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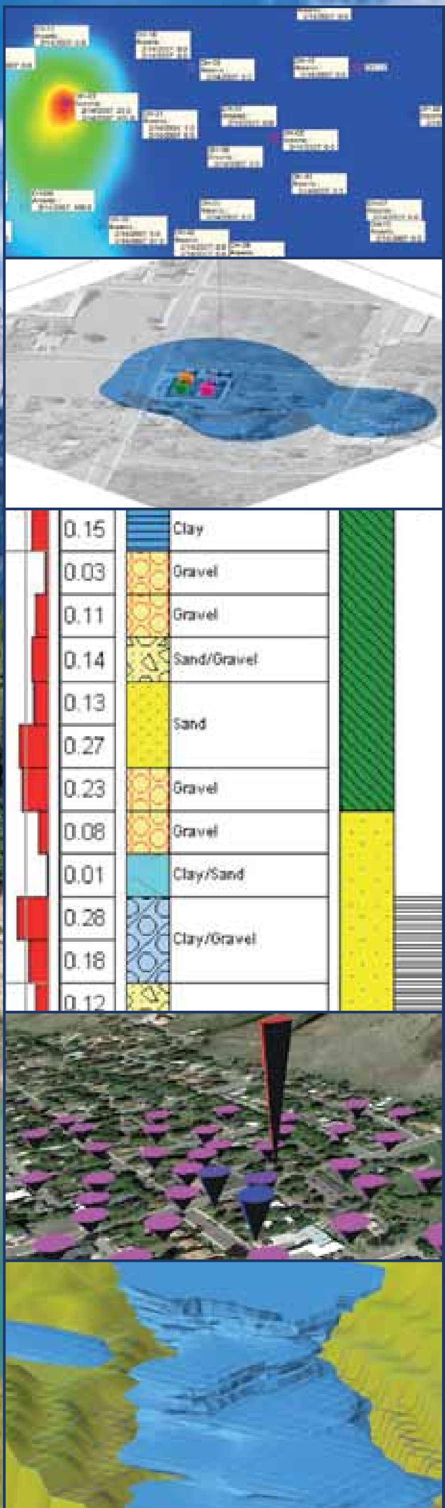
Metallic mineral resources - Meeting future demand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Peer reviewers:
We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist magazine. The content of this issue has been reviewed by E. Pirard, J. Földessy, K. Hanghoj, G. O'Donovan, F. Tornos, J. Valente, F. Viljoen, F.-W. Wellmer.

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© Bernd Lehmann. Ok Tedi mine in Papua New Guinea. 2011.

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Foreword

EurGeol. Vítor Correia, EFG President

This edition of European Geologist is dedicated to metallic mineral resources, to complement the previous issue, which focused on industrial minerals and construction materials. The majority of the articles now published describe metallic ore deposits in Europe, and this is an interesting consequence of shifting political attitudes that, until recently, were against mining.

The opposition to mining and the disinvestment in European mines arose after the 1970s, induced by growing environmental standards and the transfer of mining activities to third world countries. This situation had advantages to all parties involved: the European industry bought raw materials at lower prices; the third world countries obtained an opportunity to develop their economies; and the European politicians took credit for domestic environmental achievements.

The change started after China joined the World Trade Organization in 2001. In a couple of years China became the tool shop of the world, producing all kinds of domestic and industrial appliances. Attracted by low labour costs and higher productivity, many global brands transferred their sourcing to China, leveraging the country's know how and capabilities. In just 6 years China became an industrial giant, capable of producing high quality products, ranging from iPhones to nuclear submarines. As a consequence of China's huge growth, its domestic income was multiplied, boosting the Chinese internal market.

Suddenly China was the world's biggest importer of raw materials, competing with Europe, Japan and the USA. The history of iron ore (the most important commodity after oil) pricing illustrates this impact. After the 70s the iron price was dominated by Europe and Japan, and prices had been stable for decades at around 20USD/tonne. In 2003 China slipped past Japan to become the world's biggest importer of iron ore, and the pressure for increasing the prices started. By 2008, Chinese iron ore imports accounted for 60% of total world imports, and the pricing system that had developed between European and Japanese steelmakers and the biggest three miners (Rio Tinto, BHP Billiton and Vale) broke down. The iron ore prices exceed the 50-dollar barrier in 2008 and reached 190USD/tonne in February 2011. Iron ore prices have recovered a bit since, settling at around 100USD/tonne.

The increasing global competition for raw materials (Russia, India, Brazil, Turkey and Mexico are also new players) left Europe in a vulnerable position. As mentioned in the 2010 European Commission report of the Ad-hoc Working Group on defining critical raw materials[1] : "Europe is highly dependent on imports for many raw materials which are increasingly affected by growing demand pressure from emerging economies and by an increasing number of national policy measures that disrupt the normal operation of global markets. Moreover, the production of many materials is concentrated in a small number of countries, e.g. more than 90% of rare earths and antimony, and more than 75% of germanium and tungsten are produced in China, or 90% of niobium in Brazil and 77% of platinum in South-Africa. In addition, high tech metals are often by-products of mining and processing major industrial metals, such as copper, zinc and aluminium, which means that their availability is largely determined by the availability of the main product."

This explains why there is currently an unprecedented interest in raw materials at the highest political levels within the EU[2] . Europe is very far from self-sufficient in the supply of metallic minerals, and, although recycling rates and efficiency are growing, and substitution technologies are being fostered, the percentage of the EU's self-sufficiency concerning the supply of metallic raw materials ranges (depending on the mineral/metal), between 0% and 5%.

This is good news for geoscientists. Contrary to the views of some, Europe has valuable ore deposits and much under-explored and unexplored geological potential. But we also have a strong competition for different land uses and environmentally and socially high standards to meet. The challenge ahead will be to combine advances in exploration, sustainable exploitation and public involvement, much provided by, and all with significant involvement of a skilled geoscience workforce.

This is Anthropocene.

1 *http://ec.europa.eu/enterprise/policies/rawmaterials/documents/index_en.htm*.

2 The growing EU political support to the mining activity is expressed by recent initiatives such as the European Innovation Partnership on Raw Materials or the Horizon 2020 specific Societal Challenge "Ensuring the sustainable supply of non-energy and non-agricultural raw materials".

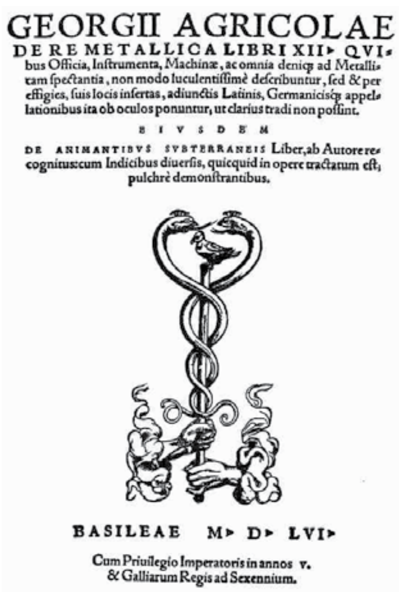
Introduction by the EFG Panel of Experts on resources and reserves - Minerals and their sustainable use

The 23rd century paradigm for minerals in Europe – Is *De re metallica* still up to date?

*Carlos Almeida**

Is Georgius Agricola's book still up to date in the European Metallic Mineral Resources scenario? According to its Wikipedia article, *De re metallica* – On the Nature of Metals, in Latin – was an extremely influential book on mining that was considered the authoritative text in Europe for 180 years after its publication. Georg Bauer, better known under his Latinized name Georgius Agricola, worked in Joachimsthal and later in Chemnitz. His treatise on the state of the art of mining, refining, and smelting metals in the German mining industry was published in 1556, a year after his death.

The papers in this issue of European Geologist Magazine emphasise the occurrence of metallic mineral resources in different types of ore deposits and focus on the sustainability and security of their supply to the geometallurgy industry. They also provide us with a global perspective on the need for critical minerals for globalised economic geology, including rare earth deposits, tungsten deposits and base and precious metals deposits in different countries in Europe. This issue also includes references to environmental and energetic issues regarding the demand for these mineral resources with the inevitable need of the standardisation of reporting for the markets of public mineral exploration companies in Europe.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Cum Priuilegio Imperatoris in annos v. & Galliarum Regis ad Sexennium.

* MSc. EurGeol C.Sci. ProfGradIMMM, Exploration Geologist - AM Almada Mining SA, Coordinator EFG PE on Minerals, PERC Secretary, CRIRSCO member

The paper by **Bloodworth and Gunn** refers to *issues related to metal supply security and sustainability*. They state that mine production of many metals has grown by one, two or three orders of magnitude since the beginning of the 20th century in response to the growing global population wishing to live a Western 'middle class' lifestyle. They also emphasise that along with volume, the variety of metals we utilise has expanded considerably in response to accelerating technological change. As a result, historic fears regarding metal scarcity and resource depletion have been reawakened Western industrialised economies in the last ten years. They conclude that this paper argues for a holistic, 'whole systems' approach to the management of both primary (earth) and secondary (recycled) metal resources.

Lehmann presents a paper concerning the *economic geology of rare-earth deposits with a global perspective*. The main focus of the article is on Rare Earth Elements (REE) and he refers to the REE market as currently still dominated by China, which has a share in global REE mine production of about 90 %. He says that this percentage will decrease over the coming years with important mine developments in the USA and Australia. He also refers to the fact that the decision taken by the Chinese government in 2011 to impose export quota for REEs has made the public and policymakers aware that some key industries in the western world are critically dependent on a safe supply of these "modern" metals. Lehmann provides us with information in his paper of the relationship of economic viability of REE deposits with the comparison of two of the largest deposits in the world, with the focus on their ratio of grade and tonnage and future feasibility.

A very specific approach is presented by **Lund and Lamberg** in a paper focussed on *geometallurgy as a tool for better resource efficiency*. Higher environmental and socio-economic demands in the exploitation of the future mineral resources require comprehensive knowledge on orebody type even in early stages. They explain that geometallurgy combines geological and mineral processing information to create a spatial model for production planning and management. Applying a geometallurgical concept can improve the resource efficiency, reduce the operational risks and help in optimising the production in a way that also considers sustainability and socio-economic factors. In conclusion, they state that with a geometallurgical model it is possible to run different production scenario starting even from an early exploration stage up to the feasibility and production stages. The model can be built using a couple of alternative ways but the mineralogical approach is generic and can be adapted to any kind of mineral resources. Their paper describes how the geometallurgical concept has been used in the mining industry and demonstrates its benefits in terms of improved resource efficiency in different ore deposits.

The paper presented by **Faria** concerns another kind of critical mineral commodity for the EU related with *Skarn-type tungsten deposits*. The area that is referred to by the author is the Tabuaço area in northern Portugal, which is host to important skarn-type tungsten (scheelite) deposits, which bear the potential to become one of the most important European producers of tungsten

– a critical raw material for the EU. Faria makes a description of these deposits with regards to their history, geologic setting, local geology and mineralisation, exploration and evaluation work.

The paper presented by **Földessy and Hartai** is entitled *"Exploration adventures in the Recsk Ore Complex"*. They focus their article on a large base metal and precious metal ore zone in the centre of Europe that has been awaiting development and commissioning for more than forty years – this is the Recsk Ore Complex in northeast Hungary. They explain the complexity of the complex and explain that it involves skarn, porphyry Cu, high sulfidation and low sulfidation epithermal mineralisations. They tell us that the Hungarian government plans to open it again, and following a significant face-lift a revised geological model and resource assessment has been inserted in the data package for the investors.

The paper presented by **Vidal**, entitled *"The need of mineral resources for low-carbon energy production"*, is directly related to the environmental sustainability issue of modern times. The author explains that fossil fuels have been at the origin of the industrial revolution, which brought major benefits to humanity but has also caused pollution and environmental damage. The author also focuses on the fact that the mineral supply to most developed nations comes mainly from foreign sources. European industries consume more than 20 % of the metals that are mined globally, yet European mines produce only 1.5 % of global iron and aluminium, and 6 % of global copper production. This situation is highly unsatisfactory for security, economic and ethical reasons, and makes European industry vulnerable to short or long-term supply restrictions. The author emphasises that green technologies should incorporate domestic mining, which reduces the financial and environmental costs of transporting metals from far-flung sources and decreases the carbon footprint, whilst providing jobs and wealth to the local community. In conclusion the paper states that currently, much of the pollution associated with mining is out-sourced to regions where the environmental impact is often uncontrolled. In Europe, things can be done better.

The paper presented by **Nurmi and Molnár** has to do with the *challenges and opportunities for future mining of metallic mineral resources in Europe*. The authors refer to several topics in the paper regarding this issue, as follows: the global importance of metallic resources and the European challenges; where metallic resources can be found in Europe; and challenges for future mining in Europe. They give information on one response to the challenges for mining in Europe through the "Green Mining" concept of Finland.

Goossens presents a paper focussing on the *zinc potential in Eastern Belgium*. The author tells us that Eastern Belgium has been known for its lead and zinc deposits for centuries, and that in the early 19th century, Belgium became one of the leading countries for zinc metallurgy. The Belgium ore deposits are contained in Paleozoic limestone and shales (Namurian, Visean and Tournaisian sedimentary sequences). It is highlighted that the new exploration programs in the Bleiberg concession in the 1980s have defined the following drill-indicated resources: 1.7 Mt of ore containing 11 % Zn, 2 % Pb and 30 g/t Ag, open laterally and at depth. The mineralised intersections are at least 7 m wide and the mineralized structure extends for 5 km. Only 1 km has been drilled and in the Vieille Montagne concession other rich zinc mineralisation has been intersected.

The paper that **Jelenkovic** presents gives information on the *metallic resources of Serbia*. The author focuses on five pillar points regarding this issue: 1 – Mineral resources which are in exploitation and are already provided with processing capacities (Cu, Pb-Zn); 2 – Mineral resources with identified, economically interesting, predominantly small reserves which are not in exploitation, and mineral resources occurring in small quantities, sufficient for brief periods of production and the supply of domestic requirements (Sn, Mn, U, Mo and Ti); 3 – Potentially significant resources with partly defined reserves, the valorisation of which depends on technical and economic parameters, as well as the partly explored mineral resources with favourable prospects for reserve increase (Ni, Co, Sb, Al, mixed Fe ores, Au and Ag); 4 – Mineral resources likely to be found in the territory of Serbia (Au, Ag and rare elements) and 5 – Mostly exhausted or non-economic mineral resources (Cr, Fe and W.). In conclusion their metalogenetic position, basic geological characteristic and mineral potential are described in this paper.

The paper presented by **Allington** is entitled *"CRIRSCO modifying factors - a guide for exploration and resource geologists"*. The author focuses on a critical issue concerning mineral reporting under the CRIRSCO standards for reporting resources. Allington clarifies that working with the modifying factors to establish technical feasibility, minimise environmental impact and ensure economic viability is often considered to be a distinct stage in the evaluation of a deposit and planning of a mine or quarry, completely separate from the exploration and modelling of the deposit itself. She also states that these activities typically involve many professionals, including engineering, production, processing, environmental assessment and operations, legal and financial specialists. She explains that there may be one Competent Person taking overall responsibility for co-ordinating the team and bringing together the reporting or there may be several, each taking responsibility for their own discipline area.

Anticipating which of the modifying factors will be important in eventually proving reserves can save time and money (e.g. by undertaking non-geological data collection and establishment of long-term monitoring when exploration and other geological field work is underway). In conclusion it is said that this approach is also conducive to supporting public participation and achieving a social licence to operate.

Corollary

Europe is making a huge effort to be reborn as a potential federation regarding mineral resources. The Raw Materials Initiative and the ERA-MIN Platform are a very good example of the joint work done by several European countries regarding the mineral resources issue. All the projects and initiatives regarding these topics will have success – in my opinion – if the politicians join efforts with the technical people in order to establish practical and usable legislation for companies to work inside Europe. It's very important that the European standard for mineral reporting (the PERC standard) is adopted in a practical way by ESMA (the European Securities and Markets Authority) and recommended for the principal Stock Exchange from several different countries to qualify mineral resources reporting, similar to what happens in Canada, the USA, South Africa, Australia, etc.

Another thing is the capability to reinvent the exploration and mining techniques for European internal resources needed not just for the present, but for the 23rd century. We really need to take strong steps in order to potentiate projects like Onegeology and support organisations like EuroGeoSource. Let's put our hands to work and apply the state-of-the-art knowledge provided by our outstanding universities to create a keep it-simple line of work in order to obtain our own European metallic mineral resources, thus avoiding the dependency on other continents. And let's do that of course respecting the rules of a free globalised market. So in the bottom line: is Georgius Agricola's book *De re metallica* still up to date?

Zinc Potential in Eastern Belgium

*Pierre J. Goossens**

Eastern Belgium has been known for its lead and zinc deposits for centuries. In the early 19th century, Belgium became one of the leading countries in zinc metallurgy, with ore deposits contained in Palaeozoic limestone and shale (Namurian, Visean and Tournaisian sedimentary sequences). We believe that the region still hosts substantial zinc reserves that should be exploited. Exploration programmes in the Bleiberg concession in the 1980s defined drill-indicated resources of 1.7 Mt of ore containing 11% Zn, 2% Pb and 30 g/t Ag, open laterally and at depth. The mineralised intersections reach a width of at least 7 m. The mineralised structure extends for 5 km and only 1 km has been drilled. Other rich zinc mineralisations have been intersected in the Vieille Montagne concession.

Dans l'Est de la Belgique, des gisements de zinc et plomb sont connus depuis plusieurs siècles. Au 19ème siècle, la Belgique est un des pays les plus avancés dans la métallurgie du zinc. Les gisements se trouvent dans les calcaires et shale paléozoïques (Namurien, Viséen et Tournaisien). Nous pensons que la région contient encore des ressources importantes qui pourraient être exploitées. Dans les années quatre-vingt, un programme d'exploration dans la concession de Bleiberg a permis de définir une ressource de l'ordre de 1,7 Mt contenant 11% Zn, 2% Pb et 30g/t Ag. La minéralisation pourrait se prolonger en profondeur et de part et d'autre de la structure. Les intersections minéralisées ont au moins de 7 m d'épaisseur. La structure minéralisée s'étend sur 5 km et seulement 1 km a été sondé. Dans la concession de la Vieille Montagne, d'autres riches minéralisations en métaux de base ont été reconnues.

El este de Bélgica es conocido por sus depósitos de plomo y zinc desde hace siglos. A principios del siglo19, Bélgica se convirtió en uno de los países líderes en la metalurgia de cinc, con depósitos de minerales alojados en caliza y pizarra del Palezoico (secuencias sedimentarias Namurian, Viséano y Tournaisiano). Creemos que la región sigue albergando reservas de zinc sustanciales que deben ser explotadas. Los programas de exploración en la concesión Bleiberg en la década de los años ochenta han definido recursos de perforación indicada de 1,7 Mt de mineral que contienen 11% de Zn, 2% de Pb y 30 g / t de Ag, abierto lateralmente y en profundidad. Las intersecciones mineralizadas alcanzan una potencia de al menos 7 m. La estructura mineralizada se extiende durante 5 km y sólo 1 km se ha perforado. Otras mineralizaciones ricas en zinc se han intersectadoen la concesión Vieille Montagne.

For centuries, galena was mined for production of ceruse and minium pigments. According to Prof. Eric Pirard (written communication), galena was already mined by the Romans (for sanitary use). Nice Roman lead ingots can be seen at the Museum of Tongeren. Calamine was largely used as an additive in copper metallurgy to get a more yellow alloy (brass, aurichalcum). After the discovery in the early 19th century of an industrial method to transform zinc oxides into zinc metal, Belgium became a leader in the production of zinc from surficial oxide minerals, mostly "calamine". During the period running from 1837 to 1936, mines in Belgium produced a total of 692,987 tons of zinc from 2 Mt of calamine (35% Zn) and 382,247 tons of zinc from 0,8 Mt of sphalerite (47% Zn) or a total of over 1 Mt of zinc metal and 250,000 t of lead metal (Dejonghe *et al.* 1993).

Ore types

Ore deposits are contained in Palaeozoic limestone and shales (Namurian, Visean and Tournaisian sedimentary sequences). The orebodies range from massive to veins, stockwerks and lenses at the Palaeozoic and Mesozoic unconformity. See ***Figures 1 and 2, Table 1***.

Massive ores are almost exclusively composed of oxides. They occur at the lithostratigraphic and tectonic contacts and are characterised by the existence of sulfides veins underneath. For example the famous La Calamine (Kelmis) massive deposit, which has produced 665,000 tons of zinc metal, is located at the contact between the Tournaisian and the Famenian, while the Schimper massive ore near Bleiberg (past production: 55,000 tons of zinc metal) is at the contact of the Namurian and the Visean.

Vein-type ore is mostly composed of Zn- and Pb-sulfides only. The Bleiberg veins – feeders for the Schimper massive oxide ore – occur within the Namurian and the Visean. The Lontzen vein is situated within the Famennian.

Stockwerk-type ore is encountered at Bleiberg.

Lens-shaped orebodies are characterised by the absence of feeder veins and are found at several localities.

Figure 1: The Zn-Pb metallic province in Belgium.

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Concessions

Two concessions have recently been explored: Bleiberg and Vieille Montagne (***Figure 3***). They are contiguous and together cover about 100 km². Both concessions were relinquished in 2005 by their holders (Umicore of Belgium for Vieille Montagne, and BRGM of France for Bleiberg). The licences have reverted to the Walloon regional government authorities ("Région Wallonne"), but, as of today, nine years later, the department responsible for mining activity has yet to confirm the relinquishment. This omission blocks all further applications by any company wishing to enter into any exploration activity in this part of Belgium.

The potential at Bleiberg

The Bleiberg concession covers an area of 1,879 hectares. The concession was held by the Société Minière et Métallurgique de Penarroya, a French mining company. In 1980, Penarroya was acquired by S.A. Metaleurop who sold it in 1988 for an undisclosed amount to Nicron Resources Limited, an Australian mining company. In 1988, the Société Anonyme Nicron France, a subsidiary of Nicron Resources Ltd., signed a contract with Goossens & Associates (which became Bugeco s.a. in 1989) to explore the concession for new orebodies. A total of 59 drill holes with a combined length of 14,000 metres was drilled. In 1994, a ministerial decree from the Region Wallonne authorized the transfer of the concession from Metaleurop to S.A. Nicron France. The shareholding of S.A. Nicron France has changed since then and it no longer has any link to Australia. Société Minière de Chessy S.A. (100% BRGM) is currently Nicron France's sole shareholder.

Local geology

Namurian formations crop out in the northern part of the concession in a sequence of NE trending folds. The thickness of the Namurian units varies between 300 m close to the Dutch border, where the beds dip under the Cretaceous, to 100-110 m in Sippenaeken and 200 m underneath Bleiberg village.

The Dinantian formations display the same reduction in thickness from 140 m underneath Bleiberg to 80 m in Sippenaeken (45 m of Visean silica-rich limestones and 35 m of Tournaisian limestones).

The main rock types hosting the Bleiberg orebodies are:

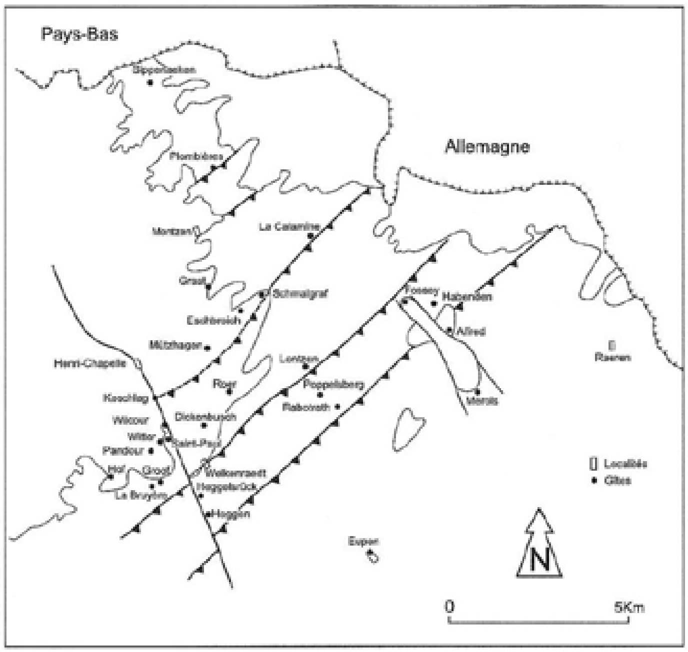

Figure 2: Location of the main Zn-Pb (abandoned) ore bodies (from Dejongue, et al., 1993).

Table 1: Major orebodies with more than 10,000 t of Pb-Zn concentrates produced (from Dejonghe et al. 1993)

	Concentrate. Pb+Zn (t)	*Contained Zn metal (t)*	*Contained Pb metal (t)*
La Calamine	*1,900,000*	*760,000*	*-*
Schmalgraf	*377,463*	*157,835*	*13,763*
Bleiberg	*225,500*	*60,675*	*80,500*
Fossey	*185,544*	*60,879*	*1,000*
Eschbroich	*113,318*	*47,641*	*2,976*
Rocheux-Oneux	*102,000*	*25,000*	*18,700*
Lontzen	*78,194*	*38,928*	*3,618*
Saint Paul	*102,534*	*37,401*	*2,115*
La Bruyère	*81,408*	*30,166*	*3,711*
Mützhagen	*46,467*	*13,824*	*3,088*
Pandour	*42,000*	*16,800*	*-*
Dickenbusch	*18,592*	*5,444*	*3,056*
Roer	*12,868*	*6,048*	*894*
Total	*3,285,889*	*1,260,621*	*133,421*

- Famennian mica-rich sandstone and shale
- Tournaisian limestone and dolomite
- Visean limestone
- Namurian sandstone and shale.

To the south, the Namurian is disturbed by a NW-verging thrust fault, known as the Bleiberg (or Plombières) fault with older (Visean limestones) overlying younger (Namurian shales). Vein mineralisation is controlled by NW transverse faulting.

Bleiberg Mineralisation

Pod type (massive ore) occurs at some intersections of transverse faults and specific "receptive" stratigraphic contacts (in French, *amas de contact*) and may owe its origin to karstic phenomena. Some of the pod type bodies carry very important tonnages.

Vein type mineralisation is represented by steeply dipping linear bodies parallel to the transverse faults which locally form large orebodies at some stratigraphic contacts.

