge and Innovation Community (KIC) on Raw Materials will be launched next year. The specific aim of KICs is to bring together industry, higher education, and research, in areas of societal challenges that are of utmost relevance for our common future.

4. Within the EU, exploration and extraction have to face increased competition for different land uses and a highly regulated environment. The revision of the Directive of Environmental Impact Assessment proposes an increasing regulatory burden on mining activities.
How can this be balanced with the need for EU policies to foster an increase in mining activity in Europe?

Under the Environmental Impact Assessments (EIA) Directive, any project that is likely to have significant effects on the environment has to be studied carefully before it is approved. This helps minimise any negative impact on the environment, and avoids problems in the longer term. Now, the general objective is to adjust the EIA Directive to developments in the policy, legal and technical context over the past 25 years. We want to correct shortcomings, reflect ongoing environmental and socio-economic changes and align it with the principles of smart regulation. The new Directive would actually provide a clearer, more coherent and simplified legal framework. It will also reduce administrative costs (both direct costs and costs due to delays), most notably by simplifying screening procedures.

« I think it is important for the community of professional geologists to listen to the needs of society and industry, to find a way how to share their expertise and to communicate with European policy makers and stakeholders in a way to make a real difference. »

Two specific objectives can be considered as essential in the revision of the EIA Directive:

1. To strengthen the quality of the assessments 2. To improve coherence and synergies with other EU laws and simplify procedures. To achieve this, the various environmental assessments should be streamlined and timeframes for the various stages of the EIA process should be introduced.

5. The global trend shows that an increasing number of geoscientists work at the international level and that the requirements for quality assurance by their clients and employers, the public, governments and insurance companies are increasing.
In the development of EU policies for decreasing reliance on imported Critical Raw Materials, how is it proposed to build in EU and wider international mobility of these essential professionals and associated quality assurance?

We organise regular contacts with our counterparts worldwide as part of the Raw Materials Diplomacy Events which are part of the Raw Materials Initiative. For example, in early December a US-Japan-EU high level workshop is being organised dealing with criticality on Raw Materials and how to foster better cooperation between the three partners. Through these contacts, expertise is being shared and it involves a wide range of experts. Again, the role of the Knowledge and Innovation Community on Raw Materials will be fundamental.

6. During your work, you are in contact with numerous geologists. Could you tell us some characteristics that you have found in common?

Through my work, I am constantly in touch with experts, as for example the ones who attend the RM Supply Group which includes Industrial Associations, Member States, NGOs; or geological surveys (data).
In particular: How do you find communication with geologists?

Generally good. Via different channels, I am in touch with geologists, through experts groups, representatives of industrial associations but also via experts from geological surveys, with whom we also share some common events. I find the exchanges with geologists very valuable and they contribute in establishing a comprehensive European policy in the field of raw materials, minerals and metals.

Do they understand and provide the information needed by the policy maker?

In my view, it is recommended to closely follow the calls for expression of interests that DG Enterprise and Industry are publishing in the field of raw materials. On a regular basis, new calls are published addressed to different stakeholders. This was the case for existing experts groups such as Call for expression of interest in the High Level Steering Group, Sherpa Group and the Operational Groups of the European Innovation Partnership on Raw Materials or the Raw Materials Supply Group, the Ad Hoc Working Groups on critical raw materials and the SIP groups (call for commitment).

Do they work effectively with policy makers to identify problems and approaches to developing solutions?

They should keep closely in contact with stakeholders, following the meetings of the experts groups in order to provide their inputs and to better understand the societal needs.

What advice would you give to the community of professional geologists to make their communication efforts more successful in supporting policy making in the EU and providing the data upon which that is based?

I think it is important for the community of professional geologists to listen to the needs of society and industry, to find a way how to share their expertise and to communicate with European policy makers and stakeholders in a way to make a real difference. Most of all, communicating in an effective and understandable way and regular exchanges of view are crucial to me.

Limestones, dolostones and derived processed products in Belgium: well-hidden important industrial rocks though still present in our everyday lives

Eric Goemaere and Pierre-Yves Declercq*

This paper focuses on the production, transformation and utilisation of Belgian carbonates. It consists of a compilation of different sources from the industrial key actors in Belgium.

Cet article est centré sur la production, la transformation et l'utilisation des carbonates en Belgique. Il résulte de la compilation de sources différentes appartenant aux acteurs clés industriels en Belgique.

Este artículo se centra en la producción, elaboración y uso de los carbonatos belgas. Consiste en una compilación de diferentes fuentes de los actores industriales clave de Bélgica.

Belgium (30,528 km^2, population 11 million) is the third smallest country in the European Union after Cyprus and the Great-Duchy of Luxembourg. Its efficient, modern infrastructure and connections with the North Sea, as well as its open borders with all of its European neighbors, have made Belgium an important trading nation. The industrial sector is strong and employs around a quarter of its workforce. Belgium is a major importer of raw materials, and exports finished or semi-finished products (Edwards, 2012).

The Belgian carbonates are well known as ornamental stones ("Petit Granit", "Blue stones", "Meuse's stones", red, black and grey "marbles"), and as hydrogeological reservoirs. But specific strata (formations) are used as industrial raw material due to their high chemical quality and characteristics. The market is dominated by five major international actors whose activities are in conflict with urbanisation processes because of the relatively small territory available.

The FEDIEX (*Fédération des Industries extractives de Belgique*) is a regional and national trade association which brings together 60 companies involved in the mining and/or processing of non-energy rocks. The total number of staff of FEDIEX member companies is more than 3,450 employees, including 919 administrative staff. FEBELCEM (*Fédération de l'industrie cimentière belge*) gathers companies active in the cement sector. The detailed picture of the extractive sector in Wallonia (the southern part of Belgium) has been recently published by Poty & Chevalier (2004).

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Table 1: Major companies in the carbonates mineral industry of Belgium and their main products.

Actors	Aggregates	Lime & derived products	PCC	Dolime & derived products	White cement	Grey cement	Derived cement products
Lhoist	x	x	x	x			
Carmeuse	x	x	x				
CBR (HeidelbergCement)	x				x	x	x
CCB (Italcementi)	x					x	x
Holcim						x	x

Table 1 introduces the products of the five main Belgian actors involved in the industrial carbonates sector.

Geological and geographical setting

Belgium is well known for its wide occurrences of industrial carbonates: limestones, dolostones and chalk. They have been mined for more than 20 centuries, thanks to their chemical, mechanical or ornamental qualities but also, for peculiar "anomalies" like cherts and flint or phosphate concentrations of some layers! They mainly outcrop along the rivers and more rarely on the plateaus.

Stratigraphically (***Table 2***), limestones lying both in the Eifelian-Givetian-Frasnian and in the Tournaisian-Visean (Dinantian) are widely mined. Dolostones are mainly restricted to the Tournaisian. Middle and Upper Devonian rocks, as well as Dinantian rocks of southern Belgium (***Figure 1***) lie in the northwestern part of the Rheno-Hercynian Fold Belt. Outcrops occur on both sides of the Midi-Eifel thrust fault zone, in the Brabant Parautochthon (north of the fault) and in the Ardenne Allochthon structural units; these units were formerly known as Namur and Dinant Synclinoria and Vesdre Nappe, respectively (***Figure 2***) (Poty *et al.*, 2001). For more information, a "redefinition of the structural units of the Variscan Front" has been recently published by Belanger *et al.* (2012).

White and grey upper cretaceous chalks are also mined as industrial rocks. The Belgian Upper Cretaceous facies differ from west to east and is divided in three basins (Robaszynski *et al.*, 2001). Only two of them are of economic interest: the Liège-Limburg area to the east and the Mons area to the west.

On the whole these rocks outcrops are localised in the southern part of the country and have contributed to important developments of the industry. The different characteristics of the limestones and dolostones are linked to the sedimentation areas and their own evolution regarding bathymetry and subsidence (Bultynck & Dejonghe, 2001; Poty *et al.*, 2001).

Carmeuse and Lhoist groups as international actors

The Carmeuse and Lhoist groups are world reference producers of limestone and dolostone aggregates, lime, lime products, dolime and dolime products and also produce high calcium limestone and dolomitic stone dedicated to various well-hidden uses. Together, they have more than 200 quarries throughout the world. The two groups have more than 150 years of experience in quarrying and in transforming limestone and dolostones into many different products. For deliveries, they use any means of transport available in Belgium (road, rail and shipping on the Meuse River).

Carmeuse has 94 production sites throughout Western Europe (Belgium, Italy, France and the Netherlands), Eastern and Central Europe (Slovakia, the Czech Republic, Hungary, Romania and Turkey) and in North America (the United States and Canada) as well as in Africa (Ghana). Its coordination center is located in Louvain-la-Neuve (Belgium). Carmeuse focuses its Belgian activity on producing aggregates (different types of sand and granulates), ground limestone, crushed limestone, quicklime, hydrated lime, limestone filler and milk of lime. The Belgian facilities are located in Wallonia, in Liege and Namur Provinces and more particularly in Engis (Visean limestones), Moha (Wanze, Visean limestones), Seilles (Andenne, Visean limestones), Aisemont (Fosses-la-Ville, Visean limestones) and Frasnes (Couvin, Devonian: Middle Frasnian limestones) (source: Carmeuse web site).

The Lhoist Group represents a great number of quarries (more than 80) and transformation plants all over the world (France, UK, Czech Republic, Germany, Poland, Russia, USA, Mexico, Brazil, Malaysia, Vietnam, China, India, and other nations), and is active in south Belgium in different sites like Marche-les-Dames (Tournaisian dolostones), Hermalle-sous-Argenteau (Visean limestones), Merlemont (Middle Frasnian dolostones), Jemelle (Gerny site: Middle Frasnian limestones). Its administrative center is located in Wavre.

The two groups are strong competitors and very innovative, with high level research and development teams. They continuously propose new products and applications answering to new societal needs with high consideration to environmental protection. If minerals and rocks are our hidden friends, quarries and plants are not really welcome in our highly populated European countries!

Table 2: Stratigraphic chart of the carbonated industrial rocks mined and transformed in Belgium. The colours correspond to the rock legend used for **Figure 1**.

STRATIGRAPHICAL POSITIONS OF THE CARBONATED INDUSTRIAL ROCKS

ERA		SYSTEM/PERIOD		SERIES EPOCH	STAGE	
CENOZOIC	ALPINE CYCLE	QUATERNARY		HOLOCENE		
				PLEISTOCENE		
		NEOGENE		PLIOCENE		
				MIOCENE		
		PALEOGENE				
MESOZOIC		CRETACEOUS		Upper	CAMPANIAN SANTONIAN CONIACIAN	Chalk
				Lower	WEALDIAN	Clay -->Grey cement
		JURASSIC				
		TRIASSIC				
PALEOZOIC	VARISCAN CYCLE	PERMIAN				
		CARBONIFEROUS	SILESIAN	(STEPHANIAN) WESTPHALIAN		
				NAMURIAN		
			DINANTIAN	VISEAN	WARNANTIAN LIVIAN MOLINIACIAN	Limestones
				TOURNAISIAN	IVORIAN HASTARIAN	Dolostones & limestones
		DEVONIAN		Upper	FAMENNIAN FRASNIAN	Limestones/(dolostones)
				Middle	GIVETIAN EIFELIAN	
				Lower		Kaolin--> white cement
	CALEDONIAN	SILURIAN				
		ORDOVICIAN				
		CAMBRIAN				

Together, these two industrial giants employ 10,000 people. Unfortunately, statistics of production are not publicly available.

Products and derived products

The major quantity of carbonates is consumed by the construction industry. Dolomite and limestone are used in similar ways; they are crushed and used as aggregate for both cement and bitumen mixes. Road builders mix it with concrete and asphalt and railroads use it for ballast. As well as limestone, dolostones are used in construction as a low-value commodity for local consumption, because of the prohibitive transportation costs.

Aggregates have classical applications in ready mix concrete, road and concrete prefabricated products. Pulverized limestones are used as a calcium source, as filler and as reactive material as well.

Lime related products are used in multiple aspects of our daily life: steel production, masonry, mortars and building materials, road construction, glass production, agro-food, paper, chemicals, plastics, carpets, paints, pollution and gas control, water treatment...

Hydrated limes have a number of applications: construction, flue gas treatment, gas desulphuration, chemical industry (for high purity products), food regulation conformity, pharma-baby food, foods…

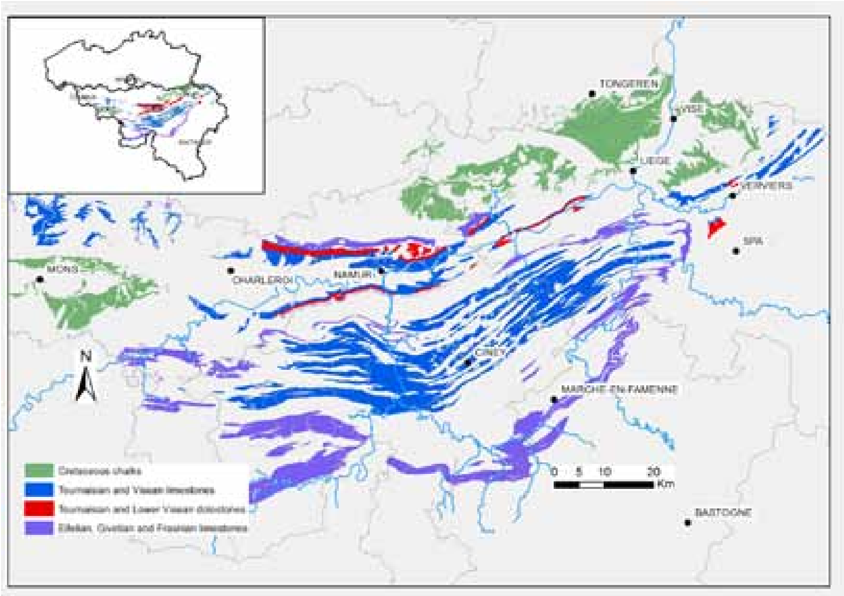

Figure 1: Lithostratigraphic map locating the carbonates units of economic importance. © GSB.

Companies have developed a range of active lime-based fillers for hot and cold mix asphalts. They can be used instead of traditional filler, without any modification of the dosing installations, or as an additive, in bulk or in bags. Hydrated lime also improves the performance of the asphalt mixes used for road surfacing. It increases their resistance to stripping, rutting and age-hardening.

Milk of lime (suspension of calcium hydroxide) is particularly suited for drinking water treatments, sludge treatments, flue gas treatments, agriculture (fertilizer), chemical industry (catalysts, neutralisation, pH adjustment), civil engineering (soil stabilisation), paper and paint industry, glass industry, and others.

Dolostones. The dolostones (also called "dolomite" in the literature) mines in Belgium are exploited in large quarries. They are formed by the replacement of calcium by magnesium before the lithifi-

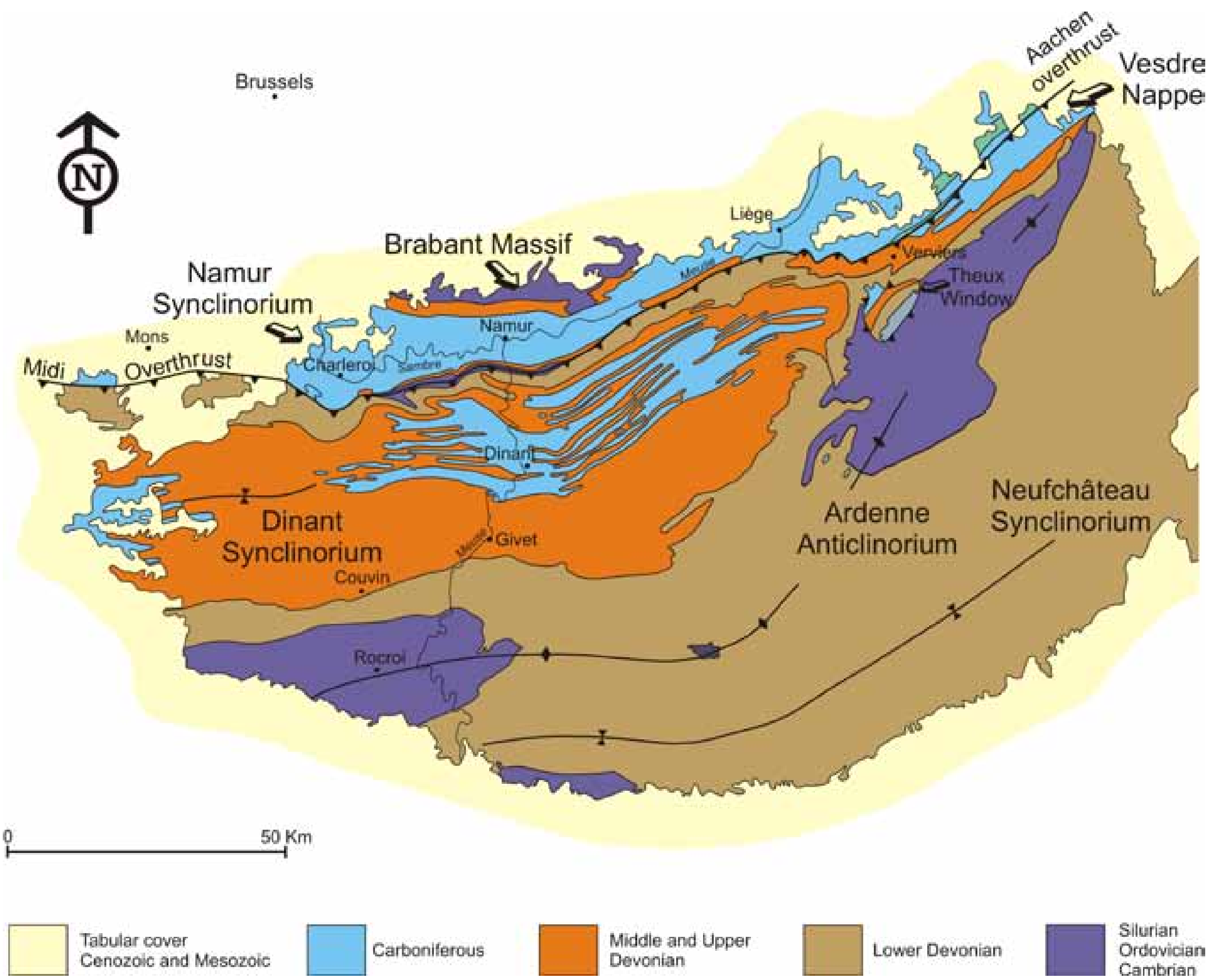

Figure 2: Structural settings of Devonian and Carboniferous formations in the Ardennes. Figure simplified after Bultynck & Dejonghe, 2001.

Figure 3: Craftsman carving a Visean limestone (Carrière de l'Etat de Gore, Andenne). (Goemaere, 2010a).

cation process occurs (diagenesis). Due to their yellowish colors, dolostones of Merlemont are used as ***building stones and gravel*** for garden paths and driveways (e.g. "golden" gravel). Finely ground dolomite is used for filler applications in plastics, paints, rubber, adhesives and sealants. Pure white (high brightness) filler grades are preferred. High-quality industrial dolomites obtained after calcination are rare and dedicated to the fabrication of high value products. Dolostones are kiln-fired in the manufacture of cement. Pure dolostones are used in the chemical industry as a source of magnesium metal and of magnesia (MgO). Pure ***dolime*** (CaO.MgO – also called dolomitic lime) is a constituent of refractory bricks for furnace linings. Dolomite is used in the production of glass and ceramics. Lime and magnesia improve the durability of the glass but magnesia also inhibits the devitrification.

Magnesium is a nutrient for plants. In agriculture, dolomite is used as a nutrient for livestock but also as a soil conditioner. Dolomite and limestone both neutralise soil acidity but only dolomite can counterbalance magnesium deficiencies in the soil. Agricultural finely crushed dolomite is called "aglime" and is used both in its natural (carbonates form) and calcined state.

Well-hidden and high performance uses

- ***Glass industry*** - Lhoist supplies the glass industry with extremely pure dolomite of very constant chemical composition and particle size. Dolomite is mainly used in the float glass industry. This source of magnesium acts as a stabilizer to improve the general resistance of glass to natural or chemical attacks. Lhoist also supplies special reagents for industrial flue gas treatment.
- ***Iron & steel*** - Lime and dolime are commonly used in converters and electric arc furnaces, where they help to form slag which draws off harmful impurities such as silicon and phosphorus. Lime is also used to improve productivity in the ore agglomeration process. The steel industry uses dolomite as a sintering agent in processing iron ore and as a flux in the production of steel. The use of dolostone as a flux has notably increased since environmental contamination has become an issue of concern, because the resulting slag can be recycled, e.g. for lightweight aggregate, without environmentally harmful effects.
- ***Building specialties*** – Limestones and occasionally dolostones have been important building stones since the Roman period. Nevertheless, other well-hidden uses have a strong economic importance. Lime-based mortars are more and more often used in masonry and in plaster mixes for building facades. In addition, lime is being used increasingly in modern building materials to make aerated concrete and calcium silicate bricks (lime-sand bricks). These materials are valuable for several reasons: they have excellent thermal and acoustic insulating properties and they are easy to work with.
    - Sand-lime bricks have been developed by Lhoist. This lime contains special elements such as silica, aluminium and iron that act as hydraulic components, improving the "green" strength of the bricks. In their manufactures, the lime, sand and water mixture is preformed in presses. These bricks are hardened in autoclaves under steam pressure at temperatures between 160 and 203 °C. Lime and quartz sand react to form compounds that give those calcium silicate bricks their compressive strength. These special bricks are characterised by their good sound-insulating properties and their high compressive strength.
    - Aerated concrete is made of lime as well as cement, sand and water. After these components have been homogenised, aluminium powder is added, which acts as a gas-forming raising agent, producing a frothy mass which is cut with wires and hardened in autoclaves. Aerated concrete facilitates construction and offers optimum thermal insulation (Lhoist web site).
- ***Environment*** - Waste incineration and many industrial processes generate flue gases which often contain pollutants such as sulphur dioxide (SO_2) and hydrochloric acid (HCl) as well as heavy metals, dioxins and furans. Lime-based products are efficient reagents for capturing these gases. Quick lime (CaO) can further be hydrated, combined with water in varying proportion.
- ***Soil stabilisation*** - Quicklime (and especially low-dust lime) is used to dry out damp soils and to improve the clay soils used in earthworks. Lime is also increasingly used to recycle excavated material from sites in urban areas. A recent application of lime is the use of hydrated lime in the cement filler that consolidates underground works such as tunnels. These new fillers extend the lifespan of mixes by improving resistance to stripping and to rutting, reducing brittleness at low temperatures, and improving resistance to strain.
- ***Civil infrastructure*** - in tunnel construction, hydrated lime is used as a component to improve the rheol-

Figure 4: Dolostones aggregates preparation in the Marche-Les-Dames (Namur) quarry. (Goemaere et al., 2010).

Figure 5: Overview of the Marche-Les-Dames (Namur) quarry. Mining Tournaisian dolostones. (Goemaere et al., 2010).

Figure 6: Overview during the wintertime of the Seilles (Andenne) quarry and plants services. (Goemaere, 2010b) (Photo: P. Timmermans).

ogy of mortars. Furthermore, quicklime dries out the rotary mud which comes from the excavation process and thus makes its handling easier. In injection works, hydrated lime is one of the components used in the definition of the injection binders.

- ***Paper*** - Lime is traditionally used to reconstitute caustic soda from the sodium carbonate left over from the pulp-making process. High-purity lime is useful for the fabrication of Precipitated Calcium Carbonate (PCC). Quicklime is usually mixed with water to form a slurry to which carbon dioxide is added. The resulting reaction produces a very fine precipitated calcium carbonate. This filler is used in paper production to enhance the paper's whiteness, opacity and texture.
- ***Refractories*** - Dead-burned dolomite is produced when dolomite is calcined at very high temperatures. It is used both as a refractory product in granular form to repair linings and for making the bricks used in the refractory linings of casting ladles and cement kilns. In the steel refining process, the use of dolime instead of pure quicklime will extend the life of refractory linings. In fact, adding dolime will create MgO in solution in the slag, which provides an excellent buffering capacity as MgO particles in suspension provide excellent coating protection. Any excess of MgO precipitates, protecting the refractories and tap holes, reducing the need for gunning and repairs.
- ***Drinking water*** - In drinking and process water preparation, lime is mainly used for pH adjustment and/or water purification. Milk of lime, among other products, is a cost-effective reagent which reduces the water's hardness by precipitating the bicarbonates dissolved in it, thus preventing the formation of scale (sources: Lhoist and Carmeuse websites).

Chalk and cement – Belgium (synthsis from Edwards, 2012 and producer websites)

In 2010, the world production of hydraulic cement was 3,300 Mt and the top three producers were China (1,800 Mt), India (220 Mt) and USA (63.5 Mt respectively. The Belgian cement industry is under the umbrella of three world reference companies: CBR (HeidelbergCement Group), CCB (Italcementi Group) and Holcim. Together, they trade a large variety of cements (white cement, Portland cement, aluminous cement, hydraulic cement and cement clinkers) and derived products. They produce +/- 6 Mt/yr of grey cement with a turnover estimated at 480 million euro. These companies produce also aggregates (from Dinantian limestones) and concretes. The total number of employees of FEBELCEM (*Fédération Belge des Cimentiers*) member companies is about 1,100.

Belgium has five integrated cement plants. Four of them are located near the French border in the Mons geologic basin, while the fifth one is located at Lixhe, in the eastern part of the country (the Meuse Valley, in front the city of Visé, very close to the German and Dutch borders). The integrated cement capacity is 6.35 Mt/yr (Edwards, 2012). Belgium consumed 4.2 Mt of cement in 2010, and exported 1.7 Mt destined for the EU, mainly to France and the Netherlands. Nearly 20% of the cement produced in Belgium was used in civil works, 36% in residential construction and 44% in non-residential construction.

Three integrated cement plants (Cretaceous chalk from Lixhe-Visé, Dinantian limestones from Tournai, and white Cretaceous chalk from Harmignies) are managed by SA Cimenteries CBR Cementbedrijven NV (owned by the German HeidelbergCement Group). It is the main cement producer in Belgium, with a total cement capacity of 4.2 Mt/yr (grey cement) and 0.18 Mt/yr (white cement). It is the only manufacturer of white cement in the Benelux region. CBR Harmignies is the only plant in the Benelux region that produces white cement. White ordinary Portland cement is similar to ordinary, gray Portland cement in all respects except for its high degree of whiteness. Obtaining this color requires substantial modification to the method of manufacture, and because of this, it is somewhat more expensive than the gray product. White Portland cement has a very low level of Fe_2O_3, so conventional silica and iron-rich clays are replaced with kaolin coming from Transinne (Libin, Belgian Ardennes, weathering of Lower Devonian rocks).

The Swiss multinational cement producer Holcim Ltd. has an integrated cement plant located at Obourg (Cretaceous chalk, Mons Basin) and has a production capacity of 1.77 Mt/yr (data 2011). The Obourg plant is supported by a grinding plant at Haccourt in the east of Belgium. It has a capacity of 0.5 Mt/yr and produces mainly blast furnace slag cement. Clinkers are exclusively sourced from Obourg. Holcim's cement operations are complemented by a raft of ready-mix concrete facilities, which are spread throughout the country.

Finally, the "Compagnie des Ciments Belges" (CCB) is owned by Italcementi Group of Italy. The Gaurain-Ramecroix plant (Dinantian limestones) has a 2 Mt/yr cement capacity and provides a variety of standard and non-standard types of cement. The Gaurain-Ramecroix quarry also produces materials for the aggregates.

Conclusions

Belgium is a "small" European country but is a very important actor in the industrial carbonates sector. Five big international companies are active in Wallonia, both mining and transforming high purity carbonates (limestones, dolostones and chalk). Belgium consumes a large part of its own production (aggregates, cement, lime, dolime, etc.) but, due to its favourable geographical situation, also exports finished or semi-finished products to the surrounding countries.

The standard of living that we are used to depends on the economic availability of an abundant supply of limestone resources. Carbonates and their derivative products play a crucial role in our daily lives, but many people don't realise that! Due to strong competition with other human activities, strict land use planning and NIMBY and NIMEY reactions, one of the main challenges of the next decades will be the accessibility to the raw material. We must pursue our efforts in communication!

Acknowledgements

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Correlations between mechanical and geometrical parameters in aggregates: a tool for quality assessment and control

*Dimitrios M. Xirouchakis**

Mineral aggregates are used in construction, and market demand dictates production quantity and quality. Correlations between mechanical and geometrical parameters can be employed as quality and performance prediction tools. For that purpose, I evaluated the correlation between the flakiness and shape index (FI–SI), dry and wet resistance to wear (MD_E & MD_S), resistance to fragmentation (LA), and resistance to polishing and abrasion (PSV–AAV) based on a large number of samples and different rock types. The FI–SI, MD_S–MD_E, and MD_E–LA are positively correlated. The PSV–AAV correlation divides aggregates into materials with (1) high polishing resistance for high abrasion resistance (high PSV–low AAV) and (2) high polishing resistance for low abrasion resistance (high PSV–high AAV).

Les agrégats sont utilisés pour la construction et c'est la demande du marché qui dicte la production, au niveau quantité et qualité. Les corrélations faites entre les paramètres mécaniques et géométriques peuvent servir d'outils de prédiction pour préciser la qualité et la performance de ces matériaux. Dans ce but, j'ai évalué la corrélation entre le pouvoir d'écaillage et une échelle de formes géométriques (FI-SI), la résistance à la compression en mode sec et humide (MD_E & MD_S), la résistance à la fragmentation (LA) et la résistance en matière de polissage et d'abrasion (PSV-AAV), basée sur un grand nombre d'échantillons et de types de roches. Les FI–SI, MD_S–MD_E, et MD_E–LA sont corrélés de façon positive. La corrélation PSV-AAV sépare les agrégats en deux catégories : (1), les matériaux avec un niveau élevé de résistance au polissage pour une résistance d'abrasion élevée (PSV élevé–AAV faible) et (2) un niveau élevé de résistance au polissage pour une faible résistance d'abrasion (PSV élevé–AAV élevée).

Los áridos minerales se emplean en la construcción y la demanda del mercado el la que controla la cantidad y la calidad de la producción. Se puede utilizar la correlación entre los parámetros mecánicos y geométricos como herramienta de predicción de la calidad y el comportamiento. Para ello se ha evaluado la correlación entre el índice de lajas y el de forma (I_L-I_F), la resistencia al desgaste en húmedo y en seco (RD_H-RD_S), el coeficiente de desgaste Los Ángeles (LA) y la resistencia al pulido y a la abrasión (CPA-CA) en base a un gran número de muestras de diferentes tipos de rocas. Los valores de I_L-I_F, RD_H-RD_S y RD_H-LA, tienen una correlación positiva. La relación CPA-CA clasifica los áridos en materiales (1) con una elevada resistencia al pulido y resistencia a la abrasión (alto CPA-bajo CA) y (2) elevada resistencia al pulido y baja resistencia a la abrasión (alto CPA-alto CA).