Three orebodies have been recognised in the concession: Bleiberg, Sippenaeken/Ter Bruggen and Graat. See ***Figure 4***.

Bleiberg, in the center of the concession, is controlled by a transverse fault. It is the only orebody to have been mined in the past, both by open pit and underground.

Sippenaeken/Ter Bruggen, in the NE of the concession, is controlled by a NS transverse fault, only recognised from exploration workings.

Graat oxide ore (calamine), in the SW of the concession, only recognised by exploration workings. The hole intersected calamine ore with 32% Zn and 4% Pb.

Drilling and mine workings have demonstrated the existence of mineralisation over a length of 3.5 km, along a transverse fault, from Boffenrath in the NW to Maarveld in the SE. The mineralised structure is open along strike to the NW and the SE, as well as at depth (***Figure 4***).

North of the Bleiberg fault, the veins are between 25 and 90 cm wide from the surface down to the contact between the Namurian schists and Visean limestones. The vein, however, often thickens from 25 cm to a massive orebody of 10 m thick by 20-50 m high, underneath Namurian schists. The roof of this orebody is Namurian schists. This body is situated at a depth of 180 m near the Bleiberg fault and at -350 m underneath Boffenrath. The swelling is important and is followed by pinching. Nicron drill holes have shown this structure to be continuous over a length of 2.5 km, from Maarveld in the SE to Braesberg in the NW. Metal grades are generally over 13% Zn and 5% Pb (with silver). Nicron exploration work shows that the same mineralisation occurs for at least another 2 km to the north, toward Sippenaeken.

South of the Bleiberg fault, massive ore has been shown to exist over a strike of more than 500 m, with 70 m width and 60 m vertical extent. This is called "the Schimper mass" which changes to a stockwerk of 20 m wide.

Bleiberg ores are composed mainly of sphalerite and galena; pyrite, pyrrhotite and chalcopyrite are minor constituents. The gangue consists of calcite and small amounts of quartz.

BRGM estimated measured and indicated resources of the new deposit explored by Nicron at 850,000 tons with 13.5% Zn, 5% Pb and 24g/t Ag. The Nicron work has also identified an extension of the ore to the north (Boffenrath), potential for an extension to the south and interesting mineralisation underneath the Schimper pod.

Figure 3: The two main concessions: Bleiberg (CB) and Vieille Montagne (CVM).

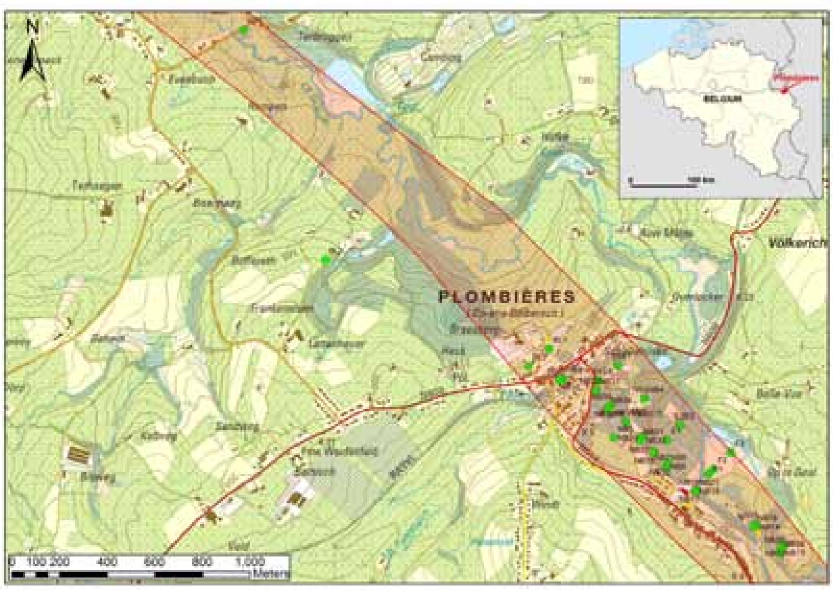

Figure 4: Drillholes near Bleiberg (Plombières) and the extension toward the NW of the possible mineralised structure.

Table 2: Diamond drilling results (unpublished records kept by Bugeco).

Drillhole	Depth of mineralised intercept (m)	True width (m)	Zn%	Pb%
NB1	205 - 208	3	17.9	0.2
NB1	205 - 213	6.85	9.5	2.6
NB1	221.5 - 232.25	10.25	13	2
NB2	187.7 - 195.7	3.65	22.5	0.2
NB4	109.6 - 205.7	6.5	4.6	0.8
NB4	200.75 - 206.4	5.5	4.3	0.8
NB4	229 - 244	14.8	14.1	4
NB6	220 - 232	12	8.1	3
NB8	220 - 230	10	16.8	6.2
NB9	221.9 - 227	5.1	4.6	0.6
NB10	283.5 - 285	1.5	26.2	3.0
NB12	90.6 - 93.5	2.9	15.4	1.1
NB12	124.2 - 125.2	1	26.8	0.4
NB13	147.35 - 150.35	3	10.8	0.1
NB14	169.3 t - 173.3	4	9.5	2.9
NB15	128.85 - 131.5	2.65	9.1	1.0
NB18	207 - 215	8	16.9	0.2
NB19	206 - 217	11	9.2	0.2
NB22	191.75 - 194.2	2.45	6.9	0.1
NB25	225.7 - 227.25	1.55	17.0	0.1
NB26	84.2 - 89.6	5.4	7.0	
NB26	221.35 - 222.85	1.5	22.7	
NB28	201- 208	7	4.13	
NB29	190 - 191.55	1.55	14.8	
NB30	209.7 - 217.2	7.5	18.35	
Average		7.3	11.1	

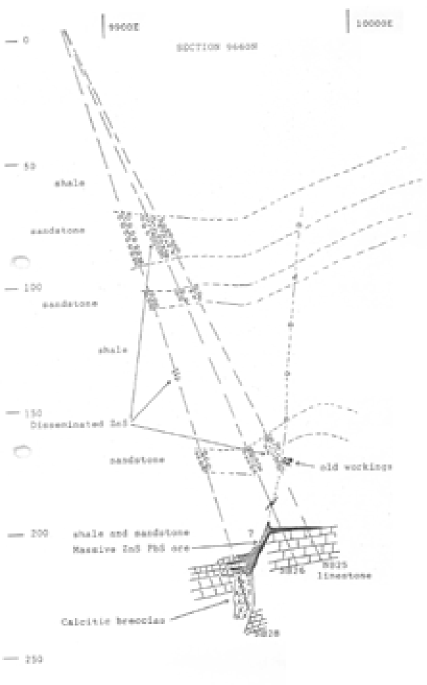

Figure 5: Three drill mineralised intersections (NB25, NB26 and NB28).

Diamond drilling results are given in ***Table 2***. The total length of cores drilled for exploration is approximately 1.5 km. The mineralised body has an average thickness of 7.3 m, an average zinc grade of 11.1% and the density is estimated at 2.9 kg/m³. We estimate the drill-indicated resource oon the order of 1.7 Mt of ore grading at 11%Zn, 2% Pb and 30 g/t Ag, i.e. with metal contents of around 187,000 t Zn, 34,000 t Pb and 1.7 Moz (51 t) Ag.

Mineralisation is open at depth and along strike in both directions, i.e. NW and SE. In addition, since all historical drill cores have unfortunately been discarded, with only the original drill logs and the original assay results (Omac lab, Ireland) remaining, a dozen new holes need to be drilled to confirm existing results. The objective of this exploration programme is to double or triple the present estimated resource.

Figures 5 to 7 show examples of drill mineralised intersections from the Bleiberg concession.

The potential at Vieille Montagne

The Vieille Montagne concession covers an area of 8,146 hectares. The local geology consists of Famenian sandstone and shale, Tournaisian and Visean dolomite and limestone and Namurian shale. Deformation during the Variscan orogeny is expressed by folding around NE trending axial planes and NW verging thrusts. NNW trending transverse faults of post-Variscan age have dislocated the lithological contacts. The same NNW trend controls a series of ore deposits.

- Bleiberg to La Calamine
- Elsembach to Schmalgraf-Lontzen
- Mützhagen to Dickensbuch
- Koschlaeg to Wilcour-Saint Paul-La Bruyère-Welkenraedt.

All the orebodies are found below the Palaeozoic-Mesozoic unconformity where a series of karsts were formed. The majority of the deposits occur within the Dinantian limestone formation, including:

- Massive mineralisation at the contact between Visean limestone and Namurian shale or at the contact between Famenian sandstone and Tournaisian dolomite
- Massive mineralisation at tectonic contacts (thrust faults)
- Massive mineralisation associated with the Palaeozoic-Mesozoic unconformity
- Subvertical mineralised veins following transverse faults
- Stockwerk mineralisation.

Ore mineralogy is similar to that encountered in the Bleiberg concession.

The concession contains important deposits, most of them mined in the past: La Calamine, Schmalgraf, Lontzen, Eschbrosich, and others.

In the 1980's, Union Minière and Vieille Montagne started a new exploration programme including several diamond drillholes. The Lontzen ore deposit was selected to perform a pre-feasibility study carried out in 1985.

Total resources were estimated at 537,000 t of ore grading 21.9% Zn and 3.6% Pb for orebodies thicker than 1.20 m and an average thickness of 1.7 m. Ore density was estimated at 2.9 kg/m³, the dilution at 10% and the mine recovery at 85%. Taking into account dilution, head grades are 19.7% Zn and 3.3% Pb.

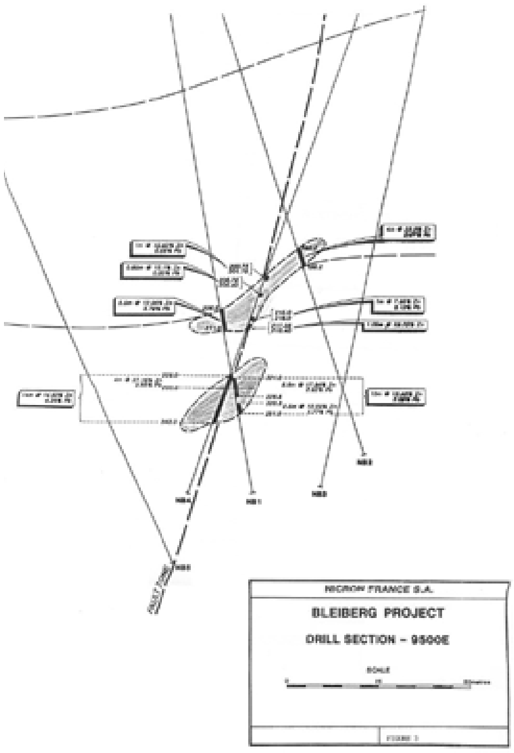

Figure 6: Mineralised intersections of four drill holes (NB1, NB2, NB3 and NB4).

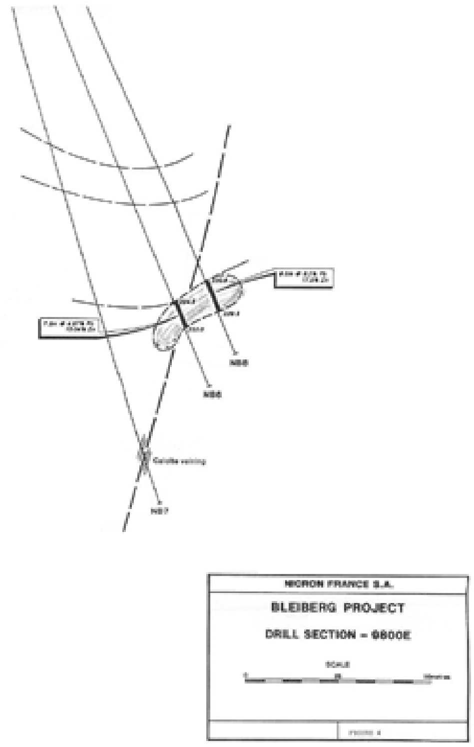

Figure 7: Mineralised intersections of three drill holes (NB6, NB7 and NB8).

Final remarks

The significant discoveries at Bleiberg (Plombières) and Lontzen show that the area merits further exploration work. The geological context and the structure are very similar to the "Irish type" Pb-Zn mineralisation. The infrastructure in the region is excellent, with roads, railways, proximity to an important zinc metallurgical plant owned by Nyrstar at Baelen, the presence of nearby ore processing plants and labs, and ready availability of qualified labour.

Discovered in 1875 by a French chemist, Gallium was extracted from zinc sulphides provided by Vieille Montagne (Prof. E. Pirard, oral communication). In recent years, the ore at Bleiberg has not been analysed for rare metals such as Ga, Ge, In or others.

Stimulating interest for further exploration, however, requires the government of the Région Wallonne to free the concessions by officially acknowledging their relinquishment, to modernise the current, obsolete mining code and to set up a Geological Survey department able to properly monitor exploration programmes by private stakeholders.

The present article, being focused on the economic side, does not cover the scientific work performed by a couple of university laboratories, among them the Katholieke Universiteit Leuven geological department (Muchez *et al.* 1994, Heijlen *et al.* 2001).

In 2014, due to the liquidation of the Bugeco Company, the Bleiberg and Vieille Montagne archives were donated to the University of Liège.

Recommendations

Following are the actions that need to be performed in order to enhance the potential of the Zn-Pb mineralisation:

1. Région Wallonne should rapidly relinquish both concessions;
2. Région Wallonne should financially assist the efforts of the University of Liège to define the Zn-Pb resources and the presence of accompanying rare metals;
3. Région Wallonne should give a clear mission to its geological survey to evaluate the regional mineral resources, to issue new exploration permits and to monitor exploration programmes;
4. Région Wallonne should modernise the present mining code, which is obsolete;
5. The author proposes a drill campaign to test the NW extension.

Acknowledgements

The author wishes to acknowledge the help of André Tahon and Arnaud W. Goossens in correcting and improving the text.

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The future of metal minerals mining in the EU

*Pekka A. Nurmi and Ferenc Molnár**

The availability of ferrous, base and critical minor metals has become one of the key priorities for modern high-tech societies, and the mining and metals industry will have a significant role to play in creating a sustainable future. The EU is one of the major global users of metals, but is heavily dependent on the import of metals from increasingly unstable world markets. In this paper, we discuss the opportunities and challenges in promoting the availability of metals from the EU's own mineral resources. There are a number of important operating mines and undeveloped deposits in Europe, and the geology indicates significant potential for discoveries of new ore deposits. However, many challenges remain to be solved. Can we develop improved technologies and practices for sustainable and acceptable mining in the EU? Do we have access to land, and companies ready to invest in mining and in mineral exploration to make new discoveries? Can we technically and economically mine the more complex, lower grade and deeper-seated deposits already known or yet to be discovered? For societal and environmental reasons, will we be allowed to mine at all in sites with economically viable ore deposits? Do we have enough skilful people to work for the intelligent mining industry of the future? The EU and its member states have much to improve to gain better self-sufficiency in metals and to achieve the aims of the EU Commission's Raw Materials Initiative and Innovation Partnership on Raw Materials.

La disponibilité de minéraux métalliques ferreux, essentiels et secondaires, est devenue l'une des priorités fondamentales des sociétés modernes, de technologie avancée. L'industrie minière et des minéraux métalliques va prendre une place significative dans l'émergence d'un futur durable. L'Europe est globalement l'un des utilisateurs principaux des ressources métalliques mais est profondément dépendante de l'importation de minéraux métalliques provenant de marchés de plus en plus instables dans le monde. Dans cet article, nous faisons le point des opportunités et défis rencontrés, en mettant l'accent sur la disponibilité des minéraux métalliques au sein des propres ressources minières européennes. En Europe, il existe de nombreuses exploitations minières et aussi des gisements qui restent à exploiter. Les données géologiques indiquent l'existence de réelles possibilités pour la découverte de nouveaux gisements miniers. Cependant, de nombreux défis restent à gagner. Pouvons-nous développer des technologies et moyens efficaces pour conférer à l'exploitation minière un caractère durable et acceptable, en Europe? Avons-nous accès aux futurs sites miniers et les Compagnies sont-elles prêtes à investir dans le minier et l'exploitation minérale pour faire de nouvelles découvertes? Pouvons-nous exploiter, du point de vue technique et économique, les gisements complexes, moins riches et profonds, connus ou qui restent à découvrir? Pour des raisons de société ou environnementales, ne nous sera-t-il pas défendu d'exploiter les gisements miniers économiquement rentables? Disposons-nous d'un nombre suffisant de personnel compétent pour répondre aux besoins d'une industrie minière intelligente, celle du futur? Il reste à l'Europe et à ses Etats membres beaucoup de travail pour tendre vers une autosuffisance en minéraux métalliques et atteindre les objectifs de l'Initiative lancée par la Commission européenne pour les matières premières, Initiative commune aux Etats membres.

La disponibilidad de metales férricos, básicos y menores críticos se ha convertido en una de las prioridades clave para las sociedades modernas de alta tecnología, y la industria de minería y metales tendrá un papel importante en cuanto a la creación de un futuro sostenible. La UE es uno de los principales usuarios mundiales de metales, pero depende en gran medida de la importación de metales de mercados mundiales cada vez más inestables. En este articulo se discuten las oportunidades y desafíos en la promoción de la disponibilidad de metales a partir de los recursos minerales propios de la UE. Existe un número de minas en operación importantes y depósitos no desarrollados en Europa, y la geología indica un potencial significativo para los descubrimientos de nuevos yacimientos. Sin embargo, aún quedan muchos retos por resolver. ¿Podemos desarrollar mejores tecnologías y prácticas para la minería sostenible y aceptable en la UE? ¿Tenemos acceso al terreno, y empresas dispuestas a invertir en la minería y en la exploración de minerales para hacer nuevos descubrimientos? ¿Podemos técnicamente y económicamente explotar los depósitos más complejos, de bajo concentracion y más profundos que están ya conocidos o aún por descubrir? ¿Por razones sociales y ambientales, tendrémos el permiso para explotar depósitos de minerales económicamente viables ? ¿Tenemos suficiente gente qualificados para trabajar para la industria minera inteligente del futuro? La UE y sus Estados miembros tienen mucho que mejorar para obtener una mejor autosuficiencia en metales y para lograr los objetivos de la Iniciativa de materias primas de la Comisión Europea y el Partenariado de Innovación en materias primas.

Globalisation, the growth of the middle class and sustainability of the accelerated development of the traditional, high-tech and environmental industries at the dawn of the 21st century have generated considerable renewed interest in mineral resources. According to the United Nations, the world population will rise to 9 billion and 3 billion new people will move to cities by 2050. The total consumption of metals will definitely be higher in the future due to the increasing world population and number of middle-class people, although consumption per capita will decrease due to improved resources efficiency, recycling, better product design and new materials (World Economic Forum, 2014). The availability of metals is critical for European industry and welfare. The combined annual turnover of the con-

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struction, chemical, automobile, aeroplane, machinery and equipment-manufacturing industries is about 1,300 billion euro, and they provide employment for 30 million people (Tiess 2010). EU member countries consume 20-30 % of the metals produced globally, but metal mine production within the EU accounts for an average of only about 3 % of global production (*Fig. 1*). Furthermore, many important metals are not produced in Europe at all.

Resources efficiency will reduce our dependency on primary minerals, but EU industries will remain vulnerable to disruptions in the metal supply and to market volatility for many decades to come. Thus, one of the challenges for the sustainability of the raw material supply chain in Europe is to enhance domestic production of not only the critical metals but also the traditional ferrous and base metals (*Fig. 1*).

The entry of new leading players such as China and India and other rapidly developing countries into the raw materials market and subsequent re-arrangement of the global structure of the mineral supply chain has strongly influenced the access of the traditional centres of technological and industrial development to mineral resources, and even to recyclable scrap metals. Among these traditional centres, the EU is the most severely affected economic region, where accelerated urbanisation, the development of environmentally sensitive societal legislation of industrial activities, and the protection of remaining pristine ecosystems and agricultural lands led to the suppression or total abandonment of mineral exploration and mining, even in traditional mining districts, by the end of the 20th century.

Evaluation of the state of mineral exploration, exploitation and processing methods has revealed that new innovative technologies in mining, mineral processing and recycling are needed in the EU to support the sustainable use of available resources (European Commission, 2008). Industrial development continuously generates needs for new raw materials: the most widely known example is the enhanced interest in rare earth elements (REE) and some of the platinum group elements (PGE), among other critical raw materials, for the high-tech industry (European Commission, 2010).

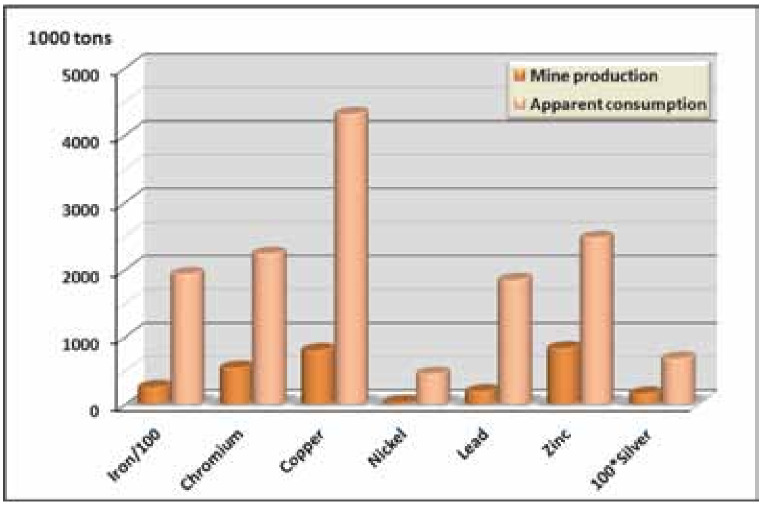

Figure 1: Mine production and apparent consumption (= production + import – export) of ferrous and base metals in the EU27 countries (data from BRGM, 2008).

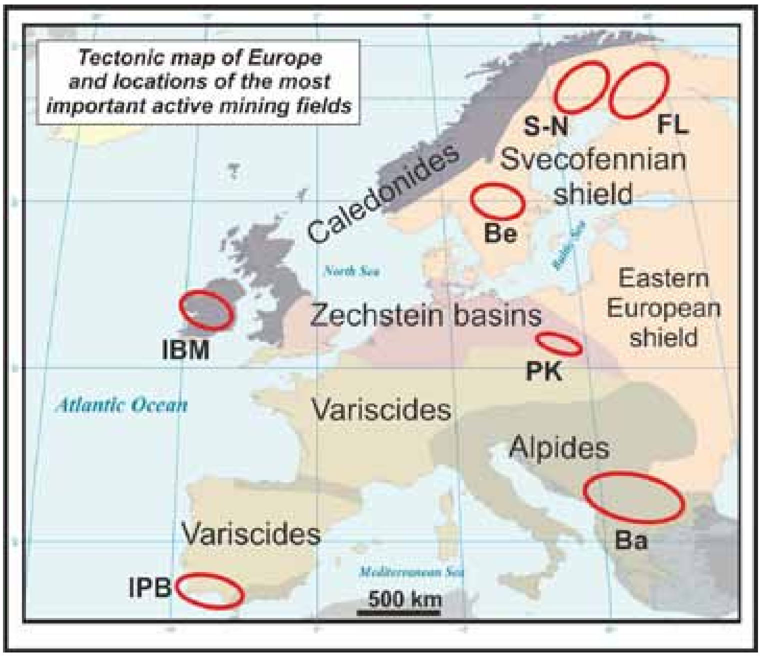

Figure 2: Tectonic map of Europe and locations of the most important mining fields. FL – Finnish Lapland; S-N – Skellefteå-Norbotten; Be – Bergslagen; IBM – Irish Base Metal district; IBP – Iberian Pyrite Belt; PK – Polish Kupferschiefer; Ba – Balkan mining district.

Important metallic mineral deposits and critical metals in Europe

Europe has a rich history of mining, mineral processing, smelting and the innovative use of metals, and the background of the traditional European leadership in industrial development is in the use of mineral resources. Europe was the leading continent for the production of mineral commodities up until the early 1900s.

The geological evolution of the European terrains repeatedly provided favourable conditions for the formation of a variety of mineral deposits and made Europe rich in metallic mineral resources. The nucleus of the European continent formed more than 3 billion years ago, and the cyclic mountain-building processes led to the periodic growth of the Fennoscandian Shield during the Svecofennian and Sveconorwegian orogenies (1.9–1.8 and 1.1–0.9 bill. years ago, respectively). During the Phanerozoic Eon, the Caledonian (400–500 million years ago), Variscan (300–400 mill. years ago) and Alpine orogenies (during the past 60 million years) were the major growth periods of the European continental crust around the old Fennoscandian and Eastern European shields (*Fig. 2*). Each of these orogenic cycles included the recurrent development of geological conditions suitable for the formation of many types of metallic mineral deposits. Thus, the European orogenic belts contain quite different resources of metallic commodities. This is due to the variable geological processes in crustal evolution and the ages of the terrains affecting the depths of erosion.

For example, the erosion level of the Fennoscandian shield is mostly 5-20 km, and

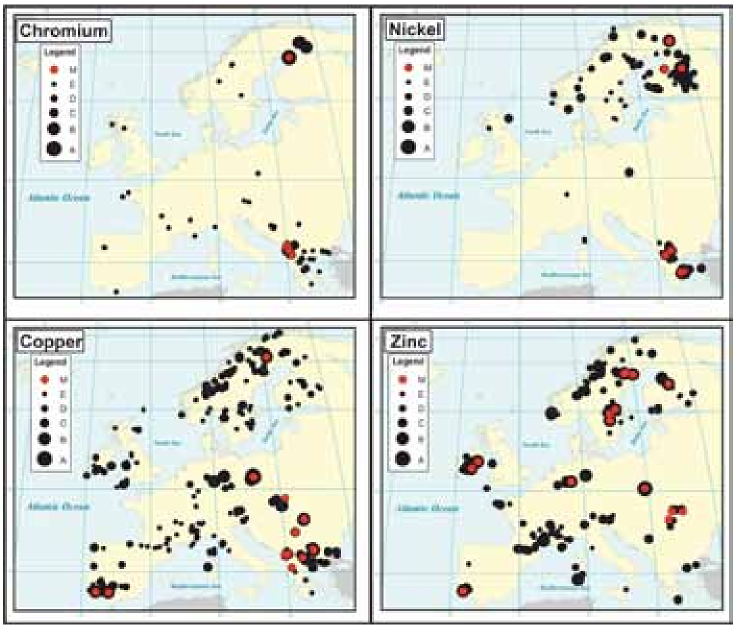

Figure 3: Ore deposits and occurrences of selected ferrous and base metals in Europe (EU27 countries). A – important; B – significant; C – medium-sized; D – small; E – mineral occurrence with unknown potential; M – active mine. The figure was compiled using the ProMine database available at promine.gtk.fi.