According to the European Aggregates Association (UEPG), the aggregates sector is the largest amongst the nonenergy extractive industries, directly and indirectly employing 250,000 people and representing a turnover of around €20 billion. Approximately 90% of all aggregates produced in EU are from quarries (49%) and pits (41%). The rest are recycled, marine, and manufactured aggregates. Aggregates are a granular material typically used in construction (concrete and asphalt plants, new construction, and repairs). Most common natural aggregates of mineral origin are sand, gravel and crushed rock. Market demand dictates production quantity and quality. The quality of aggregates strongly depends on materials properties and processing technology.

Producers of aggregates face more than one set of materials performance requirements (e.g., grading, particle shape, surface texture, durability, abrasion resistance). Therefore, aggregate testing is critical to evaluate production quality and anticipated performance. Occasionally, testing may be incomplete and product assessment may rely on a partial set of quality indicators. For this reason, I concentrated on the most common pairs of parameters used to describe particle shape, resistance to wear and fragmentation under dry and wet conditions, and resistance to polishing and abrasion. The goal was to evaluate the pairwise correlations and their potential as quality control and prediction tools. I have not attempted to correlate materials properties and processing technology because of lack of relevant data. Nonetheless, the processing industry has been exploring this relation.

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Materials and Methods

For self-consistency, only data from tests performed according to EN standard test methods were considered (e.g., EN 13043 and methods therein). The data set comprises slags, igneous, metamorphic, and sedimentary rocks. The GeoTerra database includes coarse aggregates (4/31.5) either from sites sampled once or multiple times between 2007 and 2012. Commonly, the same quarry employee at each site performed the sampling according to EN 932-1 and the same pool of laboratory technicians performed the testing. Details for the data in ***Tables 1, 2,*** and ***3*** can be found in Xirouchakis (2013) and references therein.

Construction Materials Testing (CMT) laboratories rely on the flakiness index (FI) and shape index (SI) for evaluating particle shape. The FI (EN 933-3) and SI (EN 933-4) values represent mass percentages of flaky and elongate grains. Resistance to wear under wet and dry conditions is assessed by using the micro-Deval method (EN 1097-1) and is expressed as the MD_E and MD_S value, respectively. Resistance to fragmentation (EN 1097-2) is performed under dry conditions and is reported as the LA value. The resistance of coarse aggregates to polishing and abrasion prior to use in road surfaces is evaluated by using the Polishing Stone and Abrasion Resistance me-thods (EN 1097-8 & EN 1097-8 Appendix A). Test procedures as well as precision statements are given in the standard test methods. The relative expanded uncertainty at the 95% confidence level (%U) for all non-GeoTerra data was estimated from the precision and accuracy statements in the standard test methods. For the GeoTerra data set, the relative expanded uncertainty for FI, SI, MD_E, MD_S, LA, PSV, and AAV is 5.1%, 2.0%, 5.1%, 8.0%, 6.7%, 0.6%, and 1.8%, respectively, and well within the standard limits. The relative expanded uncertainty was used to construct the error bars in ***Figs. 1, 2,*** and ***3***. To evaluate data variability for sites that were sampled over a period of years, which applies to many sites in the GeoTerra database, I opted to look at the ratio of single-year to multiple-year standard deviation ($s_{single-year}/s_{multiple-year}$) or average ($\mu_{single-year}/\mu_{multiple-year}$) as a proxy for within- to between-group variability. For low-variability data, the above-mentioned ratios should be unity or close to unity. Sampling and testing procedures are executed according to standard test methods, and thus should contribute little to variability. Consequently, mineral and rock properties are the likely source for the data variability and correlations for same-source, low-variability data.

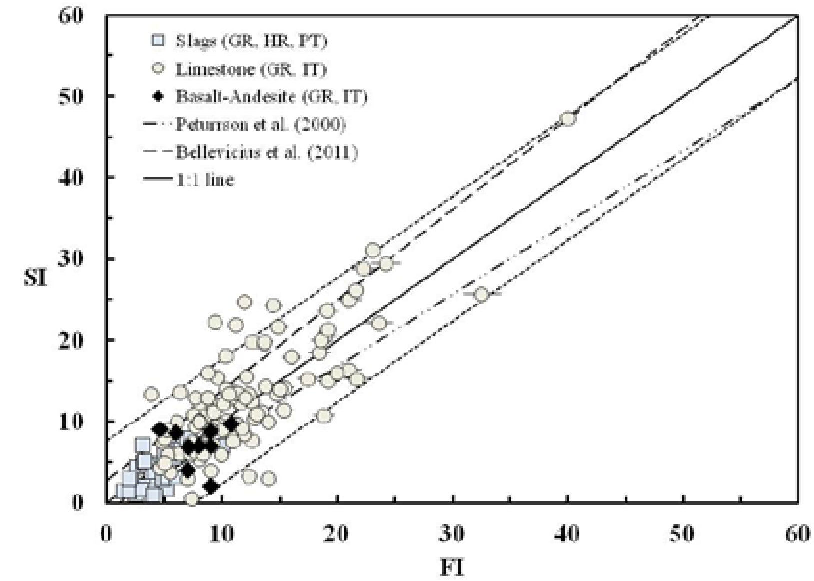

Figure 1: FI vs SI. Aggregates are from Greece (GR), Croatia (HR), Italy (IT), and Portugal (PT). Solid line is the 1:1 line and the dashed lines are the 95% confidence limits. The dot dashed and dashed lines are from Peturrson et al. *(2000) and Bellevicius* et al. *(2011), respectively.*

Results and Discussion

FI vs SI

Particle shape affects packing and mechanical stability of mixtures with and without binder as well as road surface properties. Typically, a grain is classified as flaky if the width–thickness ratio is >2.0, elongated if the length–thickness ratio is >2.5, and cubic if the width–thickness ratio is <2.0 and the length–thickness ratio is <2.5 (e.g., Uthus, 2007). Note that length (L) is the maximum, width (W) the medium, and thickness (T) or height (H) the minimum particle dimension.

According to the SI test, the grains are divided into cubical and noncubical, where the noncubical grains have a length–thickness ratio greater than 3, and SI represents the ratio of the mass of noncubical grains to the total mass of grains. FI divides particles into flaky or nonflaky and is the ratio of the mass of flaky grains to the total mass of grains. Uthus (2007) estimated that cubic and cubic rounded grains correspond to SI values of 0.083–0.056 and FI values of 10.99–8.08, whereas flaky and flaky rounded grains have SI values of 55.5–63.3 and FI values of 12.42–20.34, respectively. Hann (2009) experimentally determined the relation between the SI and shape factor F, based on which spherical and cubical grains with F between 1 and 0.785 correspond to SI values between 4 and 20.

The FI and SI values for EAF slags, limestones, and igneous rocks are listed in ***Table 1*** and shown in ***Fig. 1***. Both indices are positively correlated regardless of rock type, site, or region with a correlation coefficient of 0.83. In the GeoTerra database and for the same sampling sites, the average $s_{single-year}/s_{multiple-year}$ for FI and SI is 1.0 ± 0.1 and 0.9 ± 0.1, respectively. For comparison, the average $\mu_{single-year}/\mu_{multiple-year}$ for FI and SI is 1.0 ± 0.1 and 1.0 ± 0.1, correspondingly.

The data in ***Fig. 1*** can be equally well described by the 1:1 line or the equation FI = 1.01 × SI (R^2 = 0.63). The dashed line in ***Fig. 1*** represents the equation SI = 1.13 × FI + 1.04 that Péturrson *et al.* (2000) used to describe the FI and SI correlation in Icelandic basaltic aggregates. Bulevicius et al. (2011) reported strong correlation between FI and SI for dolomitic and granitic aggregates (r = 0.7) and fitted the data with the equation SI = 2.714 + 0.595 × FI (dot-dashed line in ***Fig. 1***). Limestone aggregates from Greece exhibit moderate correlation (r = 0.62) between FI and SI, and little to weak positive correlation between FI and LA (r = 0.10), FI and MD_E (r = 0.09), SI and LA (r = 0.15), and SI and MD_E (r = 0.36). Bulevicius *et al.* (2011) found a stronger positive correlation between LA and FI (r = 0.64–0.73) and LA and SI (0.62–0.76). Thus, the data in ***Fig. 1*** strongly suggest that hard materials will have low SIs and FIs and, therefore, higher mass percentages of nonflaky and cubical grains.

MD_S vs MD_E and MD_E vs LA

Resistance to wear and fragmentation are used to evaluate materials suitability for construction and predict long-term performance; low MD_S, MD_E, and LA values typically characterize hard, mechanically strong materials. The data for resistance to wear under wet (MD_E) and dry conditions (MD_S), and resistance to fragmentation (LA) are given in ***Table 2***. The MD_S data set is less comprehensive than the rest but nonetheless useful. MD_S and MD_E are, unsurprisingly, strongly correlated (r = 0.98), with MD_S values registered at approximately half the corresponding MDE values, regardless of rock type and di/Di fraction. Clearly, water enhances sample attrition. The MD_E and LA data are listed in Table 2 and shown in ***Fig. 2***. Dry resistance to fragmentation (LA) and wet resistance to wear (MD_E) are positively correlated (r = 0.81). In the GeoTerra data set and for the same sampling sites, the $s_{single-year}/s_{multiple-year}$ ($\mu_{single-year}/\mu_{multiple-year}$) ratio for LA is 0.9 ± 0.1 (1.5 ± 0.2) and for MD_E is 0.8 ± 0.03 (1.0 ± 0.0).

The LA–MD_E relation can be described with the equation LA = 4.95 × MD_E0.61 (R^2 = 0.69), which provides slightly better fitting than linear-type equations and better simu-

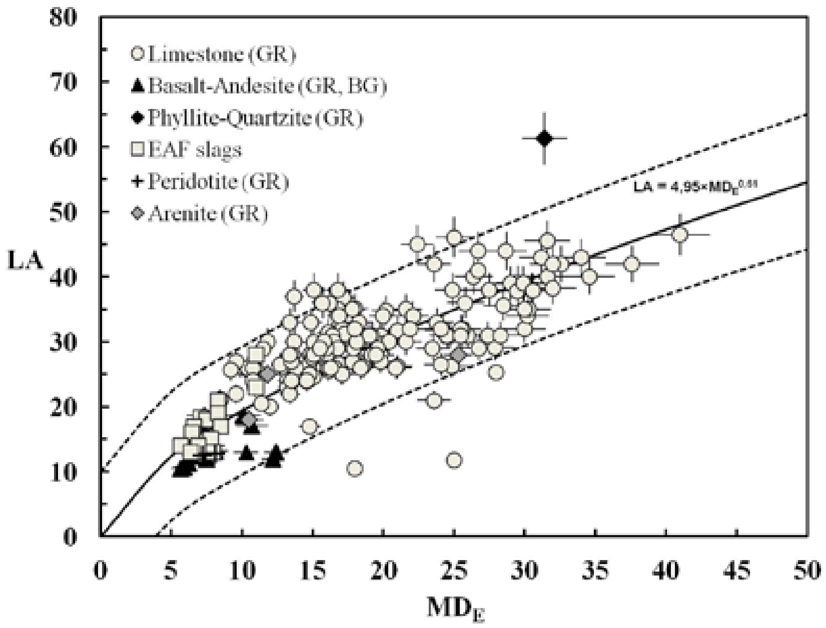

Figure 2: MD$_E$ vs LA. Aggregates are from Bulgaria (BG), Greece (GR), Croatia (HR), and Portugal (PT). Solid line represents the nonlinear fit to the data and the dashed lines are the 95% confidence limits.

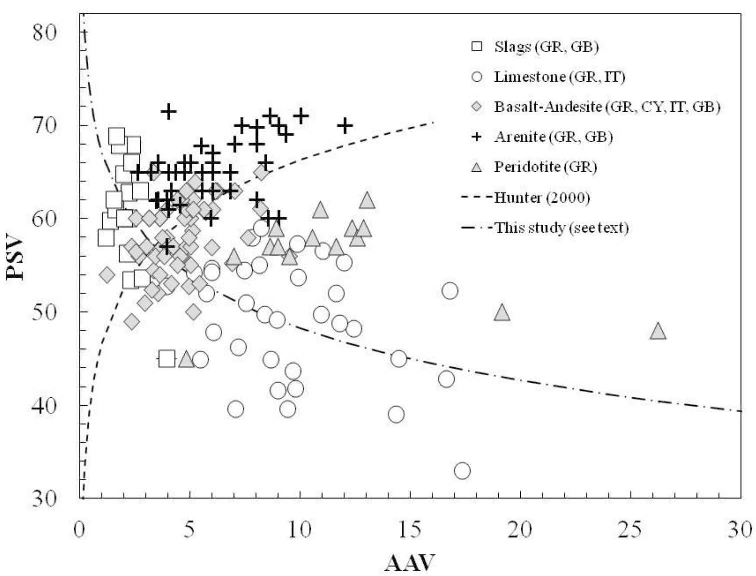

Figure 3: AAV vs PSV. Aggregates are from Cyprus (CY), Greece (GR), Great Britain (GB), and Italy (IT).

lates the subtle nonlinearity in the LA–MD$_E$ relation at low values for hard aggregates. The correlation of MD$_E$ and LA to the d_i/D_i fraction is weak (MD$_E$–di/D$_i$, r = 0.18) to moderate (LA–d_i/D_i, r = 0.40). Generally, there is neither much research in the EU for the micro-Deval vs LA correlation nor for the limits associated with good long-term performance, probably because of the past lack of common tests across the EU. In contrast, Departments of Transportation (DOTs) and Research Centers (e.g., ICAR) in North America (CA & USA) have adapted more quickly, even to a new test such as the wet micro-Deval. Despite the differences between the EN and ASTM, or CAS, standard test methods, MD$_E$ and LA exhibit moderate to strong, positive correlation (r = 0.45–0.89). Cuelho *et al.* (2008), after reviewing the US literature, concluded that aggregates with good long-term performance have an ASTM LA of less than 40 and ASTM MD$_E$ of less than 18. Despite the lack of similar research in Europe, using a limiting LA value of 30 for high-specification aggregates and the proposed equation, the corresponding limiting MD$_E$ value is 20. The LA value of 30 and MD$_E$ value of 20 encompass hard materials such as slags and mafic to intermediate crystalline volcanics.

AAV vs PSV

Resistance to polishing is required for skid-resistant road surfaces. Aggregates with a rough microtexture, maintained by differential wear or continuous plucking, or by the presence of intergranular voids, have high resistance to polishing (high PSV). Abrasion resistance is also an important parameter that characterizes road-surfacing materials. Abrasion resistance is affected by mineral hardness, grain size and orientation, and mineral weathering. The PSV and AAV data are listed in ***Table 3*** and shown in ***Fig. 3***. The data were examined and grouped according to material type. The control stone (CS, EN 1097-8) data in ***Table 3*** are from West and Sibbick (1988) and the GeoTerra stock. The control stone is a fine- to medium-grained aphyric equigranular microgabbro, and the PSV and AAV are listed to aid the reader in the evaluation of the GeoTerra data reproducibility and bias.

Two groups of aggregates and correlations are apparent in ***Fig. 3***. First, aggregates with moderately negative correlation such as limestones (r = −0.49) and slags (r = −0.63). Within this group, subgroups may exhibit stronger negative correlation than as a group, e.g., Greek limestones (mostly micritic with 90–99% $CaCO_3$) with r = −0.63 and Italian limestones with r = −0.68. The second group comprises aggregates with variably moderate positive correlation such as basalt–andesite (r = 0.39), sandstones (r = 0.44), and serpentine-poor peridotites (r = 0.79). The basalt–andesite group consists of crystalline rocks, and the sandstones are hard graywackes and gritstones. When serpentine-rich peridotites are included in the peridotites, the group as a whole exhibits weak negative correlation between PSV and AAV (r = −0.26). The dashed line in ***Fig. 3*** represents the equation PSV = 8.5 × ln AAV + 46.8 (R^2 = 0.76) of Hunter (2000) for igneous rocks and arenites that exhibit positive PSV–AAV correlation—the data in Hunter (2000) are not shown in ***Fig. 3*** or included in the analysis. Similar trends are produced by using the equation in Thompson *et al.* (2004) for such aggregates. The antithetic equation PSV = −8.1 × ln AAV + 60.9 (R^2 = 0.56) (dot-dashed line in ***Fig. 3***) of this study is for aggregates with negative PSV–AAV correlation. Apparently, such aggregates may not rejuvenate during service as mafic–

intermediate volcanics and arenites may do, through polishing by traffic during the dry months and restoration by weathering during the rainy months. Therefore, in such cases, aggregates with high PSV and low AAV need to be selected, e.g., steel slags, as they will resist polishing and abrasion.

Conclusions

The FI–SI, MD_S–MD_E, MD_E–LA, and PSV–AAV correlations were evaluated considering a large number of samples and different rock types. The FI–SI correlation is strongly positive and is well described by the 1:1 line; furthermore, the data suggest that hard materials with low FI and SI may contain a larger number of cubical and nonflaky grains. Strong positive correlation is also seen between MD_S and MD_E, and MDE and LA that can be well fitted with the equation $LA = 4.95 \times MD_E^{0.61}$ (R2 = 0.69). As anticipated, hard aggregates have low MD and LA values. The PSV–AAV correlation divides aggregates into materials that exhibit (1) high polishing resistance for high abrasion resistance (high PSV–low AAV), such as limestone and slags; and (2) high polishing resistance for low abrasion resistance (high PSV–high AAV), such as arenites and mafic–intermediate crystalline volcanics. Peridotites belong to either PSV–AAV group depending on the content of low-hardness minerals. The abovementioned correlations can serve as quality control and assurance tools, and fill in incomplete data for the quality assessment of aggregates.

Acknowledgments

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Geology of the perlite bodies at Pálháza

*Tibor Zelenka**

The perlite occurrences of the Sarmatian rhyolite-rhyodacite volcanics between Pálháza and Telkibánya in the NE part of the Tokaj Mountains of Hungary have been known for more than 200 years. The submarine extrusions formed domes or vents at the rim of a rhyolitic caldera with pumicite, hyaloclastite breccia, pitchstone, perlite and peperite bodies. Subsidence into the empty magma chamber prevented their erosion. The mined products come from glassy pipe breccias of pitchstone, perlite and lava-pumicite, massive perlite (hydrated obsidian) and pumice-bearing perlite bodies, which have optimal water content (2.5-3.5%) for swelling. Exploration was begun in 1950 and mining in 1956. Since then, more than 3.7 Mt of perlite have been exploited from the Gyöngykő Hill, South Som Hill and Páska Hill quarries. The 50,000-70,000 t/y production makes this the 3rd or 4th most productive site in Europe and the 5th most important among the continuously mined occurrences in the world.

Les occurrences de perlite au sein des formations volcaniques de Sarmatie (rhyolite et rhyodacite) entre Pálháza and Telkibánya, dans la partie nord orientale des montagnes du Tokaj, en Hongrie, sont connues depuis plus de 200 ans. Les extrusions sous-marines ont créé des dômes ou des fissures à la périphérie d'une caldeira rhyolitique avec des amas de ponces, de brèches hyaloclastiques, de pechsteins, de perlites et de pépérites. Un affaissement à l'intérieur de la chambre magmatique vide les a préservées de l'érosion. Les produits exploités proviennent de brèches de pechstein sous forme de coulées vitreuses, de perlites plus ou moins massives (obsidienne hydratée), de pierres ponces et d'amas de perlites avec éléments de ponces, roches qui contiennent une proportion d'eau optimale (2.5-3.5%) pour gonfler. L'exploration a commencé en 1950 et l'exploitation en 1956. Depuis, plus de 3.7 Mt de perlite ont été exploités à partir des carrières des monts Gyöngykő, Som Sud et Páska. La production annuelle de 50,000 – 70,000 tonnes fait de cette région le 3ème ou 4ème site le plus productif d'Europe et le 5ème en importance au monde parmi les extrusions exploitées en continu.

Los indicios de perlita de la formación volcánica riolítica-riodacítica Sarmatiense, situada entre Pálháza y Telkibánya al NE de las Montañas Tokai de Hungría se conocen desde hace más de 200 años. Las erupciones submarinas formaron domos o conductos al borde de una caldera riolítica con pumita, brechas hialoclastiticas, vidrios volcánicos, perlita y masas de peperitas. La subsidencia en la cámara magmática evitó su erosión. Los productos de mina proceden de conductos de brechas de vidrio volcánico, perlitas y lavas pumíticas, perlitas masivas (obsidianas hidratadas) y masas de perlita con pumitas, que tienen el contenido en agua adecuado (2,5-3,5%) para poder ser expandidas. La exploración comenzó en 1950 y la extracción en 1956. Desde entonces se han extraído más de 3,7 Mt de las canteras de los cerros de Gyöngykő, Sur Som y Páska Hill. Esa producción de entre 50.000 y 70.000 t/año sitúa a esta zona como las 3ª y 4ª con mayor producción de Europa y la 5ª más importante del mundo entre las que han estado en explotación continuamente.

History of the exploration

The perlite occurrences of the Tokaj Mountains have been documented in the geological literature since the beginning of the 19th century. Detailed mapping and prospecting was begun in the 1950s by the Hungarian Geological Institute (Liffa, 1953). Further prospecting projects raised the number of known occurrences and indications up to 35 (Ilkeyné Perlaky & Szöőr, 1973; Mátyás & Sántha, 1975; Gyarmati, 1982; Csillag & Zelenka, 1999). The exploration of the Pálháza Gyöngykő Hill perlite body (the name 'Gyöngykő' means 'pearlstone', or perlite) started in 1956 with shallow shafts and adits. In the period up to 1966 a three-level quarry was opened and a processing plant set up by the Hegyalja Works of the National Ore and Mineral Mining Company. Further exploration included 180 boreholes with core sampling and 200 boreholes with dust sampling in a systematic network (cca. 8000 m of drilling in aggregate).

From the 1980s the exploration was extended to the Som and Páska Hills, towards the village of Bózsva. Presently several parts of the Tokaj Mts where perlite is found are declared as protected areas, obstructing further exploration and prospecting of these occurrences, which are significant on a European scale.

Figure 1: Extrusive black perlite bodies broken through yellow tuffite, with contact breccia zone in the upper pyroclastics on the top.

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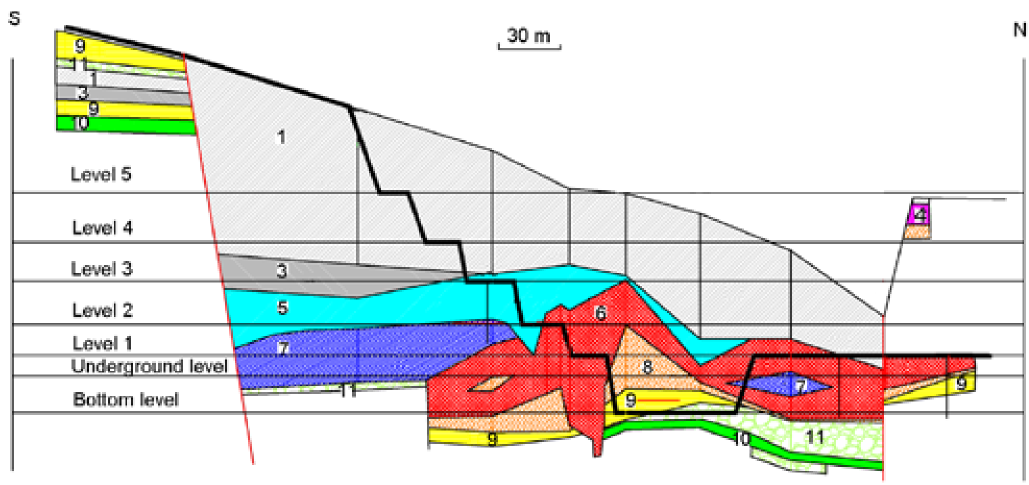

Figure 2: Cross section of South Som Hill quarry. Thick black line shows recent profile of mine wall; thin, vertical lines represent drillholes.
Legend:
– overlying complex: 1 – volcanic (pyroclastic) breccia); 2 – lava flow perlite; 3 – lava breccia
– productive complex: 4 – red brecciated perlite; 5 – brecciated perlite; 6 – columnar unaltered perlite; 7 – rhyolitic perlite (with flow texture); 8 – contactised pumiceous perlite
– underlying complex: 9 – tuffite (with clay and sandstone); 10 – pyroxene andesite; 11 – andesite conglomerate and breccia.

Geology of the deposit

The NE part of the Tokaj Mountains between Pálháza and Telkibánya comprises a Sarmatian (Upper Miocene, K/Ar age ~ 13Ma) rhyolitic-rhyodacitic volcanic range. These rocks were formed on the rim of a subduction zone from acidic, highly viscous lava and its pyroclastic derivatives. The eruptions breaking through the Sarmatian micro- and macrofaunal clay marl deposits produced glassy pyroclastics (pumicite and hyaloclastite breccia) and lava rock bodies (perlite, pitchstone, obsidian-breccia, lava-pumicite and peperite) (***Figure 1***).

In the vicinity of Pálháza, at the villages of Nagyhuta and Kishuta, a Sarmatian rhyolite caldera can be outlined. Perlite bodies lay on the rim of this structure in separate volcanic domes and pipes: Gyöngykő Hill, Som Hill (Pálháza), Páska Hill (Nagybózsva), Lackó Hill (Kishuta) and Kopcsa Hill (Kovácsvágás). The basement of these bodies consists of Badenian andesite, marine clay, tuffite and pumicite. The pipes of the submarine eruptions produced thick, polymictic hyaloclastite breccia bodies at first. The central parts of the pipes are comprised of pitchstone-perlite breccia. On the top parts there are lava extrusions, lava domes altered to obsidian (perlite), contactising the hyaloclastite breccia (Zelenka, 2008). The lava domes form columnar cooling structures like an opening flower chalice. At the contact of the extruded rhyolitic lava and the underlying wet sediments perlitic lava breccia (peperite) was formed. On the upper rim of the pipes the rhyolitic lava forms sheaths with changing facies from inside out: massive, lithophysic, lithoidic, spherolithic, perlitic and pumiceous facies.

The quarries at Gyöngykő Hill, South Som Hill (Pálháza) and Páska Hill (Nagybózsva) supply perlite and pitchstone breccia. Exploration and mining revealed several subsequent extrusive lava domes on each site. Evidences from drilling data show that perlite bodies inside the cca. 0.5 km^2 area of the pipes were subsided into the empty magma chambers of the domes down to 100 m depth, so these were preserved from the erosion (***Figure 2***).

The perlite at Pálháza was formed in seawater from glassy rhyolite lava of four major facies: massive columnar, lava flow, brecciated and pumiceous (Mátyás & Sántha, 1975). The epigenetic hydration of the obsidian causes a volume increase with several cracks; the onionskin-like arrangement of these microcracks produces the perlite structure. The raw perlite rock consists of 90-95% amorphous volcanic glass, 5-6% crystalline constituents (quartz, plagioclase and biotite with accessory amphibole, pyroxene and magnetite) and 2.5-3.5% molecular water. The raw bulk density is 1.1 g/cm^3, the swelled product's bulk density decreases to an optimal value of smaller than 50 g/l, and it has a medium breaking strength.

In a petrographic view the useful raw mining products are not confined to pure perlite; these can be classified into four types.

1. Perlite: dense mass of black 'pearl' grains of 2-5 mm diameter with 0.1-3 mm crystals of white plagioclase, quartz and dark, hexagonal biotite. In the glass with flow texture there are globulite, longite and trichite crystallites (***Figure 3***). Perlite grains include marekanite (obsidian) cores indicating that perlite was formed from obsidian.
2. Obsidian: black or dark grey, massive volcanic rock with conchoidal fracture and 0.5-1% water content. Crystalline constituents (some plagioclase and biotite grains) are cryptocrystalline.
3. Pitchstone: brown, reddish or greyish, glassy volcanic rock formed from lava of high water content, occurring mainly at the bottom of perlite bodies. The breaking strength is higher than that of perlite and the fractures are splintery.
4. Pumice: white, vesicular volcanic glass swelled by vapour and chloridic, fluoridic volcanic gas, having a lower constitution water content than perlite. Lava pumicite was formed from rhyolite lava coming suddenly into contact with water saturated sediments. The breaking strength is lower than that of perlite.

Further varieties found are: (5) perlite from the contact zones, which may be welded and rich in pumice, (6) very inhomogeneous brecciated perlite and agglomerate on the side and top rims of perlite bodies and (7) thin perlite seams in dry and crystalline-rich lava flows.

Mining of the deposit

After winding up of the state-owned Hegyalja Works in 1992 the newly founded Perlite-92 Ltd. continued the mining. More than 3.7 Mt of industrial perlite have been exploited in the past 55 years from the Gyöngykő Hill, South Som Hill and Páska Hill quarries. The term 'industrial perlite' covers the glassy pipe breccia (pitchstone – perlite – lava pumicite breccia), the massive perlite bodies formed by hydration of obsidian and the perlite with lava pumicite. In 2007 the Páska Hill quarry, which produces pitchstone breccia, was opened. The raw perlite products separated by comminution and classification are transported to the processing plants. The 50,000-70,000 t/y production (65,000 t in 2011) makes this mine the 3rd or 4th in Europe in terms of production and the 5th most important among the continuously mined perlite occurrences in the world.

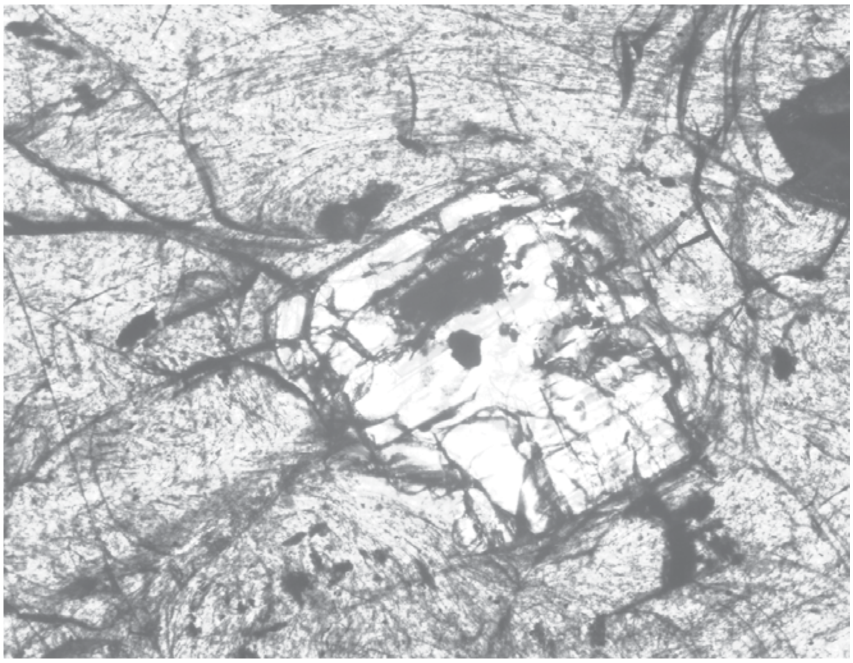

Figure 3: Plagioclase grain in perlitic volcanic glass matrix with typical perlitic cracks.