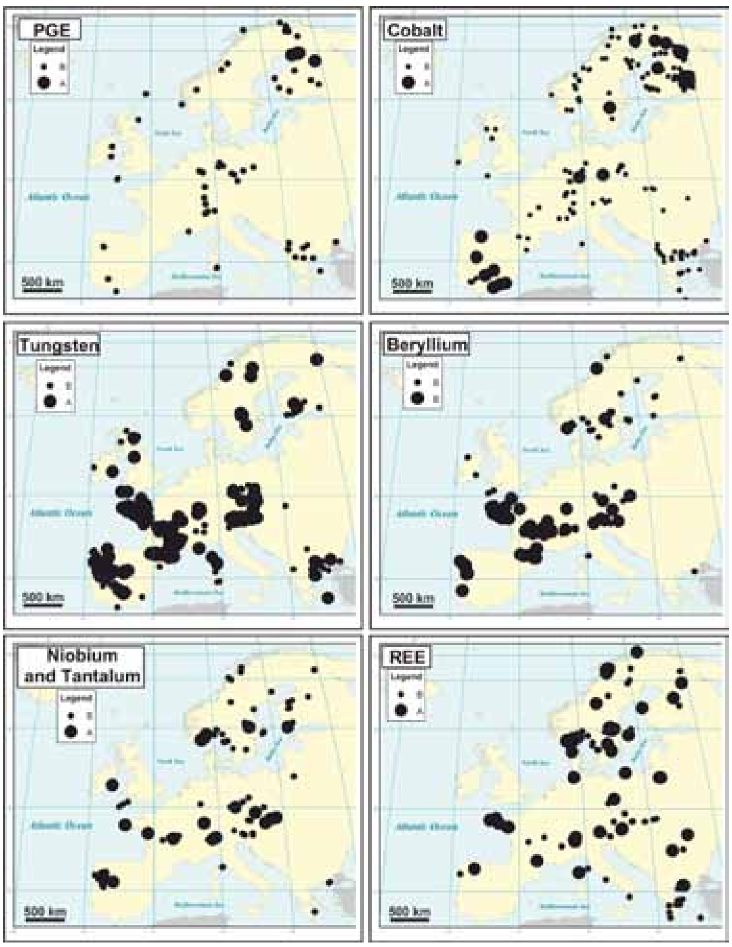

Figure 4: Critical metal bearing ore deposits and mineralisations in Europe (EU27 countries). A – significant; B – occurrence. The figure was compiled using the ProMine database available at promine.gtk.fi.

mineral deposits formed at depth a few billion years ago now crop out on the present Earth's surface. The large mafic-ultramafic layered complexes in northern Finland, which were emplaced at depths of several kilometres in the Earth's crust at around 2.44-2.05 billion years ago, and the mafic-ultramafic intrusions in the deep root zones of the Svecofennian subduction-collision zones became accessible for mining because of the deeply penetrating level of erosion. These intrusions host important magmatic nickel resources (***Fig. 3***). The Keivitsa deposit produced 8963 tons of nickel in 2013 (***www.first-quantum.com***). The ore potential of the region is high: this is well demonstrated by the recent discovery of the potentially world class Sakatti copper-nickel-platinum group elements magmatic sulphide deposit. Similar ore deposits are essentially absent from other parts of Europe. The exception is the Aguablanca magmatic sulphide deposit in the Ossa Morena zone, which is in the Variscan belt of Iberia (Tornos *et al.*, 2006). This deposit formed at a relatively shallow depth (ca. 2 km), about 350-330 million years ago. The Aguablanca deposit produced 6242 tons of nickel in 2013. Another type of nickel ore occurs in the youngest, Alpean orogenic belt in southeastern Europe. In this area, the level of erosion is locally so shallow that the weathering crusts that have developed during the warmer climatic periods of the past 60 million years on the surface of ultramafic rocks are still preserved. The cumulative production of nickel from these lateritic deposits of Greece, Kosovo and Macedonia was 39,100 tons in 2010 (***www.euromines.org***). A similar pattern in the distribution of chromium deposits in Europe may also be recognised. The mafic-ultramafic layered complexes of the Fennoscandian shield are the most significant suppliers of chromite for the European steel industry, whereas the other important occurrences of magmatic chromite ores are related to the obducted ophiolites of Mesosoic age in southeastern Europe.

In contrast to nickel, the occurrences of the most important copper deposits are more diverse in Europe (***Fig. 3***).

The porphyry copper type deposits, which form at shallow levels (1-5 km) of the Earth's crust, are mostly preserved in the least eroded, subduction/collision-related Alpine intrusive-volcanic complexes in southeastern Europe (e.g. Bor in Serbia, Assarel in Bulgaria in the Banat-Srednogorje Zone). Subduction-related intermediate-felsic shallow intrusions with copper mineralisation are also exceptionally preserved in the western and central part of the Fennoscandian Shield. The Aitik porphyry copper deposit in the Skellefte district of Sweden, with 710 million tons of reserves and an average copper content of 0.25 wt% (***www.boliden.fi***), is an outstanding example of this type of ore deposit. However, more important copper mines can be found in the post-Variscan intracontinental Zechstein Basins (Kupferschiefer – copper shale, Silesia, Poland). The active mines of the Polish Kupferschiefer Belt (***Fig. 2***) have 1,166 million tons of cumulative reserves with an average copper content of 1.56 wt% (***http://www.raportroczny.kghm.pl***).

Ore deposits of zinc with substantial copper and other base metal credits are widespread in Europe (***Fig. 3***). Important resources are related to the volcanogenic massive sulphide deposits in the preserved subduction-related back arc basins of the Fennoscandian Shield (the Raahe-Ladoge zone in Finland, Skellefte and Bergsladen districts in Sweden). In terms of cumulative resources (1,923 mill. tons of ore with 40.3 Mt Zn, 21.0 Mt Cu and 15.9 Mt Pb; Tornos, 2006), the Iberian Pyrite Belt in Spain and Portugal, in the southernmost part of the Variscan orogenic belt (***Fig. 2***), is one of the largest volcanogenic massive sulphide ore belts in the world, with more than 10 world class deposits of this kind of ore (e.g. Neves Corvo, Aguas Teñidas, Aljustel and Las Cruces). In fact, more than 20% of the largest known volcanogenic massive sulphide ore deposits can be found in this belt. Important zinc(-lead) deposits also occur in the carbonate sedimentary rocks of the post-Caledonian basins of Ireland and the post-Alpine Krakowian-Silesian district of Poland. The initial resources for the world-class Navan deposit in the Irish Base Metal District (***Fig. 2***) were 69.9 million tons with 12.7 % average zinc+lead concentrations (***www.mineralsireland.ie***).

The already known and currently exploited base metal deposits and mining districts of Europe provide an important basis for the future development of mining in Europe. In most areas, there is a good potential for new mineral discoveries, particularly at depth down to 2 km, where geological information is very limited but mining would be economically feasible.

The base metal deposits also contain minor metals that are critical for the high-tech industry. For example, magmatic nickel-copper sulphide deposits may contain enrichments of platinum group elements (mostly platinum and palladium) and cobalt. It is interesting that the European copper deposits are also associated with locally elevated platinum and palladium concentrations in the Polish Kupferschiefer and even in the porphyry-copper deposits of southeastern Europe. The active mines of the Polish Kupferschiefer Belt also produced 1274 tons of silver in 2012 (***http://www.raportroczny.kghm.pl***). Lead and zinc deposits are also potential resources of such minor metals as silver, indium, gallium, antimony and bismuth, among others. Indium is a typical minor metal in some of the world class volcanogenic massive sulphide deposits of the Iberian Pyrite Belt. Enhanced recovery of these critical metals from base metal ores through the development of new mineral processing and smelting technologies is a possible way to increase the efficiency of mining and to support industry needs.

Figure 4 presents known mineral occurrences, old mining sites, active exploration fields and mines, in which the selected critical metals (European Commission, 2014) are the potential major targets of mining and exploration according to the ProMine database (***promine.gtk.fi***). In comparison with ***Figure 3***, it is evident that critical metals are more scattered than base metals, although some geographic diversity is also present. Platinum group elements and cobalt have more potential in the Fennoscandian Shield, whereas tungsten, beryllium, niobium and tantalum have potential for exploration and mining in the Variscan granite plutons in France and Iberia. At this time, European tungsten ores are mined in Austria (Mittersil), Portugal (Panasquiera) and in Spain (Los Santos). The development of the Barruecopardo deposit in western Spain is considered to be one of the most important projects in the world for opening up new tungsten resources outside of China. Beryllium, niobium, tantalum and rare earth elements also have enrichments in alkaline igneous complexes and carbonatites in the Fennoscandian Shield. The currently most important exploration project for a rare earth element deposit is running at Norra Kärr in Sweden (***www.tasmanmetals.com***). Further research and exploration are needed to better understand the formation of economically viable rare earth element deposits in the Earth's crust.

The diversity of deposit types and distribution of metallic mineral deposits in Europe also warrants the application of different approaches to mineral exploration and mining. In addition to the geological background, the environmental circumstances and societal legislation are highly variable in different regions, which are further challenges for the future development of the mining industry.

Challenges for future mining in the EU

The European Raw Materials Initiative, first launched in 2008, is a political framework aiming to improve the availability of minerals from European ore deposits and guarantee undisturbed imports from third countries, and to reduce the dependency on primary minerals by improving resource efficiency (European Commission, 2008, 2011, 2013, 2014). The lifespan of many metal products is long and metals are recyclable in most applications. Therefore, once produced, metals remain available for future generations, and sustainable societies will create effective mechanisms for recycling and reducing the growing need for primary resources. Future manufacturing will pay particular attention to product design, which will allow effective recycling of commodities, and technological development will allow the substitution of some critical metals by other compounds. On the other hand, rapid technological development and innovations will require the use of new mineral commodities for the next-generation low-carbon, hi-tech society (Vidal *et al.*, 2013). The economy, society, energy, infrastructures, transportation and the materials will look very different in the latter half of the 21st century compared to the present. Therefore, it is impossible to estimate with a high level of confidence the global need for various metals and minerals for the next generations. In the future, metal consumption per capita will decrease but global consumption will increase due to the growing population and a couple of billion new middle-class people (World Economic Forum, 2014).

As discussed earlier in this paper, European geology provides excellent opportunities for exploitation of the currently known ore deposits, and for discoveries of new deposits containing a wide range of essential minerals, including base, ferrous, noble and critical metals and minerals. However, many questions remain to be answered. Can we develop improved technologies and practices for sustainable and acceptable mining in the EU? Do we have access to land, and companies ready to invest in mining, and in mineral exploration to make new discoveries? Can we technically and economically mine the more complex, lower grade and deeper-seated deposits already known or to be discovered? For societal and environmental reasons, will we be allowed to mine at all in sites with economically viable ore deposits? Do we have enough skilled people to work for the intelligent mining industry of the future?

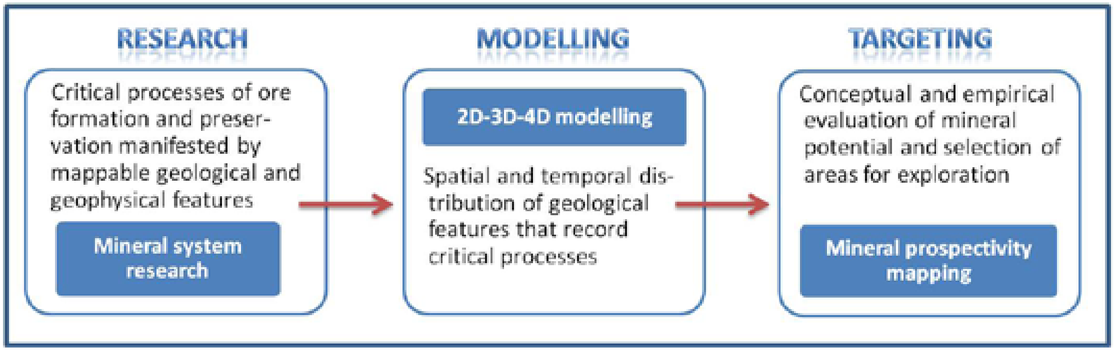

Figure 5: The role of the mineral system concept and geo-modelling in targeting areas for mineral exploration.

Mineral exploration is the key to future mining

Today, the ferrous and base metals comprise more than 70 % of global mining by mine value. These metals will also rule the global mining industry for the decades to come, but accelerating technological development will change the future demand for metals and minerals in an unpredictable way. Commodity prices will remain very volatile and new deposit types will become economically interesting. Can we find deposits for future mining in the EU?

We are currently constructing EU-wide uniform databases of known mineral resources and the geology of ore-potential areas (e.g., in EU-funded projects such as ProMine and Minerals4EU). Although this is a necessary starting point for future mining, these databases do not provide any definitive answers concerning the true existence and resources of various metals in the EU. In most ore-potential areas, very little exploration or intensive geoscientific mapping and modelling have been performed during the past decades, or ever, at a scale detailed enough for exploration purposes, or applying modern deep-penetrating geoscientific techniques. Therefore, new geological, geophysical and geochemical data are lacking for most of Europe.

Exploration in most areas of the EU has been considerably less intensive than in the major mining regions elsewhere, such as Canada, Australia and South America. Information on new deposit types and on geology and possible mineral deposits at depth is particularly scarce, and in most cases non-existent. The average global exploration cost per discovery increased by 160 % in real terms between the 1980s and 2000s and, in mature exploration jurisdictions such as Australia, by as much as 260 %. A technological breakthrough allowing easy discovery of the very contrasting types of ore deposits at depth is very unlikely, although cheaper, faster, safer, and more environmentally friendly drilling, combined with down-hole sensing technologies, fast drill-core analysis and data processing has the potential of increasing rates of discovery. Better geological understanding of the mineral systems in relation to crustal evolution and the geological structures in three dimensions down to a few kilometres is definitely needed to promote future discoveries. Geological surveys, research institutes and universities should take a much stronger role in these studies. Governments and various funding organisations need to understand that new geoscientific data, research and models are the necessary basis to promote exploration investments by the mining industry.

Evaluation of old base metal mining districts for the extension of resources and potential by-production of critical metals and exploration for metallic resources in less known target areas requires the application of new geological concepts and exploration methods. The mineral system approach, a holistic approach to understand sources, transportation pathways, deposition and preservation/re-mobilisation mechanisms of metals in the Earth's crust, forms the basis for the application of modern concepts in mineral exploration. The mineral system approach combined with new exploration methods such as high-resolution seismic and magnetotelluric surveys and *in situ* ("real time") borehole/field geochemical analytical methods, and the application of these data in computerised mineral prospectivity mapping enhance the efficiency of exploration and support the recognition of hidden resources (***Fig. 5***).

Mineral exploration is perhaps the most important R&D activity for the mining industry, and without successful exploration there will be no sustainable mining. It is, however, a highly risky business. Typically, only one out of one thousand of exploration projects leads directly to mine development, and at least several tens of millions of euro are needed to discover an ore deposit. Therefore, intensive exploration expenditure is key to future mining activities.

The exploration industry is looking for new opportunities globally. The decision making of exploration companies is not only based on the grounds of prospectivity, but increasingly on issues such as access to land, mining and environmental legislation, infrastructure, the safety of investments and the availability of the social licence to operate, which define the country risk for operations.

The Fraser Institute, a Canadian think tank, annually ranks various mining regions on the basis of their favourability for exploration investments. This is based on a survey among mining company executives. With regard to Europe, the Policy Perception Index rankings are very biased in their survey (Wilson and Cervantes, 2014). The Nordic countries of Sweden (No. 1), Finland (No. 2) plus Norway (No. 10) are at the top of the list of all the 112 jurisdictions evaluated in 2013, demonstrating the sound policy climate of the Fennoscandian Shield for exploration companies (***Fig. 6***). Ireland (No. 4) has improved its ranking and France (No. 18) is new on the list. Other European mining regions exhibit modest to poor rankings: Portugal (No. 42), Spain (No. 45), Bulgaria (No. 49), Poland (No. 59), Romania (No. 86) and Greece (No. 89). The Fraser's Best Practices Mineral Potential Index measures the region's geological attractiveness for exploration investment assuming best practice policies, and European countries have variable rankings. Denmark (Greenland) has the best position (No. 8), and Finland (No. 21) and Sweden (No. 27) have good rankings, whereas other countries are in the middle or lower half of the ranks (***Fig. 6***).

Today, only a modest 4 % of global exploration investments are directed to Europe (World Exploration Trends, 2014). Europe has much to improve to attract more exploration investments in the future in order to reduce its dependency on imports and safeguard the availability of raw materials from European sources, as stated by the European Raw Materials Initiative.

Societal acceptance of mining

Decision making for exploration investments is never based only on the geological potential, but needs to take into account numerous other issues. Tightening legislation and competition with other land use purposes, such as agriculture, housing, nature conservation and recreation, are causing increasing hurdles for mineral exploration, and there is a threat that in the future only limited areas will be available for surveys. Since mineral raw materials are unevenly distributed across the Earth (e.g., ***Figs. 3 and 4***) and are concentrated in very small volumes of the crust through distinct geological processes, their location, quantity and quality is not known in sufficient detail to make reliable scenarios for future land use and economic models of mineral potential regions. Many deposits in the EU remain undiscovered and many are too poorly known to define true resources.

The only way to obtain better information is to invest much more in geoscientific mapping, research and mineral exploration. Because intensive exploration is the only way to define the true existence of possible, and in rare cases, rich mineral deposits, it should be allowed in most areas. Exploration-related surveys can be performed in such a way that their impacts on the environment and surrounding societies remain minimal. An example is the very promising Sakatti copper-nickel-platinum group elements deposit in northern Finland discovered by Anglo American Exploration, which is located inside a Natura 2000 wetland area. The deposit is a grass-roots discovery in a very poorly studied area located 12 km from the Kevitsa nickel-copper-platinum deposit, which was put into production in 2012. These deposits could possibly allow profitable large-scale production of base metals and platinum for several decades. Societal judgement between contrasting land use purposes and a decision on possible mine development cannot be made in a balanced way without detailed knowledge of the reserves and feasibility of the mineral deposit.

People in Europe are heavily dependent on mineral-based products in their everyday lives and they are not ready to radically reduce their consumption. Despite this, many are increasingly opposed to mining activities in nearby communities, or within environmentally vulnerable areas, such as the Arctic regions, or even anywhere in the world. There are many such examples in Europe, including the Rosia Montana gold project in Romania, which was recently rejected by a parliament committee, and Eldorado Gold Corporation's mine projects in northern Greece. The mindset has also rapidly changed in Finland since 2011, following the environmental problems that occurred at the large-scale Talvivaara nickel mine. In Sweden, there has been a long battle to open a carbonate rock quarry on the Island of Gotland. In all regions, anti-mining groups are well organized and have good visibility in the media. People are also increasingly opposed to mineral exploration, and it is very difficult to make them understand the difference between exploration projects, which can operate over large areas, cause very low impacts and seldom lead to mining operations, and mining itself, which may cause high impacts in small areas.

A question has often been raised concerning the sharing of benefits. Is it right that foreign companies, as the companies often are in this global business, utilise non-renewable mineral deposits, and what is the benefit for the region? Studies in northern Finland, for example, have demonstrated that the Kittilä gold mine, operated by a Canadian company, brings important positive impacts for the local communities through employment, opportunities for economic growth and diversification, a positive public mindset and government revenues. However, there are challenges in converting natural resource wealth into sustainable economic growth and the long-term development of mining regions. In various countries, voices of resource nationalism are strengthening, demanding special mining taxes or domestic, often public involvement in the mining business, and limits on foreign ownership, or mandated beneficiation and export levies. Companies need to improve stakeholder relationships and partnerships with a commitment to delivering shared value to industry, governments and services. Societies, governments and investors will not tolerate unsustainable mining companies in the future (World Economic Forum, 2014).

Mining technology and skills crisis

An important approach to better acceptance and lower impacts comes from improved technology and new innovations. Many of the future intelligent mines will be based on safe robotics, digital technologies and safe automatic processes; they will use less energy and water, and employ the concepts of zero waste and zero accidents. Several projects and programmes are focused on developing mining technology, such as the EU-funded I2Mine project or Finland's Green Mining Programme and Sweden's Smart Mine of the Future programme. Future societies will also demand that mines be nearly invisible. Although mining will evidently be increasingly based on underground deep operations, it will be difficult to find and economically extract all the commodities needed by future communities deep from

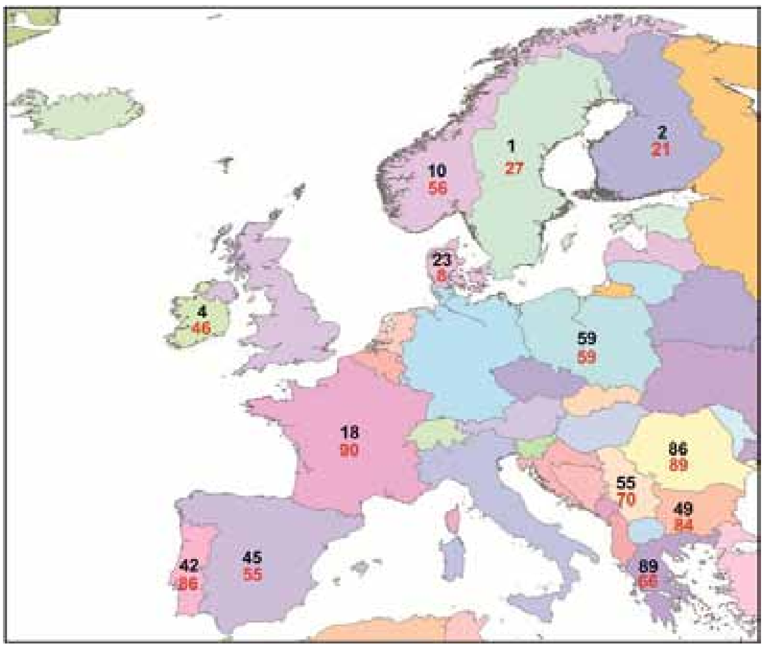

Figure 6: Ranks of some European countries according to the Policy Perception Index (black) and the Best Practices Mineral Potential Index (red) for the mining industry according to the 2013 mining company survey by the Fraser Institute (Wilson and Cervantes, 2013). The study includes 112 jurisdictions. Note: indexes for Denmark refer ranks of Greenland.

the crust, and large, low-grade, open-pit deposits cannot be avoided.

The expanding mining industry is struggling with a rapidly aging workforce and shortage of professionals. During the last two decades, economic geology and mining engineering departments and education programmes have been reduced or closed down. The problem is global. It has been estimated that the mining industry in Canada would need over 145,000 new employees by 2023 (Mining Industry Human Resources Council, 2013). A survey by the Finnish Mining Cluster (Suomen Vuoriklusteri) in 2012 indicated that the expanding minerals industry in Finland would need 5,600 new people by 2022, with over 800 having at least MSc-level academic training.

New education programmes have recently been established in various universities and lower-level institutions in the EU and globally, but it is uncertain whether these will be able to train all the people needed. Mining has a reputation for being an old-fashioned and polluting industry, which is not seen as a career of the future by most young people. Therefore, it will not be easy to attract talented students to the minerals industry, which is undergoing rapid change and increasingly employing high technology.

Finland's perspective on sustainable mining: the Green Mining Concept

Finland's bedrock is rich in a variety of mineral commodities, including chromium, nickel, copper, zinc, gold, platinum metals, phosphorus, different high-tech metals and industrial minerals (Nurmi and Eilu, 2012). There is a long mining tradition in the country and the industry is currently booming. A number of new mines have been opened, many deposits are under feasibility study and about 40 companies are performing mineral exploration.

Finland's government has been proactive in promoting the development of the minerals sector. Finland was one of the first EU countries to release its mineral strategy in 2010 (Finland's Mineral Strategy, 2010). The long-term objective of the strategy is to make Finland a global pioneer in the ecologically efficient mineral industry. According to the vision, the minerals sector will become one of the foundations of the Finnish national economy. Mining has an important role, particularly in the development of rural areas in the eastern and northern parts of the country, in sparsely populated areas where it is difficult to create other types of industries. Finnish expertise and innovation have created a globally significant mining technology cluster that today serves the minerals sector in all aspects of extraction, concentration, metallurgical refining and fabrication, as well as technical services.

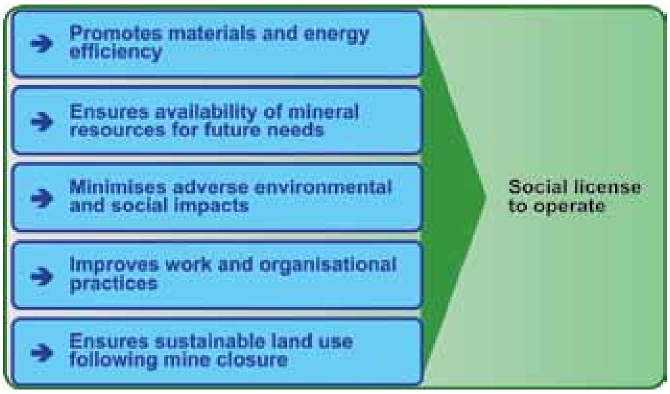

Figure 7: The Green Mining Concept of Finland.

Although almost all mines in Finland are performing in a sustainable way and according to so-called stress tests recently performed by the Ministry of Environment no major environmental risks have been encountered, there have been environmental problems, particularly with the Talvivaara nickel mine. This has been the trigger for strengthening anti-mining activities and debate in the media from 2011 onwards. The government reacted by starting so-called "round-table discussions" involving a vast range of stakeholders, led by the Prime Minister and involving the Ministers of Economic Affairs and the Environment. This process resulted in a government Action Plan, "Making Finland a leader in the sustainable extractive industry" (Ministry of Employment and Economy, Finland, 2013). The plan includes 35 recommendations for the development of mining for better sustainability, as well as acceptance by society through strengthening societal interactions and pointing out positive impacts on mining regions.

Finland's Green Mining concept was developed in 2011 as a major tool to make Finland the forerunner in sustainable mining. This concept is based on five pillars, as presented in ***Fig. 7***. Green Mining promotes material and energy efficiency, which reduces the environmental footprint of mineral-based product life cycles. The purpose is to allow the recovery of all useful minerals and by-products, and to minimise the amount of waste. Solutions for reducing raw water and energy consumption are being developed. Furthermore, Green Mining aims to ensure the availability of mineral resources for future needs through sustainable development, which requires geoscientific mapping and research, investment in mineral exploration, and the development of exploration, mining and processing techniques.

One of the goals is to minimise adverse environmental and social impacts in all stages of mining operations. At the same time, the operations strive to maximise social and local benefits, which requires research, communication and methods that allow broad-based community participation.

Work must be organised in such a way that it is safe and meaningful to employees. This can be achieved by automating processes and making them more efficient, as well as by developing new practices and working methods in cooperation with the entire staff. Occupational safety aiming at zero accidents is an important starting point in all development.

Green Mining requires sound mine closure. Mining areas will be restored to make them safe and allow other kinds of land use. Planning of the controlled ending of mining operations and the proper measures for achieving this is started well before commencing mining operations, and is developed throughout the project's life cycle with the broad-based participation of local residents and other stakeholders.

The Finnish Funding Agency for Innovation (Tekes) initiated a 60-million-euro Green Mining RDI programme in 2011. Today, the program includes over 50 projects involving close co-operation between companies, public research institutes and universities (***http://www.tekes.fi/en/programmes-and-services/tekes-programmes/green-mining/***). Last year, the Academy of Finland launched a research programme on mineral resources and alternative materials to promote knowledge-based growth in the raw materials sector. The European Innovation Partnership on Raw Materials and the Horizon 2020 Programme are both targeting outcomes similar to the Green Mining Concept at the EU level.

Conclusions

The economy, society, energy, infrastructure, transportation and materials will look very different in the latter half of the 21st century than at present. Though metal consumption per capita will decrease in the circular economies, global consumption will increase; therefore, the mining and metals industry will have a significant role to play in future societies.

The EU has a good geological background for a modern mining industry producing base, ferrous and critical metals.

Available metallic resources can be increased through investments in the development of new concepts and methods of mineral exploration and exploitation. The European Innovation Partnership on Raw materials and the Horizon 2020 programmes open up good opportunities for the innovative development of new exploration technologies, better use of currently available resources, and for seeking environmentally friendly and sustainable solutions to the metal supply for EU industry. Different types of metallic mineral deposits occur in separate parts of Europe, and their exploration and mining face different environmental and societal challenges. Thus, each European country and region must develop its own strategies and mineral policies in harmony with the overall EU interest; an example is Finland's Green Mining Concept. The education of future experts for a modern extractive industry in the EU is also a major challenge. The development and re-vitalisation of national and international centres in mining schools and initiation of new RDI programs are essential for resolving the skills crisis in this field.

Future mining has to be based on resource-efficient technology, automatic processes, high environmental standards, and a shared understanding of economic and social development. Societies, investors and governments will not accept unsustainable mining.

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The need of mineral resources for low-carbon energy production

*Olivier Vidal**

Fossil fuels have been at the origin of the industrial revolution, which brought major benefits to humanity but has also caused pollution and environmental damage. We now look forward to a low-carbon society where renewable solar, wind, geo-thermal and tidal sources of energy at least partially replace fossil fuels. Currently wind and solar energy provide only about 1% of global energy, but the contribution from wind turbines and solar energy may increase from the current 400 terawatt hours to 25,000 Twh in 2050. Since most renewable energy sources are diffuse and intermittent, harnessing this energy requires complex infrastructure distributed over large areas, both on land and at sea, and these facilities will consume large amounts of metals and other mineral products. To match the power generated by fossil fuels or nuclear power stations, solar and wind facilities require up to 15 times more concrete, 90 times more Al, and 50 times more Fe, Cu and glass, as well as sand and industrial minerals to make concrete and glass (Vidal *et al.,* 2013a), and hydrocarbon derivatives for resins and plastics. These materials will be sequestered for several decades and cannot immediately be recycled. In 2050, about 3,200 million tonnes (mt) of steel, 310 mt of Al and 40 mt of Cu will be required to construct the infrastructures that will generate the 25,000 TWh planned by the Ecofys scenario (Deng *et al.,* 2011). In the next 40 years, the yearly global demand in these elements will be boosted by 5 to 18% of the 2010 world supply; an increase similar to that driven by all industrial sectors between 1970 and 2000. The anticipated demand for the minor metals that are extensively employed in the green energy sector is more worrying: between 2010 and 2030, the yearly global demand in Ga, In, Se, Te and rare earths for photovoltaic panels and wind turbines will increase by 10 to 230% of the 2010 world supply (Öhrlund, 2011).

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The demand in raw materials for renewable energy will compete with other industrial sectors. The introduction of new technologies in the ICT, transport and green energy sectors requires a diverse set of previously little-used metals. In addition, 10% of the current world energy consumption is used for extraction and processing of mineral resources and without extraordinary advances in mining and refining technology, this fraction is set to rise as poorer and more remote deposits are tapped. Initially, the energy needed will come from fossil fuels, before renewable energy come to the fore. There is a risk that the competition for metals and fossil energy that are already becoming more difficult, and more expensive, to secure will put some limit to the transfer to renewable energy.

What should be done to address these problems? The transition to renewable energy can only work if all resources are managed simultaneously, as part of a global, integral whole. Earth's resources are rich and manifold, but they are finite. As demand grows, we must fully acknowledge the inherent trade-off between the co-production of metals and energy, and optimise procedures and technologies to use both as efficiently as possible. This requires a coordinated effort involving scientists from various disciplines (earth and environmental sciences, material sciences, economy, social sciences), engineers, industrials and decision makers. The environmental and energy costs of the construction, use and recycling of the infrastructure needed for the production, distribution and storage of renewable energy, including those of rare metals, must be built into future programs.

Designs of new products need to take into account the realities of mineral supply, with recycling of raw materials integrated during a product's entire life cycle (Vidal *et al.,* 2013b). This necessitates better cooperation in research and design in the recycling and substitution technologies. Finally, dependence on the foreign import of metals should also be considered when assessing the criticality of a resource. Mineral supply to most developed nations comes mainly from foreign sources. European industries consume more than 20% of the metals that are mined globally, yet European mines produce only 1.5% of global iron and aluminium, and 6% of global copper production. This situation is highly unsatisfactory for security, economic and ethical reasons, and makes European industry vulnerable to short- or long-term supply restrictions. Green technologies should incorporate domestic mining which reduces the financial and environmental costs of transporting metals from far-flung sources and decreases the carbon footprint, while providing jobs and wealth to the local community. Currently, much of the pollution associated with mining is out-sourced to regions where the environmental impact is often uncontrolled. In Europe, things can be done better.

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Economic geology of rare-earth elements in 2014: a global perspective

*Bernd Lehmann**

The rare-earth element (REE) market is still dominated by China, which currently has a share in global REE mine production of about 80 %, down from about 95 % in 2011. This percentage will decrease further over the coming years, with the two large carbonatite-related REE deposits of Mountain Pass (USA) and Mount Weld (Australia) coming to full production. These two high-grade open pit mines (both with about 8 % rare earth oxides) will add capacity to the global REE supply of about 50 %, and they are the reference points for any economic evaluation of other REE development projects. Only very few of the more than 200 REE exploration projects around the world will be able to survive in an increasingly competitive market.

Le marché des éléments rares (REE) est toujours dominé par la Chine qui, actuellement, produit 80% des REE, en diminution depuis 2011 (sa part était égale à 95%). Ce pourcentage va continuer à décroître dans les années à venir, en tenant compte des deux vastes gisements de terres rares associés à des carbonatites, de Mountain Pass (USA) et de Mount Weld (Australie), arrivant à un état de pleine production. Ces deux exploitations à ciel ouvert d'un minerai riche (contenant chacun de l'ordre de 8% d'oxydes de terres rares), vont augmenter la production globale de REE d'environ 50% et constituent une référence pour toute évaluation économique d'autres projets de développement des REE. Seul un très petit nombre parmi plus de 200 projets d'exploration dans le monde sera capable de survivre à un marché de plus en plus compétitif.

El mercado de elementos de las tierras raras (REE) sigue dominado por China, que actualmente tiene una participación en la producción mundial de alrededor del 80%, frente al estimado 95% en el 2011. Este porcentaje se reducirá aún más en los próximos años, con los dos grandes explotaciones de carbonatitas con depósitos de tierras raras, REE, que estan llegando a la plena producción, en Mountain Pass (EE.UU.) y Mount Weld (Australia). Estas dos minas a cielo abierto que tienen un alto grado de mineral (ambos con alrededor del 8% de óxidos de tierras raras) añadirán capacidad de oferta mundial en REE de alrededor del 50%, y son puntos de referencia para la evaluación económica del desarrollo de otros proyectos de REE. Sólo unos pocos de los más de 200 proyectos de exploración de REE en todo el mundo serán capaces de sobrevivir en un mercado cada vez más competitivo.

There was a time, only about three years ago, when the western world suddenly became alarmed that China was going to crush the high-tech sector of western economies due to its dominance in rare-earth-element (REE) mining and processing. China then had a share of 95 % of the global REE production and began to impose export restrictions. Prices rose dramatically in 2011, for some REEs up to a hundredfold. It appeared that Deng Xiaoping's famous strategic forecast "The Middle East has oil - China has rare earths" would become true.

However, the alarm was short-lived. The elevated REE prices were the incentive for a multitude of exploration and development projects around the globe. It turned out that rare earths are not as rare as their name would suggest. The Chinese share of rare-earth production now stands at about 80 % of the world market (***Fig. 1***), and several new projects outside China will add additional REE production in the coming years. Prices in 2012 were half of their 2011 peak, and half again in 2013.

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The price range expected for the coming years is about 2.5 times the pre-2010 prices, which had been relatively static for many years and drove all non-Chinese competitors out of the market. There is now fear of oversupply, given the discovery of several large and high-grade REE deposits outside of China. Only a few major low-cost REE mine projects will survive out of the more than 200 REE exploration projects of recent years. This report aims to delineate some main features of the economic geology of the rare-earth elements with a perspective for the coming years.

Economic background and geology

Rare-earth elements are the 15 lanthanide metals at the bottom of the periodic table, from lanthanum (atomic number 57) to lutetium (71), plus the chemically similar metals scandium (21) and yttrium (39) (***Fig. 2***). Some of these elements are exceptionally useful for high-tech applications such as supermagnets, lasers, solar panels, and advanced catalysts. Much of the industrial potential of these "modern" metals is still in the research stage, and demand for particular REEs is dynamic and may quickly change with technological progress. Some of the REEs are common

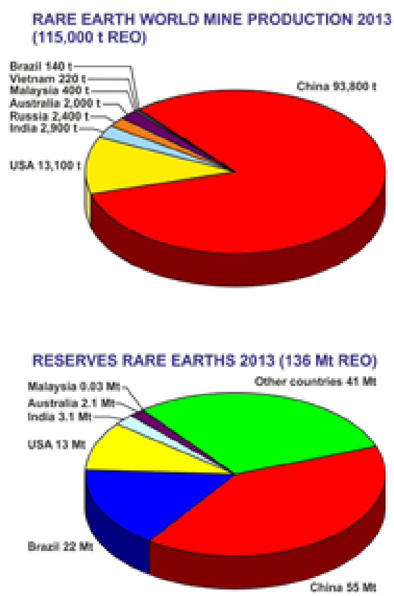

Figure 1: REE world mine production (top) and reserves (bottom) based on information from the U.S. Geological Survey (USGS, Mineral Commodity Summaries, Rare earths, February 2014). The USGS definition of reserves includes here what is internationally known as resources. REE resources are very large relative to current and expected future demand and are increasing with current exploration.

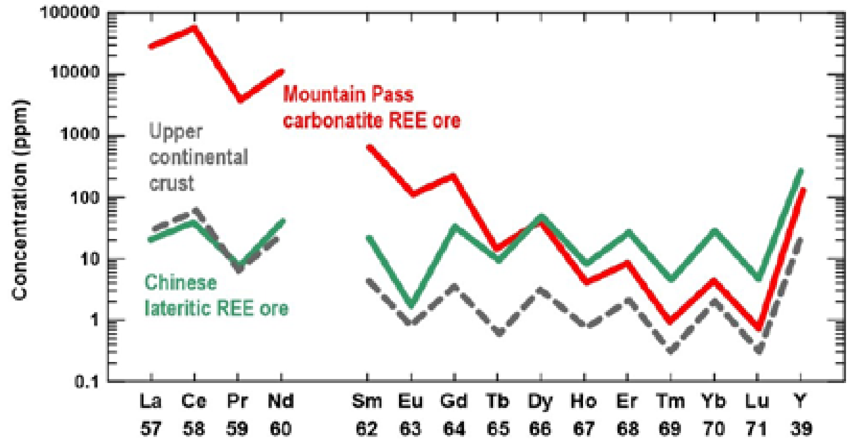

Figure 2: Abundance patterns of the rare-earth elements in the average upper continental crust and in two representative REE ore types, i.e. high-grade carbonatite ore from Mountain Pass, USA, and lateritic ion-adsorption ore from southern China. The gap at atomic number 61 is due to the fact that promethium has no long-lived or stable isotopes and does not occur in natural materials. From Haxel et al. *(2002).*

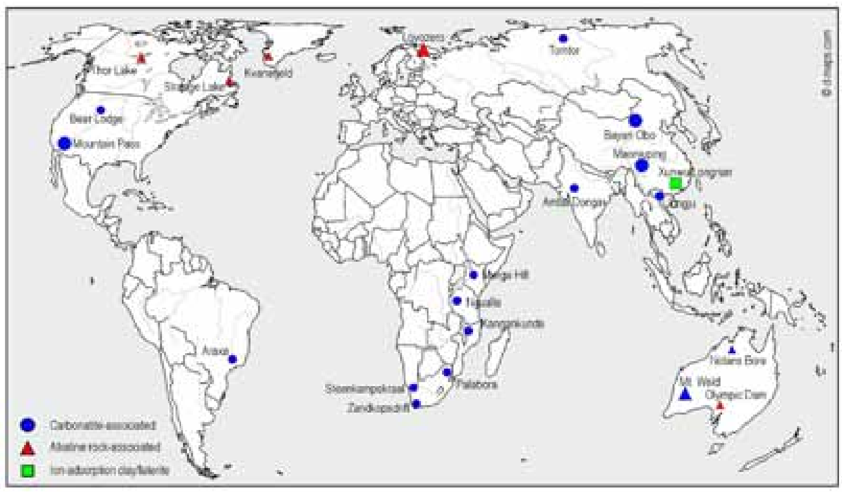

Figure 3: Major REE mines (larger symbols) and exploration/development projects (smaller symbols). Current REE production is mainly from China (Bayan Obo and Maoniuping, as well as many smaller deposits working on lateritic weathering crusts) and from Mountain Pass in the USA. The Mount Weld deposit in western Australia is scheduled to produce 11,000 t REO in 2014. Several mines in the Lovozero district (Russia) on the Kola Peninsula produce about 1000 t REO/year as by-product of niobium-titanium mining.

in the Earth's crust, i.e. comparable in abundance to the base metals copper, zinc, or nickel, with a few tens of g/t (=ppm). These are the light REEs (atomic numbers 57-63; LREE) such as lanthanum, cerium and neodymium. Some of the heavy REEs (atomic numbers 64-71; HREE) such as terbium or lutetium, but also europium, have abundances around 1 g/t, which is similar to tungsten or bismuth, but still orders of magnitude more than gold or platinum.

The prices of individual REEs are very variable and depend on both geological availability and technological demand. The group of REEs always occurs together in ore deposits, but in a specific mix for each deposit, and cannot be mined separately. This situation of "coupled elements" (Wellmer 2008) leads to an imbalance between the proportion of different REEs produced and that required by the market. There are one or a few elements in high demand (and consequently high-priced) which drive REE production. Such "drivers" are europium and terbium, used for phosphors in video screens and LEDs, and neodymium together with praseodymium and dysprosium in permanent magnets. Other REEs are relatively cheap, but technological progress may quickly modify the demand structure. The market value of the global 2013 REE mine production of approximately 115,000 t REO (grade and production of REEs are usually given as rare-earth-element oxides in the mining industry) is about 3-4 billion USD, which is orders of magnitude less than that of iron ore or copper. Most of this value comes from the processing of the ore, i.e. separation and purification of the individual metals or metal oxides, which is difficult due to the chemical similarity of the REEs. The mining cost of the ore is only about 5 % of the total production cost. This is different to most other raw materials.

In terms of value, neodymium and praseodymium dominate the global REE market, with 1.9 billion USD (23,000 t) combined. These two metals are mainly used for $Nd_2Fe_{14}B$ permanent magnets, and demand is forecast to grow at 10 % per annum, driven by the wind turbine, automobile and personal electronics sectors. Rare earth magnets are significantly stronger and have greater temperature resistance than conventional ferrite magnets. The next important market by value is phosphors (light-emitting electrodes) in which europium and terbium are mainly used (about 600 t @ 680 M USD). The big-volume elements lanthanum and cerium represent the largest share in the REE market in terms of tonnage (about 72,000 t @ 550 M USD); they are mainly used in nickel-metal-hydride batteries, super-alloys, and as catalysts for pollution control and refining of oil. There are a number of emergent markets, such as LREE polybutadiene rubber for "green" tyres with less road resistance, i.e. lower fuel consumption, and many more.

REE deposit types

The major REE mines are related to carbonatite intrusions (***Fig. 3***). REE mineralisation can be part of a magmatic intrusion, such as at Mountain Pass, USA; or it can be part of a carbonatite-associated hydrothermal system, such as at Bayan Obo, China; or it can be part of the laterite profile above a carbonatite intrusion (supergene enrichment), such as at Mount Weld, Australia, or Ngualla, Tanzania, with pristine low-grade REE mineralised carbonatite below. The carbonatite-related REE deposits are all strongly dominated by LREEs (***Fig. 2***) concentrated in the two major REE minerals of bastnaesite [$REECO_3F$] and monazite [$REEPO_4$]. Nevertheless, each ore deposit has its individual mix of REEs and therefore a specific ore value. Tonnage-grade data for the major mines and prospects are compiled in ***Fig. 4***.

REE production from carbonatites started in the 1960s with the Mountain Pass deposit in California, which dominated the REE market until the mid 1980s, when it was replaced by the Bayan Obo mine in northern China, where REEs were (and are) a by-product of large-scale iron ore mining. The resources of Bayan Obo are estimated at 1.5 Gt @ 35 % Fe with part of the orebody at 5-6 % REO. The Mountain Pass mine was a world leader in REE production from 1965 until 1985, when the cheap Chinese REE production from Bayan Obo forced this mine to stand-by for more than twenty years. Mountain Pass came back to life in 2013 after a 1.4 billion USD investment in state-of-the-art mining and processing technology. Production in 2013 was 13,100 t REO with proceeds of 42.3 USD/kg Σ REE metal and oxide products, and production in 2014 is scheduled at 19,000 t REO. The Mountain Pass open-pit mine has reserves of 18 Mt (million tonnes) at an average ore grade of 8 % REO (cut-off grade of 5 % REO), but a much larger resource. The Mount Weld project in western Australia has reserves of 24 Mt at an average ore grade of 7.9 % REO. The open pit was scheduled to operate with a cut-off grade of 2.5 % REO, but the cut-off is now revised to 4-7 % REO given the still decreasing world market prices for REEs.

Alkaline rocks host another type of mineralogically more complex REE mineralisation which has elevated contents of HREEs. These deposits usually are polymetallic and also carry mineralisation of Nb, Zr, Hf, Ti and U, but still need to prove their economic viability. A classical type example is the Lovozero district in the Kola alkaline province of NW Russia, with very large apatite and titanite deposits with current (Umbozero and Karnasurt mines) and planned (Alluaiv) REE by-production from loparite, a REE-bearing titanium-niobium oxide.

The Kvanefjeld REE-U-Zn deposit is in the Ilimaussaq alkaline complex of southwestern Greenland, which is similar to the alkaline rocks of the Kola Peninsula, and has a very exotic mineralogy. The Kvanefjeld deposit was explored since the 1970s for uranium, bound in the complex sodium-zirconium silicate of eudialyte, which carries elevated contents of U and REEs, together with other exotic minerals such as steenstrupine, a U-bearing Na-REE silicate-phosphate. The deposit is most valuable for its uranium resource with planned by-production of REEs and Zn (956 Mt @ 273 g/t U_3O_8, 1.1 % REO, 0.24 % Zn; at a cut-off grade of 150 g/t U_3O_8). However, although mining can be by open pit, REE recovery may be difficult and expensive, as for most alkaline rock-hosted REE deposits.

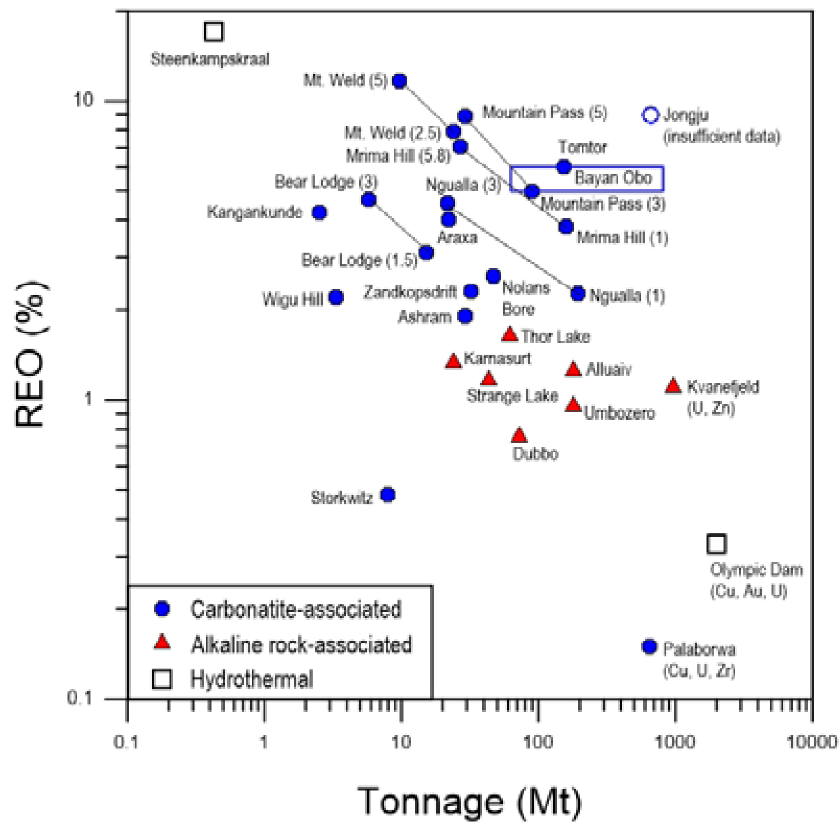

Figure 4: Tonnage-grade plot for major REE mines and exploration/development projects (for location see **Fig. 3***). Numbers in parenthesis for some deposits are cut-off grade in % REO. The large-tonnage deposits of Kvanefjeld (Greenland), Olympic Dam (Australia) and Palaborwa (South Africa) have REEs as possible by-products only. Resource data for the recently announced Jongju deposit in North Korea are currently insufficient, and the Tomtor (Russia) data are inferred resources only. The box for Bayan Obo (China) locates the various grade-tonnage estimates for this deposit. Ion-adsorption clay/weathering crust deposits from South China are not shown; individual deposits of this type are small and usually have grades around 0.1 % REO (with a dominance in HREEs and Y). The Storkwitz REE occurrence in Germany is shown for comparison; this carbonatite prospect is not only small and low grade but also at >600 m depth. Monazite placer deposits are not shown; they have a grade of <0.1 % REO. Base data from Orris and Grauch (2002), actualised and complemented by company information (Alkane Resources, Arafura Resources, Avalon Rare Metals, Commerce Resources, Frontier Rare Earths, Greenland Minerals, Lynas Corporation, Molycorp, Pacific Wildcat Resources, Peak Resources, Quest Resources, Rare Element Resources, Seltenerden Storkwitz), and Hoatson* et al. *(2011), Eilu (2012) and Elsner (2012). See the rare-earths blog at* http://www.techmetalsresearch.com *for updates and* in-situ *ore value based on proportion of REEs and actual REE prices ("basket price").*

Monazite is a common accessory mineral in all igneous rocks and can be concentrated in placer deposits together with other erosion-resistant heavy minerals such as ilmenite, zircon or cassiterite. Monazite-rich placers were an important source for REE production until the mid-1960s. Their grade is <0.1 % REO. There is currently a very minor REE by-production from titanium placer mining. The major problem of monazite mining is radioactivity due to elevated thorium content, which imposes a high cost for handling and disposal of radioactive material. However, if thorium should become an attractive raw material for thorium-based nuclear power, then monazite mining for both Th and REEs may become attractive again.

A particular type of REE deposits is lateritic weathering crusts over granitic terrain. Tropical/subtropical weathering leads to residual enrichment of REEs with preferential enrichment of HREEs and Y by adsorption to the clay fraction. This type of residual lateritic enrichment deposits has very low grade, commonly <0.1-0.3 % REO, and small tonnage, but is mined at many localities in South China due to its valuable HREE content (*Fig. 2*), and low investment cost. Mining, mostly in a semi-industrial way, is by acid leaching and produces serious environmental problems of which the local population and the Chinese government are now becoming aware.

A similar enrichment process by preferential adsorption of HREEs, but by iron-manganese oxides/hydroxides from seawater, is known from deep-sea nodules/crusts and sediments with very low clastic or biogenic input. Such REE-rich pelagic muds in the South Pacific have around 0.1 % REO, easily recoverable by dilute acid attack (Kato *et al.* 2011). Due to their vast extent, these oceanic muds hold enormous resources, although their recovery from 4,000-5,000 m water depth is currently illusionary.

A more accessible and very large REE resource is locked in apatite, which occurs both in magmatic and sedimentary phosphate deposits. The giant sedimentary phosphate deposits (annual world mine production of 224 Mt of phosphate rock in 2013, with Morocco and USA as major producers in the western world) have a few hundred ppm REEs on average, and magmatic-hydrothermal apatite deposits carry a few thousand ppm REE. There are innovative low-cost processing technologies currently in development to extract REEs from phosphoric acid and phosphogypsum which could strongly impact the REE market (Christmann 2014).