Usage of perlite

Raw industrial perlite is a volcanic glass with 68-75% SiO_2, 6-9% total alkaline and 2.5-6% molecular water content. During heating to 400 °C it loses its diffusion molecular water content, then rapid heating to 850-1150 °C (thermal shock) causes bubbling of the constitution water and expansion to 7-15 times of the original volume. This swelled perlite is a lightweight, porous silicate foam with half open, half closed porosity.

The manifold utilisation of perlite comes from its low density, relatively high strength, its fireproof, soundproof and thermal insulator nature and its high absorption capacity. It is used in the construction industry as an additive in concrete and mortar due to its great lime bounding capability, insulator characteristics and strength; in gardening due to its sterility, porosity and water adsorbing capacity, thus promoting root development and soil loosening; in the chemical and filtering industry due to its inert character and acid neutralising capacity for rapid filtering and purification of viscous liquids (vegetable oil or juice); in environmental protection for the insulation of tanks and furnaces or oil removal from water surfaces (Farkas, 2008).

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Aggregate potential mapping in Ireland

Gerard Stanley and Phelim Lally*

The Geological Survey of Ireland (GSI) commenced a programme of aggregate potential mapping (APM) both for sand and gravel, and for crushed rock resources in Ireland in 2007. The mapping system is based on scores assigned for a number of evidential layers (geological, geographic, market and social). The end result is a suite of maps providing baseline information and two main maps – one for granular materials and one for crushed rock aggregates. Each map displays five categories from 'very low potential' to 'very high potential' and is colour coded. This paper will describe the data inputs, explain the processing steps, and provide a summary of the main outputs from the programme.

L'Association des Géologues Irlandais (GSI) a commencé en 2007 un programme de cartographie potentielle des agrégats (APM) en Irlande pour évaluer les ressources à la fois en sable et graviers et en matériaux concassés. Le système cartographique est basé sur des valeurs attribuées à un nombre d'indicateurs évidents (géologiques, géographiques, économiques et sociaux). Il en résulte une série de cartes fournissant une information de base ainsi que deux cartes principales – l'une relative aux granulats, l'autre aux matériaux concassés. Chaque carte indique l'existence de cinq catégories distinctes depuis un 'potentiel d'agrégats très faible' jusqu'à un 'potentiel très élevé' avec un codage de couleurs. Cet article expose les données brutes, explique les étapes de traitement et donne un résumé des principaux résultats livrés par le programme.

El Servicio Geológico de Irlanda (GSI) comenzó en el año 2007 un programa de cartografía del potencial de áridos (CPA) del país, tanto para los recursos de arenas y gravas como para los áridos de machaqueo. El sistema cartográfico se basa en una puntuación asignada para una serie de capas de información (geológica, geográfica, mercado y social). El resultado es una serie de mapas que proporcionan la información de base y dos mapas principales, uno para materiales granulares y otros para áridos de machaqueo. Cada mapa tiene cinco categorías desde 'potencial muy bajo' a 'potencial muy elevado' con un código de colores. Este artículo describe los datos de entrada, explica los pasos del proceso e incluye un resumen de los principales resultados del programa.

Ireland has historically had an ample supply of both granular and crushed rock aggregates, and the industry has been able to acquire lands for quarrying with a minimum of regulatory or social constraints. During the late 1990s and up to the year 2007, the country experienced profound economic changes, most clearly epitomised by a building boom, during which time the demand for aggregates increased four-fold: output in 1995 was 40 mt (million tonnes), whereas in 2007 this figure is estimated to have reached 162 mt. As this market-driven phenomenon developed, several issues came to the fore which made quarrying and the search for construction materials more complex. Known resources, particularly of good quality sand, became exhausted as traditional extraction sites were worked to their limit. Environmental legislation was enacted at EU level and transposed into Irish law in a series of Acts which control or restrict the use of land available for quarrying. A minor population boom in the hinterland of the capital, Dublin, and in the outskirts of many towns gave rise to the phenomena of one-off housing and ribbon development, jeopardising the use of much land near centres of demand for aggregates. Finally, unregulated extraction began to grow, and standards in quality control were on occasions bypassed in the rush to bring product to the market.

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A need was perceived for more geological information, in order to aid the business of aggregates production on the one hand, and the work of local authorities in land use planning and resource management on the other. A balance needed to be found between preservation of high quality resources, in particular for future use within the regional economy, and the immediate needs of housing or social development. In response to this, the Geological Survey of Ireland (GSI) initiated a programme of aggregate potential mapping (APM) in 2007, and this exercise comes to a conclusion at the end of 2013. This article outlines the chief characteristics of the Irish APM project.

Evolution of the project

The concept of APM has been written about and put into practice since the early 1990s, with several of the Canadian provinces being pioneers in the field. APM is a process of evaluation and categorisation of surficial deposits and bedrock formations according to their suitability for producing fragmentary construction materials (aggregate), and then displaying their relative potential in map format. In the Irish exercise, the final maps of aggregate potential are colour-coded, with five classes from Very Low to Very High potential.

In the early 2000s, GSI carried out mapping of three of the State's twenty-six counties with financial support from county councils (local government authorities) in each case. Mapping of the remaining counties, and integration of the earlier three, began in 2007 as part of the Geoscience Initiatives Programme; funding for this comes from the government's National Development Plan 2007-2013. At the end of 2013, the results of the work will be released publicly through a viewer (ArcGIS™ Viewer for Flex) on the website of GSI's parent government department, the Department of Communications, Energy and Natural Resources. A mid-term selection of results is currently available at the site, *http://spatial.dcenr.gov.ie/APM/index*.html; the Viewer has data interrogation tools, downloads, and explanatory texts. The current material will be deactivated towards the end of 2013 in order to upload the completed project.

Methodology

At the outset, it was decided to separate potential resources into two types and perform aggregate potential modelling independently on each, in accordance with its geological characteristics. This gives rise to Granular Aggregate Potential (GAP) maps, which evaluate sands and gravels within the Quaternary subsoils, and Crushed Rock Aggregate Potential (CRA) maps, which

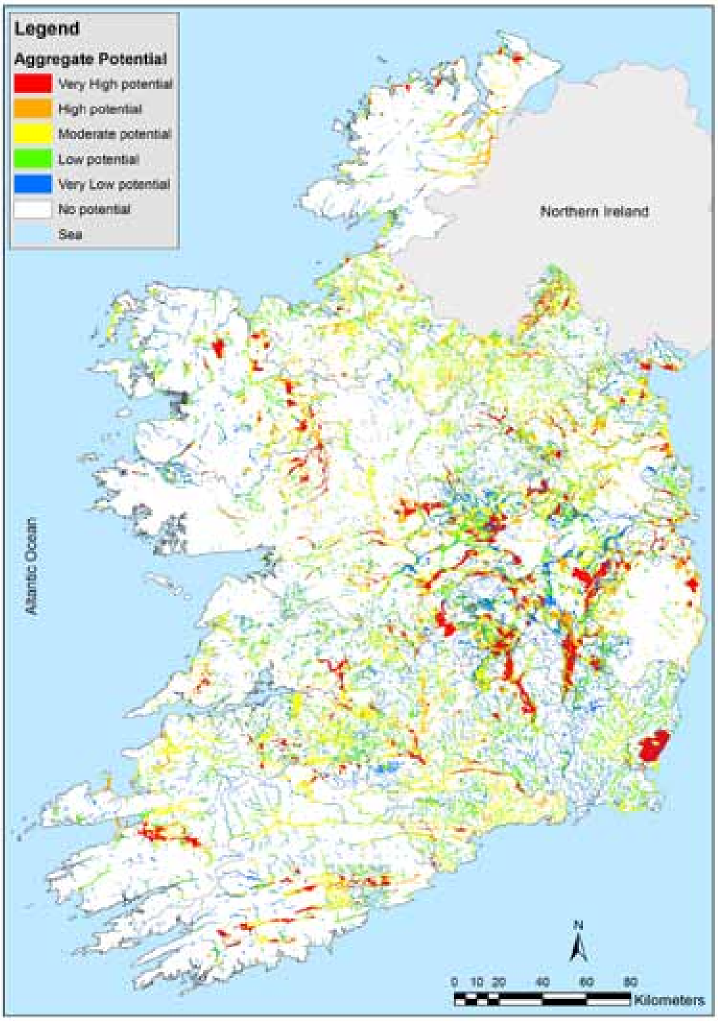

Figure 1: Granular Aggregate Potential (GAP) Map of the Irish Republic.

evaluate bedrock for the quality of crushed rock product that each formation is likely to produce.

GAP maps have an incomplete colouring, in that subsoils other than sand and gravel - or those potentially containing sand and gravel - were excluded from the analysis from the start; these include glacial till, peat, clays and areas of water, and rock within 1 m of surface. CRA maps, on the other hand, have a complete colouring, since all formations are capable of being quarried to yield crushed rock. The final maps are presented in ***Figures 1 and 2***. These figures portray the joining of 26 individual county APMs rather than an APM normalised for the entire State.

The general method employed is to bring together evidence layers, which are used to score subsoils and bedrock blocks, within a geographic information system (GIS). The evidence layers or scoring criteria are detailed below. The Irish APM is probably unique in using a variety of geoprocessing tools to subdivide parcels of land and combine scores, in what becomes a progressively more detailed mosaic of the base resource in each county. Final scores are grouped into five classes and like parcels amalgamated into one. Thus, the software is used to spatially discriminate between areas of differing overall potential.

Background studies

Background data gathering prior to GIS modelling consumed a large percentage of the total project time:

- Compiling a simplified geography base for each county, of selected towns and up-to-date road networks;
- Assembling all pits and quarries, dating back to the first Ordnance Survey maps of the 1830s, and digitising and documenting more recent ones;
- Combining alternative Quaternary Geology maps (if more than one existed), and extracting workable sand and gravel datasets from the parent map;
- Acquiring depth-to-bedrock digital maps for each county. These are essential for distinguishing sand and gravel thicknesses, or alternatively overburden thickness in the case of potential quarries into bedrock;
- Selecting topographic contours needed as scoring thresholds from Ordnance Survey digital elevation models, and converting them to polygon geometry;
- Preparing a scoring system for population density, used in the project as a proxy for demand for general construction aggregate. Census figures reported for 3,409 District Electoral Divisions across the State were acquired from the Central Statistics Office. Figures for Census 2006 were updated with those of Census 2011 during the course of the project;
- Preparing a national Road Projects Map (updated in 2011), and designing a system of buffers with decreasing scores away from each planned road scheme. Resource parcels nearer a road scheme are more attractive than parcels farther away. Many sources were consulted during compilation of the Road Projects Map, including the National Roads Authority of Ireland (NRA), long-term development plans such as Transport 21, and County Development Plans of each local authority area.

It is worth noting that each of these compilations has an attendant map. There are also simplified Formation/Rock Type Maps for each county.

Details of the scoring system

GAP maps are developed from the analysis, in the order shown, of the following layers:

a. Genetic type of the deposit, and petrology of the gravel;
b. Occurrence of gravel pits - specifically the number of pits (historic and recent) per area;
c. Area of the deposit;
d. Thickness of sediment;
e. Topographic elevation;
f. Proximity to markets – two types: general construction and road building.

CRA maps arise, similarly, from analysis of:

a. Rock type suitability;
b. Deleterious substances and features;
c. Occurrence of quarries – number per area;

d. Area of geological block – blocks being delimited by formation boundaries, faults or other structures, or county/local authority boundaries. Blocks are therefore subunits mapped within formations;
e. Thickness and character of overburden to be removed;
f. Topographic elevation;
g. Proximity to markets – two types: general construction and road building.

Thus it can be appreciated that there is a degree of similarity, but also some key differences, in the way the two resource types are modelled. Deposits/blocks receive a score for each of the lettered items on a scale of 0 or 1 to 10; scores are then combined, to arrive at a weighted sum as the final score according to the following algorithms:

GAP: 2a + 1.2b + 2c + 2d + 0.5e + 1.2f

CRA: 2.8a + 0.7b + 1.2c + 0.5d + 2e + 0.8f + 1.2g

The choice of layers to be included in the process and their relative weights were decided upon at the time of the initial development of the method in the early 2000s. Project staff combined their knowledge with the expert opinion of industry practitioners. The algorithms may differ from those used in Canada or other countries as a result of the peculiarities of geology and markets in Ireland, and indeed the nature and extent of our local datasets. In the current work, additionally, not all influencing factors which we would like to have included have been brought to bear, due to the extent of the programme, and time limitations. Detailed data such as particle size analyses, variability in subsoil profiles, and rock test data can be incorporated at a future date. It is for this reason that some room has been left in the weights given in the algorithms so that eventually they add to 10.

When integrating the data in the GIS, a Phase 1 scoring of the base resource bodies was followed by a Phase 2, involving overlay of those layers which have a different geography. It is in Phase 2 that geoprocessing takes place, and the starting units become subdivided. In the case of sand and gravel deposits, Phase 1 involves scoring for a) – c), followed by overlay of d) – f). In the case of bedrock units, Phase 1 involves scoring for a) – d), followed by overlay of e) – g).

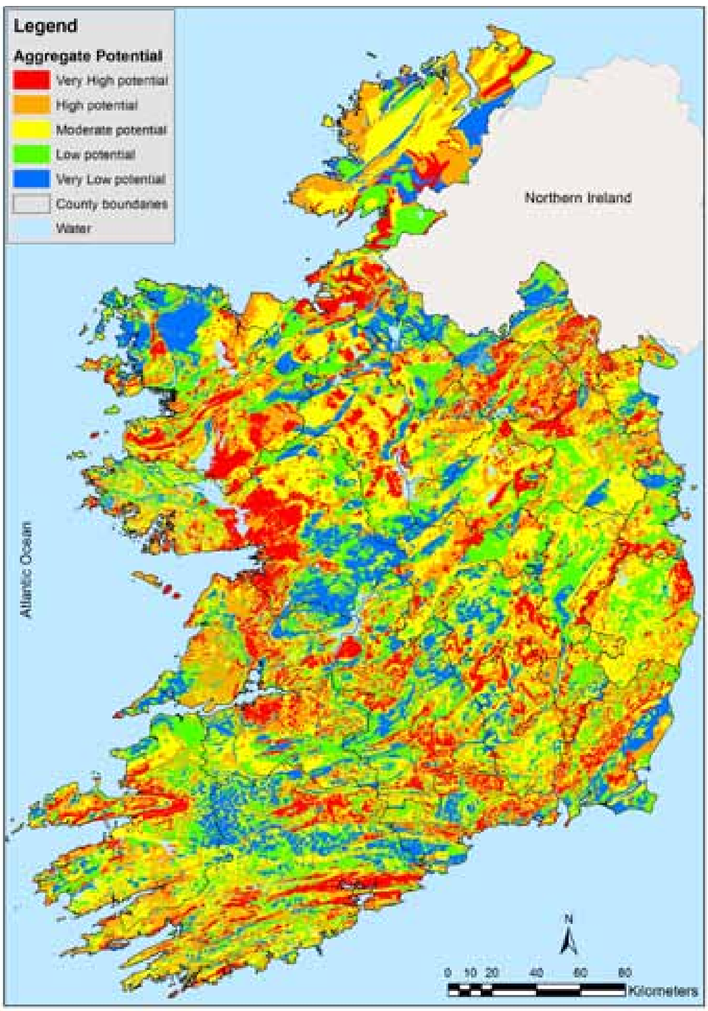

Figure 2: Crushed Rock Aggregate Potential (CRA) Map of the Irish Republic.

Characteristics of layers in granular aggregate potential (GAP) mapping

a) Genetic type of the deposit, and petrology of the gravel

Due to the subdued morphology and vegetative cover in a country like Ireland, the genesis of a glacial deposit is not usually discernible with certainty. Hence, Quaternary mapping of granular sediments has tended to identify only broad groupings, such as Glaciofluvial, Alluvial, Aeolian, etc., with some singular exceptions such as eskers or raised beaches. Within the most productive grouping – glaciofluvial sands and gravels – Irish geologists have concentrated on stone count petrology. Thus, there are granite, limestone, quartzite etc. sands and gravels in different parts of the country. The APM evaluation of deposits has included a productivity indicator for the broad genetic category, allied with the criterion of stone type.

It should be mentioned that in some areas of sediment not included in the APM, gravels are known to occur at depth. Thus, extensive workable gravels have been found beneath cutaway bog in the Irish Midlands, and there are sandy-gravelly moraine ribs with low clay contents within the ubiquitous till. The Sand and Gravel Maps – and by extension the Granular APMs – are therefore given the qualifier 'Preliminary', as much buried resource could possibly be added in the future.

b) Occurrence of gravel pits

There are approximately 700 recent gravel pits in the State, many of which are currently dormant due to the downturn in the economy. In areal extent they range from ca. 0.05 to ca. 71.5 ha, though at the upper end there are only a dozen greater than ca. 40 ha. In addition, 19th and 20th century pits of all sizes number some 11,000. A majority of these are shallow historic diggings that may be close together, though the number also includes major extractive sites of long duration.

The scoring scheme uses density of pits for comparative purposes. Pits are also weighted depending on the source database, reflecting age of the operation, and on size.

c) Area of the deposit and d) Thickness of sediment

Both of these variables are obviously important for the viability of a deposit. It was noted that many deposits labelled

Undifferentiated Alluvium, and mapped as large sinuous units, score highly under these two criteria; they therefore accumulate a high overall potential ranking. An alluvial body may have parts which are sandy-gravelly, but will typically contain much silt and clay, meaning that their potential will be uneven and unpredictable. To reflect this, weights of 2 in both these factors are reduced by half to 1 when scoring this type of sediment.

Thickness of sediment scores are inferred from depth-to-bedrock measurements. However, examination of the subsoil profile may result in a mixed succession, with a lower thickness of gravel than supposed from surface mapping.

e) Topographic elevation

This is a factor of relatively minor importance, given that a majority of granular bodies occur at low elevations. An exception is the type 'Scree'. The contour intervals used for GAP analysis are <100 m, 100-200 m, 200-300 m, and >300 m. Deposits at higher elevations are less desirable because of trucking costs and road maintenance, and hence receive lower scores.

f) Proximity to Markets

A weight of 1.2 is given to this parameter in both GAP and CRA mapping. This figure is divided between the two market types, general construction (housing, social and commercial) and road building (including bridges, embankments, etc.) The relative amount of construction type varies from county to county. The breakdown is in accordance with the destination of product as reported in available pit and quarry documents. An average ratio for all counties is 0.9:0.3 (buildings:roads) in the gravel pit sector. This means that a majority of aggregate is sold as hardcore, drainage and other fill, and in concrete. As regards the crushed rock industry, the market weight averages out at 0.5:0.7 (buildings:roads) for all counties combined, meaning that a slight majority of product goes into road building.

If one takes an estimate of volume of production in Ireland as 30% from gravel pits, and 70% from quarries (several sources), the overall input to the two markets in volume terms approximates 0.6:0.6, i.e. approximately 50% of production goes to each construction type.

Characteristics of layers in crushed rock aggregate potential (CRA) mapping

a) Rock type suitability

The basis for rock type characterisation is the seamless 1:100,000 Geological Map of Ireland (GSI), issued in digital form in 2006. Primary, secondary and minor lithologies and textures are scored for each formation and member, totalling 1,150 units. A scoring scale of 1-10 is used, based on Irish and international rock test data combined in equal proportion with an Irish Use Value. The latter represents the level of utilization or acceptance of the rock as evidenced in local quarrying files. In Ireland, Carboniferous limestone is plentiful, and is the cornerstone of much road building and concrete manufacture; limestone therefore acquires a lithology score somewhat higher than test data alone would afford it.

b) Amount of deleterious substances and features

Geological descriptions of formations are examined for mention of deleterious substances. Examples are clay wayboards, evaporites, sulphides, and mechanically deleterious occurrences such as megacrysts or large fossils. In all, some 65 individual deleterious substances and features have been noted. Formations without such items receive a high score so that when combined with rock type suitability, their potential continues to be maximised.

c) Occurrence of quarries

There are approximately 900 recent quarries in the State, many of which are currently dormant. In areal extent they range from ca. 0.03 to ca. 142 ha (quarry and ancillary plant complexes), though at the upper end there are only a dozen greater than 50 ha. In addition, 19th and 20th century quarries of all sizes number some 10,500. Many of the historic quarries among these were exploited for walling and paving stone, in an era before the wide-scale use of crushed stone for construction.

Quarries are weighted according to age and size, and the density of quarries in a formation was chosen as the scoring measure, similar to the procedure with gravel pits.

f) Topographic elevation

This factor acquires slightly more significance compared to sand and gravel pits, in that occasionally quarries are opened at rather elevated sites. The contour intervals used for CRA analysis are <200 m, 200-500 m, and >500 m. Rock at higher elevations receives a lower score.

Principal results of the mapping programme

The project has provided maps to industry and local government agencies in hard copy format or online. The end products of the analysis are two aggregate potential maps – one displaying sand and gravel potential (see ***Figure 1***), and the other crushed rock potential (see ***Figure 2***), both colour-coded for suitability.

These maps can be studied further, and the areas of higher potential in particular provide a template for the semi-quantitative estimation of aggregate resources. For example, a minerals surveyor may wish to select sand and gravel deposits where the thickness is greater than 5 m and which have a contiguous extent greater than 30 ha. The detailed APM mosaic will allow selection of parcels which fit these criteria. Data can be downloaded, if desired, from the public viewer and modelled with other resource constraints in the user's own GIS; for instance, to eliminate areas overlain by peat and bodies of water, or those within a set distance of urban development. The maps can also be used by planners, in conjunction with locations of heritage assets and protected areas, to formulate development plans which include the interests of the natural resources sector.

The survey of pits and quarries carried out by this project is the most comprehensive in Ireland to date; the county maps have proved to be of special relevance to local authorities faced with decisions concerning the granting of planning permission based on historical precedence of quarrying.

Summary conclusions of a geological nature have become apparent from the collection and processing of the data. For instance, in relation to Ireland's Quaternary deposits, sands and gravels at surface make up a minor part of the Irish landscape – just 9% of the total area. With Water, Made ground and Rock within 1 m of surface excluded, they comprise 10.8% of the Quaternary cover per se. Clearly, where buried deposits can be uncovered and exploited, it could mean a boost to the local economy. On a regional scale, Ireland's deglaciation history, combined with the location of its mountains, has meant that the eastern half of the country, including the East Midlands, has relatively more sand and gravel than the south, west and northwest. With regard to bedrock, the relative proportions of rock trade groups used by industry can be stated, with limestones leading the way at 39% of the total, followed by sandstones at 22%, and within all groups further subdivisions can be made.

Finally, it is the hope of GSI that the Irish APM exercise can invite comment and comparison from partner EU geological surveys that have aggregates programmes in place, or are contemplating the study of their aggregate resources in the future.

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2. TECCO® mesh holds back 270 metric tons of gravel
3. Maximum inclination angle of 85° during the field test


1


2

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3

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Using engineering geosciences mapping and GIS-based tools for georesources management: lessons learned from rock quarrying

Helder I. Chaminé, Maria José Afonso, José Teixeira, Luís Ramos, Luís Fonseca, Rogério Pinheiro and António Carlos Galiza*

The heterogeneity of the geological properties of rock masses is very important in engineering geosciences and rock engineering issues. The study of discontinuous rock masses has developed enormously. In particular, the assessment of in situ block size plays a key role in rock engineering design projects such as mining, quarrying and highway cutting operations. The application of Geographic Information Systems to engineering geosciences has become more common. In this article, the importance of an integrative comprehensive approach to rock engineering is discussed in the context of quarrying operations, i.e., from field mapping surveys to geomechanical assessment. This approach led us to a better understanding of the appropriateness of exploitation of raw material aggregates and to reduced uncertainty about sustainability of georesources in relation to their management and the environment.

L'hétérogénéité des propriétés géologiques des masses rocheuses est très importante dans les problèmes des géosciences de l'ingénierie et d'ingénierie des roches. L'étude des masses rocheuses discontinues s'est énormément développée. En particulier, l'évaluation des dimensions du bloc in situ joue un rôle clé dans les projets de mécanique des roches, telles que les mines, les carrières et les opérations de coupe de chaussées. L'application de systèmes d'information géographique à les géosciences de l'ingénierie est devenue plus courante. Dans cet article, l'importance d'une approche intégrative en ingénierie des roches a été discutée dans le contexte d'exploitation de carrières, c'est-à-dire à partir de la cartographie sur le terrain et jusqu'à l'évaluation géomécanique. Cette approche nous a conduit à une meilleure compréhension de l'adéquation des exploitations des agrégats de roches et à réduire l'incertitude quant à l'exploitation durable des géoressources en ce qui concerne leur gestion et de l'environnement.

La heterogeneidad de las propiedades geológicas de los macizos rocosos es muy importante en las cuestiones relativas a las geociencias de ingeniería e ingeniería de rocas. El estudio de los macizos rocosos discontinuos ha tenido un gran desarrollo. En particular, la evaluación del tamaño del bloque in situ juega papel relevante en proyectos de ingeniería de rocas, como: minería, explotación de canteras y desmonte en carreteras. La aplicación de los Sistemas de Información Geográfica en geociencias de ingeniería se ha hecho habitual. En este artículo, se discute la importancia de una perspectiva integradora de la ingeniería de rocas aplicada a la explotación de canteras; por ejemplo desde los trabajos de cartografía de campo hasta la evaluación geomecánica. Este enfoque nos ha llevado a una mejor comprensión de la relevancia de la explotación de áridos, reduciendo las incertidumbres en aspectos de sostenibilidad, medio ambiente y gestión.

Geosciences, Mapping and Georesources

The geologist Ruth D. Terzaghi stated this important issue: *"Because of the significant influence of joints on important engineering properties of hard unweathered rock, a description of such rock is inadequate for engineering purposes unless it includes reasonably complete and accurate information concerning the spacing and orientation of the joints."* (Terzaghi, 1965: 287). This remarkable quotation is the basis for the key role of geology in field site investigations for rock engineering purposes. Hopefully, nowadays any skilled professional (e.g., geologist, engineering geologist, engineering geomorphologist, geological engineer, geotechnical engineer, mining engineer, civil engineer, or military geologist/engineer) engaged in the practice of applied geosciences must keep this in mind to reduce all geological uncertainties and variabilities. According to De Freitas (2009) the safest way through such uncertainties relies on good case histories, which should be on the desk of every engineering geologist and used as frequently as the electronic calculator. Regarding this, ***Fig. 1*** represents a modern overview of the interdisciplinary and multidisciplinary scientific field called ***Geotechnics***, which can be practiced by several types of professionals and in most situations encompassing expertise teams with complementary skills. Engineering geoscience is concerned with the application of geology and geomorphology in engineering practice.

Geotechnics is the science that focuses on the mechanics of soil and rock to characterise and assess the engineering behaviour of the ground and the sustainable interaction design with the environment. Currently, this approach has become a standard practice for professional geologists and engineers aiming at the planning, design, construction and maintenance of engineering structures and works (e.g., foundations, slopes, dams, underground excavations, mining, quarrying, retaining structures, highway cutting operations, landfills, etc.),

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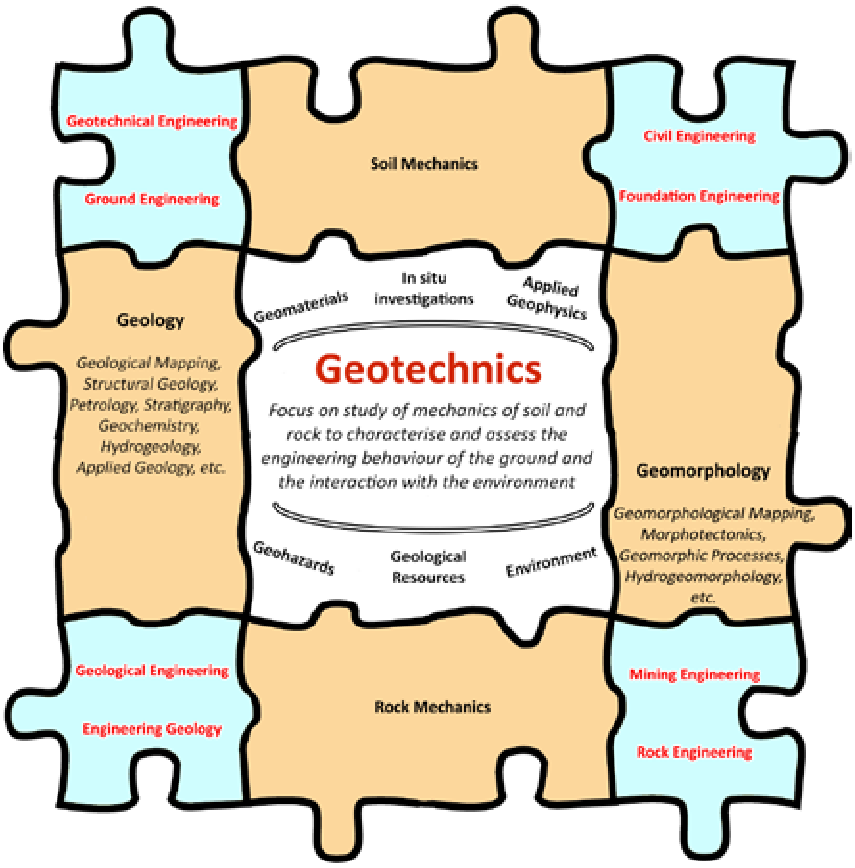

Figure 1: A modern overview of Geotechnics: major scientific areas – geosciences (geology and geomorphology), soil mechanics and rock mechanics – and practitioners.

chastic). All the models must be robust, calibrated and supported on a permanent back-analysis scale based on a logical understanding of the real ground behaviour (Dinis da Gama, 1983). Particularly, rock engineering deals with jointed/faulted anisotropic material and fluid-bearing media, the so-called rock mass (Barton, 2012). The rock engineer must be able to predict the consequences of a particular excavation design. In addition, incomplete or inaccurate geologic and geotechnical site characterisation can lead to the selection of unsuitable models, geotechnical properties, and design values (Terzaghi, 1965; Griffiths and Stokes, 2008; Keaton, 2013; Dinis da Gama, 2013).

The potential for geology to support engineering occurs at every scale, from regional geological structures to molecules found on mineral surfaces and in the fluids passing over them (De Freitas, 2009; Price, 2009). However, the input of geological data for engineering purposes is only adequate if it is supported by the appropriate rock property values (Zhang, 2005 and references therein). The assessment based on engineering geosciences, geohydraulic and geotechnical features of rock masses involves combining parameters to derive quantitative geomechanical classifications for rock engineering design purposes (Barton, 2012, and references therein). Barton (2012) stated that discontinuous behaviour provides rich experience for those who value reality, even when reality has to be simplified by some lessons learned during the development of the empirical parameters.