Conclusions

The decision by the Chinese government in 2011 to impose an export quota for REEs has made the public and policy-makers aware that some key industries in the western world are critically dependent on a secure supply of these "modern" metals. This is particularly true for electric power from wind turbines (a modern 3 MW wind turbine uses 300-600 kg Nd+Pr), automobiles (a conventional car has currently about 0.5 kg of REEs, and electric/hybrid cars need 20-30 kg of REEs), or for billions of smart phones and light-emitting phosphors (LEDs) with <1 g REE each.

The rare-earth metals are not rarer than the more familiar industrial base metals such as lead, zinc, copper, or tin. Their perceived rareness is a consequence of the apparent rareness of their occurrence in ore deposits, which is largely due to decades of low REE prices and consequent lack of exploration. The price hike in 2010/2011 induced a significant global exploration effort with the discovery of dozens of new REE deposits. For some applications, it also induced the substitution of REEs by other raw materials. Exploration and development success led to an increase in REE mine production outside China, concomitant with significant decreases in price. Several new mines will add REE mine capacity over the next few years. Only low-cost producers with high ore grade, favourable mineralogy, and know-how in complex processing technology will survive. Development of the giant Tomtor deposit in northern Siberia or confirmation of the recent reports on the apparently very-large and high-grade Jongju deposit in North Korea could markedly disturb the REE price structure.

There may be short-lived supply shortages (and corresponding price increases) for some specific REEs, but it can be expected that global reserves and resources of REEs are large enough to meet global demand for a very long time to come, even if high growth rates in demand should actually occur. The REE market of the last years has shown the effectiveness of the self-regulating "feedback control cycle" of mineral supply, i.e. increase in price triggers response both on the supply side (mine development, recycling) and in demand (substitution and new technologies) (Wellmer and Dalheimer 2012). In the past, a Chinese monopoly in REE production came about due to too low prices, even though REE resources are widespread over the globe. Now, however, the supply risk is decreasing due to a more geographically balanced mine production pattern, and this situation is expected to continue for the near future.

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Exploration adventures in the Recsk Ore Complex

*János Földessy, Éva Hartai and Tibor Zelenka**

A large base metal and precious metal ore zone in the centre of Europe has been waiting for development and commissioning for more than forty years – this is the Recsk Ore Complex in NE Hungary. Being a deep undeveloped complex of ore bodies, it has offered great challenges for both explorationists and mining engineers. Now its opening is again being planned by the Hungarian Government, and following a significant face-lift, a revised geological model and resource assessment has been inserted in the data package for the investors.

Un vaste gisement de minerai métallique incluant une zone de métal précieux, au centre de l'Europe, est en attente de développement et d'investissement depuis plus de quarante ans – il s'agit du Complexe minier de Recsk, au Nord-Est de la Hongrie. Constitué par un ensemble complexe, non développé, de corps minéralisés profonds, il a représenté un défi majeur à la fois pour les ingénieurs en exploration et en exploitation. Aujourd'hui, son exploitation est à nouveau programmée par le Gouvernement hongrois, et, à la suite d'une rénovation significative, un nouveau modèle géologique et une nouvelle évaluation des ressources potentielles ont été incluses dans le dossier des données, destiné aux investisseurs.

Una gran zona de metales comunes y de metales preciosos en el centro de Europa ha estado esperando su desarrollo y puesta en marcha durante más de cuarenta años – se trata del Complejo Recsk Ore en el noreste de Hungría. Siendo un yacimiento profundo, no desarrollado y complejo, ha ofrecido grandes desafíos tanto para los profesionales encargados de la exploración, como para los ingenieros de minas. El Gobierno de Hungría está planificando ahora su apertura, y después de un importante lavado de cara, un modelo geológico revisado y evaluación de los recursos ha sido insertado en el mercado de valores para los inversores.

Recsk – a large ore complex in the centre of Europe

For economic geologists the Recsk ore complex is a textbook item. A cluster of ore deposits, significant enough to rank among the world's largest occurrences, and yet undeveloped, has been sleeping silently under water. Recsk, a village some 120 km east of Budapest, has experienced several ups and downs over the last five decades (***Fig. 1***). Large-scale long-term plans mingle with real-time short-term downturns. The town of 3,000 people is awaiting a better future.

Figure 1: Location of the village of Recsk.

Enargite breccia ores – a century old small enterprise at the Lahoca Hill

The discovery and mining of small copper ore veins near Recsk goes back to the 1770s. Adits and drifts testify to the early efforts of miners, which were unsuccessful until the first larger finds of copper ores in Lahóca Hill in 1852. Since that time the artisanal mine has served as a workplace for several generations, through intermittent active periods with an annual production reaching maximum 50,000 tons of low grade 0.6 % Cu refractory copper ores with significant gold and silver credits, under frequently changing ownership. After becoming state owned in 1926, a flotation mill was installed in 1931, and actively served the mine until its closure in 1979. Meanwhile, repeated exploration campaigns were aimed at stabilising the resource background of the small mine, leading to the discovery of eleven small, isolated enargite-luzonite-pyrite breccia ore bodies in Paleogene andesite volcanics. The last of these discoveries was made by accident in 1970, prolonging the life of mining by almost ten years. Between the beginning and 1979, 3.1 Mt of siliceous hydrothermal breccia was exploited with enargite copper mineralisation and gold indications (Földessy & Szebényi 2008).

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Porphyry copper and skarn complex in the depth

One of the exploration models used in searching the continuation of the Lahoca was, in brief: go deep. This strategy was tested successfully in the thirties by drilling a 1000 m deep hole (Parád-3) in Lahoca Hill, which discovered mineralised deep

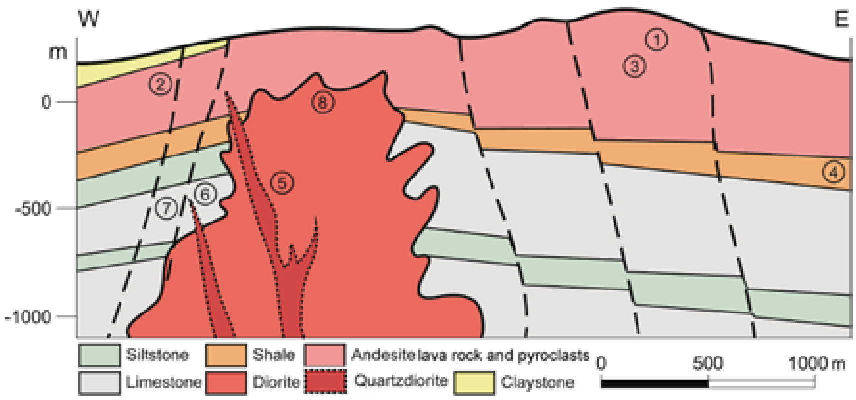

Figure 2: W-E cross-section showing the position of the Mesozoic/Paleogene interface relative to the surface and the mineralisation types. Siltstone, limestone, shale: Mesozoic; andesite, diorite, quartzdiorite: Eocene-Oligocene; claystone: Upper Oligocene. Mineralisation types: 1: HS Cu-Au, 2: LS Au-Ag, 3: Cu-pyrite-enargite-luzonite, 4: stratiform Zn-Cu, 5: mesothermal porphyry Cu, 6: skarn Cu, 7: skarn Zn, 8: low-grade porphyry Cu.

roots of a known orebody. The next plan in 1962 was to drill four 1000 m deep holes in the northern and southern foreground, and the unexpected result was intersecting significant Pb-Zn metasomatic orebodies at greater depth, in the underlying Mezozoic carbonate rocks. In 1965 the subsequent step-out drilling westward also brought a surprise: two drillholes discovered mineralised Cu-Mo bearing diorite porphyry in 170-330 m mineralised thickness, from 700 to 1000 m depth. This hit rapidly triggered a large-scale drilling exploration, which was completed in 1980, after deepening 130 holes for a total length of 155 km and an average depth of 1200 m. Several important other mineralisation types have also been identified (***Fig. 2***), like skarn Cu-Au orebodies on the contacts and large high grade metasomatic Pb-Zn ore zones in the limestones (Baksa *et al.* 1988).

The resource estimates in that period gave 779 M tonnes 0.65 % porphyry and skarn Cu ore (JORC non-compliant, inferred) with an additional 85 Mt 1.01% Pb, 2.68% Zn, and 0.37% Cu hydrothermal metasomatic ores (Cseh-Németh *et al.* 1984).

The state-owned mining company was financed from the central government budget to make steps towards the opening of the mine.

A full scale mine for exploration? – Shafts to 1250 m depth

The chosen strategy was to build a fully installed mine for the exploration stage, parallel with the underground definition drilling. Shaft sinking was started in 1970, and two 1200 m deep shafts (8 m internal diameter, located 2 km apart from each other) were completed diagonally to the axis of the porphyry ore-body. The shafts were connected by drifts at 900 m and 1100 m depths for underground drilling exploration (more than 500 diamond drillholes, with a total length of 88,000 m). As a result, the central core of the occurrence was explored to indicated-inferred level, and 7.3 Mt 2.34% Cu, 3 Mt 5,53 % Zn ore was delineated (Földessy & Szebényi, 2008) (***Fig. 3***).

The increasing financial difficulties in covering the exploration costs finally resulted in the suspension of the underground explorations (1983), although the facility was maintained in operation until 1998. Dewatering was carried out by the draw-off of 2.5 m^3/s water. In 1998 the pumps were stopped, and the facility has become flooded.

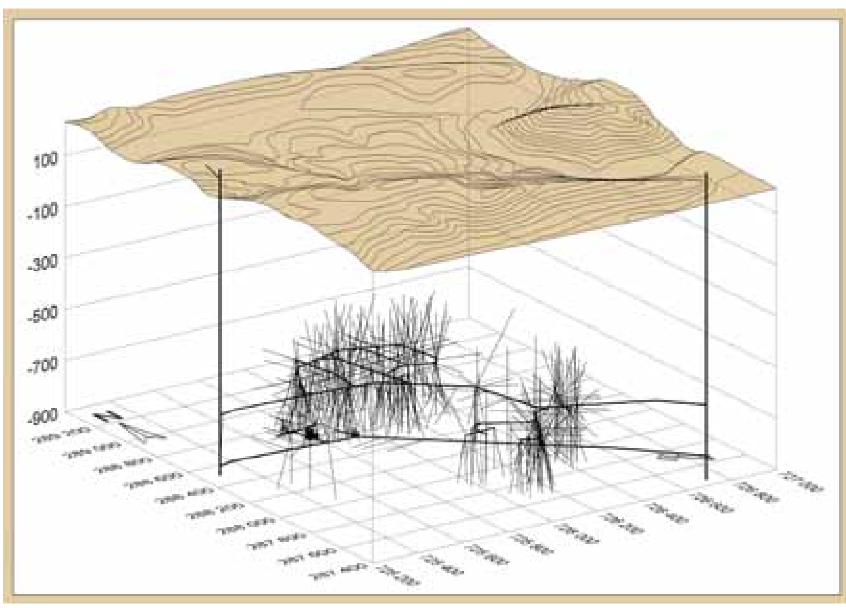

Figure 3: Spatial arrangement of underground exploratory works in the Recsk Deep. Thick line – drift or shaft, thin line – borehole, vertical scale – altitude in m, northing and easting – national ('EOV') coordinates in m, elevation contour interval is 10 m (Szebényi et al. *2008)*

Privatisation failures

Once the need to pull in external funds became obvious, starting in the late 1970s several attempts were made by the Hungarian Government to attract investors to take part in the financing of the project. Several major mining companies visited the occurrence but declined the opportunity. Other interested parties were also involved at a certain stage in the negotiations. The last public tender was announced in 2008. These attempts, however, have not been successful, mainly due to the significant geological risk, time and investment needs of further explorations at this great depth.

Gold – an exploration alternative

From 1993 an interesting alternative exploration direction has been opened by the re-interpretation of the Lahoca Cu-Au mineralisation, and commencement of gold explorations by an Australian junior company, Rhodes Mining. In three years more than 10,000 m of diamond holes were drilled and a 1.5 M ounce gold deposit (inferred and indicated) was defined near the surface, some 1 km east of the porphyry copper mineralisation. The relatively low grade (1.45 g/t Au) ore did not prove to be economic, due to the depressed gold prices at that time, at levels around 250-280 USD/oz. The junior company gave up its efforts in 1997. Although the presence of juniors has been continuous since that time, exploration efforts have been only sporadic.

Going underwater – flooding and maintenance

Flooding of the Recsk Deeps was decided and executed in 1998. This step meant stopping the pumps and letting water rise to flood the deep mine levels. The headframes were demolished, and the shafts plugged with concrete. When the last of the tenders for the Recsk Deeps in 2008 brought no success, the government decided to cut back the maintenance costs further and put the facilities in the status of long-term closure. This period meant the surface reclamation of the dumps and shaft yards. The sample materials and the database have been kept in good standing. Academic research however, did not stop, and substantial new interpretations have emerged since 2008, like the re-interpretation of the gold and rhenium content of the Recsk Deeps ore types, increasing the importance of the unexplored and neglected geological details of the mineralisation.

New decisions coming

The EU's Raw Material Initiative (2008) was the first moment of the dramatic recognition of the growing demand and deficiency of raw materials in Europe. The initiative and the consequent actions regarding the EU mineral policy have also had an impact on the Hungarian mineral policy, which has slowly turned back to recognising and appreciating the domestic mineral resources. As their crown jewel, the Recsk Complex is among the first on the list. With a resolution brought in December 2013, the government decided to re-assess the economic parameters of the Recsk Ore Complex. This finally raises again the hope for a happy end to this half-century-long exploration story, and gives challenging tasks to a series of geologists, technologists and market experts to overcome the difficulties and weaknesses of this important but problematic resource.

Acknowledgements

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EFG/PERC Conference **MIN WIN-WIN: ESTABLISHING EUROPE-WIDE MINERALS RESOURCES AND RESERVES REPORTING STANDARDS**

THE KEY TO REDUCING RISK AND INCREASING INVESTORS' CONFIDENCE

> *Safe the date: 20 and 21 November 2014*

> *Venue: Brussels, Belgium*

> *Organisers: European Federation of Geologists (EFG) and Pan-European Reserves & Resources Reporting Committee (PERC)*

> *Supported by: CRIRSCO, EuroGeoSurveys, Euromines, ICMM, IMA, IOM3, IUGS Task Group on International Geoscience Professionalism*

Background

The continuing rise in global population and living standards, as well as technological innovation, leads to increasing requirements for a broader range of metals, minerals and other raw materials.

EU manufacturing and improved positioning of EU enterprises in the global value chain is currently highly dependent on imports of mineral raw materials from outside Europe. This dependency is associated with the contraction of primary mining in the EU over several decades, driven by lower costs outside the EU and pressures to protect the natural environment within the EU ("not in my back yard"). Increasingly, EU supply chains for raw materials are adversely affected by growing demand pressure from emerging economies and by an increasing number of national policy measures that disrupt the normal operation of supply chains. This dependence on supply chains that are largely beyond EU control gives rise to risks related to security of raw materials supply, but also highlights opportunities for expanding primary extraction and recycling within the EU in line with sustainable development objectives.

In this context, the European Commission launched the European Raw Materials Initiative (RMI) in 2008. The principal objectives of the RMI are:

- to stabilize long-term commodity prices by removing market distortions;
- to provide alternative approaches to meeting demand;
- to support the transition to a low carbon and resource-efficient economy.

The RMI itself is structured around three pillars:

- access to raw materials on world markets;
- increasing the sustainable supply of raw materials from within the EU;
- enhancing resource efficiency and promoting recycling.

Fundamental to the second pillar of the RMI is an improved knowledge base of mineral deposits at EU level. Any improved knowledge base requires comparability and harmonization of national reporting where this includes information relevant to the exploration for and the exploitation of primary mineral resources. To face this challenge, standard definitions and approaches for the estimation and reporting of mineral reserves and resources is vital to ensure data comparability and of ensuring consistency at a range of scales and with a range of objectives:

- Maximising opportunities at EU or Member State level - updating raw material resource inventories, and developing and implementing spatial planning policies aiming to avoid sterilization of raw materials that could be exploited sustainably;
- Reducing risk and creating opportunities at financial market level – ensuring that investors have access to reliable information to underpin investment decisions, and providing regulators with consistent information to ensure the highest standards;
- Reducing risk and creating opportunities at company level and for regulators – maintaining mineral resource information using a standard basis that is suitable for business planning and monitoring, regulatory compliance and return of reliable and relevant information to planners and policy makers.

Aim

This conference aims to promote the adoption of a common reporting standard in the EU. Such an approach will contribute to the convergence of terminology and the comparability/compatibility of data, thus facilitating the creation of a solid European Knowledge Database on mineral resources and to the successful delivery of the RMI. Such harmonization is equally important to government policy-makers and to companies within the minerals industry - the users and the providers of data on mineral resources and reserves.

Speakers

There will be presentations from speakers representing a range of relevant European policy areas linked to solid mineral raw materials, as well as from experts drawn from EU regulatory authorities (including those of Member States). There will also be contributions from representatives of financial investment companies, the mining industry and academia.

Audience – who should attend?

The conference provides a unique opportunity to learn about and discuss concrete steps regarding mineral reporting in a cross-disciplinary environment, including EU policy makers, national government officials, academics, minerals company executives, finance and industry experts.

More information and registration soon available at *www.eurogeologists.eu* **and** *www.percstandard.eu*

Skarn-type tungsten deposits of Tabuaço area, northern Portugal

*A. Filipe Faria**

Economic skarn-type scheelite deposits occur at Tabuaço, in the Douro valley region of northern Portugal. Tabuaço has the potential to become an important European tungsten producer. The deposits are hosted by meta-carbonate horizons included in a lower-Cambrian sedimentary sequence, within the contact metamorphic zone of a Variscan granite intrusion. The mineralisation was first discovered and explored, to a limited extent, around 1980. Extensive exploration work conducted since 2008 has delineated two deposits, with a total resource of 2.7 Mt averaging 0.56% WO_3, and there is potential to increase this significantly. The orebodies are thick, gently dipping and richly mineralised. Their composition is very favourable for the production of high-purity scheelite concentrates, with plant rejects free of contaminants.

Un gisement économique de scheelite, de type skarn, existe à Tabuaço, dans la région de la vallée du Douro, au Nord du Portugal. Tabuaço peut devenir un producteur européen important de tungstène. La minéralisation est contenue dans des niveaux méta-carbonatés appartenant à la série sédimentaire du Cambrien inférieur, dans la zone de contact métamorphique d'une intrusion varisque de granite. La minéralisation fut d'abord découverte et explorée, à un degré limité, dans les années 1980. Des travaux intensifs d'exploration exécutés en 2008, ont délimité deux gisements, avec des ressources globales estimées à 2.7 Mt et une teneur moyenne de 0.56% de wolfram, et il existe des possibilités d'augmenter ces chiffres de façon significative. Les corps minéralisés sont massifs, avec un pendage modéré et une teneur élevée. Leur composition est très favorable à la production de concentrés très purs de scheelite, avec des rejets d'exploitation dépourvus de contaminants.

Depósitos económicamente rentables de scheelita tipo skarn se encuentran en Tabuaço, en la región del valle del Duero en el norte del Portugal. Tabuaço tiene el potencial de convertirse en un importante productor europeo de tungsteno. Los depósitos se encuentran dentro de niveles de meta-carbonato formando parte de la secuencia sedimentaria del Cámbrico inferior, dentro de la zona de contacto metamórfico en una intrusión de granito Varisco. La mineralización se descubrió y exploró, de forma limitada, en torno a 1980. Trabajos de exploración extensiva llevados a cabo desde el año 2008 han delineado dos depósitos, con un recurso total de 2,7 Mt y un promedio de 0,56% WO_3, y un potencial de aumento significativo. Los yacimientos son depositos, moderamente inclinadas y ricamente mineralizados. Su composición es muy favorable para la producción de concentrados de scheelita de alta pureza.

Tungsten in Portugal

In June 2010 the European Union declared tungsten as a "critical raw material for the EU". Tungsten is in great demand worldwide due to a shortage of supply, and tungsten prices are close to all-time highs.

Portugal is well endowed with tungsten deposits in its central and northern regions (***Figure 1***), where tungsten mineralisation occurs throughout the Central Iberian and the Galicia Trás-os-Montes zones of the Iberian Variscan Orogen (Martins, 2012). The country has historically been one of the most important tungsten producers in Europe, and several mines were in operation until the 1980s. Most of these have since closed down, as a consequence of low tungsten prices in the intervening years. Only the Panasqueira mine, ranking among the largest tungsten mines in the world, has remained in production almost continuously to date.

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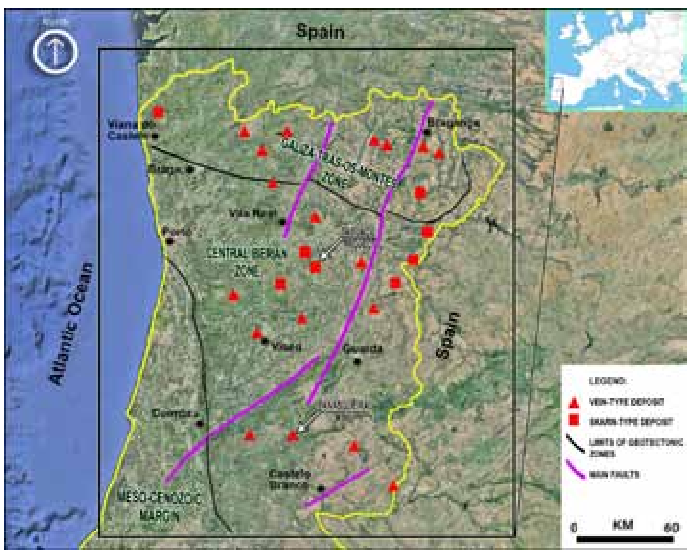

Figure 1: Location of main tungsten deposits in northern and central Portugal.

Portuguese tungsten deposits are spatially and genetically related to Variscan (Upper Palaeozoic) granite intrusions, and may be of two distinct types, namely vein-type deposits and skarn-type deposits (***Figure 1***). The former have wolframite ($(Fe,Mn)\ WO_4$) as their most frequent tungsten mineral, while scheelite may occur locally; economic concentrations of the tin mineral cassiterite (SnO_2) can also be present in some deposits.

The tungsten skarns, on the other hand, have scheelite ($Ca\ WO_4$) as their primary

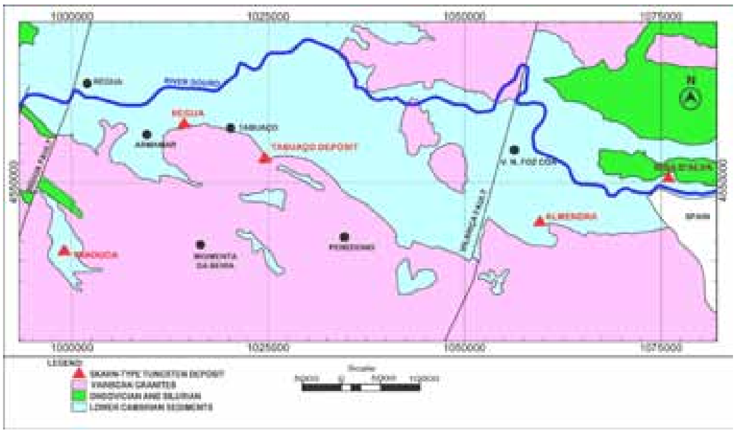

Figure 2: Geologic setting of the Tabuaço tungsten deposits – Simplified geology of the Douro valley region.

tungsten mineral, and are hosted by metasedimentary suites within the contact metamorphic zones of Variscan granite plutons. Two distinct sequences can host potentially economic tungsten skarn deposits, namely: the lower-Cambrian "Schist Graywacke Complex" (e.g. at Tabuaço, Régua, Tarouca – ***Figure 2***); and the Silurian volcano-sedimentary suite (e.g. at Covas, Cravezes).

Most of the outcropping wolframite vein deposits in Portugal had been discovered by the mid-20th century; however, the generally inconspicuous scheelite skarn deposits remained mostly undetected, until modern exploration programs were implemented, initially by government geologists in the 1970s (Pinto, 1979; Ramos and Viegas, 1980), and then followed up by exploration companies.

Exploration History

The Tabuaço tungsten project is situated in the scenic Douro valley region of northern Portugal, well known for its extensive vineyards, and the world famous port wine. The outcropping scheelite-bearing skarns were first discovered by government survey geologists in the late 1970s through geological and UV-light prospecting, oriented by new mapping developments in the region (Sousa *et al.*, 1980).

Shortly after discovery, the Tabuaço area became part of a vast exploration licence held by a joint venture between a Portuguese state mining company, SPE, and a French company, SEREM (a branch of BRGM). Their campaign at Tabuaço, between 1980 and 1982, comprised surface geologic and exploration work, and the drilling of six holes (Alves, 1982). The results from this drilling pointed towards a significant resource potential for the São Pedro das Águias (SPA) deposit. Nevertheless their exploration program was interrupted due to a combination of a complicated landownership situation and low tungsten prices in the early 1980s.

Exploration rights over the area were granted to Colt Resources Inc. in December 2007, as part of its wider Armamar-Mêda exploration licence. The company resumed tungsten exploration at Tabuaço in 2008, with surface geological work, prospecting and sampling, which confirmed the very favourable widths and grades of the skarn beds outcropping east of the Távora River (Faria *et al.*, 2009). A diamond drilling programme carried out in early 2010 (9 holes) verified the SPE-SEREM results and confirmed the economic potential of the SPA deposit (Gruenwald, 2010). This provided the basis for further exploration and evaluation, via an intensified drilling programme that started in late 2010, and continued without interruption until January 2013 (O'Donovan *et al.*, 2012). In addition to the drilling at SPA, the Aveleira deposit was also discovered in February 2012 by drilling based on a geochemical anomaly.