Rock is a natural material that forms the crust of the Earth (Smith *et al.*, 2001). Rocks are formed in an continuous geodynamic cycle (involving numerous internal and external processes) throughout the geological time, that result for engineering purposes (e.g., Price, 2009; De Freitas, 2009) in ***hard rocks*** (unweathered, strong and durable), ***soft rocks*** (weak and easily

as well as in exploitation and management of geological resources and environmental issues (***Fig. 2***). In short, all geotechnical practitioners aim to contribute to the correct study of the ground behaviour of soil and rock, its applications in sustainable design with nature and environment (McHarg, 1992) and to the development of society (De Freitas, 2009).

Understanding the complexity of Earth systems is possible through the use of ground models (Griffiths and Stokes, 2008). Thus, a typical site characterisation should be outlined based on Earth systems analysis which form the core for building models to create scenarios using different approaches (e.g., Hudson and Cosgrove, 1997; Griffiths and Stokes, 2008; Keaton, 2013 and references therein), such as: i) ***ground models*** (geologic and/or geomorphological models with engineering parameters); ii) ***geotechnical models*** (ground models with predicted performance based on design parameters); iii) ***geomechanical models*** (geotechnical models based on mathematical modelling (i.e., probabilistic, deterministic or sto-

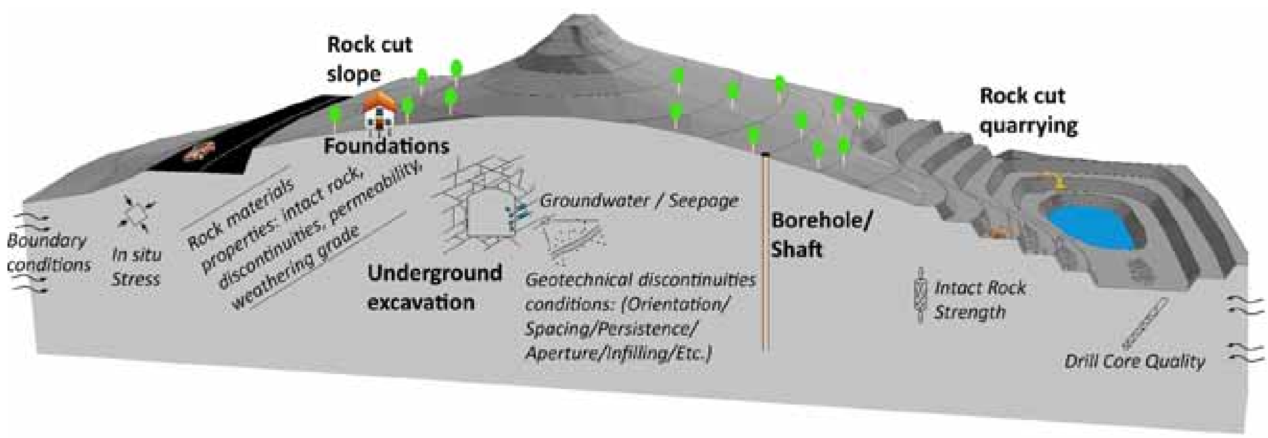

Figure 2: Typical rock engineering works and related ground behaviour.

deformable) and ***soils*** (unconsolidated sedimentary deposits overlying bedrock) (***Fig. 3***). Nevertheless, it does not cover the earthy materials forming the ground in which plants can grow ("soil" in a pedological sense; Smith *et al.*, 2001). Rocks may be surveyed in several backgrounds: i) at the surface and subsurface (outcrops, cliffs, quarries, etc.), ii) underground (tunnels, mines, boreholes).

Since the dawn of civilization, rock has been used as a construction material. Diverse constructions and structures have been built on, in or of rock, including houses, bridges, dams, tunnels and caverns (Zhang, 2005), as shown in ***Table 1***. Particularly, crushed rock aggregates are fundamental to the man-made environment and represent a large proportion of the raw material produced by the quarrying industries and used in construction (Smith *et al.*, 2001).

Rock engineers deal with large volumes of rock which will contain variable amounts of fluid in their network discontinuities, such as joints, fractures, faults, sedimentary or tectonometamorphic surfaces (bedding planes, schistosity, shear zones, folds, etc.) and vein structures. These natural rock structures render the fabric of the rock mass discontinuous (Zhang, 2005; Price, 2009). The general term "discontinuity" in rock engineering refers to any break in the rock continuum having little or no tensile strength (Hudson and Cosgrove, 1997). Intact rock refers to the unfractured blocks (ranging from a few millimetres to several metres in size) between discontinuities in a typical rock mass (Zhang, 2005).

According to Hudson and Cosgrove (1997) providing a clear structural geology framework is a key requirement for the investigation of all rock engineering projects. The geological structures of rock masses (discontinuities, *sensu lato*) significantly influence their hydrogeomechanical properties, such as permeability, cohesion, roughness, aperture and in situ stress. It is thus the structure, at several scales, of the geomaterials that controls the engineering behaviour of the ground. For this reason, it is fundamental in the mapping of rock exposures, whether outcrops, road and railway cuttings, underground excavations or quarry exploitations to collect discontinuity data. Conclusively, the success of a given construction or excavation is related to the accurate knowledge of the general framework of site investigations, particularly that associated with the geology and geomorphology of the studied area (Griffiths, 2002, and references therein). In that perspective, mapping (general or sketch maps, geological maps, engineering geology maps and geotechnical maps, at diverse scales) assumes a critical importance in further stages of geotechnical investigations and modelling. It is also important to emphasise also the value and cost-effectiveness of mapping for geoengineering, georesources and planning purposes compared with other activities (Griffiths, 2002; Price, 2009). Thus, mapping plays a central role as a standard technique in engineering geosciences for in situ geotechnical investigations, ground

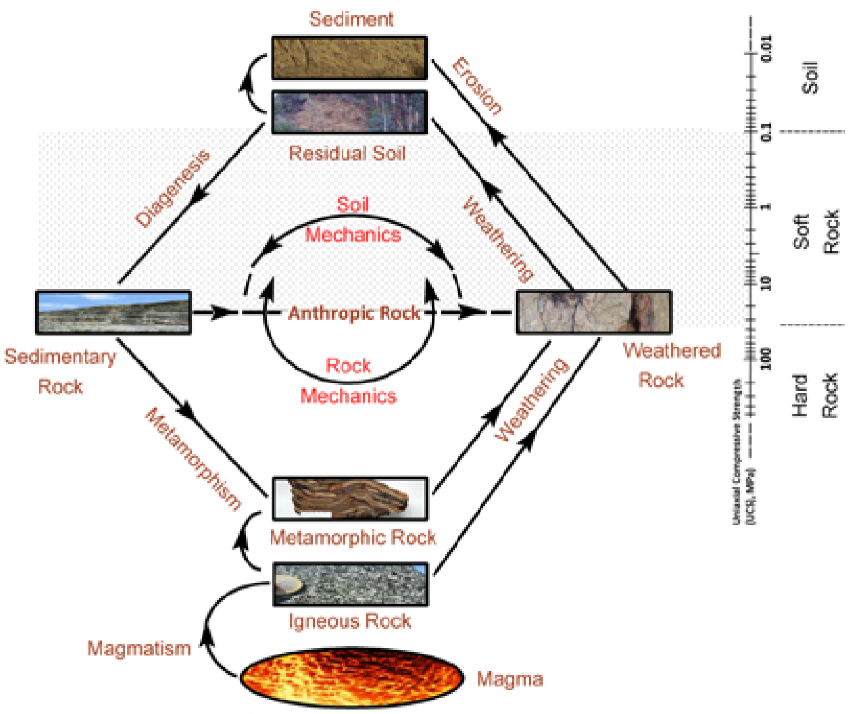

Figure 3: The rock cycle in the perspective of the engineering geosciences framework: an outlook for rock mechanics and soil mechanics issues (adapted from Dobereiner and De Freitas, 1986). Anthropic rocks is a collective term for those rocks made, modified or moved by humans (Underwood, 2001).

Table 1: Main types of structures built on, in or of rock (adapted from Brown, 1993; in Zhang, 2005).

Field of application	*Types of structures*
Mining	*Surface mining (rock slope stability and/or excavation; rock mass diggability; drilling and blasting; quarrying fragmentation);* *Underground mining (shaft, pillar, draft and stope design; drilling and blasting; fragmentation; cavability of rock and/or ore; amelioration of rockbursts; mechanized excavation; in situ recovery)*
Energy	*Underground power stations (hydroelectric and nuclear); underground storage of oil and gas; energy storage (pumped storage or compressed air storage); dam foundations; pressure tunnels; underground repositories for nuclear waste disposal; geothermal energy exploitation; petroleum development including drilling, hydraulic fracturing, wellbore stability*
Transportation	*Highway and railway slopes; tunnels and bridge foundations; canals and waterways; urban rapid transport tunnels and stations; pipelines*
Utilities and Environment	*Dam foundations; stability of reservoir slopes; water supply tunnels; sanitation tunnels; industrial and municipal waste treatment plants; underground storages and sporting and cultural facilities; foundations of surface power stations*
Building construction	*Foundations; stability of deep open excavations; underground or earth-sheltered homes and offices*
Military	*Large underground chambers for civil defense and military installations; deep basing of strategic missiles*

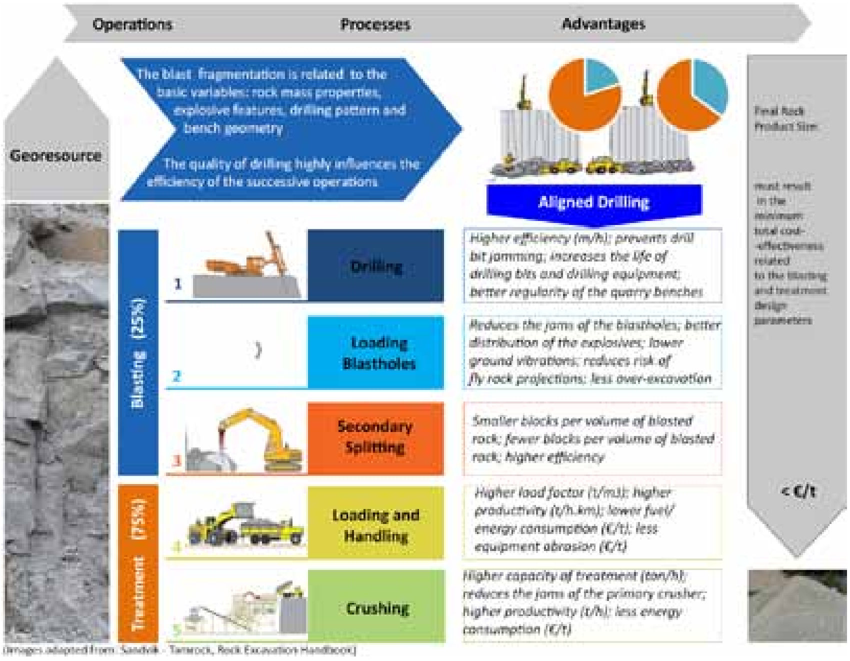

Figure 4: Illustration of the blasting and treatment processes of rock quarrying development for raw material aggregates: a general overview.

modelling, geological resources assessment, and military works and operations (e.g., Kiersch, 1998; Smith *et al.*, 2001; Griffiths, 2002; Griffiths and Stokes, 2008; De Freitas, 2009). Despite the accuracy of field survey and mapping for engineering purposes, Price (2009) stated several important issues: i) it must never be forgotten to produce engineering maps that are of immediate use to the engineer; ii) maps must be 'user friendly', easily understood and easily read; iii) mapping for rock quarry engineering purposes requires large scale maps (detailed surveys: ranging 1:50 to 1:250; general framework: 1:1000 to 1:10000).

Geographic Information System (GIS) techniques have brought new insights to cartography, particularly to geosciences mapping. GIS techniques, supported by high-resolution Global Positioning Systems (GPS), permit large amounts of data from the field survey and rocks sample testing to be overlaid. GIS-based mapping is also useful in providing accurate thematic maps, spatial data analysis and data geovisualisation aiming, for example, at the assessment of discontinuous rock mass systems.

In this article GIS-based mapping was produced to highlight the importance of the geotechnical zoning map as an excellent tool to support rock mass quarrying investigations and development. The fractured hard-rock masses assessment was enhanced by this integrated approach and should contribute to sustainability management.

Selected site: coupling engineering geosciences mapping and mining geotechnics

The strength of jointed rock masses is influenced by the degree of interlocking between individual rock blocks separated by discontinuities such as faults and joints. Drilling is one of the operations involved in rock mass fragmentation by blasting. Dinis da Gama (1983) demonstrates that in full-scale bench blasts, less energy is required to fragment a discontinuous rock than a homogeneous rock.

Correctly performed rock blasting produces very clean faces with a minimum of over-break and disturbance. Rock drilling assumes an important role in technical and cost-effectiveness issues, as well as in the subsequent operations such as loading, handling, splitting and crushing (Singh, 2000). Rock mass blasting involves three groups of parameters (e.g., Dinis da Gama, 1983; Singh, 2000; Smith *et al.*, 2001; Dinis da Gama, 2013): i) petrophysical, geotechnical and geomechanical patterns of the rock fabric and intact rock; ii) top hammer and bench drilling tools; iii) blast design.

It is quite challenging to comprehend how structural geology, geotechnical and rock mechanics features and parameters interact among themselves. In addition, we must take into consideration all of the equipment, technologies, models and brands of drilling tools and different methodologies, as well as the overall cost-effectiveness of the processes involved. The aim for rock cut quarrying is to produce an aligned drilling that permits blasting with enhanced rock fragmentation, lower vibrations and optimisation of drilling and explosive quantity. The global costs of the main operations involved in the quarry industry are not equally distributed (***Fig. 4***). Treatment is the last operation of a global process related to exploitation of the rock georesources, which represents over 75% of the total costs. However, its effectiveness depends on the global quality of the earliest operations to reach high productivity of the entire process.

A comprehensive integrated study of georesources was carried out at a selected site in NW Portugal. The study coupled GIS-based mapping with assessments of structural geology, engineering geology and rock mechanics. Thematic maps were prepared from multi-source geodata, namely remote sensing, topographic, morphotectonic and geological mapping, as well as geotechnical field surveys. These maps were converted to GIS format and then integrated with the purpose of elaborating a geotechnical zoning map intended to support the georesource conceptual site model and further stages on blasting engineering. The basic techniques of mapping, engineering geosciences and rock mechanics (e.g., Griffiths, 2002; Price, 2009, and references therein) were applied at the study site ((***Fig. 5***).

In the first stage a field survey was conducted in order to define the main geological and morphotectonical constraints of the rock mass in the quarry site and nearby area. This assessment focussed on several features, such as: i) regional and local geology and morphostructure, ii) lithological description; iii) mapping of macro and mesostructures; iv) identification of the weathering areas and mapping of their thickness; v) location of the seepage and hydrological constraints. In the next stage, a detailed geotechnical description of the rock mass was made and in situ geomechanical testing was performed (particularly the Schmidt Hammer and Point Load Test). This integrative approach allowed the basic description of rock masses and established an engineering geosciences zoning map (following particularly the recommendations of several organisations: ISRM – International Society for Rock Mechanics, CFCFF – Committee on Fracture Characterization and Fluid Flow, GSE – Geological Society Engineering Group Working Party and IAEG – International Association for Engineering Geology and the Environment). The scanline sampling technique was applied to the study of free rock mass faces on different benches to characterise the rock mass discontinuities and to define the in situ block size. The structural geology data collected at the site were analysed with stereonets and rose diagrams. The scanline technique involves laying a tape along the length of an outcrop or exposure. This approach was also supported by: i) geo-referenced data using a high-precision GPS for the fieldwork survey, ii) the use of geo-calculator applications (particularly, *"GeoTech|CalcTools"* and *"MGC-RocDesign|Calc"*) to support the analysis, design and modelling, iii) GIS-based mapping and application tools.

Monte do Fojo rock quarry site (Paredes de Coura, NW Portugal)

The selected study site, Monte do Fojo granitic rock quarry (NW Portugal, Iberian Peninsula), is located in the vicinity of regional fault zones (e.g., the Vigo – Vila Nova de Cerveira – Régua fault zone). Monte do Fojo quarry is found NE of Ferreira and Vale parishes (the village of Paredes de Coura), (***Fig. 6***). The geology comprises crystalline fractured bedrock of a deformed Palaeozoic metasedimentary rocks and Variscan granites. There are some prevailing tectonic lineaments (NE-SW and NNE-SSW to N-S). The granitic basement is also crosscut by aplite-pegmatite veins and sills. Locally, the geomorphology is characterised by steep slopes and entrenched valleys.

The main activity in the Monte do Fojo quarry is the extraction, treatment and production of crushed rock aggregates for the civil engineering industry. The quarry area is over 7 ha, including also the strategic reserves and the equipment compounds. The extraction site occurs in an open pit, and the blasting is headed northwest, with 5-m-high benches.

The Monte do Fojo rock-mass comprises two-mica granite, which is medium to fine grained, and yellowish to grey colour.

The rocks exposed in the quarry face range from fresh to slightly weathered rock (W_{1-2}). Moderately (W_3) to highly weathered (W_4) outcrops are observed on surrounding upper slopes. The granitic rock mass is crossed by joint sets with NNE-SSW to NE-SE, NW-SE, ENE-WSW orientations. Discontinuity surface conditions can be summarised as the : i) fracture intercept (F) being mainly wide to moderate spacing (F_2 to F_3); ii) the aperture varies from open to closed, iii) the persistence is low to moderate; iv) there is the presence of soft clay and gouge infillings; v) surfaces are plane to undulating and with a low roughness; vi) rock uniaxial compressive

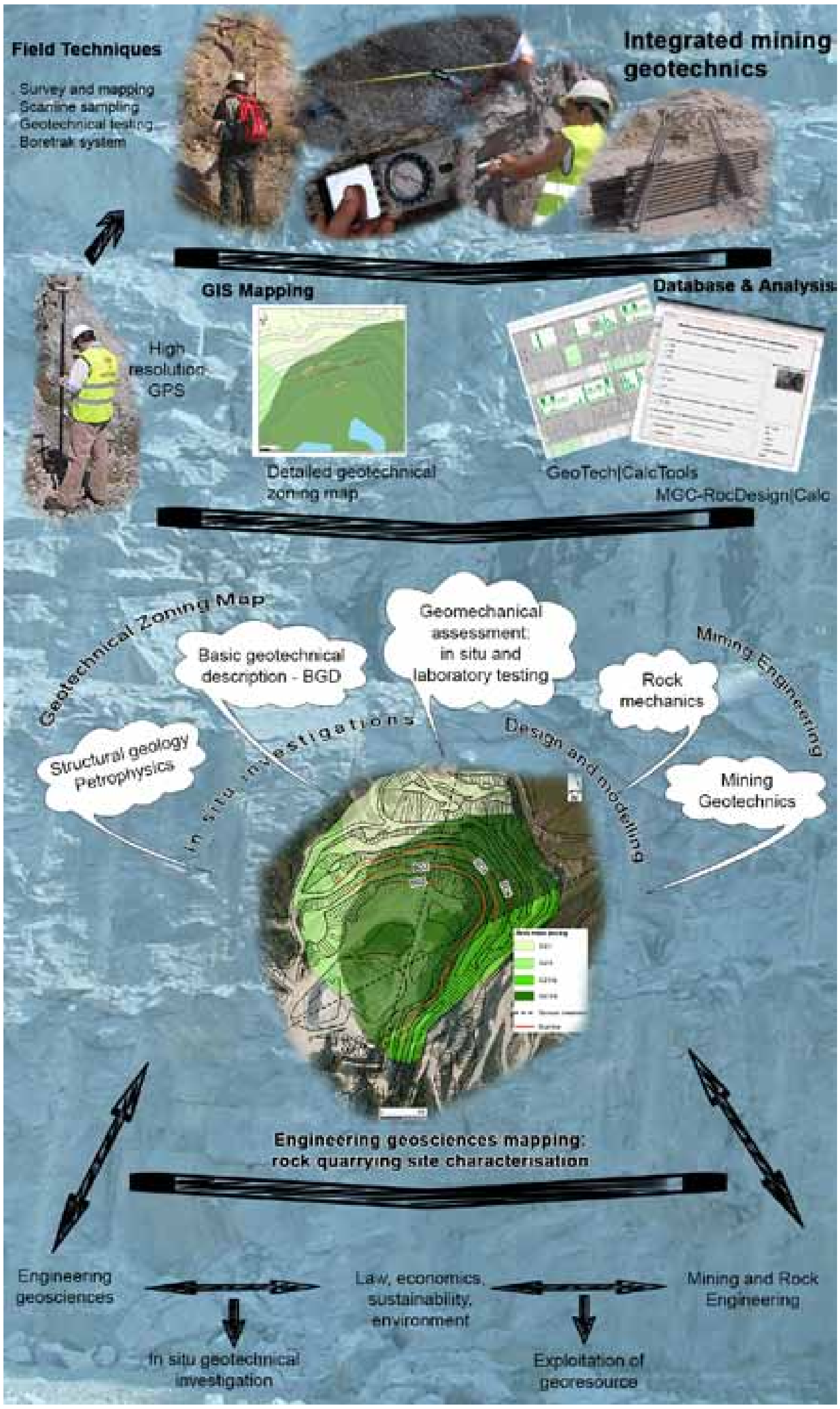

Figure 5: Engineering geosciences mapping on rock quarrying site activities: a general outlook on an integrated georesources exploitation framework ("GeoTech|CalcTools – Rock Mass Database"* by L. Ramos, L. Fonseca, A.C. Galiza and H.I. Chaminé; and* "MGC-RocDesign|Calc – Mining Geomechanics Classification systems for rock engineering design"*, by R. Pinheiro and H.I. Chaminé]).*

strength is moderate to high (S_3 to S_2); vii) and the Geological Strength Index (GSI), based on rock structure versus discontinuity surface condition, ranges from 75-65 for the rock quarry area exposure (i.e., blocky to very blocky, interlocked partially disturbed rock mass consisting of cubical to multifaceted angular blocks, formed mainly by orthogonal discontinuity sets and random fractures; which is compatible with rock blasting techniques). The possibility of integrating these geo-databases into a dynamic GIS allowed the definition of different scenarios and approaches to be evaluated, which have culminated in the geotechnical zoning map of the Monte do

Fojo quarry site. Therefore, geotechnical units for the rock quarry site and surrounding area were defined as shown in ***Figure 6***. In short, integrative studies offer a reliable multi-scale approach for investigating the on-site mining geotechnics. Thus, this methodology has proven to be highly valuable for a better understanding of the overall georesources system.

Concluding remarks

Mapping has widespread applications, such as military operations, oil industry, mining engineering, geotechnical engineering, engineering geosciences, environment, and planning. This paper has focused on the importance of coupling engineering geosciences mapping and mining geotechnics to site characterisation for rock quarrying design and modelling. Quarrying activities are the key source for the extraction of aggregates for construction projects. Aggregates are used in concrete, asphalt, mortar, railway ballast, drainage courses and bulk fill. Blasting processes affect the productivity and efficiency of quarrying. Blasting design depends on many variables, especially on the rock mass properties. Blast performance is influenced by geologic structure, rock fabric and intact rock strength. In mining geotechnical practice it is recognised that rocks are normally heterogeneous. The geometry of the discontinuities, intact rock fabric and their geotechnical conditions (e.g., spacing, roughness, aperture, infilling, seepage, etc.) are some of the factors that have a major effect on blasting. The assessment of blast fragmentation required the consideration of some basic variables, i.e. rock mass properties, explosive properties, drilling pattern and bench geometry.

The integrative approach presented in this paper contributes to a better definition of rock quarrying design parameters, and these play a key role in economic excavation, the development of sustainable mineral production, and the supply of raw aggregates. Professor Ralph B. Peck summarised that perspective in an unusual way: *"if you can't reduce a difficult engineering problem to just one sheet of paper, you will probably never understand it"* (DiBiagio and Flaate, 2000: 28). This impressive quotation must be the motto for any geoengineering approach.

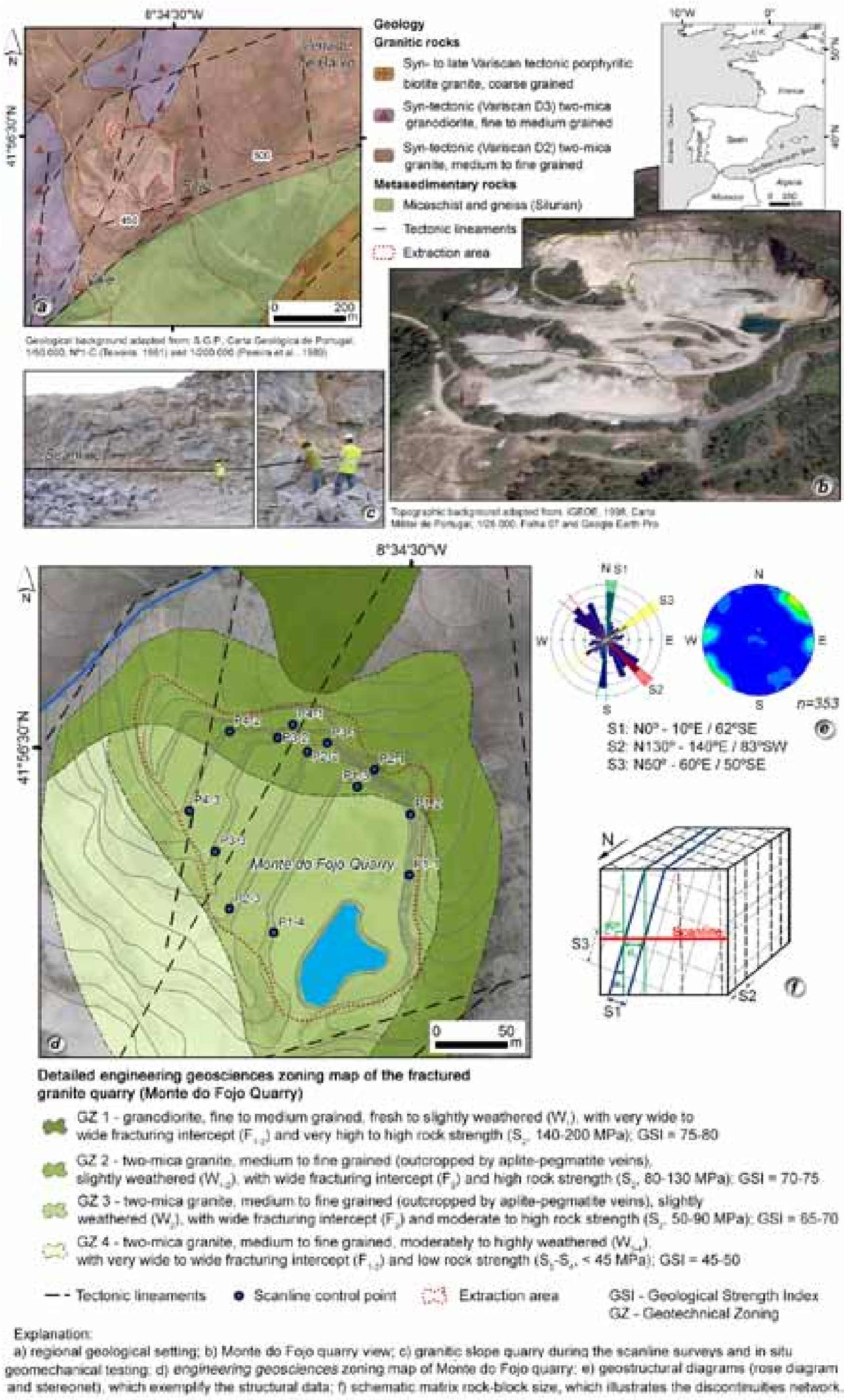

Figure 6: Monte do Fojo granitic quarry site (Paredes de Coura, NW Portugal) framework: an example of engineering geosciences site mapping.

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Industrial minerals & rocks: our invisible friends

*Manuel Regueiro y González-Barros**

Minerals and rocks have accompanied human beings since man's earliest origins and are no doubt the basement upon which development has been built. But for most citizens that same development has slowly turned these once fundamental solid and visible bricks of their welfare into the invisible foundations of modern society. Without minerals and rocks, many everyday things would disappear and man would be forced to go back to the Stone Age.
Dimensional and construction stone, glass, ceramics (roof tiles, bricks, floor tiles, porcelain), soap, detergents, filters, fibres, gunpowder, iron, oil, steel, dynamite, paper, cement, gypsum board, lime, aggregates – all are made of industrial minerals or rocks. But also computers, mp4 players, digital cameras, bicycles, golf clubs, automobiles, aircraft, plastics, textiles, or even space shuttles and the most modern satellites are loaded with minerals in the form of active fillers or new materials, which have not only improved the behaviour of the most modern materials employed, but have also reduced their costs. Flint and microchips have one thing in common: silica, a versatile compound that serves as a conductor line through the history of how minerals have helped humanity to become what it is today.
This paper reviews the chronology of the use of industrial minerals and rocks in the manufacture of materials from its earliest days in the remote past to the present day, and will give a glimpse of what the future of the use of minerals can bring to mankind.

Minéraux et roches ont accompagné les êtres humains depuis le premier homme et représentent sans aucun doute le socle sur lequel tout développement s'est construit. Mais pour la plupart des citoyens, ce même développement a lentement transformé ces éléments fondamentaux de leur bien être, auparavant apparents et solides, en fondations invisibles de la société moderne. Sans minéraux et roches, nombre d'objets quotidiens disparaîtraient et l'homme retournerait à l'Age de Pierre.
Les roches monumentales et de construction, le verre, la céramique (tuiles de toit, briques, carreaux de sol, porcelaine), le savon, les détergents, filtres, fibres, la poudre à canon, le fer, l'huile, l'acier, la dynamite, le papier, le ciment, le plâtre, la chaux, les agrégats – tous sont fabriqués à partir de minéraux industriels ou de roches. De plus, les ordinateurs, lecteurs de vidéo, appareils de photo numériques, les bicyclettes, clubs de golf, automobiles, avions, plastiques, textiles ou même les navettes spatiales et la dernière génération de satellites contiennent des minéraux sous la forme d'éléments de recharge ou de nouveaux matériaux qui, non seulement, ont amélioré le fonctionnement des matériaux utilisés les plus modernes mais ont aussi réduit leurs coûts. Flint et puces électroniques ont une chose en commun : la silice, un composé polyvalent utilisé comme fil conducteur dans l'histoire humaine pour comprendre comment les minéraux ont aidé l'humanité à devenir ce qu'elle est aujourd'hui. Cet article passe en revue la chronologie de l'utilisation des minéraux et roches industriels pour la fabrication de matériaux, depuis le premier moment d'un passé lointain jusqu'à aujourd'hui, et va aborder ce que l'utilisation future des minéraux peut apporter à l'humanité.

Las rocas y minerales han acompañado al ser humano desde sus orígenes más remotos y son sin duda el sustrato sobre el que se ha se ha construido el desarrollo. Pero ese mismo desarrollo ha convertido lentamente y para la mayoría de los ciudadanos, a esos en su momento sólidos y visibles ladrillos fundamentales de su bienestar, en los cimientos invisibles de la sociedad moderna. Sin ellos, muchas cosas cotidianas desaparecerían y el hombre regresaría a la Edad de Piedra.
Las rocas ornamentales y de construcción, el vidrio, la cerámica (tejas, ladrillos, baldosas, porcela-na), el jabón, los detergentes, los filtros, la pólvora, el hierro, el petróleo, el acero, la dinamita, el papel, el cemento, la escayola, la cal, los áridos, todos se fabrican a base de rocas o minerales industriales. Pero también los ordenadores, los mp4, las cámaras digitales, las bicicletas, los palos de golf, los coches, los aviones, los plásticos, los tejidos o las lanzaderas espaciales e incluso los satélites más modernos, están cargados de minerales en forma de cargas industriales activas o nuevos materiales, que no sólo han mejorado los nuevos materiales empleados, sino que también han reducido su coste. El pedernal y los microchips, por ejemplo, tienen una cosa en común: la sílice, que es un compuesto muy versátil que sirve de hilo conductor a la historia de cómo los minerales han ayudado a la humanidad a convertirse en los que es hoy.
En este artículo se repasa la cronología del uso de los minerales industriales y las rocas en la fabricación de muchos materiales desde sus orígenes en el remoto pasado, hasta hoy en día, y nos dará una rápida visión de lo que el futuro del uso de los minerales puede traer a la humanidad.

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The history of the use of minerals

There is no doubt that raw materials have been fundamental in the development of the different human civilizations. In fact the first steps of what in archaeology is called industry were labelled employing rocks and metallic minerals, as is clearly reflected in the names given to human prehistorical periods: the Stone

Age, Copper Age, Bronze Age or Iron Age, named for their respective tool-making technologies.

Those first steps of mankind were marked by a progressive increase in the use of minerals which then represented a huge array of technological innovations and industrial applications throughout the whole world. The use of gold goes back to 6000 BC, copper around 4200 BC, silver 4000 BC, lead 3500 BC, tin 1750 BC, iron 1500 BC, mercury 750 BC (Cramb, 2007), and these seven metals were, at a certain moment, the base of civilization.

If in the past minerals were crucial, today a modern society cannot be conceived of without them. It is thanks to minerals that our world is as it is, and, what is even more important, our future world will be even more dependent on minerals to develop new technologies based in materials science and engineering. This is why it will be necessary to progress in mineral exploitation and processing of our inseparable companions of the voyage of society towards its future: minerals. (Regueiro y González-Barros, M. 2010).

Our remote past

What we today define as mining probably started as a human activity during the Stone Age (ca. 3 My – ca. 4000 BC in Europe). The need for tools to cut skins and for hunting probably developed the ability to chip stones to obtain cutting edges. The raw material used – probably after some trial and error – were flintstone, sandstones, volcanic rocks and, where found, sillimanite (fibrolite). But stone was also used all around the world in those times for the construction of religious structures and tombs, particularly using huge massive stones. It has also been proved that dwellings were built in Neolithic houses in the north of Europe by mixing clay with straw and letting it dry to become adobe. The need for local stones did not deter our ancient relatives from also using rocks or minerals that were located far from their regions, as is the case of obsidian from the island of Milos (Aegean Minoic cultures) (***Figure 1***), which has been found to have been exported throughout Europe.

Construction with clay and stone

As commented above, the use of adobe as a construction element was already widespread in the North of Europe in the Neolithic, and this reflected the transition from a society of hunters-gatherers to permanent residences for farming producers in areas without natural shelters such as caves.

Figure 1: Obsidian. Photo: IGME.

There is also a clear relation between the geological environment and the construction technology employed. Ancient Mesopotamia, today's Iraq, is a territory of flat alluvial plains, with scarce stone and no woods, thus the only option was the use of clay. Mesopotamia was the area where the first main development of various construction materials took place. By 4500 BC Mesopotamians were already using wall coverings of gypsum plaster and rainproof floors and ceilings, employing the widespread asphalt, pouring out in lakes in many areas of the region. Dry clay prismatic bricks are recorded as being in use by 3500 BC and fired clay bricks between 3200 - 2800 BC. Buildings had baths and drains of bricks also isolated with asphalt by 2300 BC. By 700 BC water mains were built with a concrete base (lime, sand and limestone fragments) and a layer of asphalt with a stone pavement on top. Trial and error (usually meaning the collapse of buildings by frequent earthquakes) gave way to solutions such as brick foundations; as no windows glass was yet available, these were built with a terracotta grill. In Mesopotamia arched brick ceilings were also common. Last but not least, the cuneiform writing (drawn on clay tablets) emerged in the Sumerian civilization of southern Iraq around 3400 BC.

At approximately the same time in the Nile Valley, extensive use of dry clay in buildings is recorded. Stone in the time of the Pharaohs was a state monopoly. Many impressive constructions were built that today bear silent testimony to ancient expertise, such as the Cheops Pyramid (2600 BC) built during the 4th Dynasty, where 2.3 million cubic metres of limestone were employed but there is no evidence of the tools used. Limestone was used extensively up until 1900 BC (the 11th Dynasty), later it was decided to use sandstone as beams, since this rock had more resistance. Quarries and mines were huge, several hundreds of metres in length. By 1500 BC complex forms (columns & statues) were being made. The material used in sculptures and sarcophaguses was frequently granite. Basalt was commonly used in pavements, while the roofs of official buildings had stone tiles. The use of proper foundations in buildings was scarce up until 600 BC (the 25th Dynasty). Later they employed platforms of bricks several metres thick.

The Aegean Minoian culture (2400-1450 BC), with its centre in Crete, developed its own construction technique with a stone basement and dry clay walls in frames of crossed wood beams. The famous Knossos Palace (Middle Minoian) was built with ashlars' walls jointed with a clay mortar. The building has a superstructure of dry clay bricks or stones in a framework of wooden beams, and the upper walls were plastered with lime and painted.

In ancient Greece the first buildings and temples were made of dry clay brick walls on a stone base and had wooden roofs covered with raffia. Fired bricks do not appear here until the middle of the 4th century BC.

Figure 2: Parthenon, Acropolis, Athens. Photo: M. Regueiro.

The Greek classical period saw the splendid use of marble and limestone marble in many buildings. Porous limestone was plastered with lime and then painted with frescos. The Greeks were extraordinary masons and used metal clamps (iron or lead) to fix stone pieces together. The roofs of the buildings were covered with brick or marble roof tiles (the Parthenon and other Acropolis temples are good examples) (***Figure 2***). The flourishing art of sculpture also brought some innovations, such as the use of iron beams in statues supports and iron spikes to fasten terracotta, wood or stone lining. Such a luxurious use of stone had its source of material north of Athens, in the marble quarries of the Pendelikon Mountain, quarried since the 5th century. But there are still remains of other huge marble quarries in Paros (Naxos) and sandstone quarries at Mount Hymettus, Syracuse, were today we can visit abandoned quarries 2 km long and 27 m high, from where more than 40 Mill m^3 of stone were extracted. By 413 BC around 7,000 Athenian slaves worked in the quarries.

In contrast with Greece, marble does not appear in Roman buildings until the 1st century BC. But the Romans fathered many construction innovations, such as the pozzolana, volcanic ashes mixed with lime, that forms an extraordinary cement that sets underwater and resists fire. The use of the cement and the clever employment of scaffoldings made brick domes possible. Pozzolana mortars (Pozzolana and sand) were as hard as aggregates, and many Roman buildings are still silent witness to a new era in construction techniques. Although Romans were at the front face of development, dry clay brick was extensively used up until the times of August (63-14 BC). The emperor boasted of having received a Rome made of brick and transformed it into a Rome of stone. In spite of this, it is from his times that the use of fired brick was extended in the empire. Plastered and painted brick walls were common in Rome (Davey, 1971). Somehow Rome reinvented the brick, and brick masonry was many times lined with stone. Stone use was, as many other things in the Roman empire, strictly regulated and standardised, thus they called opus quadratum stone walls with regular formats joined with metallic clamps, whereas irregular blocks of tuff jointed with mortar was called opus incertum (Vitruvius, 23-27 BC (1931)).

From the 1st century onwards, concrete is the most common construction material (Pozzolanic cement and limestone, tuff or brick aggregate). There is evidence of widespread construction of stone arches and domes using wedged blocks and scaffolding. Rome also designed roofs with overlapped terracotta tiles. Surprisingly enough, the use of glass windows was recorded in the empire from the 1st century BC. Iron and bronze was extensively used in construction at that point.

The use of stone in Rome also depended on the existence of quarries in the surroundings. The most common stone, travertine, a soft porous easily cut rock, was and still is quarried close to Tivoli, and both the impressive Colosseum and the catacombs were built with this stone. But for more demanding uses such as paving or sanitation, a harder rock (basalt) was used, which they called silex or lapis siliceous. This stone was used to build the famous Via Sacra or the sewers (Cloaca Máxima), which we can still admire today. The now famous Carrara quarries, later used by Michelangelo (1475-1564), were located near a village called Luna in Roman times. A singular witness to those times is an open air museum with tools and block cutting devices (the use of a copper wire to cut stone (AD 75) is the first antecedent of the modern wire cutting technique). After the fall of Rome (476) a lot of ashlar stones from the Roman monuments were reused, particularly in the Vatican City. But the Roman use of stone reached the confines of the empire, and there are remnants of Roman granite and porphyry (purple stone) quarries in Egypt (***Figure 3***). Egyptian sculptors cut stone with stone balls, bronze tools and emery.

Being the immediate descendant of the Roman Empire, the Byzantine period employed similar construction techniques to those used in Rome. But due to the particular geological setting of the capital, earthquake resistant construction systems were developed, such as concrete walls with inter-calated brick or wood layers. These can still be admired in the jewel of Byzantium, the Hagia Sophia in Istanbul, which was built during the time of Justinian I from 532 to 537, in his capital, then called Constantinople.

Figure 3: Roman granite quarry in Egypy. Photo T.Heldal, Geological Survey of Norway.

The Gothic period (1200-1540), saw the widespread use of masonry in religious buildings, particularly cathedrals, and the development of an extraordinary masonry precision craft called stereotomia (stone cut). Builders used deep foundations and in general layers of stone and gravel, but frequent foundation failures or poorly built walls produced tower falls. The main brick producing areas in the Middle Ages were the north of Italy, the north of Germany, The Netherlands, Spain and France.

Mining: the first industry

Archaeologists believe that it was during the Copper Age (Chalcolithic) that the first social stratification in human societies happened, and that this was due to the fact that copper was harder to find and to use than the stone most of the world's inhabitants were at that time using as tools, weapons and ornaments, and so only specialists could work it. Those specialists became an elite class that sold its products to other elite, rich or powerful individuals.

Mining techniques were already highly advanced by 500 BC. Lavrion is a well documented mining site east of Athens where lead, iron, zinc and silver were exploited from Mycenaean times (2000 BC) (Dermatis, 2004). The Athenians worked the mines from 600 BC. There is evidence of Roman smelting at the mine's surface for which an extensive use of wood was needed as well as milling, washing and ore separation techniques and sites. These mines were closed from AD 100, then reopened in 1860 and finally exhausted in 1981. The ancient Greek mining techniques are similar to those used by the Japanese in the mid-19th century.

The Greek kilns produced cast iron (a serendipitous finding). The famous artist, engineer and inventor Theodore of Samos (750 BC) is thought to have discovered how to smelt iron in order to produce statues.

In Roman times, mining was a clear objective when new lands were conquered. A quick glance at the Roman mining sites in Europe (Davies, 1935) shows that the Romans were undoubtedly the best explorers. Although they obviously did not have systematic knowledge of geology, they applied successfully and empirically the geological knowledge they had acquired with respect to configuration and characteristics of the deposits and occurrences that usually showed distinct and common features in morphology, type of terrain and associated rocks.

Their mining techniques were also highly advanced, with the aqueduct as a system of water supply for washing of minerals, and systems to raise water to dewater mines (such as those found in Rio Tinto). The famous Roman mines of Las Medulas, in Leon (Spain) were exploited by a method called ruina montium or "collapse of mountains", which is characterized by a progressive collapse of huge loose ground masses by the combined use of water and underground shafts and galleries. The result is the formation of huge gullies with heights close to 100 m (***Figure 4***). At Las Medulas thousands of millions of tonnes of materials were removed. Their tools were similar to prehistoric tools, but there was more use of iron (i.e. the wedges of double point picks).

Mining in the Middle Ages showed maximum activity in central Europe, in what at that time was called Saxony (today´s Germany). Everywhere in Europe, the word Saxon was used when miners were needed. Saxons started mining operations in the Czech Republic (745), Saxony (1170) Bohemia (1561) and Norway (1623).

A global description of the minerals known in the 13th century is included in the fantastic Lapidarium, commissioned by Alfonso X "The Wise" of Castile (1252-1284), and finished in 1279 (EDILÁN, 1982). The book, which has not yet been completely deciphered, includes a description of minerals and rocks from all the parts of the known world, ordered by zodiac ascendency.

Another historical book on minerals and mining is De Re Metallica (1556) written by Georg Bauer (1494-1555), or Agricola, in 12 volumes. Bauer, a former medical doctor in Joachimsthal, describes the advantages and drawbacks of mining, the life of the miner, the research and excavation of deposits, the tools and mining machinery, the processing of minerals, the technology of metallurgy (gold, silver, lead, copper, salt, soda, alum, vitriol, sulphur, bitumen and glass), and the drainage and ventilation of mines.

The new science of "alchemy" made mining less relevant, particularly in the Muslim states, due to the new chemical production of metals.

Glass, a brief history

As early as the Bronze Age (2000 B.C.) objects have been found made with a mixture of silica, lime and alkali (Na, K). In Mesopotamia, Egypt (mosaic glass), Cyprus, Crete, Anatolia, Syria, Palestine, glass was rare (as were metal and ivory). The manufacturing techniques such as clay moulds were developed from other crafts (ceramics, metals, stone), but to the common peasant, these technicians were magicians (Fernández Navarro, 2003). From

Figure 4: Las Medulas Roman exploitation. Leon, Spain. Photo IGME.

1200 to 1000 BC glass objects were scarce, but during the 10th century BC a rebirth of the technique is recorded. The Etruscan and Carthaginians (6th to 4th century BC) saw the birth of the mould technique. The rod technique was developed in the 3rd to 1st century BC.

During the Hellenistic period there was ample development in glass production with many production centres. During Roman times glass moulding with two-piece moulds was developed, as well as new designs and colours. Glassblowing seems to have been first recorded in Syria in the first century BC, but was apparently acquired and further developed by the Romans. In fact glassblowing can be considered a great Roman innovation (AD 14-69). During the first part of that century glasses were multicoloured, but during the second half the technique of colourless glass was developed. It might sound strange, but in Augustian times, handmade glass covered the windows of some palaces.

In the beginning glass colours were the result of a mixture of contamination and working conditions, but by the 4th century BC glass was already being intentionally coloured by the addition of metallic oxides, or even colourless (manganese & antimony) and dichroic glasses.

During the Middle Ages there was a decline in the use of glass, as knowledge was lost. But at the same time, it is the period of the wide development of stained cathedral glass works (12th, 13th and 14th centuries).

But soon we see in Venice the greatest development in glass production of the time. The island of Murano was the main European glass making production centre during the 15th-16th and 17th centuries. The materials then employed in glass making were simple and easily accessible: soda (sodium carbonate) obtained from wood ashes, calcium carbonate (from limestone) and silica sand, potassium (from seaweed ashes). The improved whiteness that could be obtained from crushed and fired flint stone pebbles came into use instead of silica sand. A legendary Murano glass-maker, Angelo Barovier, is said to have made many discoveries in glass technology, such as crystalline glass – by adding manganese that decoloured the Venetian sodium glass – ice glass and milky glass (opaque white), but it was not until 1676 that the British George Ravenscroft added lead oxide to a batch of flintstone and potassium glass and obtained lead crystal. The advancements that gave way to what we call today true glass were enormous, but the new material had improved the polishing and cutting properties that allowed its use in optical instruments. Nevertheless, the modern industrial glass making technology of flat glass took a long time to develop. In the 18th century, flat glass for windows was scarce; only the European Royal glass factories had the financial support and the technology to achieve relevant developments. In Spain Charles III built a modern factory north of Madrid in a wooden area called La Granja that produced flat glass for body-sized mirrors, a technological wonder in those times. By the end of the 19th century, the production of industrial glass was widespread, but it was halfway into the 20th century, in 1950, when Sir Alastair Pilkington introduced the floating glass method in which the fused batch is poured over a bed of melted tin, a technical revolution that is used today in 90% of the world's flat glass production. The rest of the 20th century and the first decade of the 21st century have seen huge technical advances in glass making, far superior to those of former times.

Ceramics: the oldest manufacture

Ceramics have been a friendly companion of the development of the human kind. The oldest known in Europe were found in Anatolia (Turkey) and have been dated at 9,000 years old. In China there have been found ceramics remains since Neolithic times and some decorative techniques such as slip coatings were originally from there, but also found in ancient Egyptian decorated pieces. The Classic Greek times saw a widespread development of pottery. The first recorded use of glazes is mentioned in the Assyrian culture in the 9th century, where ceramic pieces with a tin glaze were found. This type of glaze was highly improved during the 15th to 18th centuries. The technique was introduced in Italy in the 13th century via Spain. In Italy ceramic pieces with such a glaze were called majolica, and had widespread development during the 15th and 16th centuries.

The oldest known porcelain is from the T'ang dynasty (618-907), although its quality was highly improved during the Yüan dynasty (1279-1368). Chinese potters made porcelain out of a mixture of feldspar rocks and kaolin (earth from Mount Kao-ling), which was then moulded and fired at 1450 °C. Obviously the technology developed there through seven centuries made slow but crucial improvements based on trial and error, as the Chinese did not know the science behind the ceramic process. In Europe, medieval potters, testing to discover what was called the arcane, produced first an artificial porcelain or soft paste (clay and ground glass) fired at 1200 °C (in Florence in 1575), but true porcelain was not discovered until 1708 in Dresden (Germany) then under the rule of Augustus II, elector of Saxony and King of Poland, and by Johann Frederick Böttger (Gleeson, 1998). He first used a mixture of 9 parts kaolin and 1 part calcium carbonate (calcareous alabaster). From 1724, the factory, then in Meissen, used a mixture of kaolin, feldspar and silica sand (the true formula of china). The race to manufacture porcelain led to the development of many factories in Europe apart from Meissen, such as in Nymphenburg (Germany) and Chelsea and Bow in England. Wedgwood, the famous bone china manufacturer, was built in the middle 18th century. The factory first developed gres ceramics (1775), and then in 1800 started the production of bone china.

Paper

The word paper comes from a plant called papyrus that was used by the Egyptians to produce flat sheets which could be dried and decorated. The earliest papyrus was dated 2400 BC. Something similar to what we call paper is thought to have been invented in China by Ts'ai Lun (AD 105), a Chinese court official who recorded the procedure to make this material using a mixture of plant fibres, nets and textiles. He mixed mulberry bark, hemp and rags with water, mashed it into pulp, pressed out the liquid, and hung the thin mat to dry in the sun. Imperial toilet paper is thought to be an early use of his invention. But it wasn't until 793 that the first common paper was manufactured in Bagdad.

The real boom of paper production came of age in the 14th century, when paper factories were recorded in Spain, Italy, France and Germany. From the mid-14th century paper was made in Europe by pulping linen and canvas rags derived from flax and hemp plant fibre. Paper production increased dramatically when, in 1450, Gutenberg invented the first printing press. There were no changes in the process of paper production up until the 18th century, when cotton rags were added to the mix, so line and cotton fibres were the main raw materials used to manufacture the paper pulp. The discovery of chlorine in 1774 was a turning point in the colour of paper; because the paper pulp could then be treated to whiten it, the old pale yellowish colour of paper became history. Around 1859, the demand for paper was so huge that the technique was improved to produce pulp exclusively from wood.

The use of minerals in paper started way back in 1900, when coating minerals – notably china clay (kaolin) because of its white colour and absorption capacity – were added to improve the reproduction of printed colours. Kaolin was also added as filler between the pulp fibres, as such fillers improved the absorption capacity of paper as well as its mechanical resistance. Other mineral fillers such as titanium oxide were also used to increase brightness, opacity and surface properties (smoothness and ink absorption). In the last 15 years the manufacturing process has changed from acid (boiling the material in sulphuric acid) to basic and since then kaolin has been partially substituted as filler by calcium carbonate, cheaper and with excellent similar properties.

Gunpowder

Originally from China, gunpowder appeared in Europe in the mid-13th century. Gunpowder, also called black powder, was then manufactured with a mixture of charcoal, sulphur and potassium nitrate (crystallised from cow dung) (Ponting, 2006). The current standard composition for black powder manufactured by pyrotechnicians was adopted as long ago as 1780. Proportions by weight are 75% potassium nitrate, 15% softwood charcoal, and 10% sulphur.

Soap

Soap is a Teutonic innovation from the Middle Ages. This now common bathroom companion is the result of the decomposition of animal fat by boiling it with soda ash. Soap was first used to treat textiles and was the first industry to use coal intensively and systematically.

Cement

Cement is one of the oldest construction materials. Some Roman cements can still be seen in many places of Europe. Roman construction techniques included a specialisation, the production of pozzolanic cement. This cement was produced by mixing the volcanic rock pozzolan with lime. The resulting material, once soaked, was so strong that Roman buildings are still standing all over Europe. In 1753 a new development appeared, hydraulic lime, but it was not until 1825 that Joseph Aspdin invented Portland cement by mixing limestone and clay and firing the mix at high temperature (Davey, 1971). He called it so because the resulting material (clinker) was as grey as a limestone in Portland. Many new types of cement are have originated from his idea, including white cement, which uses kaolin instead of common red clay.

Plaster

Plaster is no doubt the oldest construction material. The use of plasters made of fired gypsum has been documented in Egyptian pyramids (2500 B.C), some of which are still hard and in good shape. In ancient Greece painted stuccos were common, and such stuccos were manufactured with plaster from fired gypsum.

Lime

It has been well known from earliest times that the burning of limestone, once combined with water, produces a material that hardens with age. The earliest documented use of lime as a construction material was approximately 4000 BC, when it was used in Egypt for plastering the pyramids. The beginning of the use of lime in mortars is not clear but it is well documented that the Roman Empire used lime-based mortars extensively (Vitruvius, 23-27 BC).

Oil

Asphalt has been known from Mesopotamian times and was used as a construction material, in lighting and as a medicine. The conquest of the west in America led to a huge demand for kerosene and oil sources. New deposits were then sought for and as a result of this, in 1859, E.L. Drake drilled a 21 m hole in rock (an enormous feat at the time) and found oil in Pennsylvania. This was the first step to the search and exploitation of deep oil resources. Oil is now the fuel that moves the engine of development and thus the depletion of world oil reserves is one of the main global concerns. A considerable debate is now going on globally on the need to substitute other means of energy production for oil consumption, among them atomic energy and renewable alternatives (wind, hydroelectric, solar and geothermal energy). The role of minerals in these old and new energy sources is already evident.

Conclusions: a perspective on the future of minerals use by mankind

Minerals are today essential building blocks of our everyday lives and it looks as if in the coming future minerals will still be critical for our well being. The very brief history on some of the materials described above shows how minerals have been used by man from earliest times, and how this use has evolved with time, from the simple flintstone to produce fire to the now common mobile phone with hundreds of different minerals.

The future is still a minerals future. The difference is already obvious in the pharmacological industry, which uses many minerals in their medicaments, but of very high purity and with constant properties. The minerals used in the high-tech industry are very pure minerals, either synthetic or strictly selected natural minerals. Users will demand homogeneous and pure minerals with ever finer grain sizes from producers, and only those with the technology and the resources to produce those quality products will prevail in the market. Nanotechnology is already a reality but will further develop in everyday products that have not yet reached the market today.

New uses for old minerals, treated minerals (surface, structural, etc.) and new synthetic minerals will appear in all fields of manufacture, and developments will be so fast that we will be discovering and using them sooner rather than later. Lighter and at the same time stronger super-tough materials, super-abrasives, new ceramics, new refractories, textiles, transparent concrete, iron-strong plastics, and a long list of new materials are already in preparation.

Many of all those new materials will use minerals, so minerals will be ever more critical for the development of our high-tech society. But minerals will also be there to help in the development of the under-developed, because there is no development without minerals. There are still places where the humble clay brick represents an immense technical advance, where using crushed rocks for road-making is a luxury, or cement is imported at jewel-price costs. Things we take for granted in our comfortable Western homes do not exist in many places of the world, and the difference between growing or stalling is an economy based on the use of minerals.

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Hard rock – the raw material of mobility

*Donat Fulda**

We use hard rocks in our everyday life, mostly unaware of doing so. They form one of the foundations of the Swiss transport infrastructure, and thus of our mobility. However, high quality hard rock deposits in Switzerland are spatially limited to a belt along the fringe of the Alps between Lake Geneva and Lake Constance. Because of opposing usage and protection claims in existing and potential mining areas, conflicts increasingly inhibit the expansion of existing quarries or finding new, suitable mining locations. An expert committee addressed this problem and proposed solutions for the future supply of Switzerland with domestic high quality hard rocks. As part of these negotiations a doctoral thesis of the Swiss Federal Institute of Technology examines the most important Swiss hard rock, siliceous limestone, with new scientific approaches and analytical methods.

Nous utilisons des roches dures dans notre vie quotidienne, en ignorant ce fait, le plus souvent. Elles constituent l'un des piliers de l'infrastructure suisse de transport et donc de notre mobilité. Cependant les dépôts de roches dures de qualité supérieure, en Suisse, sont confinés spatialement le long d'une ceinture en bordure des Alpes, entre les lacs de Genève et de Constance. En raison de l'opposition exercée au niveau utilisation des roches et protection de l'environnement contre les mines existantes et les sites miniers potentiels, les conflits freinent de façon croissante le développement des carrières en exploitation ou la recherche de nouveaux sites favorables à une exploitation. Un comité d'experts s'est penché sur ce problème et a proposé des solutions pour l'approvisionnement futur de la Suisse en roches dures locales d'excellente qualité. Faisant partie de ces discussions, une thèse de doctorat préparé par l'Institut Fédéral suisse de Technologie étudie les roches dures les plus importantes de Suisse, les calcaires siliceux, avec de nouvelles approches scientifiques et méthodes d'analyse.

Usamos rocas en nuestra vida cotidiana, pero en general no nos damos cuenta. Forman los cimientos de las infraestructuras suizas de transporte, y por lo tanto de nuestra movilidad. Sin embargo, los yacimientos de rocas de alta calidad en Suiza están limitados geográficamente al borde de los Alpes entre el Lago Ginebra y el Lago Constanza. Debido al conflicto de intereses entre los ecologistas y los empresarios del sector en las áreas mineras potenciales y actuales, se está inhibiendo la expansión de las actuales canteras o la búsqueda de zonas mineras adecuadas. Un comité de expertos estudió este problema y propuso soluciones para el futuro suministro suizo de rocas de elevada calidad. Como parte de esta negociación una tésis doctoral del Instituto Suizo de Tecnología estudia las rocas suizas más importantes, silíceas y calcareas, con nuevos enfoques científicos y métodos analíticos.

Everyone who uses Switzerland's roads or railways automatically comes into contact with high quality hard rock. This important raw material has been used for decades for both pavement construction and railway construction.

Most occurrences of suitable hard rocks in Switzerland, as well as their specific properties, were already known in the last century. At that time, the rock was primarily used as paving stone, brick or pedestal stone (ASTRA, 2004; Niggli *et al.*, 1915). In the first half of the 20th century the Swiss Federal Railways (SBB) started to replace the previously used rounded gravel with crushed rock in railway construction. In road construction, the qualitative advantages of using chippings for the pavement were also discovered. Various studies in the past have showed that the quality and therefore the lifetime of transport infrastructure can be significantly increased through the use of suitable hard rocks (ASTRA, 2004).

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Increasing mobility, increasing burden placed on transport infrastructure

As current traffic statistics (BFS, 2013) show, the lifetime of transport infrastructure plays an increasingly important role: passenger transport services (***Figure 1***), the motor vehicle fleet as well as the density of the traffic on railroads have been constantly growing for decades. Furthermore, freight transportation services have significantly increased since the 1980s.

Due to the high quality of the Swiss road and railway network and the dense public transport service, longer commuting distances are no longer a problem these days. It is thus expected that the mean distance per person will further increase in the public and private motorised transport sector (BFS, 2013).

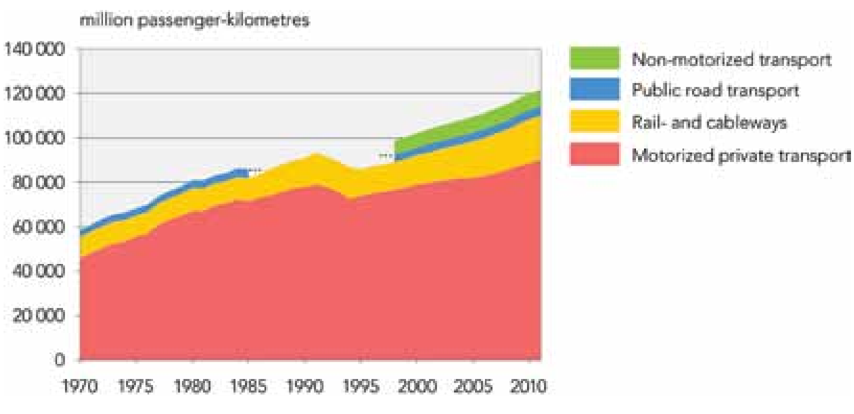

Figure 1: Passenger transport performance 1970 – 2011 (FSO Federal Statistical Office, 2013).