The company has now progressed well beyond the exploration phase of the project, having already done a great deal of deposit modelling and resource estimation work, engineering studies, geotechnical work, metallurgical testwork and environmental studies, culminating in September 2013 with a Preliminary Economic Analysis of the tungsten deposits. The deposits are now covered by an experimental mining concession held by Colt, and the plan is to develop a sustainable underground tungsten mine with minimal environmental impact, maintaining the port wine vineyards and the historical architecture at the São Pedro das Águias medieval convent. This will involve locating the industrial infrastructure of the mine at the Passafrio plateau, where it will be mostly hidden from view by the visitors to the Távora river valley (***Figure 3***).

Geologic Setting

The Tabuaço tungsten deposits are located within the Central Iberian Zone of the Variscan orogen, positioned in the contact zone between two major geologic units, the Beiras orogenic granite batholiths and the lower-Cambrian sediments of the "Schist-Greywacke Complex" (SGC) – ***Figure 2***.

The SGC comprises several recognised sedimentary formations (Ferreira and Sousa, 1994), mostly made up of metapelites and metapsamites, with subordinate conglomerate and carbonate beds. These rocks were folded and regionally metamorphosed during the Variscan orogenic cycle (Upper Palaeozoic). They were also intruded by Variscan granitoids, which created the important contact-metamorphic aureoles. Late to post-orogenic faulting has caused several significant displacements, both vertically and laterally.

The most promising tungsten deposits are hosted by the lowermost unit of the SGC, the so-called Bateiras formation, which is characterized by black graphitic schists at the base, and grey schists with intercalated carbonate beds above. This formation outcrops only at the core zones of Variscan anticlinoria, being easily recognised by the distinct appearance of its basal graphitic schists. The carbonate beds are the host rocks for the tungsten mineralization, after being exposed to the metamorphic and metasomatic processes at the contact zone of granite plutons. These processes originate the transformation of the original mineral assemblages of the carbonate rocks (carbonate minerals, clay minerals, silica, etc.) into new mineral assemblages of the so-called calcsilicate minerals (epidote, garnet, amphibole, pyroxene, vesuvianite, etc.) that make up the skarns and calcsilicate rocks.

Project Location and Geology

Skarn tungsten mineralisation outcrops some 5 km southeast of the town of Tabuaço, along both banks of the Távora river, a 1st order tributary to the Douro River. The Távora runs in a northeast trending narrow valley with steep slopes, and heights ranging from 175 m AMSL at the valley bottom, to above 900 m AMSL at the top of the adjacent Armamar-Tabuaço granite mountain (***Figure 3***).

Land occupation mostly consists of vineyard farms, with minor olive, almond and fruit tree groves; there are a couple of small village settlements, and a proportion of the project area is covered by forest, bush and grassland.

The geology of the area (Sousa *et al.*, 1980; Alves, 1982; Faria *et al.*, 2009) is characterised by a granite-metasediment contact zone, where the SGC's Bateiras metasedimentary formation nears the late-Variscan Armamar-Tabuaço granite pluton, the youngest of the several syn- to post-tectonic granite intrusions that crop out along the Tabuaço-Penedono-Escalhão antiform (Ferreira and Sousa, 1994).

Regional metamorphism is low in grade (low greenschist facies), whereas the superimposed contact metamorphic phenomena are very strong. The local structure is marked by the Távora anticline, which has a NW-SE trending axis with a gentle plunge to NW. Its core zone is marked by the black graphitic schist unit, which outcrops at the bottom of the Távora river valley (***Figure 4***). The northeast and southwest limbs of this anticline outcrop at the eastern and western slopes of the valley, respectively.

Scheelite mineralisation is hosted by the meta-carbonate beds, which are stratigraphically close above the basal black graphitic schists, and include skarns, calcsilicate rocks and calcschists, of which only the skarns have economic mineral contents.

Scheelite-bearing skarns have been recognised on both limbs of the Távora anticline. Those on the NE limb (Quinta do Paço, Azenha Velha) are generally narrow in width, poorly mineralised, and dip around 45-55º to NE, and are therefore of less economic interest.

The most prospective scheelite skarns (e.g., SPA and Aveleira) are located on the SW limb of the anticline, i.e. on the western slopes of the valley, spreading south to north from the Herédias farm, through the São Pedro das Águias and Aveleira farms, to the area around the Quintã village (***Figures 3, 4***). They are generally thicker, richer in tungsten mineralisation (due to their close proximity to the granite) and have gentle westerly dips, features that, when combined, make them attractive for mining.

Figure 3: Panoramic view of the Tabuaço tungsten project area, at the western slope of the Távora river valley. The São Pedro das Águias and Aveleira vineyard farms are at the lower part of the slope, with the Tabuaço granite mountain above.

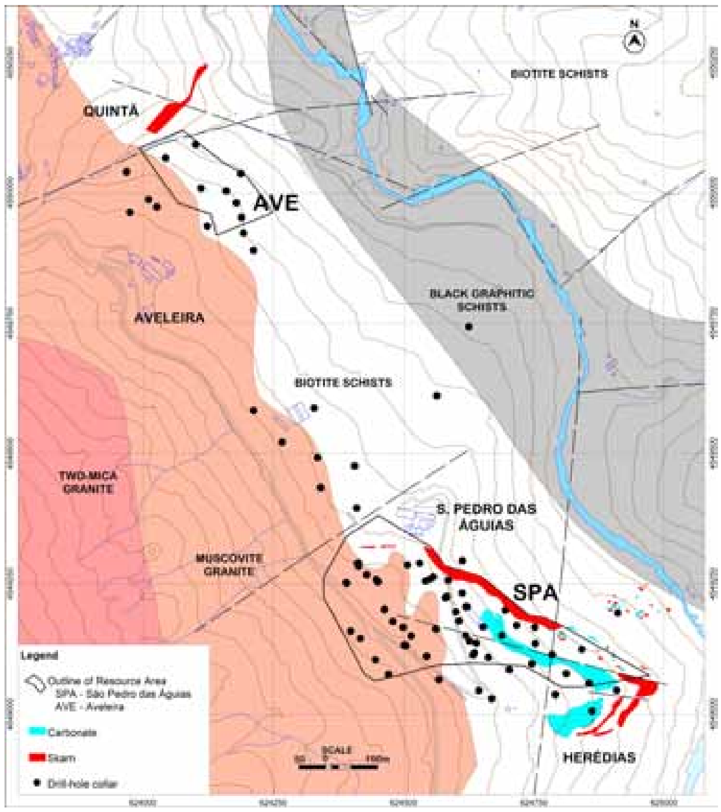

Figure 4: Geology of the Tabuaço tungsten project, at the western bank of the Távora river, showing the most important skarn outcrops and the outline of the São Pedro das Águias and Aveleira resource areas.

Exploration Work

After the initial discovery of tungsten-bearing skarns at Tabuaço, a number of exploration methods were employed, with varying rates of success, to fully investigate the known mineralisation and to try and locate additional mineral occurrences (Faria *et al.*, 2009; Gruenwald, 2010):

- Stream sediment surveys, including both geochemical and pan-concentrate sampling – geochemical W and (especially) anomalous scheelite in pan-concentrates are both good indicators of mineralisation in the catchment area;
- Night-time "Mineralight" (UV-lamp) prospecting, in order to detect anomalous areas with scheelite-bearing outcrops, float, or even scheelite debris in soils, since this mineral glows with a bright bluish white fluorescence under short-wave UV light;
- Geologic prospecting and reconnaissance mapping, accompanied by the collection or rock chip samples of skarns and other calcsilicate rocks, for examination under UV light as well as chemical analysis;
- Soil geochemical surveys, with multi-element chemical analysis – anomalous values for both W and skarn indicator elements (such as Ca, Ti, Sr, Mg, Mn) were instrumental in the positioning of the first drill hole that led to the discovery of the Aveleira skarn tungsten deposit, a sub-outcropping hidden under the vineyard terraces of the Aveleira farm (***Figure 4***);
- Trenching in order to expose, map and sample the bedrock in anomalous areas – unfortunately this was limited, in order to avoid damaging the vineyards.

Follow-up, advanced exploration and

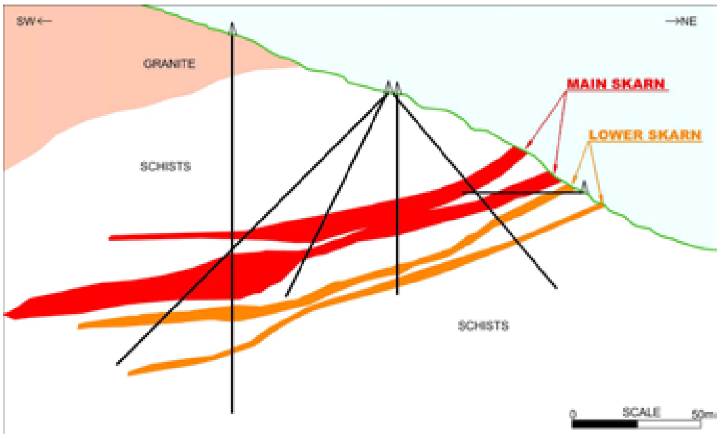

Figure 5: Cross section of the São Pedro das Águias deposit; illustrating the extension of the metasedimentary suite and the mineralised skarns underneath the Tabuaço granite, and the bifurcation of the skarn zones.

Table 1: Selection of Mineralised Drill Intersections from Tabuaço Deposits.

Hole	Inclination	Azimuth	From (m)	To (m)	Interval (m)	True Width (m)	WO_3% (avg.)
			São Pedro das Águias deposit				
DHT-01B	-90	-	19.15	37.95	18.80	17.67	0.71
DHT-02	-90	-	52.60	66.20	13.60	12.78	0.99
DHT-08	-90	-	42.40	54.40	12.00	11.28	0.60
DHT-09	-45	N210	93.60	115.20	21.60	19.40	0.54
DHT-12	-90	-	58.35	68.00	9.65	9.07	1.33
DHT-13	-50	N030	92.80	100.45	7.65	7.13	1.11
DHT-14	-90	-	77.30	85.65	8.35	7.84	1.29
DHT-15	-60	N055	108.35	122.55	14.20	13.95	0.89
DHT-25	-65	N210	53.78	64.62	10.84	10.75	0.95
DHT-26	-90	-	14.10	27.50	13.40	12.59	0.76
DHT-31	-60	N126	147.75	154.75	7.00	5.88	0.74
DHT-33	-50	N330	18.20	24.40	6.20	4.11	0.84
DHT-51	-90	-	60.35	66.35	6.00	5.64	0.99
			Aveleira deposit				
DHT-49	-90	-	24.40	30.35	6.05	5.69	1.25
DHT-70	-90	-	67.00	78.00	11.00	10.34	0.88

Table 2: Tabuaço Resource Inventory.

Resource category	tons of ore	avg. grade (% WO_3)	contained metal (MTU WO_3)
Indicated	1,495,000	0.55	815,000
Inferred	1,230,000	0.59	720,000
Total	2,725,000	0.56	1,535,000
Note: 1 MTU (metric ton unit) = 10 kg			

evaluation of the identified tungsten occurrences comprised:

- Detailed geologic mapping and structural studies;
- Channel sampling of skarn outcrops for tungsten assay and multi-element analysis;
- Diamond drill hole campaigns, first comprising reconnaissance holes for confirmation of the extent of the mineralisation at depth; then grid drilling for resource delineation. In total 82 exploration and evaluation holes (9,760 m) have been drilled by Colt to date;
- In addition, a number of diamond drill holes were drilled for metallurgical testwork (8 holes, 736 m), as well as for geotechnical purposes (2 holes, 154 m).

Mineral Deposits

Two economic mineral deposits have been delineated thus far at Tabuaço, west of the Távora River, namely at the São Pedro das Águias (SPA) and Aveleira deposits (***Figure 4***), which have the following geologic features in common (Gruenwald, 2010; O'Donovan *et al.*, 2012):

- Two skarn horizons richly mineralised in scheelite (Main Skarn and Lower Skarn), separated from each other, as well as from the basal black schists, by micaceous, pelitic to psamitic schists; each of these skarn horizons may be displaced by faulting, or repeated by folding, leading to the bifurcation shown in the drill sections of the SPA deposit (***Figure 5***);
- Occurrence locally of one carbonate, or calcschist horizon (sometimes with moderate scheelite mineralisation), above the Main Skarn, and also separated from it by micaceous schists (***Figure 4***);
- Both the skarn and carbonate horizons have widths occasionally exceeding 20 m, and generally gentle dips (~20º) to W or SW;
- The deposits are in very close proximity to the marginal, leucocratic facies (albitic-muscovitic) of the Armamar-Tabuaço granite intrusion (***Figure 4***);
- The metasedimentary sequence, including the skarns and carbonates, have been confirmed by drilling to extend westerly under the edge of the granitic intrusion (***Figures 4, 5***);
- Aplitic rocks (sills), often with metre widths, frequently intrude the skarns as well as their enclosing schists;
- Late faults, with several orientations, cut through the whole sequence and sometimes have significant vertical and/or strike-slip displacements.

The mineral assemblages of the Tabuaço skarns are made of various combinations of sodium-plagioclase, K-feldspar, vesuvianite, epidote, zoisite/clinozoisite, diopside, garnet (grossular), hornblende, tremolite-actinolite, quartz, sericite, calcite, fluorite, apatite and scheelite.

During exploration drilling, two distinct types of skarn have been distinguished in the project area, which are interpreted to have resulted from original carbonate rocks with distinct compositions, namely:

- "M-type" skarn, most frequent in the Main Skarn Horizon (upper); coarser and more massive, largely composed of albitic plagioclase and vesuvianite; generally richer in scheelite;

- "L-type" skarn, most frequent in the Lower Skarn Horizon; finer grained and more layered, principally made of K-feldspar, epidote-group minerals, vesuvianite and diopside; generally lower in scheelite contents, though still of economic value.

Economic Potential

The SPA and Aveleira deposits also share a number of characteristics that make them particularly attractive from a mining perspective:

- Thick mineralised bodies (skarn horizons), normally in the 5-20 m range (***Table 1***), with strike and dip extents of some hundred metres, and a gentle inclination (***Figures 4, 5***);
- Richly mineralised in scheelite, with generally high tungsten grades (***Table 1***);
- The scheelite mineral has a high degree of purity, being essentially devoid of molybdenum (a penalising element);
- Metallurgical testwork indicates the possibility of obtaining high-grade (70%) WO_3 concentrates through the application of a combination of gravity and flotation methods;
- Possibility of recovering fluorite as a by-product with significant commercial value;
- Good quality ore gangue, mostly made up of silicate minerals and practically without sulphides or heavy metals (contaminants), therefore minimising the need for the treatment of plant tailings, and being furthermore suitable for constitution of material for the back-filling of the underground mine.

The current resource inventory of the Tabuaço tungsten project (O'Donovan *et al.*, 2012), comprising both indicated and inferred resources from the SPA and Aveleira deposits, totals 2.725 million tons of ore averaging 0.56 % WO_3, equating to a total contained metal of 1.535 million metric ton units of WO_3 (***Table 2***). Around 71 % of this total resource originates from São Pedro das Águias deposit, and the remainder from Aveleira.

Colt still considers that there is significant potential to increase the resource inventory in the near future, namely by:

- Confirming the extension of the SPA deposit to the West, underneath the granite (***Figure 5***);
- Increasing the Aveleira resource through additional drilling;
- Delineating additional resources in the gap between the SPA and Aveleira deposits, where some scout holes have already intersected well mineralised skarns (***Figure 4***);
- Locating the likely continuation of the mineralized skarn horizons beyond Aveleira, buried at depth to the northwest of the Quintã skarn outcrop (***Figure 4***).

Acknowledgements

The writer is grateful to the management of Colt Resources Inc for allowing the publication of this article about the company's Tabuaço project. The current status of knowledge about the deposits, as summarised in this paper, owes much to all geologists and prospectors of Colt's exploration team, as well as to external consultants who contributed to the exploration project between 2008 and 2013. Finally, a particular word of gratitude to geologist Rosa Santos for having prepared most of the figures for this article.

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A brief overview of the metallic mineral resources of Serbia

*Dr Rade Jelenkovic**

The most important group of metallic mineral deposits of Serbia includes Cu (+Au) and Pb-Zn (+Ag).Considerably less important are the Sb, Mo, Ni-Co, U, Sn, W, Mn, Ti and Fe ores. They were formed during numerous geological epochs. In future geological exploration, greater attention should be given to the porphyry Cu-Au, the related high sulphidation Cu-Au massive-sulphide ores, sediment-hosted gold deposits localized in the Bor region, the porphyry Cu-Au deposits in the Lece district, the Pb-Zn-Ag deposits in the Serbian-Macedonian province, and to deposits of ferro-alloy metals. The potential of uranium ore will depend on the strategy of the state concerning the planned utilisation of these energy resources.

Le groupe le plus important de minéraux métalliques de Serbie inclut le cuivre (+ l'or) et le plomb-zinc (+ l'argent). En quantité nettement moins importante, on rencontre des minéralisations d'antimoine, de molybdène, de nickel-cobalt, d'uranium, d'étain, de wolfram, de manganèse, de titane et de fer. Elles se sont formées lors des différentes périodes géologiques. Pour les futures explorations géologiques, on devrait privilégier les minerais porphyriques cuivre–or, les sulfures massifs cuivre-or avec un fort degré de sulfitation, les dépôts sédimentaires aurifères localisés dans la région de Bor, les dépôts porphyriques cuivre-or dans le secteur de Lece, les minéralisations de plomb-zinc-argent de la province serbe-macédonienne, et les dépôts métalliques avec alliage ferreux. Le potentiel du minerai d'uranium dépendra de la stratégie gouvernementale en matière d'utilisation de ces ressources énergétiques.

El grupo más importante de minerales metálicos de Serbia incluye Cu (+ Au) y Pb-Zn (+ Ag). Considerablemente menos importantes son los minerales de Sb, Mo, Ni-Co, U, Sn, W, Mn, Ti y Fe. Se formaron durante numerosas épocas geológicas. En exploraciónes geológicas futuras, mayor atención se debería dar a las pórfidos de Cu-Au, sulfuros de Cu-Au de alta concentracion, los depósitos de oro alojados en los sedimentos, región de Bor; los depósitos de pórfido Cu-Au en el distrito Lece; los depósitos de Pb-Zn-Ag en la provincia de Serbia-Macedonia, y a los depósitos de metales ferroaleaciones. El potencial del mineral de uranio dependerá de la estrategia del estado relativa a la utilización prevista de estos recursos energéticos.

The metallic mineral resources of Serbia and the metallogenic units within which they are located are constituents of larger regional metallogenic and geotectonic units that extend outside of its territory. Accordingly, the position, time and conditions of their formation depended to a large extent on the geotectonic evolution of that broader territory and accompanying volcanic, sedimentary and metamorphic processes. From the metallogenic point of view, all of them are incorporated into the NE Mediterranean Sector of the Tethyan-Eurasian Metallogenic Belt (Jankovic, 1990, 1997), or, the Alpine-Balkan-Carpathian-Dinaride metallogenic and geodynamic province, which is part of the Tethyan (or Alpine-Himalayan) orogenic system that extends from Western Europe to South East Asia (Heinrich and Neubauer, 2002; Schmid *et. al.*, 2008). A more detailed territorial grouping of these units is based on an analysis of the relationship between mineral deposits and the geological environment with which they are genetically and territorially associated (Jelenkovic *et al.*, 2008).

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The origin and evolution of mineralisation

Metallic mineral deposits of the Serbia are concentrated into four regional metallogenic units that spatially extend out of the territory boundaries of the country: 1) the Dinaridic metallogenic province (DMP), 2) the Carpatho-Balkan metallogenic province (CBMP), 3) the Serbo-Macedonian metallogenic province (SMMP) and 4) the Dacian metallogenic (DcMP). All these are subdivided into several metallogenic zones, ore districts and ore fields (***Figure 1***).

According to the current understanding of plate tectonics and of the geotectonic and metallogenic development of the terrain in Serbia, the most important metallic mineral resources within its territory can be classified as: 1) deposits related to intracontinental rifting; 2) deposits related to ophiolite complexes; 3) deposits of subduction-related setting and 4) deposits related to continent-continent collision (Jankovic, 1990).

Deposits related to intra-continental rifting. The processes of rifting, both of the initial and advanced stages, lasted from Early to Late Triassic, but in some sectors of Serbia (Dinarides, Vardar zone) the continued lateral spread of the sea-floor led to the opening of an ocean during the Late Triassic – Late Jurassic. This tectonic setting is now characterised by elongated and mostly subparallel horst-graben structures. Two principal groups of magmatic rocks are distinguished in relation with these processes: 1) quartz-keratophyres, porphyrites and albite-granites (formed by processes of intracontinental rifting) and 2) diabases and basalts (spilites) (formed by processes of opening and spreading). The dominant metals of ore mineralisation include lead-zinc and subordinate copper. They are classified as follows: 1) hydrothermal volcano-sedimentary and hydrothermal stockwork and vein types, and 2) hydrothermal massive sulphide ores and hydrothermal veins in relation to the ophiolite melange. Several other groups of mineral deposits are also present: high temperature hydrothermal Fe-veins and lenses, Fe-Mn oxides and carbonates accompanied by minor Pb-Zn and Fe sulphides; Hg-deposits and bauxite deposits developed on karstified limestone.

Ore deposits related to ophiolite complexes. The ophiolites form two distinct belts: the Western Belt located in the Inner Dinarides, and the Eastern Belt extending from the Vardar zone. The ophiolites of the Western Belt are characterised by the dominance of lherzolite-peridotite, gabbro-pyroxenite and ortho-pyroxenite. Endogenous ore deposits related to these ophiolitic complexes are mostly the Ni-Co-Cu-Fe sulphides, pyritic copper ore deposits, sporadic magnetite deposits and also minor gold mineralisation. The ophiolites of the Eastern Belt consist mainly of Mg-rich peridotite and dunite. Their metallogeny is characterised by major chromite and significant pyritic copper ore deposits, locally Ni-silicate and Ni-Fe deposits.

Deposits of subduction–related setting are located in East Serbia (the Upper Cretaceous subduction related magmatic rocks and mineral deposits, referred to as the Banatitic Magmatic and Metallogenic Belt, or the Apuseni-Banat-Timok-Srednogorie Belt). The most important deposits include those of porphyry copper mineralisation, related high sulphidation Cu-Au massive-sulphide mineralisation, and less important Pb-Zn ores. The ore elements are derived mostly by lateral secretion from the host rock (andesites and analogous plutonic rocks) by convectional systems using fluids derived from the subducted oceanic plate and partly dehydrated continental crust mixed with descending solutions.

Deposits of continent-continent collision-related setting. The closure of a branch of the Tethyan Ocean along the Vardar-Izmir-Central Anatolia zone started in the Oligocene. This event was followed by the progressing collision between Africa and Europe plates, resulting in increased magmato-tectonic activity. Ore deposits formed along the active continental margin are related to intermediate volcanic and magmatic rocks. Magmas are derived from the lowest levels of up-domed continental crust, but during upward movement they can be contaminated by some elements from ophiolite complexes (Cu, Au), or by some lithophile elements taken from the continental crust (Sn, W, Nb, Ta). The Tertiary volcanic rocks are characterized by

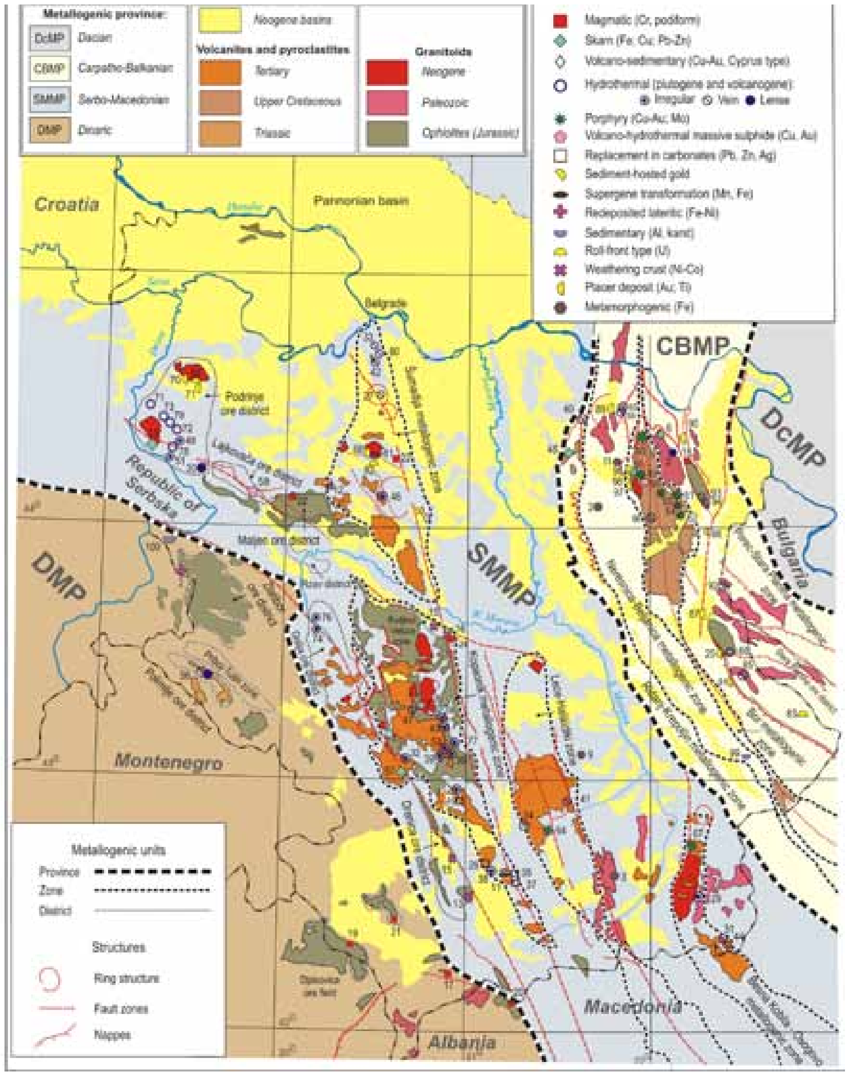

Figure 1: The main metallogenic units and metallic mineral deposits of Serbia.
Iron deposits: 1. Beljanica, 2. Mokra gora, 3. Čar Sedlar, 4. Duge Njive, 5. Lipovac, 6. Rudna Glava, 7. Suva Ruda, 8. Suvo Rudište, 9. Žitni potok, Manganese deposits: 10. Drača, 11. Laznica, 11. Novo brdo. Nickel deposits: 12. Ba, 13. Glavica, 14. Staro Čikatovo, 15. Rudinci, 16. Veluće. Chromium deposits: 17. Brezovica, 18. Deli Jovan, 19. Deva, 20. Nada, 21. Orahovac, 22. Planinica, 23. Trnava, 24.Veluća. Titanium deposits: 25. Žukovačka reka. Lead-Zinc deposits: 26. Ajvalija, 27. Babe, 28. Belo Brdo, 29. Blagodat, 30. Bobija, 31. Conjev kamen, 32. Crnac, 33. Crveni breg, 34. Dražnja, 35. Farbani potok, 36. Jelakce, 37. Kiseli potok, 38. Kišnica, 39. Koporić, 40. Kučajna, 41. Lece, 42. Ljuta strana, 43. Marušić, 44. Podvirovi, 45. Reškovica, 46. Rudnik, 47. Sastavci, 48. Tisovik, 49. Trepča, 50. Valja Saka, 51. Veliki Majdan, 52. Zijača, 53. Žuta prlina. Copper deposits: 54. Bor, 55. Cerovo, 56. Čadinje, 57. Karavansalija, 58. Lajkovača, 59. Lipa, 60. Majdanpek, 61. Veliki Krivelj, 62. Čukaru Peki, 63. Valja Strž, 64. Kiseljak. Tungsten deposits: 65. Blagojev Kamen. Bismuth deposits: 66. Aljin do. Molybdenum deposits: 67. Mačkatica. Tin deposits: 68. Cigankulja, 69. Cernička reka, 70. Lešnička reka. Antimony deposits: 71. Brasina, 72. Dobri potok, 73. Dolići, 74. Gliječ, 75. Krajnji del, 76. Lisa, 77. Rajićeva gora, 78. Rujevac, 79. Stolice. Mercury: 80. Šuplja stena. Uranium deposits: 81. Paun stena, 82. Preturica, 83. Dojkinci, 84. Iverak, 85. Mezdreja. Gold deposits: 86. Bela reka, 87. Beli Timok, 88. Blagojev kamen, 89. Pek, 90. Porečka reka, 91. Trgoviški Timok, 92. Vratarnica, 93. Ginduša, 94. Rusman, 95. Korkan, 96. Bigar Hill, 97. Kraku Pešter, 98. Zlaće. Bauxite deposits: 99. Babušnica, 100. Aluge.

an increased content of lead and zinc and by a diminished content of copper. The principal ore deposits associated with this geotectonic condition (in the territory of the Vardar zone and the Serbo-Macedonian Massif) occur as skarn-type, hydrothermal metasomatic and veins, locally porphyry Cu-Au and stockwork-disseminated Mo-types. The dominant metals are Pb-Zn, Ag and Sb. Ore elements were leached from host rocks by fluids from the subcrustal magmas of I-type, strongly contaminated by the crustal material and mixed with the heated descendent solutions.