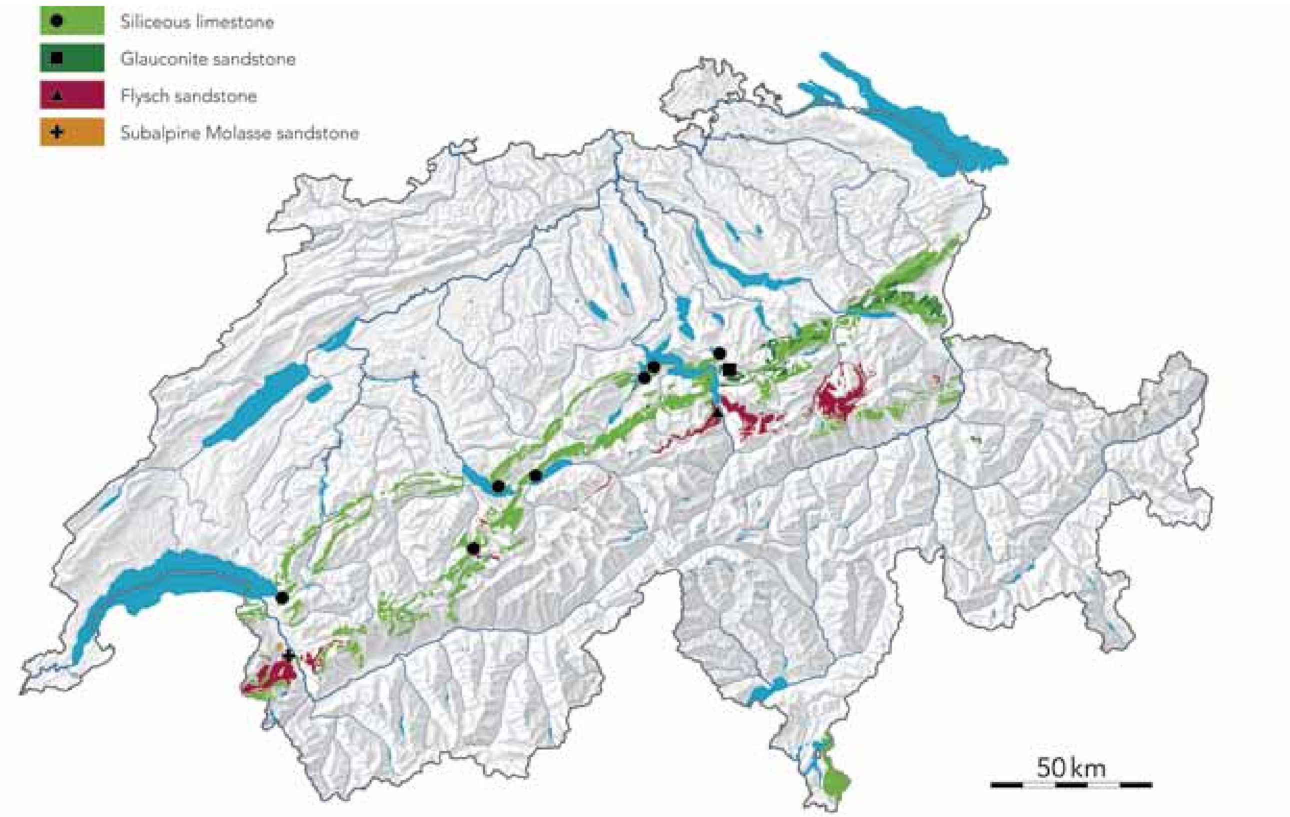

Figure 2: Potential occurrences of high quality hard rocks in Switzerland (colour) and quarries (symbol) where hard rock is currently mined (topography: Atlas der Schweiz).

High quality hard rocks

Maintenance and expansion of the intensely used transport infrastructure require high quality hard rocks. According to the classic definition (De Quervain, 1969), hard rocks have a compressive strength larger than 140 MPa and contain more than 25% of hard minerals (Mohs hardness >5.5). Increasing demands on the transport infrastructure in terms of speed and traffic volume require stricter guidelines. Standards of where and in what proportion hard rocks have to be used were set. To satisfy these standards, quarry operators had to improve their treatment process to remove unwanted fractions of minor quality.

Rocks that fulfil the additional standards are classified as "high-grade hard rocks". Swiss granites and gneisses, which are typical hard rocks according to the traditional definition (De Quervain, 1969), do not meet these new standards due to their high content of micas and their fabric.

In Switzerland, primarily siliceous limestone, flysch sandstone and sandstone of the subalpine Molasse are mined for high quality hard rock products. However, deposits in Switzerland and neighbouring countries are limited: they are predominantly concentrated in a narrow belt along the northern fringe of the Alps, stretching from Lake Geneva in the SW, via the Bernese Oberland and Central Switzerland to the Rhine Valley above St. Gallen (Bärtschi, 2012) (***Figure 2***). High quality hard rock is currently mined at 10 sites.

Siliceous limestone – Switzerland's most important hard rock

Siliceous limestone, the most commonly used hard rock in Switzerland, was the subject of a doctoral thesis at the Federal Institute of Technology (ETH) Zurich (Bärtschi, 2011), supervised by the Swiss Geotechnical Commission (SGTK). Apart from a detailed description of the geology and petrology of the various siliceous limestones found in Switzerland, the study also focuses on mineralogical characterisation and technical testing of the rocks. It is shown that the proportion and structure of silicification considerably affect the rock behaviour under mechanical stress: the higher its silica content and the denser and more interlocked its siliceous cement, the more stable the framework (***Figure 3***). Recording

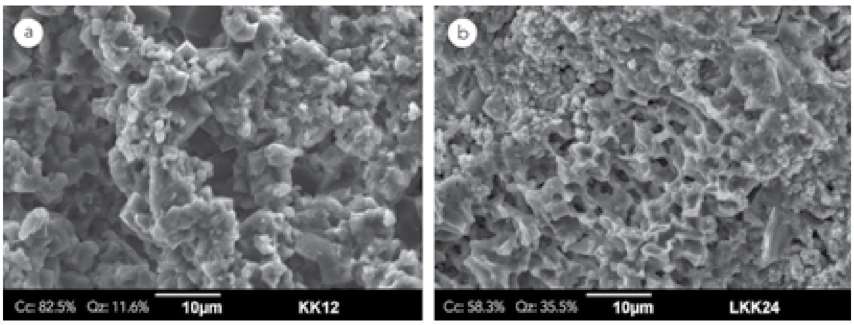

Figure 3: Scanning electron microscope image of siliceous limestone treated with hydrochloric acid (10%). a – siliceous limestone with low SiO_2-content and heterogeneously coordinated Quartz microaggregates without noticeable framework. b – dense microcrystalline silicification structure and intense framework of a silica-rich siliceous limestone.

potential weaknesses and heterogeneities in the mineral assemblage permits an estimation of the rock's behaviour when mechanically stressed. The author offers recommendations such as how traditional procedures for testing hard rocks could be simplified and improved. Particularly the LCPC[1]-stress test is considered an application-oriented procedure for hard rock that can be used in excavation material management, as well as for classifying solid rocks into hard, semi-hard and soft rocks. Only small sample volumes are required to assess the quality of a given deposit and test results can be easily and quickly obtained (Bärtschi, 2012).

Conflicting interests cause supply shortage

A Round Table with representatives of the Swiss Hard Rock Quarries Association (VSH) and various Federal Offices held in 2003 determined that Switzerland needs two million tonnes of hard rock annually. This number has since been objectively confirmed. From this figure, 800,000 tonnes are high-grade material used for road pavements while 600,000 tonnes are required as ballast for railway lines (ARE, 2012). The remaining 600,000 tonnes are sold as aggregates for other applications (eg. concrete).

To determine Switzerland's annual demand for hard rock, recycling and substitution as well as imports from neighbouring countries were considered. As transport of mass commodities is economically expensive and ecologically questionable, importing of high quality hard rocks is only feasible where foreign quarries are close to the border. But it has to be considered that also foreign quarries leave scars on the landscape.

So far, Switzerland's demand for high-grade hard rock for railway and road has been met by domestic production. A survey of the Federal Office for Spatial Development (ARE) and the SGTK considering the already granted mining projects and the time limit to the respective licences, however, showed looming supply shortage (ARE, 2008b). The survey predicts that Swiss domestic production of hard rock will fall to one million tons per year by 2020 at the latest. This shortage is not explained by exploited deposits, but rather by the conflicting interests of quarry operators and associations for nature conservation or homeland protection, as some of the potentially exploitable deposits are located within regions contained in the Federal Inventory of Landscapes and Natural Monuments of National Importance (ILNM). Furthermore, these areas whose sceneries are largely still intact are often used for tourism (Hirstein, 2009).

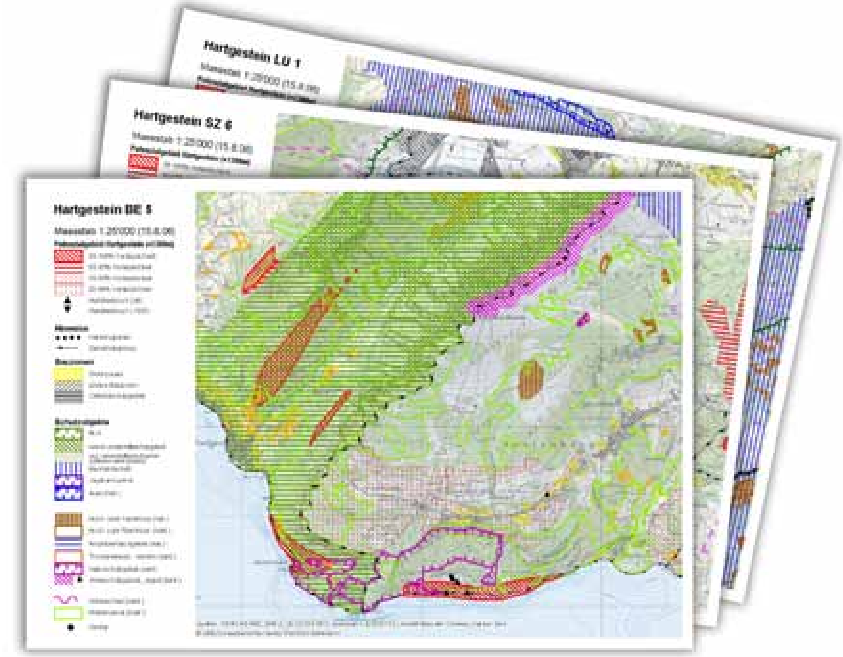

Figure 4: Potential maps show where, from a geologic point of view, potential high quality hard rock deposits are situated. The maps do not instruct about their suitability or economic viability. They further contain information about the relevant Federal or Cantonal inventories (e.g., ILNM), about building zones and partially about areas of water protection. They are suitable to reach a decision in the first planning steps, but are, however, not appropriate for detailed clarification.

Geological potential maps as possible approach

The conflicting interests of hard rock supply and conservative concerns and the resulting imminence of a supply shortage led to the development of a national concept. Within it, on behalf of the ARE, the SGTK compiled a geological baseline survey to identify potentially exploitable high quality hard rock deposits outside the ILNM. So-called potential maps were created to show where, from a geologic point of view, suitable hard rock deposits are located (***Figure 4***). To represent geologic data from different sources on a mutual and binding level of display, a reliability parameter was defined for all recorded hard rock areas. The parameter indicates how safe and reliable the geologic data of a specific area or its boundary is for further analysis. Its calculation is based on three indices, which respect the most prominent differences of the data used (SGTK, 2006; ARE, 2006):

A: precision of the rock classification for a specific area with respect to the desired hard rock lithology: siliceous limestone, glauconite sandstone, flysch sandstone and subalpine Molasse sandstone,

B: accuracy of the boundaries as reproduced from the map with respect to geographic reference, and

C: general validity of the study with respect to modern scientific interpretation.

By this, hard rock areas can be classified into five gradational categories.

The surveys conducted within this national concept were incorporated into a document that was published by the ARE in 2006 as a guideline for planning new exploration sites (*Planungshilfe für die Standortplanung*). It is still considered a milestone regarding the treatment of the above-mentioned conflicts of interest. Apart from potential maps, the document contains comments on national interests in nature conservation, homeland protection, and hard rock production for the infrastructure, as well as a list of criteria for the early consideration of both user and protection interests. The document was composed as a guideline without being legally binding.

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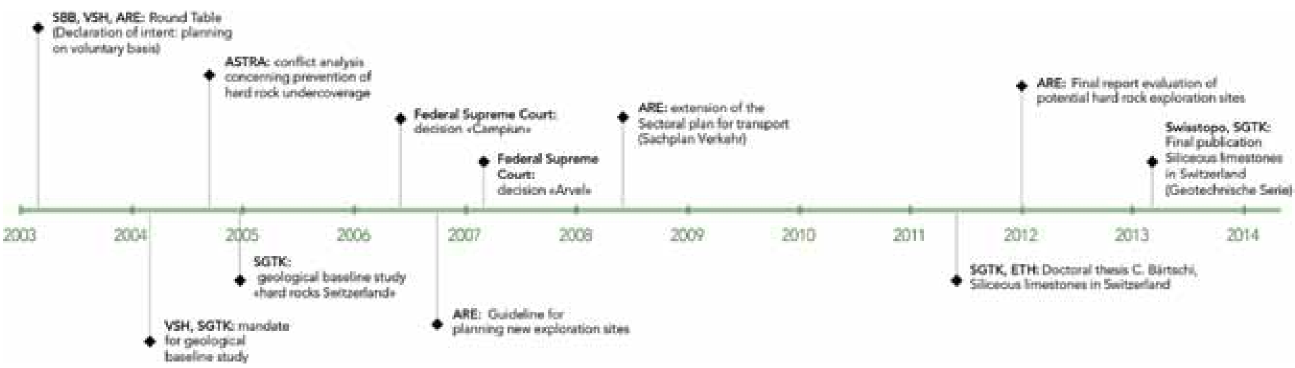

Figure 5: Overview of the "hard rock debate" and the most important milestones.

Sectoral plan for transport as a quick solution

The conflicting interests between hard rock exploration and nature and homeland protection culminated in 2007 in two Federal Supreme Court decisions prohibiting the expansion of already existing quarries within ILNM areas. Simultaneously, the jurisdiction of the Federal Supreme Court asked for binding national planning of hard rock quarries should conflicts arise in protectorates. The Federal Supreme Court judgement of the case could not be based on the guideline for planning exploration sites as the document lacked legal binding force.

The Federal Court decisions further exacerbated the situation of hard rock supply. In order to maintain the Swiss transportation infrastructure supply without perforating landscapes of national importance with hard rock quarries, the ARE and the Federal Office for the Environment (FOEN) initiated an adaption of the sectoral plan for transport, which included policies for Switzerland's supply with hard rocks. This adaption was introduced into the sectoral plan for transport by the Swiss Federal Council in 2008 and contains the following policies, among others (ARE, 2008a):

- In areas listed in the Federal Inventory of Landscapes and Natural Monuments of National Importance (ILNM) interference with nature is only permitted if the protection targets of the respective ILNM object are conserved.
- New surface quarrying projects or expansions of already existing quarries that impair the conservation of protection targets are only permitted if no exploration sites for national supply are feasible outside ILNM areas, and when a comprehensive weighing of interests has been conducted.
- To secure the long-term supply of hard rock, an early evaluation of suitable sites outside the ILNM perimeter is necessary.

By adapting the sectoral plan for transport, licencing of new quarries within ILNM areas is now possible provided the quarries are of national importance. A quarry is of national importance if it is able to supply at least 5% of the total demand of highest-quality railroad ballast or at least 10% of the gross requirements of hard rock (ARE, 2008a).

How to combine geologic, economic and ecological interests

To take full account of the jurisdiction of the Federal Supreme Court and to attain an inter-cantonal or national planning of hard rock quarries, it had to be shown whether there were alternative sites outside the ILNM perimeter. For this reason a survey with all significant participants was conducted on a national level; an encompassing project team was established. The Swiss Hard Rock Quarries Association (VSH) took the lead, the geological background was compiled by the SGTK and the ARE, together with FOEN and the Federal Office of Topography (swisstopo), as well as representatives from different cantons. The task force was appointed to incorporate environmental aspects and maintain coordination between the different participants. A supervising group was established and comprised representatives of environmental organizations, other Federal Offices and the Swiss Federal Railway, as well as the Association for Regional and State Planning (VLP).

The survey identified 34 potential sites for hard rock exploration, all of which reached maximum reliability (between 80-100%) in the baseline survey and were located outside the ILNM perimeter. These sites are, with three exceptions, distributed along the northern fringe of the Swiss Alps. The project team then evaluated and rated each of the 34 sites according to geologic, economic and ecological criteria (ARE, 2012).

- Geologic criteria were based on the geologic potential maps.
- Economic criteria included the estimated potential total volume and its connection to processing and treatment; the development of a potential site as well as its accessibility by road or railway were of interest.
- Ecological criteria comprised conservation and protection targets (residential areas, negative emissions, nature and landscape, water, forest) and other claims of land use in general (agriculture, tourism).

Examination of political support

In a second step, the project group submitted 15 out of the 34 originally defined areas to the cantonal governments to test their feasibility and political acceptance. In Switzerland, it is not the federal government but the cantons that are authorised to plan and approve raw materials extraction activities. The consultation of the cantons revealed that at three sites outside the ILNM perimeter good basic conditions exist to initiate the planning of two new quarries and the extension of an existing extraction place. In the future, these sites could contribute to the national supply of hard rock according to the sectoral plan for transport. Whether a project will get political support and will be accepted by the affected people and stakeholders will only be seen after detailed planning. However, since the main geological, corporate and environmental requirements concerning the planning of the project are known, there is a good chance that the project will gain the necessary political acceptance. Conversely, it can be concluded that detailed planning for new projects in areas, which are not recommended to the cantons or hard rock companies, cannot be fully excluded. The exclusion of an area will only be obvious if exclusion criteria are actually present (ARE, 2012).

Situation defused, but not yet completely solved

For the long-term supply of Switzerland with hard rock, the new potential locations that are outside the ILNM perimeter are likely to temporarily defuse conflicts with mining projects inside the ILNM perimeter, but will obviously not solve them. Making a reasonably optimistic assumption that two new quarries could be realised in a time frame of 10 years, it is likely that an additional amount of about 600,000 tonnes of hard rock will be available annually as of 2021. Together with the already licenced quarries outside the ILNM perimeter it would be possible to extract a total of about 1.2 million tonnes of hard rock per year. However, this still represents only about 60% of the total demand of 2 million tonnes. Furthermore, the above-mentioned mobility statistics as well as underestimated consumption for rail maintenance work suggest that this total demand in the medium term is unlikely to decrease. Consequently, mining sites inside the ILNM perimeter will have to be considered to ensure the future supply of hard rock (ARE, 2012).

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Salt in the UK

*Mark Tyrer**

The production of salt in the United Kingdom traces its history to ancient times and salt workings are known back at least to Neolithic times. Two major salt types are mined in this country; halite and related minerals and potassium salts ("potash") are dominant industrially. The applications are very wide, providing the raw materials for numerous products and processes, not least food use and de-icing salts used in road transport. In the UK, halite, sylvite, sylvenite, carnalite and polyhalite are all minened commercially. The origins of these compounds are reviewed along with their historic and current uses and the future evolution of the market for natural salts is discussed. The article considers commercial applications along with the technologies used in processing salts and their ultimate use.

The ubiquity of these minerals places them at the heart of modern society. Internationally, the market is dominated by five countries (USA, Canada, Chile, India, and Germany) yet the UK domestic market is stable and expanding, new operations in both potash and fluorite are being developed and the future market for each salt type looks promising.

La production de sel en Grande Bretagne remonte historiquement aux anciens temps et les travaux d'exploitation sont connus au moins à partir du Néolithique. Deux sortes de sel sont exploités dans le pays : la halite avec minéraux associés ainsi que les sels de potassium (la potasse), ressources industrielles dominantes. Les utilisations sont très diverses, constituant les matières premières pour nombre de produits et de procédés de traitement, ne serait-ce que le sel de cuisine ou le sel utilisé pour dégeler les routes et faciliter le transport. En Grande Bretagne, la halite, la sylvinite, la carnallite et la polyhalite font toutes l'objet d'une exploitation commerciale. Les origines de ces composés sont ici examinées en même temps que leur histoire et leur utilisation courante. L'évolution du marché pour les sels naturels fait aussi l'objet d'une discussion. L'article fait état des applications commerciales et des technologies utilisées pour le traitement des roches salifères et leur utilisation in fine.

L'ubiquité de ces minéraux les place au cœur de la société moderne. Internationalement, le marché est dominé par cinq pays (USA, Canada, Chili, Inde et Allemagne) ; cependant le marché en Grande Bretagne est stable voire en expansion ; de nouvelles activités pour la potasse comme pour la fluorine sont en développement et le futur marché pour chaque sorte de sel semble prometteur.

La historia de la producción de sal del Reino Unido se puede retrotraer a los tiempos más remotos y se sabe de extracciones de sal desde el Neolítico. En este país se explotan dos tipos de sal principales: la halita y minerales relacionados y las sales potásicas (potasas), que dominan el sector industrial. Las aplicaciones son muy variadas, ya que proporcionan las materias primas para numerosos productos y procesos, entre otros los usos alimentarios y las sales para el deshielo utilizadas en el trasporte por carreteras. En el Reino Unido se explotan comercialmente halita, silvina, silvinita, carnalita y polihalita. En este trabajo se estudia el origen de estos compuestos junto con sus usos históricos y actuales y se discute la evolución futura del mercado de las sales naturales. El artículo analiza las aplicaciones comerciales junto con las tecnologías utilizadas en el tratamiento de las sales y sus aplicaciones más recientes. La ubicuidad de estos minerales los coloca en el corazón de la sociedad moderna. Desde el punto de vista internacional el mercado está dominado por cinco países (EEUU, Canadá, Chile, India y Alemania), pero el mercado doméstico del Reino Unido es estable y está en expansión, se están desarrollando nuevos proyectos tanto en potasio como en fluorita y el mercado futuro de cada tipo de sal parece prometedor.

Background and history

The working of salt in Britain has been practiced since at least the Bronze Age and evidence of salt recovery from seawater and saline springs can be seen from neolithic archaeological evidence worldwide. Its culinary use as a food preservative can be traced to the earliest civilizations and in Britain, shallow pottery vessels and supporting pillars (*briquetage*) are probably our earliest evidence of salt refining and date from the Bronze Age. Evidence of such early "salt-making" is concentrated in eastern England, suggesting that evaporation of seawater was the source of salt in these regions, yet similar (though less common) ceramic vessels in Cheshire, Worcestershire and Wales are associated with iron age rock salt refining. By that time, such ceramic vessels were widespread in western England and were replaced during the Roman occupation by lead evaporating dishes. Examples of these vessels are held in several museum collections and some those of the Nantwich Museum are inscribed with the names of Roman salt makers such as: *Viventius, Veluvius, Lutamus* and *Cunitus*. These western archaeological sites are associated with rock salt and brine springs, rather than sea water and are concentrated in three areas, (Cheshire and Worcestershire in England and Carrickfergus in Northern Ireland) all lying on Permian sediments. Salt workings in Europe have a better-documented early history; Hallstatt in the Salzkammergut region of Austria, being the oldest (12th century B.C.) and lending its name to the archaeological *Hallstatt period*, which originated somewhat earlier (about 700 B.C. or even earlier) and expanded substantially with the development of those salt mines.

The British town of *Nantwich* has one of a distinctive group of place names associated (but not exclusively) with salt. Originally derived from the Latin *vicus* (meaning place) it was adopted by the Anglo-Saxons and evolved into the word *wic* (meaning dwelling place) and by the 11th century, use of the 'wich' suffix in place names was associated with places with a specialised function including that of salt production. Several English places carry this suffix and are historically related to salt, including the four Cheshire 'wiches' of *Middlewich, Nantwich, Northwich* and *Leftwich* (a small

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village south of Northwich), and *Droitwich* in Worcestershire. *Middlewich, Nantwich, Northwich* and *Droitwich* are known as the *Domesday Wiches* due to their mention in the Domesday Book; an indication of the significance of the salt-working towns in the economy of the region, and indeed of the country at the time of the Norman conquest.

From the middle ages, the lead salt pans favoured by the Romans, were replaced by iron vessels, largely as a result of the higher temperatures associated with coal-fired drying (which melted lead vessels) as wood was replaced by coal as a fuel. By the industrial revolution, the mining and refining of salt was a well-established industry in Britain and paralleled the growth of the chemical industries.

Important early uses in the leather and textile industries made increasing demands of salt mining and as the process became mechanised, so new markets were developed to supply the growing chemical industries. In the nineteenth century, the demand for alkalis grew rapidly and was met through a technological step-change developed by the Belgian industrial chemist Ernest Solvay (1838-1922). Briefly, the Solvay process takes sodium chloride (brine, from rock salt) and calcium carbonate (limestone flour) and reacts them (using ammonia gas as an intermediary, which is recovered) to produce calcium chloride and sodium carbonate. This latter ("Soda Ash") remains an important precursor to many industrial processes to this day, supplying diverse industries such as glass-making, water softening, soaps and detergents, paper making and dyestuffs amongst many others. The calcium chloride is sold into other industries (such as fine chemicals) and is a component in drilling fluids.

Geological setting

The formation of the UK salt deposits in the upper Permian sediments is similar to that across northern Europe, as the Zechstein sea dried out, leaving its solutes behind as salt flats. There probably is no similar environment on earth today and although comparisons with the Persian Gulf have been made, it is evident that the drying of the Zechstein included several marine regressions, leaving salts at different stratigraphic horizons. In the late Permian (~250 Ma) a considerable are of northern Europe was covered by this shallow sea, when Europe was close to the equator. Although fed by rivers (carrying additional dissolved solids) the rate of evaporation exceeded the rate of re-charge and between 200 and 300 million years ago, a varied sequence of evaporates was deposited, including sulphates (especially gypsum and anhydrite) carbonates (the Zechstein magnesian limestones of the NE coast of England) and importantly, a range of halides. Subsequent burial by (and diagenesis of) the overlying sediments left salt bodies at depth and some of them have subsequently risen by buoyancy *"halokinisis"* as diapirs, forming the salt domes of northern Europe and the North Sea. These structures are of great economic significance in the North Sea oil province, where they form traps for rising oil. In the UK, four important salt horizons are known in the Permian Zechstein sandstones and are worked commercially in Cheshire, North Yorkshire and Carrickfergus in Northern Ireland.

Figure 1: Approximate extent of the Zechstein basin.

Mineralogy

Owing to differing solubilities of the salts deposited, the mineralogy of these evaporates differs from region to region. In Britain, two distinct mineral assemblages are important, the sodium-rich salts of Cheshire and Worcestershire and the potassium-rich minerals ("potash") of North Yorkshire.

Naturally occurring sodium and potassium halides (halite and sylvite respectively) form cubic crystals, which reflect their lattice structures, although well-developed crystals of halite are much more common than sylvite. At atmospheric pressure and temperature, the two salts do not show extensive solid solution between the end-members (they show a "miscibility gap") and drying of a mixed solution results in separation into two, intimately mixed phases, known as sylvinite; an important source of potassium. The same is true when a molten mixture of the two salts cools and re-crystallises, the miscibility gap 'splits', resulting in two phases on solidification. Pure sylvite is a relatively rare mineral, potassium more commonly occurring in mixed mineral assemblages, such as sylvinite.

In addition to potassium chloride, a number of other important potassium minerals are mined in the UK, from the Boulby mine operated by Cleveland Potash in North Yorkshire. Both carnalite $KMgCl_3.6(H_2O)$ and polyhalite $K_2Ca_2Mg(SO_4)_4.2H_2O$ are worked commercially and the polyhalite reserves at Boulby are the only commercially worked deposits in the world. The vast majority of the potassium salts (~90%) worked are used as fertilizers with the remainder being consumed by the chemicals and glass industries. This has operational advantages as these potassium minerals do not need to be refined (separated into individual phases) before use as fertilizers, but can be blended or used directly.

Mining and production

Modern salt mining in the UK is either by cut and blast methods or by continuous mining. In the former, a horizontal slot is cut below the mass of salt to be recovered using an 'undercutter' (reminiscent of a very large chain saw) and charge holes drilled, to allow blasting of the undercut reserve; around 1,000-1,500 tonnes per charge. The rock salt is then recovered by a combined feeder-breaker to manageable pieces about the size of a football and is

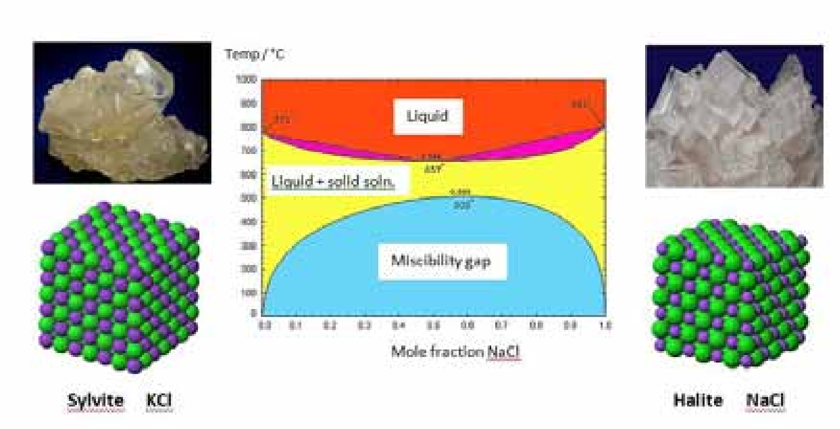

Figure 2: Although the structure and stoichiometry of halite and sylvite are similar, they do not form a solid solution at atmospheric pressure and temperature.

then sent for further crushing and screening by conveyor belt. Continuous mining by comparison, uses a rotating cutter head, armed with tungsten carbide teeth, which produces smaller pieces than by the cut and blast method and the recovered salt is fed continuously to a conveyor for processing. In each case, support of the overlying rock is of the greatest importance, so the geometry of the worked horizons is one of chambers and pillars, arranged in a grid pattern of *'rooms'*. The *'stopes'* (pillars) which remain contain valuable salt reserves, but can only be recovered at the end of a mine's working life, when an engineered backfill is emplaced, allowing the remaining reserve to be recovered. Owing to the risks associated with this approach, many mining companies across the world do not recover this final reserve, choosing to leave the stopes in place. The operation is performed on a massive scale; at the Winsford mine in Cheshire, the 'rooms' between the pillars are some 20m wide and 8m high,

Figure 3: Continuous cutters at Boulby (left) and Winsford (right).

Figure 4: Undercutter in the Winsford salt mine (left) and an excavator in working in the Boulby Mine (right).

with pillars of $20m^2$ in plan section.

The alternative method of salt recovery is that of solution mining, where a borehole is drilled into a salt dome and fresh water injected into to the primary well is recovered from a secondary 'production' well. The solubility of sodium chloride in water is around 26% by mass at 20°C and the British Salt operation at Middlewich recovers salt in this way. It has also been considered by Cleveland Potash as an option at their Boulby mine. The brine is recovered from depths of ~180m at Middlewich and is pumped some 5km to the refining works and largely sold directly into the chemicals industries as brine.

Applications and markets

Overall, the UK produces around 5.8 Mt p.a. in 1984 (down from its 1980 peak of around 7 Mt p.a.). Around 70% of this total is used directly in the chemicals and food industries, the remaining 30% is used for road de-icing. Of this total, over 80% is produced in Cheshire. The most familiar form (table salt, ~1 Mt p.a.) is refined from brine by vacuum drying, to produce what is called *white salt*, which with the addition of anti-caking agents (and for some markets, iodine salts) is then ready for use.

The four principal UK producers are shown in ***table 1***.

Primary brine consumed by the heavy inorganic chemical industries is the precursor for very many processes. The *cloralkali* process involves direct electrolysis of sodium chloride brine in a reaction vessel separated into two chambers by an ion selective membrane. This has effectively replaced the *Castner-Kellner* process for electrolytic production of sodium hydroxide and chlorine. The reaction products are (naturally) chlorine at the anode and hydrogen at the cathode, whilst sodium hydroxide forms in the electrolyte at the cathode and is concentrated and prevented from re-mixing with the bulk solution as it is unable to easily cross the membrane. By re-combination, both sodium hypochlorite (the *Hooker Process*) and sodium chlorate are synthesised in the same plants and although the whole process is energy intensive, it is the principal route by which these important chemicals are produced. The chlorine recovered is used to produce chlorinated solvents (*i.e.* 1,2 dichloroethane) vinyl chloride for PVC and many other products such as bleaches and detergents. Sodium hydroxide is similarly a principal product of the salt industry and is used widely in detergents, paper making and in

Table 1: Main UK salt producers.

Operator	Location	Owner	Capacity (Mt p.a.)	Depth	Recovery method
British Salt	Middlewich, Cheshire	Tata Chemicals	800,000	180m	Solution mining
Salt Union	Winsford Mine, Cheshire	Compass Minerals	1,000,000	189m	Cut and blast Room and pillar
ISME	Kilroot Mine, Carrick-fergus, NI	Irish Salt Mining and Exploration Company Ltd	500,000	180m	Cut and blast Room and pillar
Cleveland Potash	Boulby Mine, Cleveland, North Yorkshire	ICL Fertilizers	1,000,000	1,500m	Continuous mining

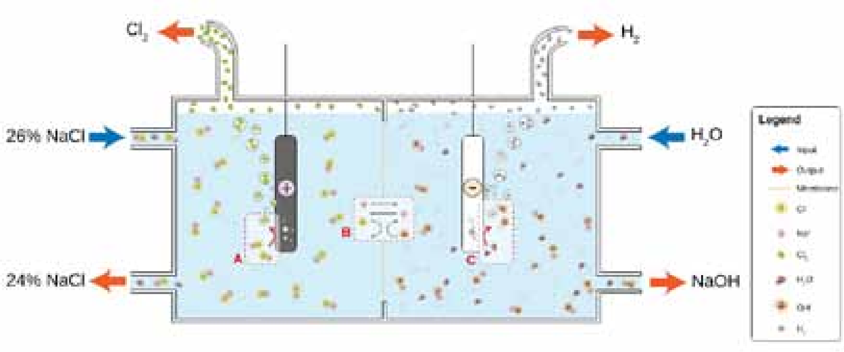

Figure 5: Schematic diagram of the Chlor-alkali process membrane cell. Chlorine is generated at the anode (left) and hydrogen and sodium hydroxide are produced at the cathode (right).

the petrochemical, textile and detergent industries.

Conclusions

The ubiquity of salt cannot be overstated and without its abundant supply, many modern industries would grind to an abrupt halt. Mankind's reliance on these essential minerals continues to demand ever increasing supplies, but even at our current rate of consumption, known reserves are likely to last for centuries. In the UK alone, projections in excess of two hundred years scope only those rock salt reserves already in production. Potassium however, is already the subject of concern as the need to feed a growing world population places increasing demand on fertilizer availability. Manning (2007) cautioned that the price of potash has risen by a factor of three in less than a decade and emphasises the growing demand on potash and phosphate reserves for agriculture.

A final thought: What might one do with an empty salt mine vault? By its very nature it is extremely low humidity environment and of course dark and stable. The Winsford mine lets out former workings as a document store to Deep Store Ltd (Owned by its parent company, Compass Minerals). The secure store holds documents from the National Archive amongst others and spans 1.8 million square metres. Elsewhere, completed brine extraction cavities have been used for gas storage (Teeside and Yorkshire) allowing the industry to meet sudden demands for fuel gas. A further storage facility planned for the Preesall Saltfield in Lancashire was refused planning permission in April 2013 owing to *'uncertainty surrounding the two proposed potential cavern development areas, given the lack of hard geological data to demonstrate their suitability for underground gas storage'*. The Boulby mine is the deepest in Britain at 1.1km, which uniquely in the UK, provides a vast amount of shielding from background radiation. It was chosen for the site of the nation's deep underground laboratory, initially for work on cosmic rays and the search for dark matter. Subsequently, other projects have begun, including studies of cosmic rays and climate, astrobiology and life in extreme environments, development of techniques for deep 3D geological monitoring and various gamma spectroscopy studies of radioactivity in the environment. There is a lot which can be done with a hole in the ground!

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PERC, CRIRSCO, and UNFC: minerals reporting standards and classifications

Stephen Henley and Ruth Allington*

There are two internationally recognised systems for classification and reporting of reserves and resources of solid minerals: the CRIRSCO family of reporting standards and the United Nations Framework Classification (UNFC). Despite a common perception that these are in competition, they are in fact closely linked, and they address different sets of requirements. The CRIRSCO standards, which include PERC, JORC, and the Canadian CIM standard among others, were developed for public reporting by companies listed on stock exchanges to provide a consistent terminology as well as quality assurance in company estimates of mineral resources and reserves. The underlying objective is protection of the public (in this case investors) by ensuring that the reports produced use consistent terminology and core content so that they can be understood and compared, and that those who prepare public disclosure reports are competent to do so and are prepared to take personal responsibility for their own work. There are minor differences among the CRIRSCO standards as a result of differing regulatory regimes in the countries in which they are used, but all share identical core definitions and classification. The United Nations classification was developed to provide an all-inclusive system that could be used for mineral inventories and minerals policy planning by governments and companies alike. Where the two systems overlap, CRIRSCO provides the detailed specifications for the corresponding UNFC categories. This paper outlines the history and use of the two systems.

Il existe deux systèmes, avec reconnaissance internationale, concernant la classification et le compte-rendu des réserves et des ressources minières : le CRIRSCO définissant les modalités de rapport et le Système de Classification des Nations Unies (UNFC). Bien que ces deux systèmes soient perçus communément comme en compétition, ils sont en fait étroitement liés et répondent à des besoins différents. Les standards du CRIRSCO qui incluent entre autres les standards du PERC, du JORC et du canadien CIM ont été établis pour les rapports publics émis par les compagnies représentées à la Bourse, pour fournir une terminologie cohérente et aussi une assurance qualité dans l'estimation par une Compagnie des ressources et réserves minières. L'objectif sous-jacent est la protection du public (les investisseurs ici) en garantissant que les rapports émis utilisent une terminologie cohérente, un exposé de la réalité de telle manière qu'ils puissent être compris et comparés et que ceux en charge d'élaborer les rapports destinés au public soient compétents pour le faire et prêts personnellement à assumer leur responsabilité pour leur propre travail. Il existe quelques différences mineures dans les standards CRIRSCO provenant des différents systèmes de régulations pour les pays où elles sont utilisées mais tous les rapports partagent les mêmes définitions de fond et la même classification. L'UNFC a été créée pour fournir un système complet pouvant servir aussi bien pour un inventaire minier que pour un programme de politique minière définie par les gouvernements et les compagnies. Là où les deux systèmes se recouvrent, le CRIRSCO fournit des spécifications détaillées pour les catégories correspondantes de l'UNFC. Cet article décrit l'histoire et l'utilisation des deux systèmes.

Existen dos sistemas de clasificación y declaración de recursos minerales reconocidos internacionalmente: la familia de los códigos CRIRSCO y la Clasificación Marco de Naciones Unidas (UNFC). A pesar de que existe una cierta percepción de que ambas compiten entre ellas, en realidad están íntimamente relacionadas y se refieren a una serie de requisistos diferentes. Las normas CRIRSCO, que incluyen –entre otras- a las PERC, JORC y la norma canadiense CIM, se desarrollaron para la declaración pública de compañías cotizadas en las bolsas de valores, con objeto de proporcionar una terminología unificada así como el control de calidad en las estimaciones de recursos y reservas de las empresas. El objetivo de fondo es la protección del público (en este caso los inversores) asegurando que los informes emitidos tienen una terminología y contenido nuclear congruente de modo que se puedan entender y comparar y que los autores de esos informes para el público tengan la adecuada competencia y estén dispuestos a asumir la responsabilidad personal que implica su firma. Hay pequeñas diferencias entre las normas CRIRSCO como consecuencia de los diferentes regímenes regulatorios en los países en los que se utilizan, pero todas tienen las definiciones y clasificaciones fundamentales idénticas. La clasificación de Naciones Unidas se desarrolló para proporcionar un sistema global que se pudiera utilizar en inventarios minerales y en planes de planificación minera tanto por Gobiernos como por empresas. En aquello en que los dos sistemas se solapan, CRIRSCO proporciona las especificaciones detalladas para las categorías UNFC correspondientes. En este artículo se describe la historia y el uso de los dos sistemas.

Mineral resources and reserves have been estimated systematically for many decades, but with expansion of the minerals industry internationally, and with increasing involvement of capital markets in financing mining ventures, it became clear during the 1980s and 1990s that systematisation and regulation were needed. An early warning sign came in 1970-71 when a major nickel discovery by Poseidon in Western Australia sparked a wave of speculative company flotations, many based upon unsubstantiated estimates of resources. A much more serious case was the Bre-X fraud in 1997, in which a Canadian company announced a gigantic gold discovery in Indonesia based on data from drill-hole core which had been 'enriched' before assaying with extra gold grains. In both cases - and in many other smaller scale

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cases - investors were defrauded of huge sums of money.

Professional organisations of geologists and mining engineers around the world decided that it was necessary to take action to rationalise and regulate the reporting of mineral resources and reserves. The first to produce a formal regime – consisting of a simple classification and a set of professional standards regulating its use – was the 'Joint Ore Reserves Committee' in Australia and New Zealand - now better known as JORC. This was closely followed by similar initiatives in Canada, the USA, South Africa, and the United Kingdom. The initial UK initiatives led to pan-European co-operation through the involvement of EFG and IGI.

There was much in common among these standards: in particular the concept of the "Competent Person" (or in Canada the "Qualified Person"), and the same classification was adopted by all. Standards committees from the five countries listed above formed CRIRSCO in 1994, and agreed on an initial set of common definitions in 1997 at a meeting in Denver, USA. Initial UK representation evolved into European participation through the formation of PERC in 2006. Chile joined CRIRSCO in 2004, and Russia in 2011.

Since 1999, CRIRSCO has formally been a participant in developing the United Nations Framework Classification (UNFC) in a project led by the United Nations Economic Commission for Europe (UNECE).

There are two distinct types of public reporting of mineral resources and reserves:

- Disclosure for companies quoted on stock exchanges. Objectives: reliable, transparent information for investors and potential investors. This is the role of the CRIRSCO family of standards
- Governmental, inter-governmental, or NGO reporting of mineral resource estimates and forecasts. Objectives: a reliable mineral inventory to underpin minerals policies (especially cross border, e.g. Europe), available to exploration and mining companies to attract inward investment and exploration activity. This is the role of UNFC.

It should be noted that there is no conflict between CRIRSCO and UNFC, since the CRIRSCO classification itself provides the specifications for corresponding categories within UNFC.

The CRIRSCO Family of Reporting Standards: PERC as an example

In 1991, a simple code was published by the Institution of Mining and Metallurgy in London, intended to be used for reporting of mineral resources and reserves by companies with stock exchange listings. This code evolved rapidly and converged with JORC and other reporting standards. In 2001 a major revision was published, incorporating the best features of all of the other codes. This code was prepared with the active involvement and support of the European Federation of Geologists, the Geological Society of London, the Institute of Geologists of Ireland, and the Institution of Mining and Metallurgy. It was named simply "The Reporting Code", and the intention was that it would act as a reporting standard for Europe but potentially could become a worldwide minerals reporting standard. The reason this did not happen is discussed below. However, it succeeded in its European objectives. In 2006, in light of the further development and improvement of other standards, especially the publication of JORC 2004 in Australia, there was seen to be a need for further updating, so the European committee was reconvened as PERC. PERC had an

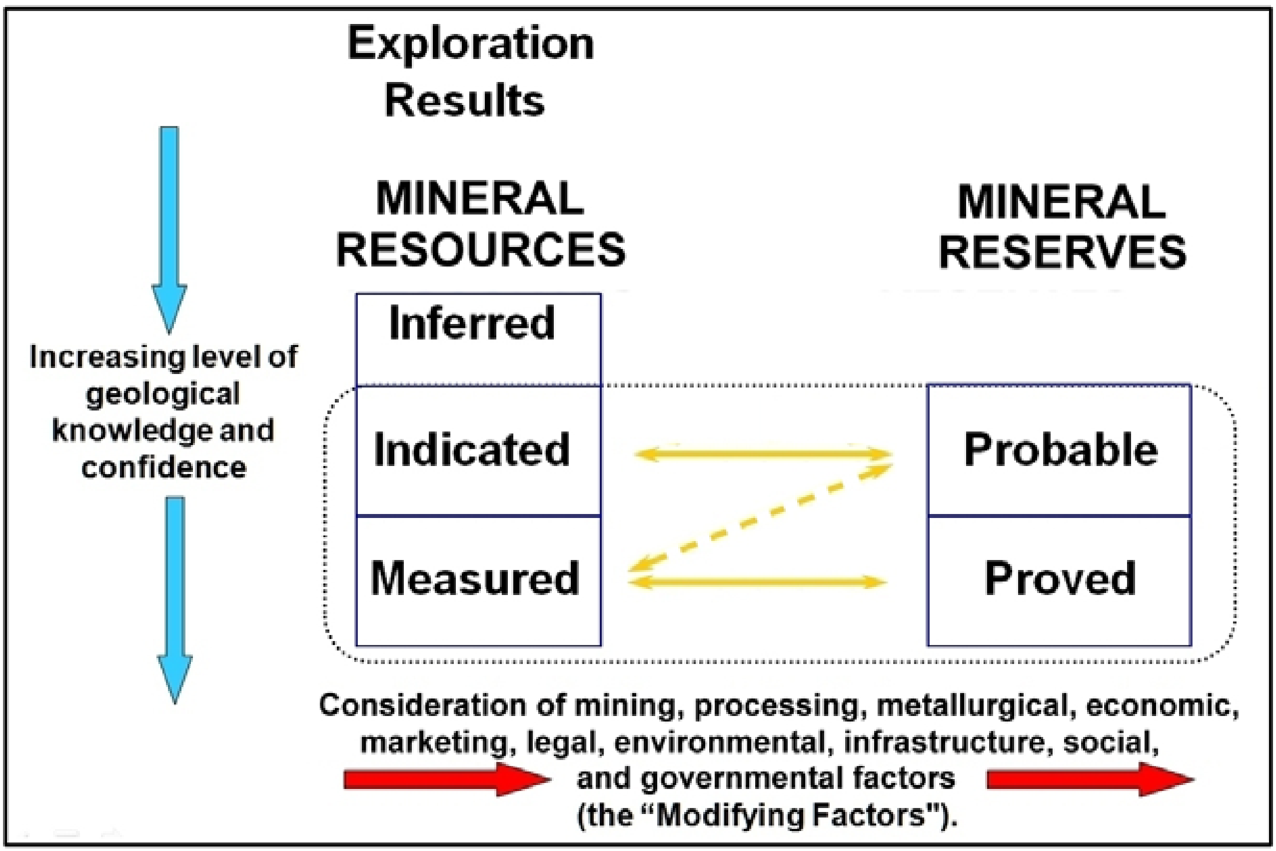

Figure 1: The CRIRSCO standard classification now used by all reporting standards that are aligned with CRIRSCO.

additional role in assisting the integration of Russia into the CRIRSCO family by first developing a method for conversion from the Russian State (GKZ) classification to the CRIRSCO classification, followed by development of a Russian national reporting standard. The PERC Code was issued in 2008, and an update has been published in 2013.

PERC is now recognised by the European Securities and Markets Authority for use on all European stock exchanges, as well as by the Canadian regulators for use within the Canadian reporting system (National Instrument 43-101). Other regulators – such as in Australia and South Africa – mandate the use of only their own national standards, although these still recognise Competent Persons who are accredited in accordance with other CRIRSCO Codes and Standards and by overseas professional organisations elsewhere.

The role of CRIRSCO

CRIRSCO, which was formed in 1994 under the auspices of the Council of Mining and Metallurgical Institutes (CMMI), was established as a grouping of representatives of organisations that are responsible for developing mineral reporting codes and guidelines in Australasia (JORC), Canada (CIM), Chile (National Committee, from 2004), Europe (PERC), Russia (NAEN/OERN, from 2011), South Africa (SAMREC) and the USA (SME). The combined value of mining companies listed on the stock exchanges of these countries accounts for more than 80% of the listed capital of the mining industry.

The international initiative to standardise market-related reporting definitions for mineral resources and mineral reserves had its start at the 15th CMMI Congress at Sun City, South Africa in 1994. The mineral definitions working group (later called CRIRSCO) was formed after a meeting at that Congress, and was made up of representatives from the countries listed above (except for Chile and Russia, which joined later), with the primary objective of developing a set of international standard definitions for the reporting of mineral resources and mineral reserves.

In 1997, the five initial participants reached agreement (the Denver Accord) for the definitions of the two major categories, Mineral Resources and Mineral Reserves, and their respective sub-categories of Measured, Indicated and Inferred Mineral Resources, and Proved and Probable Mineral Reserves. This classification is shown in ***Figure 1***.

In 1999, agreement was reached with the United Nations Economic Commission for Europe (UNECE), which had since 1992 been developing an International Framework Classification for Mineral Reserves and Resources (UNFC), to incorporate into the UNFC the CMMI-CRIRSCO resource / reserve definitions for those categories that were common to both systems. This agreement gave true international status to the CMMI-CRIRSCO definitions.

Following these agreements, an updated version of the JORC Code was released in Australia in 1999 (and more recently, in 2004), followed by similar codes and guidelines in South Africa, USA, Canada, UK / Ireland / Western Europe, Chile and Peru. The JORC Code (Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists, and Minerals Council of Australia) has played a crucial role in initiating the development of standards definitions for these codes and guidelines.

In 2002 CMMI was disbanded. CRIRSCO is now a partner of, and partly funded by, ICMM, the International Council on Mining and Metals, which is a worldwide consortium of minerals companies and mining industry associations whose purpose is promoting high environmental and ethical standards in the industry.

The similarity of the various national reporting codes and guidelines enabled CRIRSCO to develop an International Minerals Reporting Code Template in 2006, which is available on the CRIRSCO web site. This can act as a “core code and guidelines” for any country wishing to adopt its own CRIRSCO-style reporting standard, after including provisions for country-specific requirements such as those of a legal and investment regulatory nature.

CRIRSCO serves as an international advisory body without legal authority, relying on its constituent members to ensure regulatory and disciplinary oversight at a national level.

All CRIRSCO standards follow the same set of principles and use the same classification.

CRIRSCO’s scope includes all solid minerals (metals, gemstones, bulk commodities, aggregates, industrial minerals, energy minerals such as coal and uranium) and its overall aim is promoting international best practice in the public reporting of mineral exploration results, mineral resources and mineral reserves by achieving international consensus on reporting standards, and by encouraging consistent and high quality reporting through maintenance of Competent Person standards (see below).

The core of the various standards is practically identical (and becoming ever more closely aligned), but inclusion of national regulatory requirements provides small but important differences – which is why CRIRSCO cannot offer a single worldwide standard. However, for the geoscientist a report prepared under one national standard can readily be referenced to the requirements of another, since they all use an identical classification (***Figure 1***) and an identical set of core definitions. ***Table 1*** summarises the current CRIRSCO member standard-setting organisations and their professional organisation sponsors.

The United Nations Framework Classification

The United Nations Framework Classification (UNFC) has a very different purpose from the codes and standards which are aligned with CRIRSCO. Its development was begun in the 1990s by UNECE and proceeds under a global mandate from the UN Economic and Social Council. The UNFC classification is more complex and more extensive than CRIRSCO’s; it covers oil and gas resources as well as solid minerals, and its principal objective is to provide a method of standardisation for regulatory and statistical purposes, both governmental and intergovernmental. It may also be useful to larger minerals groups with many sites for their internal planning and management of their mineral inventory.

Key definitions and terminology used for reporting solid mineral reserves and resources (and exploration results) within these two classification systems have been aligned through extensive co-operative efforts between CRIRSCO and UNECE since 1999. A parallel collaboration has taken place between SPE (the Society of Petroleum Engineers) and UNECE for oil and gas, with the PRMS (Petroleum Resources Management System) classification.

UNFC is a generic classification framework for solid minerals and oil and gas. It is an important tool for global and governmental communication. It should be emphasised that it is not a public reporting standard; there are no underlying principles as there are in a reporting standard, and it has no recognition by market regulators. It is a classification and carries no concept of any certification of Competency. In other words, it does not define a Competent Person who takes personal responsibility

Table 1: National Minerals Reporting Standards and their Sponsor Organisations.

The following countries are currently represented on CRIRSCO. Member organisations include all bodies that have a direct influence on the form and content of national reporting standards although they may be more or less active in the affairs of the national committee.

South Africa	
National Committee	South African Mineral Resource Committee (SAMREC)
Member organisations	South African Institute of Mining & Metallurgy (SAIMM) South African Council for Natural Scientific Professions (SACNASP) Geological Society of South Africa (GSSA) Geostatistical Association of South Africa (GASA) South African Council for Professional Land Surveyors and Technical Surveyors (PLATO) Association of Law Societies of South Africa General Council of the BAR of South Africa Department of Minerals and Energy Johannesburg Stock Exchange (JSE) Council for Geoscience South African Council of Banks Chamber of Mines of South Africa (CoM)
Australia	
National Committee	Joint Ore Reserves Committee
Member organisations	Australasian Institute of Mining & Metallurgy (AusIMM) Australian Institute of Geoscientists (AIG) Minerals Council of Australia (MCA) Australian Stock Exchange (ASX)
Europe	
National Committee	Pan-European Reserves Committee (PERC)
Member organisations	European Federation of Geologists (EFG) The Geological Society of London (GSL) Institute of Materials, Minerals and Mining (IoM3) Institute of Geologists of Ireland (IGI)
Canada	
National Committee	Canadian Institute of Mining, Metallurgy and Petroleum (CIM)
Member organisations	CIM
Chile	
National Committee	National Committee for the Certification of Competency in Mineral Resources and Reserves
Member organisations	Mining Council (Consejo Minero) SONAMI (small + medium sized mining companies) Institute of Mining Engineers of Chile Association of Geologists Association of Engineers
Russia	
National Committee	NAEN
Member organisations	NAEN / OERN Association of Experts of Russia on Mineral Resources
United States of America	
National Committee	Society for Mining, Metallurgy and Exploration (SME)
Member organisations	Society for Mining, Metallurgy and Exploration (SME)

for estimates, nor does it provide mandatory requirements or guidance as to the way in which reports are to be written. Another difference from CRIRSCO is that the UNFC includes the categories "Undiscovered" and "Uneconomic" material, which cannot and must not be included in a CRIRSCO-compliant report. The UNFC provides a neutral framework for mapping from/to complete reporting systems (such as CRIRSCO and PRMS).

The CRIRSCO classification is two dimensional, with axes for geological knowledge and for modifying factors; UNFC is three dimensional (***Figure 2***) with axes for geological knowledge, project feasibility, and socio-economic viability. In other words, the 'modifying factors' axis of CRIRSCO has been separated into two axes representing technical feasibility and non-technical factors.

Where the categories in the two classifications correspond, CRIRSCO resource categories are mapped to corresponding UNFC categories (i.e., there is common terminology). The CRIRSCO Template is the set of commodity-specific definitions in UNFC for all solid minerals for these categories.

On 26 April 2013, the UNECE Expert Group on Resource Classification (EGRC) reached consensus on:

- specifications for UNFC 2009. CRIRSCO and SPE (and its PRMS partners) were thanked for their ongoing support and cooperation in providing the solid minerals- and petroleum-specific specifications, respectively, for UNFC-2009;
- A Technical Advisory Group to be established (to develop governance guidelines and provide detailed technical advice);
- UNFC-2009 to be applied also to nuclear fuel and renewable energy resources.

Consensus was reached under a global mandate with broad representation from both UNECE and non-UNECE member states.

The Competent Person

What makes a CRIRSCO-aligned reporting standard much more than simply a classification is the requirement that any report be prepared and signed by a Competent Person. By signing the report, the Competent Person takes personal responsibility for its contents (whether they are employed to produce the report as an individual or as an employee of a company). This is what allows the use of a simple classification rather than a highly complex prescriptive system which would need to take account of all possible deposit types and geological settings – the Competent Person is expected to use their professional skill, judgement and experience rather than following a prescriptive set of rules.

It is the Competent Person's qualifications and, even more, their relevant experience, which give the user of a report the assurance of its veracity and reliability. CRIRSCO standards provide a simple definition of who can be accepted as a Competent Person

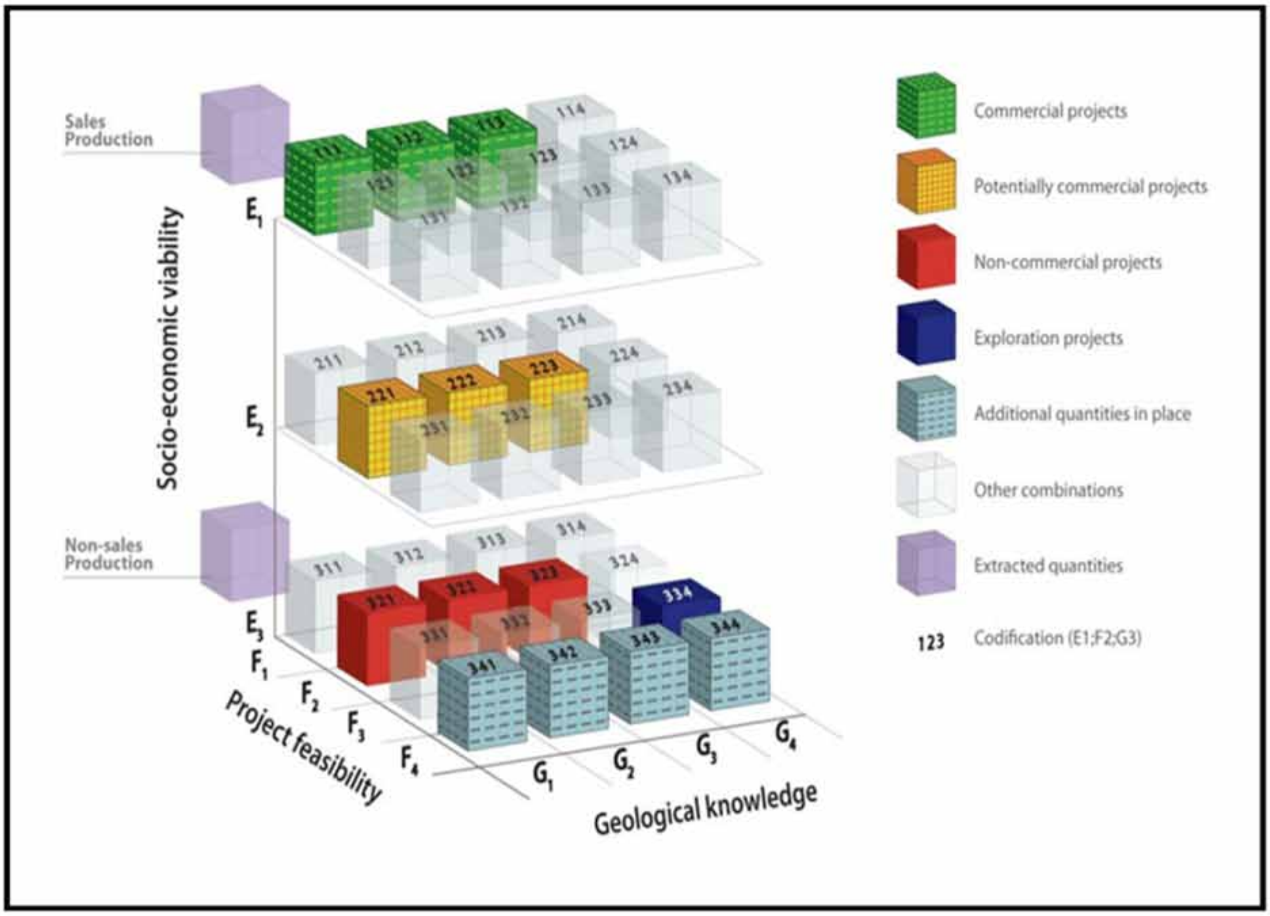

Figure 2: The United Nations Framework Classification.

– this is the definition from the PERC Standard 2013:

A Competent Person is a minerals industry professional, defined as a corporate member, registrant or licensee of a recognised professional body (including mutually recognised international professional organisations) with enforceable disciplinary processes including the powers to suspend or expel a member.

A Competent Person must have a minimum of five years relevant experience in the style of mineralisation or type of deposit under consideration and in the activity which that person is undertaking. Acceptable professional bodies and classes of membership under the Standard, which meet these requirements, within Europe or elsewhere (an 'RPO') are listed in Appendix 5 or in updated lists which may be published from time to time.

This definition of 'Competent Person' is subject to any additional restrictions or conditions which may be required by the appropriate stock exchange or regulatory authority.

Membership of the recognised professional body – a list of which is included in an Appendix to the Standard – will carry with it the requirement to have tertiary-level qualifications such as a university degree, as well as some years of experience in the minerals industry.

The associated guidelines in the Standard add some further explanation:

It is expected that the Competent Person will usually be a geoscientist for reporting Exploration Results or Mineral Resources, but for reporting Reserves may be qualified in other fields such as mining engineering or mineral processing.

The Competent Person may of course have relevant qualifications or experience in more than one field or type of work.

The key qualifier in the definition of a Competent Person is the word `relevant'. Determination of what constitutes relevant experience can be a difficult area and common sense has to be exercised. For example, in estimating Mineral Resources for vein gold mineralisation, experience in a high-nugget, vein-type mineralisation such as tin, uranium etc. will probably be relevant whereas experience in (say) massive base metal deposits may not be. As a second example, to qualify as a Competent Person in the estimation of Mineral Reserves for alluvial gold deposits, considerable (probably at least five years) experience in the evaluation and economic extraction of this type of mineralisation would be needed. This is due to the characteristics of gold in alluvial systems, the particle sizing of the host sediment, and the low grades involved. Experience with placer deposits containing minerals other than gold may not necessarily provide appropriate relevant experience. Similarly, sulphidic nickel deposits form a type of their own with nickel being distributed between silicate and sulphide minerals, only the latter being economically extractable. Experience with other types of sulphide deposits may not have given sufficient background in evaluating nickel deposits.

The definitions (in **bold** type) are identical in all CRIRSCO standards, and although the text of guidelines (in italics) can vary, all carry the same message. A CRIRSCO reporting standard requires a suitably experienced person to take personal professional responsibility for the content of any report.