The present state and potential of the metallic mineral resources of Serbia

There are 214 registered metallic mineral deposits and 990 metallic mineral occurrences within the territory of Serbia (Jelenkovic, 2011). Many of them were exploited until as late as the end of the 20th century. Today, however, mining production has been either abandoned (Fe, Cr, Mn, W, Ni and others) or greatly reduced (Pb-Zn, Cu, Au, Ag, Sb) as a consequence of the previous high-grading of their ore reserves in order to reduce production costs. There has also been an exhaustion of economic reserves of Cr, Mn, W and other ores, as well as a considerable reduction in the volume of geological exploration. Base metals (Cu, Pb-Zn), precious metals (Au, Ag), occasionally Ni, Sb, and some others, have been more thoroughly explored and their resources have been augmented, so that they still represent, in spite of numerous problems attending their exploitation, the developmental potential for Serbia.

The economically most important metallic mineral resources of Serbia may be grouped as follows (Jankovic *et al*., 2003):

- Metallic mineral resources with significant reserves, which are in exploitation and are already provided with processing capacities, and which continue to be the basis of the industrial development of the country. The basic characteristics of these deposits are a predominantly low metal content and substantial ore potential. Currently 6 Pb-Zn deposits, 4 Cu deposits and 4 Sb deposits are in operation (WEB GIS, 2014)
- Mineral resources with identified, predominantly small mineral resources which are not in exploitation, or mineral resources occurring in minor quantities, sufficient for brief periods of production and the supply of domestic requirements. This group includes Mo, Sn, Mn, U, and Ti.
- Potentially significant, partially defined metallic mineral resources, the value of which depends on technical-economic parameters (Fe, Al, Au), as well as partly explored deposits with favourable prospects for reserve increase (Ni, Co, Sb).
- Mineral resources likely to be found in the territory of Serbia. The metallogenic analyses carried out so far show that new resources of gold are likely to be discovered in Serbia (sediment-hosted gold deposits, porphyry copper-gold and related epithermal Cu-Au deposits, low sulphidation epithermal gold mineralisation, etc.). Today metallic mineral resources are being explored in 86 exploration licence areas in Serbia (42 Au, 22 Cu, 14 Pb-Zn, 3 Sb, 2 Ni, 1 Mo, 1 Fe, 1 REE).
- Mostly exhausted or non-economic mineral resources include metallurgical grade Cr and Fe deposits and W. Prospects for the discovery of new, economically significant reserves are small (***Table 1***).

Non-ferrous metals and precious metals are economically the most important group of metallic mineral resources of Serbia.

Copper. The most important copper ores of Serbia are located in: 1) the Bor metallogenic zone (porphyry copper and related high sulphidation massive-sulphide deposits), 2) the Lajkovača ore district (Cyprus type of hydrothermal volcano-sedimentary massive-sulphide deposits), and in 3) the Lece ore district (Kiseljak porphyry Cu-Au deposit).

The metallogenic analyses and geological explorations carried out so far in Serbia have indicated areas with geological features that show that they are likely to contain new Cu-Au deposits, predominantly of porphyry type, and, to a lesser extent, of massive-sulphide ore types. One of them

Table 1: Metallic mineral resources of Serbia (Ministry of Natural Resources, Mining and Spatial Planing of Serbia,2013; modified).

	Measured + Indicated Resources			*Inferred Resources*		
	Tonnage	*Grade*	*Metal*	*Tonnage*	*Grade*	*Metal*
Cu[1] *Au*[1] *Ag*[1]	*1250 Bt*	*0.38 %* *0.138 g/t* *1.04 g/t*	*4.75 Mt* *173 t* *1295 t*	*1350 Bt*	*0.37 %* *0.11 g/t* *0.95 g/t*	*4.99 Mt* *149 t* *1285 t*
Cu[2] *Au*[2]				*300.5 Mt*	*0.27 %* *0.26 g/t*	*811.4 t* *78.13*
Cu[3] *Au*[3]				*63 Mt*	*2.6%* *1.5 g/t*	*1.638 Mt* *94.5 t*
Au[4]	*46.3 Mt*	*1.56 g/t*	*72.3 t*	*8.7 Mt*	*1.3 g/t*	*11.31 t*
Pb *Zn* *Ag*	*16.27 Mt*	*4%* *3%* *95 g/t*	*0.65 Mt* *0.49 Mt* *1545 t*	*2.69 Mt*	*4%* *3%* *82.8 g/t*	*0.11 Mt* *0.08 Mt* *223 t*
Pb[5] *Zn*[5] *Ag*[5]	*31.26 Mt*	*4.1 %* *3 %* *110 g/t*	*1.28 Mt* *0.94 Mt* *3438 t*	*24.47 Mt*	*4%* *3%* *70 g/t*	*0.98 Mt* *0.73 Mt* *1713 t*
Fe + *Ni*[6]	*3.97 Mt* *-*	*37.53 %* *-*	*1.49 Mt* *-*	*115.4 Mt* *90 Mt*[6]	*23.99%* *0.7%*	*27.68 Mt* *0.63 Mt*
Mn	*-*	*-*	*-*	*9.5 Mt*	*20 %*	*1.9 Mt*
Cr	*89000*	*15.7%*	*13973 t*	*0.02 Mt*	*15 %*	*3000 t*
Ti	*-*	*-*	*-*	*56000t*	*42%* TiO_2	
Ni	*19.92 Mt*	*0.75 %*	*149400 t*	*18.73 Mt*	*1.14 %*	*213522 t*
Co	*19.92 Mt*	*0.08%*	*15936 t*	*18.73 Mt*	*0.07%*	*13111 t*
Sb	*0.98 Mt*	*1.53 %*	*14994 t*	*1.2 Mt*	*1.3 %*	*15600 t*
Al	*2.69 Mt*	*44-48%* Al_2O_3	*-*	*1,2 Mt*	*35-40%* Al_2O_3	*-*
SnO_2	*5.49* Mm^3	*286.3* g/m^3	*1572 t*	*20*Mm^3	*167* g/m^3	*3340 t*
Ta-Nb	*4.96* Mm^3	*86.01* g/m^3	*427 t*	*20* Mm^3	*10* g/m^3	*200 t*
Mo	*150 Mt*	*0.044 %*	*66000 t*	*164.5 Mt*	*0.07 %*	*115150 t*
W	*0.33 Mt*	*3.5%* WO_3	*11500 t* WO_3	*0.025 Mt*	*1.65%* WO_3	*412.5 t* WO_3
Hg	*0.083 Mt*	*0.33 %*	*27390 t*	*-*	*-*	*-*
U	*2.154 Mt*	*338 g/t*	*728.1 t*	*1.5 Mt*	*310 g/t*	*465 t*

Explanation: [1]: RTB Bor. [2]: Kiseljak deposit. [3]Čukaru Peki. [4]: Potaj Čuka-Tisnica. [5]: Kosovo. [6]: Mokra Gora basin.

has been recently discovered, the Čukaru Peki deposit, located ~5 km south of the Bor. The inferred resource of massive-sulphide mineralisation includes 65.3 Mt @ 2.6 % Cu & 1.5 g/t Au (Reservoir Minerals, 2014). The underlying porphyry type mineralisation has been drilled to ~700 m with 0.8-0.9 % CuEq grade; the potential size of resources is 0.5-1.0 Bt, respectively.

Gold occurs either together with copper deposits or separately. The potentials for gold are great. According to results of geological explorations performed in the period 2008-2013, along the western margin of the Timok magmatic complex a previously unrecognised sediment-hosted style of gold mineralisation has been discovered; it extends over a strike length of more than 30 km and is up to 8 km wide. The most important is the Potaj Čuka–Tisnica ore zone, where the Korkan, Kraku Pešter and Bigar Hill gold deposits are located. Mineral resources estimated in 2013 are: indicated resources of 46.3 Mt ore @ 1.56 g/t Au and inferred resources 8.7 Mt ore @ 1.3 g/t Au (Avala Resources, 2013).

Lead and zinc. The Pb-Zn deposits of Serbia are numerous and economically significant. The greatest number of these deposits are located within the territory of Kosovo. The unexplored potential resources are also substantial and are located in the vicinity of known deposits, and in environments with favorable metallogenic conditions, predominantly in the region of calc-alkaline, volcano-intrusive complexes of Neogene age within the SMMP. The conversion of lead-zinc mineral resources or a part of them, into reserves will however require considerable time and further exploration investments.

Tin. The resources of tin are small and cannot meet domestic demand over a long period. Tin is found in greisen and placer deposits. The primary Sn occurrences are not economically interesting because of the small resources and low grade, while the placer deposits are on the verge of economic viability. It should be pointed out, however, that not much attention has been devoted to the prospecting of the Sn deposits in the past.

Aluminium. Deposits of bauxite are located in western part of Serbia (Aluge), within Kosovo (Klina), and in the Eastern part of Serbia (Babušnica). They are of small economic significance, limited extent and poor quality.

Resources of iron and ferroalloy metals are rather limited and do not meet the requirements of domestic metallurgy.

Iron. The economically most important iron ores are: 1) the easily workable limonitic ores from Majdanpek deposit; 2) the magnetite ores from skarn deposits, metamorphic deposits and porphyry Cu deposits; 3) the complex oxide-carbonate-silicate ores of the volcano-sedimentary type and 4) lateritic and re-deposited lateritic Fe-Ni-Cr ores. The mineral potential of the re-deposited Fe-Ni-Cr ores is great, but they have not been sufficiently tested from a metallurgically point of view (Mokra Gora basin).

Manganese. The most important manganese ores in Serbia are: 1) the oxide and silico-manganese ores from the volcanogenic-sedimentary deposits which originated in association with ophiolitic mélange, or less frequently, porphyrite-chert formation of Middle Triassic age, and 2) the Fe-Mn carbonate ores. The first type was exploited in the past, but at present there are no more known reserves. The potential environments for the discovery of new deposits are the Priboj-Tutin and the Rzav zone. Another area is Šumadija, but here the technological characteristics have not been fully tested. The determination of the mineral potential of manganese in Serbia requires systematic geological exploration and technological analyses.

The Fe-Mn carbonate ores of manganese in Serbia originated in association with the sulphide Pb-Zn deposits in the Kopaonik metallogenic zone. They have not been much exploited in the past, although they contain iron in addition to carbonates.

Titanium deposits of Serbia are small and economically limited. In contrast to primary types, the mechanical sedimentary deposits have significant amounts of ilmenite, which under certain conditions may be of economic importance (Žukovacka reka, Knjaževac).

Chromium was exploited in Serbia from 1945 to 1970. Mining production was primarily from the mining complexes in Djakovica and Brezovica (Kosovo). Today, the production of chromium has ceased due to the exhaustion of known reserves and limited possibilities for finding new resources.

Nickel and cobalt deposits of Serbia are associated with the lateritic zones of serpentinites of Drenica district, within the Rudjinci-Veluće ore zone, etc. More detailed exploration is necessary, however, to determine the economic potential of this area.

Molybdenum. There is only one molybdenum deposit in Serbia (Mačkatica). Several occurrences of molybdenum have been found in the Besna Kobila metallogenic zone, but no full geological and economic estimate of them has been made so far. Only preliminary explorations have been made in the case of the other occurrences (the contact zones of the granitoides of the Podrinje district, Kopaonik zone, and the Mo-mineralization in the Majdanpek porphyry copper deposit).

Tungsten. The resources of tungsten are small. They are mainly concentrated in quartz-scheelite veins in the Blagojev Kamen zone, the Golija district and the Kopaonik zone. It is possible that future exploration will lead to the discovery of new occurrences of scheelites within skarns, but the economic significance of this is impossible to assess.

Resources of minor metals and related non-metals are of limited economic importance in Serbia. The most important of them are antimony deposits.

Antimony. The western part of Serbia, despite the prevailing exhaustion of known ore bodies, is still the most interesting area in terms of antimony mineralisation. Mineral resources in a number of deposits are significant but marginal or sub-economic. Special interest has been paid to the complex Sb-Pb-Zn-As Rujevac deposits. Its resources may be treated only as conditionally economic until technological issues are resolved obtaining commercial antimonite concentrate. Potential yet un-identified mineral resources of jasperoide antimony ore-type, especially in western Serbia, are considered significant but an under-researched and under-explored target.

Radioactive metals. The most significant concentrations of uranium in the territory of Serbia are associated with the granitoide complexes of Hercynian and Tertiaty age, sedimentary series of Permian age, and Neogene basins in the fringe zones of granitoides. Uranium deposits associated with the granitoide complexes belong to the group of hydrothermal vein and stockwork types located in the fault zones, while uranium deposits related to the sedimentary series belong to the group of ore of roll-front type mineralization. The further exploration of uranium resources will depend on the strategic decision of the state to use them as the raw material for the production of energy.

Conclusion

The end of the 20th century and the beginning of the 21st century marked a period of substantial decline in mining production of many metallic mineral deposits of Serbia. This is a consequence of several factors, the most important being: 1) intense exploitation of higher-quality ores; 2) substantial reduction of investments in basic and applied geological exploration, and 3) inadequate investments in the development of new technologies for the preparation and processing of mineral resources which would enable the valorization of lower quality ores. Further development of the metallic mineral resources of Serbia will depend on the mineral policy of the country, the new mining law, the strategic decisions concerning future investment into systematic geological exploration of deposits and prospective terrains, the development and introduction of new technological methods of ore processing, the adaptation of the existing procedures of ore processing to newly discovered deposits of mineral resources, and the increased profitability of exploitation.

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Geometallurgy – A tool for better resource efficiency

Cecilia Lund and Pertti Lamberg*

Higher environmental and socio-economic demands in the exploitation of the future mineral resources require comprehensive knowledge on ore bodies even in the early stages of the mining process. Geometallurgy combines geological and mineral processing information to create a spatial model for production planning and management. Applying a geometallurgical concept improves resource efficiency, reduces operational risks and helps in optimising production in such a way that sustainability and socio-economic factors also are considered. With a geometallurgical model it is possible to study different production scenario starting from exploration to the feasibility and production stages. There are some alternative ways for building a geometallurgical model but the mineralogical approach is generic and can be adopted to any kind of mineral resources. This paper describes how a concept like this has been used in the mining industry and demonstrates the benefits in terms of improved resource efficiency in different ore deposits.

Les demandes accrues du point de vue environnemental et socio-économique, touchant l'exploitation future des ressources minérales nécessitent de connaitre parfaitement les corps minéralisés à partir même des phases initiales de traitement. La Géométallurgie associe les données géologiques et de traitement des minéraux pour créer un modèle spatial destiné à faciliter l'organisation de la production et sa gestion. Utiliser un concept géométallurgique améliore la gestion des ressources, réduit les risques opérationnels et optimise la production de telle manière que les critères socio-économiques et de durabilité sont également considérés. Grâce au modèle géométallique, il est possible d'étudier différents scenarii de production, depuis la phase d'exploration jusqu'à celles de la faisabilité et de la production. Il existe quelques autres moyens de créer un modèle géométallique mais l'approche minéralogique est fondamentale et peut être appliquée à n'importe quel type de ressource. Cet article décrit comment un tel concept a été utilisé pour l'industrie minière et met en évidence ses avantages en termes de gestion optimisée des ressources pour différents types de minéralisation.

Exigencias ambientales y socio- económicos más altos en la explotación de los futuros recursos minerales requieren un conocimiento amplio sobre minerales metalicos, incluso en las primeras etapas del proceso minero. Geometalurgia combina la información geológica y de procesamiento de minerales para crear un modelo espacial para la planificación y la gestión de la producción. La aplicación de un concepto geometalúrgico mejora la eficiencia de los recursos, reduce los riesgos operativos y ayuda en la optimización de la producción de tal manera que los factores de sostenibilidad y aspectos socio-económicos también se consideran. Con un modelo geometalúrgico es posible estudiar diferentes escenarios de producción a partir de la exploración hasta las fases de viabilidad y de producción. Hay algunas formas alternativas para la construcción de un modelo geometalúrgico pero el enfoque mineralógica es genérico y se puede adoptar a cualquier tipo de recursos minerales. Este artículo describe cómo un concepto como este se ha utilizado en la industria minera y demuestra los beneficios en términos de mejora de la eficiencia de los recursos en los diferentes depósitos de minerales metallicos.

The cross-discipline approach known as geometallurgy connects two different but closely related areas in the mining industry, namely geology and mineral processing. It involves understanding and measuring of the ore properties relevant to its successful processing. Geometallurgy takes both geological and metallurgical information to create a spatially-based (3D) predictive model for a mineral process (Lamberg, 2011). Industrial applications are called geometallurgical programs and they improve the knowledge of the resource and therefore lower the risk in the operation related to the unknown variation within the ore deposit. The geometallurgical concept ranges from ore characterisation to the economic optimisation of the mining operation (GeoMet 2011 and references therein, 2011).

Northern Scandinavia is famous for the Kiruna type of iron-apatite ore bodies, with Kiirunavaara and Malmberget being the largest. They are high grade and show only moderate variation in their mineralogy and processing properties. The potential benefits of applying geometallurgy in these types of existing mines are relatively low. However, there are a number of iron deposits in the region showing lower grades, large geological variations within the ore and much more challenging mineralogy for the production of saleable iron concentrate (***Fig. 1***). An example of such is Hannukainen (Finland) where magnetite needs to be separated from the sulphides as the pyrrhotite is monoclinic and thus magnetic (Arvidson, 2013).

Today, only few mines have a geometallurgical program but this concept will become more common in the future due to requirements for more effective utilisation of the existing ore resources. The challenge is to create a predictive metallurgical model of the ore body during development of the deposit. When the geometallurgical model finally is incorporated with economic information the model will inform us accurately whether the project will be feasible or not.

The aim of this paper is to describe what the geometallurgical concept is and how it can be used in the mining industry. In addition, we demonstrate how geometallurgy is an essential tool in improving resource efficiency in different types of ore deposits.

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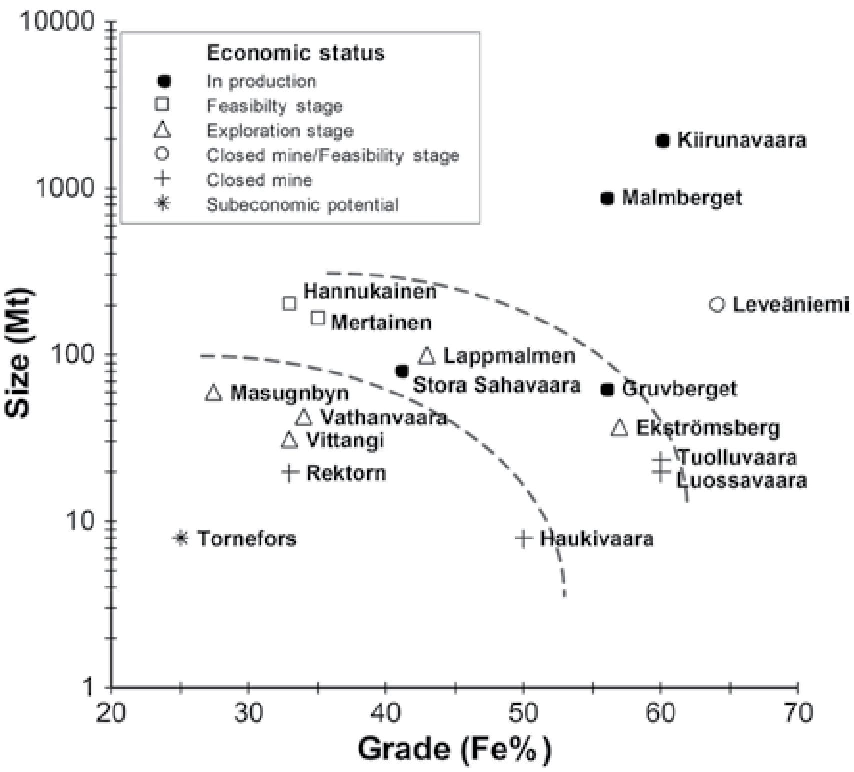

Figure 1: Grade and tonnage relationship of iron ore deposits in northern Finland, Norway and Sweden. Lines show equal metal content.

What is geometallurgy?

Geologists have a long tradition of creating 3D models of ore bodies for variation in metal grades and lithology. For the process plant they provide daily forecasts on head grades, tonnages and main ore types or lithologies. The idea of geometallurgy is to improve the knowledge of an ore by developing methods to measure parameters important for processing. This information is to be used to designing a suitable mineral process for a given ore body, to manage and optimise the production (Batterham *et al.*, 1992). The last decade has been a period of fast evolution in the field of geometallurgy, and one of the large contributors has been the development of automated mineralogy (Gottlieb *et al.*, 2000). Due to this important tool many regard geometallurgy a synonym for process mineralogy. The latest and broadest view uses the term geometallurgical sustainability performance (GeoMet 2011 and references therein, 2011) by incorporating other external factors that influence the context of geometallurgy in a global market perspective, such as the business dimension (interpretation, analysis, evaluation and validation of all technical aspects), mine planning, risk management, sustainability (water, energy consumption and CO_2 emission levels) and the geotechnical approach (e.g. identification of variable rock mass conditions (GeoMet 2011 and references therein, 2011) that also embraces socio-economic demands when exploiting mineral resources.

Benefits of the geometallurgical concept

The aim of geometallurgy is to run and simulate different production scenario even in the exploration stage and thereby predict factors affecting the production both in cost and technical aspects. Justification for the geometallurgical program comes

Table 1: There are few applied geometallurgical programmes implemented to control the production (Leinonen, 1998; Alruiz et al.*, 2009; GeoMet 2013 and references therein, 2013; Lamberg, 2011; Niiranen and Böhm, 2012).*

Mine site	*Type of deposit*	*Geometallurgical approach*	*Resource efficiency*
Collahuazi	*Copper (Cu) ore*	*Geometallurgical tests*	*Making better use of the resource, daily targets give better possibilities for optimisation -> better recoveries*
Western Australia Iron ore	*Iron (Fe) ore*	*Geometallurgical tests*	*Making better use of the resource by increasing the variables in the database for optimisation*
Kiirunavaara	*Iron (Fe) ore*	*Geometallurgical tests*	*Predicting the processing quality of crude ore such as lowering the risk of high SiO2 in the magnetite concentrate*
*Mogalakwena**	*Platinum (Pt) ore*	*Geometallurgical tests*	*Forecasting production by incorporating ore variation in the mine plan and comminution and flotation circuits*
*Morro do Ouro**	*Gold (Au) ore*	*Geometallurgical tests*	*Predicting mineral processing characteristics -> optimising production (recovery, Au, Bond work Index) in terms of ounces per hour*
Canahuire	*Gold-Copper-Silver (Au-Cu-Ag) ore*	*Geometallurgical tests*	*Improving the ore characterisation by the identification of key drivers to impact the process recovery*
Kemi	*Chrome (Cr) ore*	*Mineralogical*	*Gaining the knowledge for making a good blend of the ore qualities*
Namakwa Sands mine	*Titanium-Zircon (Ti–Zr) ore*	*Mineralogical*	*Improving ore characterisation and making a proper blending -> allows optimisation of the mineral resource management processes*
DeGrussa	*Copper- Gold (Cu-Au VHMS) ore*	*Mineralogical*	*Gaining knowledge of geological and process variation for optimisation -> better Cu recoveries and grades*
** These mine sites do not have fully established programmes yet*			

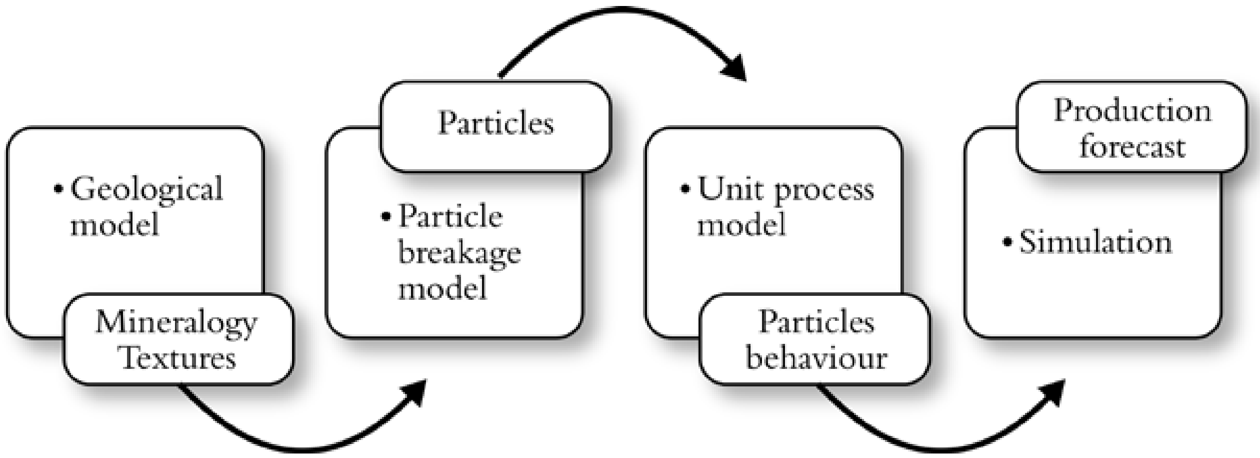

Figure 2: The particle-based geometallurgical concept, modified from Lamberg (2011). Modal mineralogy and textures link the geological model and the process model. In the process model minerals are treated as particles. From the mineral information, the particle population is generated through the particle breakage model.

from the potential to bring some of the following benefits compared to the traditional approach:

- Better utilisation of the ore resources because ore boundaries are defined also in order to forecast the metallurgical performance.
- Better metallurgical performance because it is possible to tune the process according to information of the plant feed beforehand.
- Better controlled mining due to more comprehensive knowledge of the ore body.
- Better changes in plant optimisation because the variation in the plant feed is low, or at least better controlled.
- Better changes for new technological solutions because ore-derived problems are identified well ahead and research programs can focus on solving these.
- Lowering risks in the operation though better knowledge of the ore body and the process and through a more controlled process chain.
- Better possibilities for economical optimising of the full operation considering metal prices, alternative products and costs of commodities.