Central to the accreditation process is the concept of peer review and the role of the professional organisation. The European Federation of Geologists is accepted by all of the CRIRSCO standards as a recognised professional organisation, and the European Geologist qualification establishes a person as potentially a Competent Person. To be able to act as a Competent Person in the context of a particular mineral deposit, of course they must also satisfy the second criterion, that of relevant experience. This is normally done by personal affirmation within the report, always subject to challenge, and therefore the Competent Person must be able to substantiate this experience by reference to previous projects. Breach of these conditions will always be a breach of the Code of Ethics or Code of Conduct of the Competent Person's professional organisation. Such breaches can and do lead to disciplinary action by professional organisations against any of their members who represent themselves as Competent Persons when, in fact, their experience, qualifications or the quality of their work falls short of the standards required.

Conclusions

A question that commonly arises is whether CRIRSCO or UNFC is better, and if CRIRSCO is to be used, which Standard should the user adopt?

If preparing a report for a company listed on a stock exchange, the choice is made by the stock exchange regulator: usually one of the CRIRSCO-aligned standards is mandatory. In the European Union, for example, the choice is among a specified list of all the recognised CRIRSCO-aligned standards.

In other situations, there is not a question of "competition" or "choice" between the CRIRSCO reporting standards and the UN Framework Classification. Effectively UNFC provides a big umbrella within which consistent and comparable public reporting can be carried out at a range of scales and for a range of purposes, and national mineral inventories can be developed and maintained. Its complexity can, however, be challenging. If users find it easier to follow the CRIRSCO classification, they can do so in full confidence that this is also compliant with UNFC with the 'added value' of the Competent Person concept.

Decisions on disclosure and quality assurance are independent from decisions on classification.

- CRIRSCO addresses both disclosure/QA and classification.
- UNFC-2009 requires preparers and users to agree on disclosure/QA issues.

UNFC provides a method for governments and NGOs to incorporate published industry data (using the CRIRSCO classification) into databases, mineral inventories, etc. It also provides a mechanism for companies to use a standardised internal classification beyond the publicly reported CRIRSCO categories if they wish to do so, although if they are quoted companies they are normally forbidden by stock exchange regulators to publish such internal classifications.

CRIRSCO standards require all publicly declared resources to have reasonable prospects for eventual economic extraction. Reports must not include any inventory of all mineralisation regardless of economics, or of any supposed mineralisation that is not supported by adequate geological evidence.

Short and medium term planning should use resources and reserves reported under CRIRSCO standards as a solid and reliable basis for financial modelling. Longer term planning can simply migrate to UNFC, with the inclusion of prospective estimates of mineral potential, but these cannot be reported publicly.

References

The following web sites carry further information:

PERC – *http://www.percstandard.eu*
EFG - *http://www.eurogeologists.eu*
CRIRSCO – *http://www.crirsco.com*
UNFC-2009 - *http://www.unece.org/energy/se/reserves.html*

European Minerals Day – an industry-led success story

*Amina Langedijk**

Launched in 2007, the European Minerals Day was celebrated for the fourth time in May this year. This pan-European awareness raising event, led by the mineral raw materials sectors, has proven to be a welcome communication platform for both decision-makers and a wide range of stakeholders to highlight the essential role of mineral raw materials for a sustainable and competitive Europe.

The European Minerals Day is truly unique in that it mobilises key stakeholders at all levels – EU, national and local – whereby it aims at contributing to more informed decisions and a greater public understanding and acceptance of mining operations. Through the Open Days, companies reach out to their local communities, showing good practices and raising awareness of the importance of mineral raw materials in our everyday lives, thereby aiming at facilitating stakeholder dialogue. The result is an enthusiastic and pleasantly surprised crowd. So the journey continues!

A historic overview – how it all begun

This biannual pan-European Open Day was initiated by IMA-Europe in 2006. On the one hand, it was a logical next step following its Awareness campaign "Essential, Smart and Beneficial Minerals – Your World is made of them." Industrial minerals, not being very well known by the public as they are not recognisable as such in the end-use applications, require additional communication efforts. On the other hand, joining forces with other mineral raw material sectors and stakeholders was strongly acknowledged as the way forward; the public does not make a distinction between the type of quarries in their perception of mining activities. Enhancing the image of the mining operations overall had to be the objective.

The first EMD welcomed more than 30.000 visitors at 106 plants in 17 European countries, mostly neighbouring communities eager to find out more about the world of minerals. During plant and quarry visits, the visitors learned how geology determines where the minerals are and how they can be mined most sustainably. Biodiversity was one of the key themes from the start, as quarry operations provide for unique habitats for many rare and endangered plant and animal species. Many Natura 2000 areas or nature reserves are actually former quarries. The EMD therefore presents an excellent occasion for the sector to show how mining activities can be compatible with biodiversity and how the sector contributes to the preservation of nature (see *www.mineralsday.eu* for case studies or the short film "The minerals sector - Together for a sustainable future").

From the beginning, young people have been in the spotlight, with the aim to enthuse them about a career in the minerals sector. The companies offer a wide variety of entertaining and educational activities, such as guided visits, plant tours, open days, workshops, biodiversity (school) projects,

Figure 1: Visitors discover a rich biodiversity in the rehabilitated Valleche site, a former limestone quarry in Moha (Belgium) (Picture: courtesy of Carmeuse).

Figure 2: A school class takes part in EMD 2009. (Picture: Courtesy IMI Fabi, Italy).

Figure 3: EMD 2013 at Carmeuse, Bosnia.

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Figure 4: 3D model of the Bird Island project (VCS, Beroun).

exhibitions, geology tours & events, fossil hunting, jeep safaris, and many more. The activities are designed to show how essential minerals are in our daily lives and how they are sustainably mined and processed.

Within the local communities, schools have occupied a central place; school children as well as students have been participating very enthusiastically from the start and have become one of the key target audiences. This also allows small and medium sized enterprises (SMEs) with limited means to take an active part in the EMD. The type of event is left for the companies to decide – whether it is an Open Day with hundreds of people, or a school event welcoming one or more school classes. The result is a large variety of creative events.

« The European Minerals Day is an excellent way to inform, educate and enthuse European citizens about the importance of the minerals sector in providing raw materials that are essential for so many everyday products. The sector is vital for Europe's competitiveness and its success is built on sound principles of sustainability and innovation. » (former EC Vice-President Günther Verheugen, Prague, 14 May 2009)

The European Associations partnering up in the EMD define the key themes and messages and ensure that the same messages are broadcast all over Europe by means of press releases, a PR Workshop bringing together the local & corporate organisers, etc. The EMD branding and supply of templates in addition contribute to a unique brand identity, while all events are announced (and later reported on) on a dedicated website – *www.mineralsday.eu*.

The first EMD was a great success in terms of company participation and partnership with other sectors: Euromines, EuLA (now a member of IMA-Europe), EMCEF (now IndustriAll), EFG, media partner EurActiv.com, and the national federations. In Germany, even Chancellor Angela Merkel in person lend her support to the launch of the first European Minerals Day and prepared a written opening address for the Open Day at Kreidewerk Rügen.

This industry-led initiative was immediately picked up by the European Commission, who welcomed it warmheartedly and cited it in its Communication "The Raw Materials Initiative - meeting our critical needs for growth and jobs in Europe" (COM(2008) 699 final). Since then, the EMD has been able to count on the active support of the European Commission. This led in 2009 to the organization of the first European Launch Event, attended by European Commission Vice-President Günter Verheugen. The event took place under the Czech EU Presidency in Prague and included a most interesting site visit to the limestone operations of Vapenka Certovy Schody (Lhoist Group). This was a very interesting visit from a geological point of view due to its unique location in the middle of the Czech Karst. The quarry is situated just adjacent to the famous Koneprusy caves in Beroun and a Natura 2000 area. The visitors learned about the carefully managed explosion practices, and were shown, with the help of a 3D model, the long-term restoration plan for creating a bird island. It was already possible to witness the design taking shape, although the operations will still continue for another 20 years. The aim was to raise awareness that before a mining permit is issued in Europe, the restoration plan already needs to be in place. The day ended with a highly interesting visit to the Koneprusy caves and the Geopark and Museum of the Czech Karst in Beroun. EMD 2009 welcomed the following new EMD partners: CEMBUREAU (cement) and UEPG (aggregates) as well as EuroGeoSurveys.

In 2011, the European Launch Event took place in Bulgaria, kindly hosted by Kaolin. Even though he could not attend in person, European Environment Commissioner Janez Potocnik prepared a video message on biodiversity which was broadcasted during the Opening Ceremony at the quarry site in front of more than 150 key Bulgarian stakeholders, who were proud to host the EMD Launch event.

The European Minerals Day 2013 – A new dimension

European Minerals Day 2013 was celebrated on 24-26 May 2013 at 113 sites in 24 countries, welcoming around 30,000 children and adults at more than 170 events.

At the EU level, the timing of the European Minerals Day 2013 coincided perfectly with the launch of the European Innovation Partnership Initiative and a stepped-up EU Debate on raw materials. In February, the European Commission announced to all stakeholders that the European Minerals Day would be the principal communication channel on the European Innovation Part-

Figure 5: MEP Panayotov, Mrs Benini, Member of Cabinet Tajani and Mr Reuss, IMA-Europe President, at the opening of the EMD Exhibition in the European Parliament, 7 May 2013.

Figure 6: EC Vice-President Antonio Tajani at the launch of the EMD 2013 in Vipiteno, Italy.

nership on Raw Materials (EIP RM). The EIP RM, which brings together Member States and other stakeholders, aims to make Europe a world leader in sustainable and resource-efficient exploration, extraction, processing, product use, reuse and recycling of raw materials by 2020 and beyond.

The current European Minerals Day partners strongly welcomed this decision by the European Commission and, in view of creating further synergies, decided to open the scope of the European Minerals Day to all raw materials stakeholders, including downstream industries. The EMD 2013 Partners are: IMA-Europe, CEMBUREAU, EuroGeoSurveys, EuroMetaux, Euromines, EuSalt, and the European Technology Platform for Sustainable Mineral Resources (ETP SMR). The EMD 2013 Supporters: IndustriAll and EFG – both of which have supported the EMD since 2007 –, ELO (landowners), EBCD (European Bureau for Conservation and Development), IUCN (International Union for Conservation and Nature), Cerame-Unie and UEPG.

In line with the EIP RM objectives, the European partners decided to focus in particular on innovation and resource efficiency – in addition to the recurring theme of biodiversity – and illustrate the role of mineral raw materials in products and processes throughout the whole value chain. Whilst companies demonstrated the integration of these key concepts in their mining operations, the EMD Partners at EU level organised several events in the European Parliament for the EU stakeholders in Brussels in the run up to the pan-European open days. The European Commission and five Members of European Parliament – Paul Rübig, Prof. Vladko Panayotov, Jo Leinen, Roger Helmer and Konrad Szymanski – lend their active support to the initative.

One of the key EU events consisted of a unique and tailor-made EMD exhibition, entitled "The European minerals sector – an essential, innovative industry, throughout the value chain". It told the story of sustainable mineral extraction, leading the visitor through the exploration, extraction, processing, end-use, and recycling stages, thereby incorporating all sectors and stakeholders partnering up under EMD 2013: mining, industrial minerals, salt, cement, metals, geological surveys, FP7 research projects and European technical platforms on sustainable mineral resources (see *Image library*). The exhibition was extremely well received. More than 150 stakeholders attended the Opening Ceremony and the EP exhibition reached more than 2,000 people. In addition, several parallel events on raw materials were directly linked to the EMD exhibition & EIP RM themes, among which a high level dinner on the EIP on RM hosted by Paul Rübig MEP on 13 May and an EP lunch debate by the EP Business & Raw Materials Working Group on 15 May.

« From the perspective of lead coordinator, this joint collaboration and partnership around the EMD is always very inspirational. We embark together on a shared vision, with an idea of what we wish to accomplish together, and then deliver something of value that surpasses what one person could achieve on his/her own; that is what makes this event truly unique. »

On 24 May, European Commission Vice-President Antonio Tajani officially launched the 4th European Minerals Day in Vipiteno, Italy. In the presence of Italian and international stakeholders and the media, Vice-President Tajani addressed the objectives of the European Innovation Partnership on Raw Materials as well as the vital role of raw materials for Europe, acknowledging the mineral raw materials sector as being one of the key drivers of European competitiveness: "Raw materials are the lifeblood of EU industry, with at least 30 million jobs in the EU and 70% of EU manufacturing production depending upon them."

The Vice-President participated with much interest in the visit to the modern underground mining operations and processing plant operated by Omya (a member of IMA-Europe). It represented an excellent showcase linked to the EIP RM, illustrating modern, sustainable and resource-efficient mining operations. It was however pointed out that going underground was not possible for all mining operations, as the extraction methods are greatly determined by geology, type of ore, available technology and economic factors.

In conclusion, through the partnerships and synergies created at EU, local and national level, the European mineral raw materials sector has been able to raise its visibility as a key contributor to innovation, resource efficiency and biodiversity, all of which are elements essential for meeting the EU Horizon 2020 agenda on sustainable growth.

IMA-Europe hereby wishes to thank its members, partners and supporters – among them the EFG – for their strong and continuous support to the European Minerals Day since its launch in 2007. This continuity and synergy are the real success factors of this pan-European awareness raising initiative. Together with our partners, we look forward to the next event in 2015!

The Minerals Sector – Together for a sustainable future. *www.mineralsday.eu*

Figure 7: VP Tajani visits the underground mining operations in Vipiteno (24 May 2013).

Exploratory research in mining: defining FET* research topics supporting the ICT challenges of mineral extraction under extreme geo-environmental conditions

Ben Laenen, Balazs Bodo, Günter Tiess and David Lagrou*

** FET: the Future and Emerging Technologies Programme of the European Commission*

EXTRACT-IT

SEVENTH FRAMEWORK PROGRAMME

Present day mining-ICT (information and communication technologies) research is industry-driven, focusing on the development of tools that increase the autonomy of extraction and ore processing (such as driverless haul trucks, automated loading systems, remote control systems for ore processing), facilitate rapid data evaluation in remote control rooms, and allow a better understanding of ore bodies. These research efforts will push the technological and economic feasibility of mineral extraction to greater depths, but they still lack the "paradigm change" that will be required if the truly extreme geo-environmental conditions are to be mastered by technology. Achieving such paradigm change will require the development of novel high-risk, exploratory research areas in mining.

EXTRACT-IT (Project Number: 318149) was supported by the FP7 FET ICT Programme[1], which is the European Commission's *"pathfinder for new ideas and themes for long-term research in the area of information and communication technologies"*. The overall objective of the project was to define, develop and describe several Call Topics that could support exploratory mining-ICT, opening up new, multidisciplinary areas for longer-term research. The project objective was achieved with the help of a foresight exercise that included surveys and a series of complementary workshops. EXTRACT-IT eventually defined nine Call Topics corresponding to three Thematic Areas. An additional two "cross-cutting" Call Topics have also been defined with the objective of keeping this initiative alive through future Coordination Action type projects.

Thematic Area I – "Evolution Underground" (3 Calls)

Underground and burrowing animals demonstrate overwhelming superiority when compared to present-day underground mining equipment. They have evolved to feed, reproduce, form colonies and to manipulate the underground environment according to their needs. Their relative strength may exceed a hundred times the performance of the most powerful mining machinery, whilst they are energy efficient, self-organizing and able to navigate perfectly in subsoil environments. The objective of this Call is to map the underground animal kingdom (arthropods, worms, but also vertebrates) and develop dramatically new concepts for bio-inspired underground mining systems (including drilling, navigation, feeding, communication, actuation and collective behavior) drawing inspiration from underground biology.

Thematic Area II – "Resilient Artificial Ecosystems" (3 Calls)

Latest developments in artificial collective systems point towards increasing the total heterogeneity, using functionally and structurally different robots, involving bio-/chemo-hybrid elements by combining chemistry, biology and mechatronics. Such diverse artificial systems will create artificial ecologies, where different types of artifacts and computational networks will collaborate, evolve and impact each other in achieving their goals, e.g. mining, exploration and maintenance. Future robotics underground will require the development of new paradigms for lifetime learning and physical adaptation to changeable and unexpected working conditions: they must be able to respond to individual failures and remain operational in environments where human supervision is impossible. These units must be capable of operating under sub-optimal conditions (while par-

1 http://cordis.europa.eu/fp7/ict/programme/fet_en.html

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tially damaged) and capable of learning how to keep operating without using the damaged systems. A further aim is to investigate and demonstrate how heavy-duty mining machinery can be designed to be "machine-repairable" from the very beginning and how to develop the corresponding systems to perform these repairs automatically.

Thematic Area III – "Broadband through the Rock" (3 Calls)

Next generation communication solutions will need to be developed for the "sense, communicate and control" smart mining paradigm. The challenges are: provide full coverage, connectivity of sensors with different bandwidth requirements, resilience, re-configurability, self-organization, self-healing and easy deployment in a harsh environment. Research is required at the basic-science level for the development of radically new ways of communication technologies that exploit radio, seismic/vibrational, acoustic signals and high energy particles for communication, directly through heterogeneous non-uniform materials and rock substrates. The network concepts should also make efficient use of the mine characteristics: completely new modes of radio propagation, waveguide propagation through tunnels, exploitation of the metallic infrastructure (such as wiring and pipes) and the ore body itself. Research should address the use of multiple parallel solutions for achieving high aggregate transmission rates for in-mine broadband.

The 11 Call Topics that were defined for the above Themes could support the development of completely new research avenues for mining-ICT, starting from the level of basic/exploratory sciences that could mature into technological solutions via applied research and demonstration by 2050. For more detailed information and project reports kindly refer to the project website at *www.extract-it.eu*.

The EXTRACT-IT Partnership:

- VITO, Flemish Institute for Technological Research, Belgium
- Centro Futuro, La Palma Research Centre for Future Studies, Spain
- MinPol, Agency for International Minerals Policy, Austria

Book review:

Minerales en la vida cotidiana

*Isabel Manuela Fernández Fuentes**

Minerales en la vida cotidiana (Minerals in daily life)
by Manuel Regueiro

Published by: Instituto Geológico y Minero de España and Catarata, 2013 and Catarata 2013 (www.catarata.2013), Colección Planeta Tierra
Year of publication: 2013
ISBN: (IGME) 978-84-7840-895-5
(Catarata) 978-84-8319-795-0
How to order: http://libros.igme.es/product_info.php?cPath=30&products_id=85 or http://www.catarata.org/libro/mostrar/id/827
Price: 14€

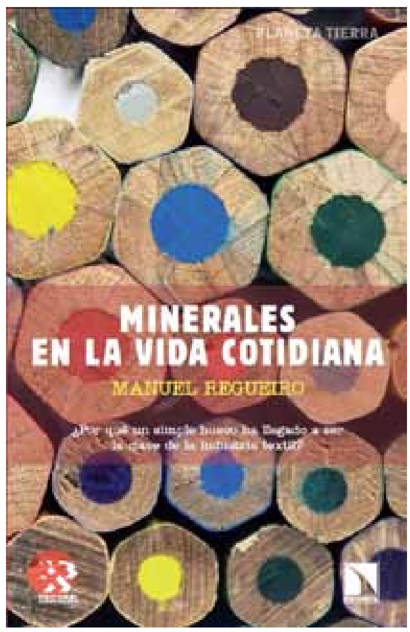
This book is an excellent example of dissemination of Earth Sciences at the Society's service. The book is part of the series 'Planet Earth', published jointly with the Geological Survey of Spain (IGME) and addressed to non-specialist readers interested in learning about Geosciences.

The book analyses thoroughly and in an informative way the use of minerals in daily life. The author presents the classification of mineral resources, historical uses, and the impact of minerals today. Concepts like "critical minerals" and "strategic minerals" are analysed in a reader-friendly way and depict the impact they can have on our economy and in policy making.

The readers thereby assimilate and understand the value of minerals in all products that surround us, and therefore, the impact of mineral resources on the present and future of industry and the economy. Technical information is mixed with more enjoyable information such as the arcanes myteries of porcelain or the high impact of some minerals (rare earth) on today's telecommunications industry.

The book focuses on minerals, their use, where we can find them and existing resources. However, each chapter enters many subtopics that keep the reader's attention. Thus, for example the reader performs a walk through the history of glass, ceramics, or paper, their mineral content and their applications in our environment. The importance of minerals in food and their influence on health is also presented in an entertaining way, evoking the presence of minerals in traditional poisons or illnesses related to their use.

Finding a balance between supplying the raw materials industry, remaining competitive, and doing so in a sustainable manner and with respect for the environment is a challenge for the future. This book provides an introduction to the world of minerals that can be useful for the dialogue with society and policy makers.



Manuel Regueiro graduated in Geological Sciences from the Universidad Complutense de Madrid (UCM), and has worked for many years as a specialist in industrial rocks and minerals, Area Industrial Rocks and Minerals, Geological Survey of Spain (IGME). Today he is Head of the External Relations and Transfer of IGME, and Associate Professor, Department of Crystallography and Mineralogy of UCM.

News corner:
*Compiled by Isabel Fernández Fuentes and Anita Stein**

Hydrogeology Workshop - European water policy: challenges for Hydrogeologists

Date: 22-23 November 2013
Venue: Royal Belgian Institute of Natural Sciences, Rue Vautier 29, B-1000 Brussels
Organiser: EFG Panel of Experts on Hydrogeology
Supporting organisations: International Association of Hydrogeologists (IAH), The European Water Platform (WssTP), EuroGeoSurveys and the Belgian Geological Survey

This workshop highlighted those areas where hydrogeologists are playing an important role in the implementation of the Water Framework Directive and the new business opportunities now opening to firms in hydrogeology with the publication of the Blueprint. The Workshop also provided a unique opportunity to obtain an official acknowledgement of this role by the European Commission.

The publication of the EU Commission's Blueprint to Safeguard Europe's Water Resources policy document introduces a new strategy to reinforce water management within the EU. The "Blueprint" outlines actions that concentrate on better implementation of current water legislation, integration of water policy objectives into other policies, and filling the gaps in particular as regards water quantity and efficiency. The objective is to ensure that a sufficient quantity of good quality water is available for people's needs, the economy and the environment throughout the EU. As with surface waters, groundwater has to be evaluated, monitored and protected to meet human needs and also environmental requirements. Hydrogeology has a crucial role in this process, because groundwater is the "hidden" component of the water cycle, and is not easy to analyse.

An in-depth and first-hand knowledge of this new European policy is essential for firms and professionals in Hydrogeology. Hydrogeologists must be involved in this process, offering their irreplaceable knowledge and ability in several topics of great importance, such as the identification of groundwater flow to wetlands, the reduction of over-abstraction, the calculation of water accounts in river basins, the effect of climate changes, and others. The hydrogeological community, adopting a modern multidisciplinary approach, has the capacity to investigate and develop innovative solutions to these issues and challenges.

The conference was divided into 4 sections: Land use and ecological status; Chemical status and pollution; Water efficiency; Vulnerability. The workshop finished with a Final Declaration prepared by the EFG Panel of Experts on Hydrogeology.

EFG survey on users' needs on geological data

In summer 2013 EFG contributed to the European Geological Data Infrastructure Scope project (EGDIScope; *http://www.egdi-scope.eu/*) through the establishment of a questionnaire addressed to all European Geologist title holders. The aim of this questionnaire was to better understand the needs of geologists who look for geological data.

The importance of the availability of digital geological data has been recognised at the European level. This data can help to address challenges such as the mitigation of natural hazards, the supply of water, sustainable energy and (rare) mineral resources or the safe storage of substances such as radioactive waste or other contaminants.

The EGDI-Scope project therefore responds to a call issued by the European Institutions for the development of a common European geological knowledge base.

The EGDI-Scope project will deliver an implementation plan to build a pan-European Geological Data Infrastructure. This infrastructure will enable European geological surveys to serve and maintain INSPIRE-compliant, interoperable geological data and information. The project is coordinated by the Geological Survey of the Netherlands.

Following a first survey issued by EGDI in spring 2013, EFG launched a new survey in July and August 2013 with the aim of validating the results of the previous one. However, the new survey was addressed to a specific target group, European Geologist title holders. This group includes experienced geologists working in several countries both in and outside Europe, mostly specialised in the engineering and mining sectors. From the total number of nearly 800 active European Geologists, 105 completed the survey. The survey revealed that 96% of the respondents have already looked for geological data on the web and 85% of them do so at least once per month. Geologists mainly consult data such as articles and maps (in pdf or excel format) while preparing reports. Furthermore, the survey also reveals that the use of geoportals is not very common for the research of geological data, with the exception of onegeology (fewer than 10% of the participants use it frequently). Geologists mostly consult data on the websites of Geological Surveys or through Google.

The results of the survey show that the simplicity of the search engine and the possibility of downloading files are success factors that explains the use of Google and the demand for pdf or excel formats. Considering that people look for data at the websites of national geological surveys, it can be expected that a user-friendly pan-European Portal will be a sucessful initiative.

* EFG Office, info.efg@eurogeologists.eu

PERC

This has been a very active period for the Pan-European Reserves & Resources Reporting Committee, PERC, including participation in several EU projects. Particularly notable is that presentations on PERC, CRIRSCO, and UNFC were given by Eddie Bailey and Steve Henley at the inaugural meeting of the Minventory project, whose purpose is to develop a database of European solid mineral resources, where the use of PERC and related standards is vital to the integrity of the data. PERC is also represented in the Extract-IT project and in the European Innovation Partnership on Raw Materials.

We sadly report the death of Dan Germiquet in the Paris train crash in July. He was a long-standing and active member of the committee, and was to have taken responsibility for developing PERC's training programme. His place as EFG representative on PERC is to be taken by Pim Demecheleer of Sibelco. Newly co-opted member Ed Sides of the consultancy firm AMEC will lead our training activities. In July, Steve Henley led a 'masterclass' on minerals reporting for a group of Russians visiting IOM3 in London. Such masterclasses can be made available more generally, but are no substitute for the full training courses that are to be developed.

New participants in PERC will be the Council of Mining Engineers Associations of Spain, to be recognised as an organisation which can award appropriate professional qualifications (EurIng) through its membership of FEANI. They will then join the Spanish geologists who are already recognised through their participation in EFG (EurGeol members of EFG's Spanish member association, ICOG).

New website of the IUGS Task Group on Global Geoscience Professionalism

The Task Group on Global Geoscience Professionalsim (TGGGP) was formed in 2012 with the purpose of ensuring that geoscientists, active in all areas of geoscience, are fully engaged in the transformation of their profession – a profession that is increasingly relied upon by the public to provide expert opinions and service, and to safeguard the public interest. The European Federation of Geologists is one of the sponsoring organizations of this Task Group and backs its activities through administrative support.

One of the first actions of the Task Group was to establish a website communicating its objectives and activities. This new site is now available online at *http://tg-ggp.org/*.

The new website will provide information on professionalism in geoscience, and the activities of the TGGGP, to the global geoscience community including:

- Applied geoscience professionals
- Learned geoscience societies
- Geoscience researchers
- Geoscience educators
- Early-stage geoscience graduates
- Geoscience students and those considering geoscience studies
- Governments
- NGOs
- Academic institutions, and
- Members of the public interested in Earth Science.

The information on this site will benefit society and the global geoscience community by acting as a forum for collaboration on matters of professionalism in geoscience on a local, national, and international level, by facilitating:

- Rapid conversion of research findings to applied geoscience technologies and methodologies;
- Greater relevancy in applied geoscience at the university level;
- Increased education in professional skills at the university level;
- Research project design and fund allocation through greater appreciation of societal needs;
- Clear pathways and assessment criteria for geoscience graduates seeking to attain professional qualifications; and
- A greater understanding of geoscience professionalism by employers, governments, NGOs, academic institutions, and the general public.

GEOTRAINET events

GEOTRAINET is now established as an association which will:

- deliver training and certification programmes recognised all over Europe in the field of shallow geothermal energy,
- provide benchmark standards for consistent voluntary further education in participating countries.

The training programme is aimed at GSHP installers and designers and will provide the market with trained experts in the field of shallow geothermal technology who can both design install and commission efficient systems.

With the launch of the new organisation, two events were organised in November 2013 with the aim of improving the knowledge of planning for and national developments in shallow geothermal in Europe and helping to keep stakeholders informed about the future of Shallow Geothermal Training in Europe.

Planning and good practice, 14 November 2013: During this event the benefits of shallow geothermal energy in the light of the European sustainable energy framework were reviewed and practice examples discussed.

Update Training for trainers, 15 November 2013: This course was aimed at those who had received training during the preceding GEOTRAINET project, in order to update their knowledge and skills. It could also serve as an introduction to those new to GEOTRAINET who are interested in pursuing further training activities in their home country.

Audience:

- GEOTRAINET National Coordinators,
- GEOTRAINET Trainers or those interested in becoming one,
- Local and Regional planners in charge of the certification of geothermal installers (implementation of the RES Directive).

More information: *www.geotrainet.eu*.

EAGE/EFG Photo Contest 2013

In 2013, the European Association of Geoscientists and Engineers (EAGE) and the European Federation of Geologists (EFG) are for the first time jointly organising a photo contest. The theme of this year's contest is ***'Geoscientists at work'***. All EAGE and EFG members were invited to submit photos that portray some aspects of the theme by, for example, depicting geological features of the earth relevant to geoscientific work, geoscientific activities (such as field geophysics, mapping or modelling) or the geoscientist's roles in particular sectors (such as oil and gas, natural hazards, water resources, construction or mining and minerals). After an impressive amount of entries, the selection of a professional jury and the voting of EAGE and EFG members, the 12 best photos were announced in May 2013. These 12 photographs were exhibited during the 76th EAGE Conference & Exhibition in London (10-13 June) and are currently displayed at the Belgian Museum of Natural Sciences in the context of the EFG Hydrogeology Workshop (22-23 November 2013, Brussels) and Council Meeting (23-24 November 2013, Brussels). The winning photographers will furthermore receive an EAGE/EFG calendar for 2014 that includes their own photos.

From June to August 2013 EAGE and EFG members had the chance to cast their votes for their favourite pictures both during the exhibitions and online. The contributors of the most popular photographs receive the following prizes:

- First prize: an iPad
- Second prize: 'Untouched Nature' (book) + EAGE bookshop voucher worth EUR 100,-
- Third prize: 'Untouched Nature' (book) + EAGE bookshop voucher worth EUR 50,-
- Top 12: custom-made 2014 calendar with the photographs included

The book 'Untouched Nature' is kindly sponsored by eoVision.

More information:
www.houseofgeosciences.org.

1st prize: Bart Zwemmer, EAGE, View from the Rotary Table.

2nd prize: Daniele Andronico, Consiglio Nazionale dei Geologi/EFG, Volcanic eruption observsation.

3rd prize: Michiel van der Meulen, KNGMG/EFG, Realmonte salt mine.

Submission of articles to European Geologist magazine

Notes for contributors

The Editorial Board of the European Geologist magazine 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 magazine publishes feature articles covering all branches of geosciences. EGM 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 magazine 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) 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 summarize 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 ame followed by 'et al.' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions
- Figure captions should be sent in a separate doc or docx file.

References
- 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.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- 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.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
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E-mail: *info.efg@eurogeologists.eu*

Note

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