These benefits can only be fully utilised if the geometallurgical model is available in the feasibility study stage.

In existing mines such as the Kiirunavaara deposit (Niiranen and Böhm, 2012) the expected benefits of a geometallurgical program may be limited. Production scheduling might be difficult or even impossible to change, especially in underground operations. Similarly, to run the process in campaigns, i.e. one ore type at certain periods, might not be possible or not feasible. The benefits can therefore come from knowing what the limitations are of the material coming at different times. Alruiz *et al.* (2009) developed a predictive geometallurgical model for Collahuasi copper. The models are able to forecast the throughput and copper recovery on a daily basis. This knowledge in itself will not lead directly to any improvement in production but having realistic daily targets makes it easier to reach this maximum level.

Applying geometallurgy in practice

Applying a geometallurgical approach in an ore project includes many challenges that require careful consideration. The concept of geometallurgy should be implemented as early as possible in the ore project; preferably already in the exploration stage. Ore characterisation techniques applied should be fast, inexpensive and above all practical. This means that they would give quantitative data relevant to processing of the ore and they could be applied routinely.

Developing an industrial application called a geometallurgical program commonly includes the following steps (modified after Dobby *et al.*, 2004; Lamberg, 2011 and references therein).

1) Collection of geological data through drilling, drill core logging, measurements, rock mechanical analyses, petrophysical parameters and chemical analyses. 2) An ore sampling program for metallurgical testing where geological data is used in the identification of preferred locations for the samples. 3) Laboratory testing of these samples in order to extract process model parameters (sometimes called ore variability testing). 4) Checking the metallurgical validity of the geological ore-type definitions and, where necessary, developing new ore-type definitions called geometallurgical domains. 5) Developing mathematical relationships for the estimation of important metallurgical parameters across the geological database. 6) Developing a metallurgical model of the process. The model consists of unit operations which use the metallurgical parameters defined above. 7) Plant simulation using the metallurgical process model and the distributed metallurgical parameters as the data set. 8) Calibration of the models via benchmarking for existing operations.

In geometallurgical programs the weakest points are normally in inadequate information collected from the drill cores and the small number of samples collected for variability testing. In the laboratory tests quite a small number of samples should represent large tonnages of the ore. Commonly, 30 to 50 carefully selected and prepared samples are tested but there are examples where the whole program is based on less than ten samples (Lamberg, 2011 and references therein)). This sets high requirements for sample selection, sampling and sample preparation to avoid the sampling error rising so high that it limits the usefulness of collected data (Gy, 1982). There lies also a dilemma in selecting and preparing metallurgical samples based on geological information: tested samples should represent the full variability of the ore in terms of metallurgical response and this can be known only after the tests have been done.

Basically two different approaches exist for linking the steps listed above to establish a geometallurgical model. The first one relies on geometallurgical testing and the other approach is based on mineralogy (Lamberg, 2011).

Approach based on geometallurgical testing

The majority of geometallurgical programs rely on the metallurgical response measured by geometallurgical testing without the mineralogical information (***Table 1***). Geometallurgical tests are small-scale laboratory tests which aim to directly measure the metallurgical response of the samples. Examples of such are the GeM Comminution Index test, the JK Mineral Separability Indicator test (Lamberg, 2011 and references therein) and the Davis tube test (Niiranen and Böhm, 2012).

Mineralogical approach

A pure mineralogical approach in geometallurgy means that the geometallurgical model is fully based on the mineralogy. The model uses mineral parameters, such as modal mineralogy, mineral textures, mineral association, mineral grain sizes and their relation to the liberation characteristics. Based on a particle approach modified after Lamberg (2011), a geometallurgical model can be established in three sub-models (***Fig. 2***): a geological model, a process model and a production model.

a. Geological model

The geological model relies on a proper ore characterisation and provides quantitative mineralogical data in such a way that elemental grades or lithology are not needed. The components of the geological model are the modal composition (mineral composition by weight percent) and the texture information (mineral association and grain sizes).

The mineralogical approach requires a quick and inexpensive modal analysis method considering the need to produce that information in a large number (>10 000) of samples. The element to mineral conversion is a technique where the mineral grades are calculated from chemical assay using the information on the chemical composition of the minerals. Mathematically, the problem is a system of linear equations, and generally it is solved with a non-negative least squares technique (Paktunc, 1998). This method is a robust and cost-effective method which is developed with emphasis to routinely calculate the modal mineralogy directly for ore samples after chemical assays. If the mineralogy is complex, an additional technique may be needed, e.g. Satmagan or quantitative X-ray. The combination of X-ray fluorescence (XRF) and X-ray diffraction (XRD) for modal mineralogy has the potential to be a powerful tool with a high capacity.

Besides variation in modal composition, many ores show variation in mineral grain sizes and in other mineral texture parameters. Therefore the ore texture information is needed in the second part of the geological model. The traditional geological description of textures is mostly qualitative and includes parameters like grain size (coarse, moderate, fine), grain shape (euhedral, prismatic, anhedral) and associated minerals. Descriptions such as these are insufficient from a geometallurgical perspective, and there is a need to develop a textural analysis which gives a numeric description of the textural properties by using additive parameters. Only then can the textural information be used both in modelling and geostatistics.

There is no generally accepted method to measure and quantify mineral texture but a technique developed by Lund (2013) proved that information like mineral textures was essential and must be included in the geological model to forecast the metallurgical outcome. Much more work is needed before this technique can be implemented and used in a routine process and this research is now being addressed by a research consortium called REsource CHAracterisation at the Nordic Rock Tech Centre, Luleå University of Technology.

b. The process model

The process model takes the information of the geological model and transfers it to information on the metallurgical performance. In mineral processing, ore is comminuted to liberate the minerals and to make the particle size suitable for downstream processes. As mineral textures and the liberation characteristics are closely associated with comminution target particle size, an effort was made to link the textural properties and the mineral liberation distribution by particles (Lund, 2013). A new definition for mineral texture has been developed: two samples are texturally different if the liberation distribution by size (compensated against modal mineralogy) is different after being comminuted under similar conditions (Lund, 2013). In other words samples are texturally similar if they produce a similar type of particles when comminuted. Using this definition the ore body is divided into textural classes called archetypes. The comminution behaviour is characterised for different types with a method developed by Mwanga (2014). The behaviour of different type of particles is determined using particle tracking methodology (Lamberg, 2011 and references therein).

In the process model finally comminution and other unit operations are combined, providing a forecast of the metallurgical response of any given ore type or block given by the geological model. Different flow sheets and processing strategies can be tested, e.g. to find the most optimum grinding fineness for different geometallurgical domains.

c. The production model

In the production model the geological model and the process model are combined, and this tool is used to manage the production for the best possible result. This includes the production schedule and economic model with product value and productions costs, giving an approach that is applicable to any kind of mineral resource.

Conclusion

A geometallurgical model combines geological and mineral processing information to create a spatial model for production planning and management. To run and simulate different production scenarios a concept like this should be implemented from the exploration stage through the feasibility and production stages. While only a few mines have a geometallurgical program today, this will become more common in the future due to requirements for more effective utilisation of the existing ore resources. The mineralogical approach described here is generally valid, meaning that it could be applied to any type of deposit.

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CRIRSCO modifying factors - a brief guide for exploration and resource geologists

*Ruth Allington**

All of the codes and standards for reporting resources, reserves and exploration results in the CRIRSCO[1] family include identical definitions, which are represented in ***Figure 1***.

Progression from inferred to measured resources is primarily the province of geoscientists and is all about reducing uncertainty regarding the quality, recoverable quantity and continuity of the minerals. The Competent Person (CP) responsible for public reporting of resources is likely to be an exploration or resource geologist. However, exploration and resource geologists may not have much experience or expertise pertaining to the 'modifying factors' and may consider that such things are really nothing to do with them.

Working with the Modifying Factors to establish technical feasibility, minimise environmental impact and ensure economic viability is often considered to be a distinct stage in the evaluation of a deposit and planning of a mine or quarry, completely separate from the exploration and modelling of the deposit itself. These activities typically involve many professionals including specialists in engineering, production, processing, environmental assessment, operations, legal and financial disciplines. There may be one Competent Person taking overall responsibility for co-ordinating the team and bringing together the reporting or there may be several, each taking responsibility for their own discipline area.

Modifying Factors are defined in the CRIRSCO family of codes and standards as "considerations used to convert Mineral Resources to Mineral Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors. Modifying factors also include any other factors which impact on the feasibility of the project."[2]. This seems to say that consideration of 'modifying factors' plays no part in the evaluation of Mineral Resources but that they are used, once a Resource has been defined, to convert to Mineral Reserves. Whilst the author agrees that a thorough consideration of the impact of 'modifying factors' is essential to allow any deposit or part of a deposit to be classified as a 'Reserve', this is not the same as saying that there need be no consideration of 'modifying factors' until the resource evaluation is complete. This view is supported by the definition of Mineral Resources as "a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction"[3]. In order to state that a mineral resource has 'reasonable prospects for eventual economic extraction', those responsible for classifying a deposit or part of a deposit in this way will need to have assessed whether this pre-requisite has been satisfied – in short, it would be expected that, whilst detailed feasibility assessments would not have been carried out at the resource evaluation stage, any 'show stoppers' would have been identified. Examples of such 'show stoppers' might be:

- Resource in a remote location with no access to market without significant investment in transport infrastructure, rendering the project uneconomical.
- A need for significant quantities of water for mineral processing and a deposit in a desert location with no groundwater available.
- Very high stripping ratio in an open pit setting making the extraction inherently uneconomic.

Giving appropriate weight to Modifying Factors throughout the progression from exploration through resource evaluation to feasibility studies and operational planning depends not only on ensuring that the right team is assembled but also that all members of the team have an awareness of the major constraints on reasonable prospects for eventual economic extraction in addition to their specialist geoscience or engineering skills. The following simple model illustrates the appropriate balance that must be achieved at every stage (***Fig.2***).

Establishing iteration and inter-disciplinary co-operation and information sharing helps to ensure that even early stage, con-

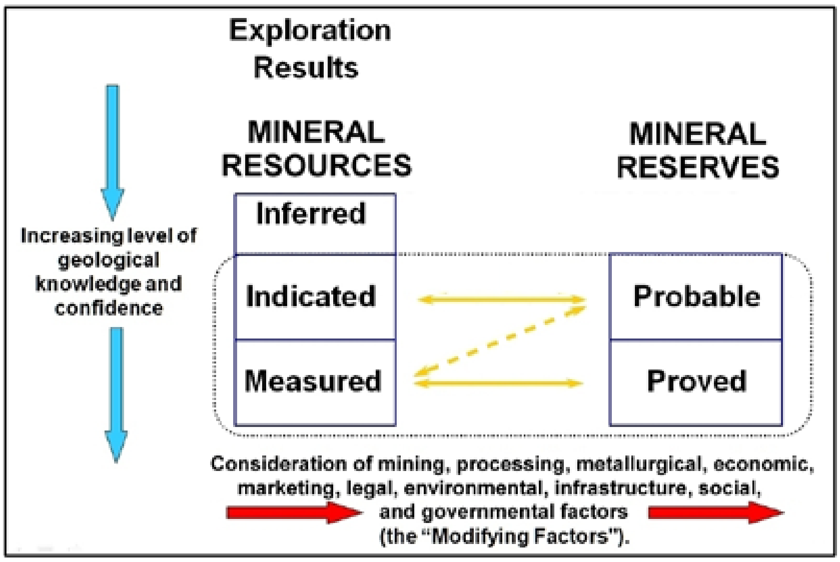

Figure 1: The CRIRSCO standard classification now used by all reporting standards that are aligned with CRIRSCO.

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ceptual, broad brush mine designs, created for the purpose of estimating resources, are based on realistic, inherently economic assumptions and working limits. These provide a framework for planning a feasibility study and anticipating more extensive studies that will be needed to support the move from resources to reserves.

Anticipating at an early stage which of the Modifying Factors will be particularly important in eventually proving reserves (and which are critical to success or failure) can save time and money (e.g. by undertaking non geological data collection and establishment of long term monitoring when exploration and other geological field work is underway, or by developing cutoff values for ratios or other parameters that are critical to economic viability). The early consideration of Modifying Factors in a manner that aims to achieve the balance illustrated in ***Figure 2*** is also conducive to public participation and achieving a 'social licence to operate' because the consideration of matters of special concern to the public (particularly mitigation of social and environmental impacts) is integral to the process right from the start.

This short paper is based on part of a presentation made by the author at the Mineral Deposits Study Group Conference, January 7th 2014, Keble College, Oxford, United Kingdom.

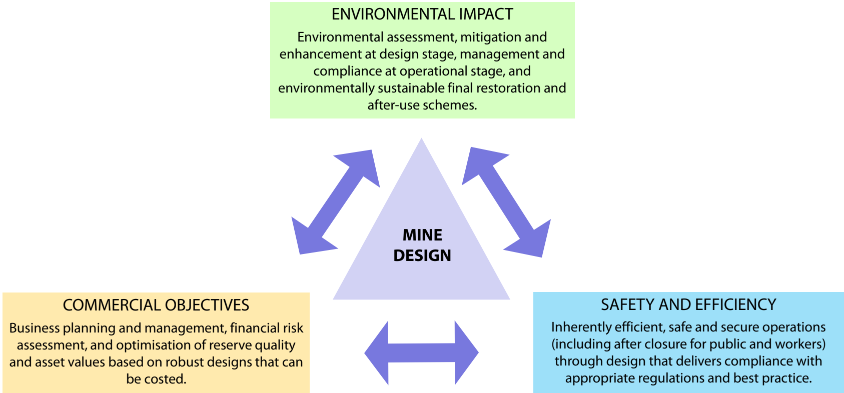

Figure 2: Design objectives – achieving an appropriate balance.

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[1] Committee for Mineral Reserves International Reporting Standards, ***www.crirsco.com***

[2] PERC Standard 2013, Clause 11; ***www.percstandard.eu***

[3] PERC Standard 2013, Clause 20 (underlining added by the author for emphasis); ***www.percstandard.eu***

Metal supply security and sustainability: understanding the whole system

Andrew Bloodworth and Gus Gunn*

In the last 100 years, the volume and variety of metals we utilise has expanded considerably in response to population growth and accelerating technological change. More recently, old concerns about metal scarcity and resource depletion have returned to the Western industrialised economies. Thus far, metal resources from the Earth's crust and the anthropogenic environment have been treated as wholly separate sources of supply. This article argues for a holistic, 'whole systems' approach to the management of both primary (earth) and secondary (recycled) metal resources.

Durant les cent dernières années, le volume et la diversité des minéraux métalliques utilisés se sont considérablement développés en réponse à l'augmentation de la population et à l'accélération du changement technologique. En conséquence, les préoccupations anciennes sur la rareté des minéraux métalliques et l'épuisement des ressources sont à nouveau au cœur de l'économie des pays industrialisés occidentaux. Jusqu'à présent, les ressources minérales métalliques issues de la croute terrestre et de l'activité humaine ont été traitées comme des sources d'approvisionnement, totalement séparées. Cet article défend une approche globale, holistique, de la gestion concernant à la fois les ressources minérales et métalliques primaires (la croute terrestre) et secondaires (par recyclage).

En los últimos 100 años, el volumen y la variedad de metales que utilizamos se ha expandido considerablemente en respuesta al crecimiento demográfico y la aceleración del cambio tecnológico. Como resultado, viejas preocupaciones en cuanto a la escasez de metales y el agotamiento de los recursos han vuelto a las economías industrializadas occidentales. Hasta ahora, los recursos de metales de la corteza de la Tierra y del medio ambiente antropogénico se trataron como fuentes totalmente independientes de suministro. En este artículo se argumenta a favor de un enfoque holístico de 'sistemas completos' con respecto al manejo de los recursos metálicos primarios y secundarios (reciclados).

In response to human population growth and demand created by the aspirations of millions in the emerging economies to a Western lifestyle, mine production of many metals has grown by one, two or three orders of magnitude since the beginning of the 20th Century (BGS, 2014). Along with volume, the variety of metals utilised has expanded considerably, generally in response to the accelerating pace of technology change and uptake. As a consequence, over the past decade old fears relating to security of metal supply and physical depletion of resources have returned to the Western industrialised economies.

Critical metals

A disparate group of metallic elements that are considered critical in delivering new digital and low-carbon energy technologies are the focus of worries about supply security and environmental sustainability. Threats of interruption to the export of rare earth elements from China in 2009 brought this issue to global prominence. The distribution in the Earth's crust of 'technology metals' such as rare earths, indium, niobium and rhenium and the geological processes which lead to their concentration are poorly understood compared to 'industrial metals' such as iron, copper and aluminium. Despite growing demand linked to their importance in key technologies, they are generally produced in low volumes (hundreds or thousands of tonnes) compared to industrial metals (millions or billions of tonnes). For example, global mine production of tungsten in 2012 was just 74800 tonnes, compared to 47.0 million tonnes of primary aluminium and 1.5 billion tonnes of crude steel in the same year (BGS, 2014). As a consequence, production of technology metals has commonly become concentrated in a very few locations. Because of geopolitical and socio-economic risks, this production concentration is widely regarded as a risk to supply security. This is compounded by barriers to the commercial development of both primary and secondary (recycled) technology metal resources. These barriers include difficult extractive metallurgy (which might attract environmental opposition in some locations), as well as markets which tend to be relatively small, complex and volatile when compared to industrial metals.

Growing demand for technology metals and their vital role in delivering a prosperous low-carbon future presents a series of problems that the scientific, industrial and policy communities must work together to solve. The initial response to this challenge was (and continues to be) the commissioning of numerous generic metal 'criticality' assessments (Graedel *et al.*, 2014). Whilst these are useful in identifying key issues and bringing these to the attention of industry and policy makers, they also generate a good deal of sterile argument as to what metals should or should not be on the 'critical list'.

Many of these overview criticality studies are difficult to utilise at a practical level because they tend to apply a generic approach to identify generic solutions. In part, they have led to the development of high-level resource management strategies which imply that technology metal supply security in Europe and the UK can be achieved largely through recycling. Although politically appealing, this approach does not fully recognise the essential role of primary resources in meeting

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rapidly rising demand for some technology metals. Whilst recycling is a very important tool in our management of industrial metal stocks, its application to technology metals is more limited and not as straightforward as some imply. A more subtle approach based on understanding the whole system of stocks and flows of individual technology metals is required if interventions aimed at securing supplies, improving resource efficiency and mitigating environmental impacts of resource use are to be effective.

Primary resources

Demand for metals used in digital and low carbon energy technologies has grown strongly in the last 40 years from a low base (Hageluken and Meskers, 2010). Subject to technology development and uptake, this growth looks set for the foreseeable future.

In the face of this demand, concerns have been expressed about physical scarcity of technology metals and some commentators have concluded that exhaustion of some metal stocks is likely (Cohen, 2007). However, most of these rather apocalyptic forecasts fail to take into account that reserves are dynamic entities which depend on a combination of scientific/technical know-how and the price of the mineral or metal. Reserve levels will therefore expand or contract depending on changes in one or both of these variables. Advances in technology and/ or price increases have ensured that, despite substantial increases in production over the last 50 years, global reserve levels of most metals (including technology metals) have remained similar or have actually grown (Crowson, 2011). Beyond reserves, our knowledge of global resources is relatively poor, especially for technology metals, many of which have been of little economic interest until relatively recently.

Limits to metal recycling

Secondary metals, recycled from end of life products provide a valuable supplementary resource which generally require less energy to recover than those from primary sources. However, in a world of increasing resource use, the stock of secondary metal available for recycling will always be insufficient to meet growing demand, even if recycling efficiency is 100 per cent.

Once mined and refined, technology metals are utilised in a very wide range of applications. A pallet of approximately 45 different elements is used in the manufacture of digital electronic components which then go on to be incorporated into devices ranging from mobile phones to motor vehicles (OECD, 2010). In most of these applications the technology metals are effectively dissipated because, within an individual manufactured unit, they are present in very small quantities, often in combinations that are not found in nature.

Whether or not a metal is recovered at the end of life of the device depends on its intrinsic value, concentration and technical recyclability when combined with other materials in the device (UNEP, 2013). Unsurprisingly, the recovery of high value precious metals (platinum group metals and gold) is the main target in pyrometallurgical processing of end of life circuit boards. Separation of these metals is achieved through the co-recovery of lower value copper as a 'carrier' metal, as well as antimony and indium. However, the thermodynamics of this process mean that incompatible metals such as tantalum, gallium, germanium and rare earths are oxidized and are effectively lost in the form of minor constituents in the smelter slag (Hageluken and Meskers, 2010). Recycling of technology metals is most economically attractive where target metals are present in high grade concentrates such as those from manufacturing scrap. For example, current technology used in the production of flat screen displays is not very efficient and approximately 70 percent of the indium used in this process finds its way into manufacturing scrap which is then recycled (Schwarz-Schampera, 2014). However, the reality is that most of the technology metals used in complex assemblies such as circuit boards are not currently recovered at end of life because they are too low value, too dispersed and may be combined with other materials from which they cannot readily be separated.

Figure 1: Niobium metal process scrap for recycling, Brazil NERC Copyright 2014.

Understanding whole systems

Measurement of individual technology metal stocks and understanding the manner in which these move through the natural and anthropogenic environments will highlight potential supply constrictions and help identify resource inefficiencies. This analysis requires appraisal of metal flow through a whole system comprising discrete stages which include mining, concentration, extractive and process metallurgy, manufacturing, use, re-use, re-cycling, dispersal and disposal (Cullen *et al.*, 2012). This can be measured directly in terms of metal recovered or lost, or indirectly in the form of energy or water consumed in the process.

Quantification of losses as metals flow along the whole system is likely to be revealing about where the most effective interventions can be made in improving resource efficiency. Only about 75 percent of the

Figure 2: Train loaded with bauxite, Western Australia NERC Copyright 2014.

tungsten content of mined ore ends up in the concentrate which goes to the smelter. This compares to recovery rates of over 90 per cent for gold in sulphide ores and suggests that improvement in concentration technology would have a major impact on tungsten resource efficiency. Although platinum group metals (PGMs) can be recovered from used autocatalysts with an efficiency of more than 90 percent, only 50-60 percent is actually recovered from European end of life cars because the remaining material is lost as old cars are exported to places where no autocatalyst recycling facilities exist. Understanding how PGMs move through the whole system would allow an objective comparison of say, an intervention to improve recovery from these lost autocatalysts to a scheme which attempted to recover PGMs from road sweepings.

Figure 3: Cobalt ore - skutterudite - cobalt nickel arsenide, Morocco NERC copyright 2014.

Mapping a whole system for an individual technology metal is a challenging activity. In many cases, volumes produced are relatively low. As a result, data for the whole life cycle of many of these metals is hard to find and can only be acquired through close cooperation between researchers and those working in the supply chain.

Living in a material world

Like it or not, we live in a material world. As the global population and economy expand we are consuming mineral and metal resources at an increasing rate. Managing these resources efficiently is imperative if we are to survive, prosper and avoid irrevocable damage to our natural environment. Whilst the industrial metals will remain fundamental to our economy, a secure and sustainable supply of a larger group of technology metals will be increasingly important as we move to a digital, low carbon economy.

Responses by the Western industrialised economies to concerns over securing supplies of technology metals have changed in the last few years. Near panic over physical depletion and geopolitical muscle-flexing has, in some cases, given way to a dangerously complacent assumption by certain policy makers that recycling is the answer to addressing future supply problems.

The shift toward increasing consumption of a much broader suite of metallic elements presents an opportunity to develop a more holistic approach to resources. The 'one size fits all' notion that recycling is always good and material from primary sources is always bad needs to be challenged because it ignores the reality of delivering a low carbon economy. Although uptake of all the environmental and energy technologies currently under development seems unlikely, large-scale adoption of some is inevitable and demand for metals such as lithium, rare earths, gallium, tellurium and germanium will grow rapidly from what is currently a relatively low base. Restricted availability of recyclable stocks of these technology metals means that much of this growth in demand will have to be supplied from primary sources. If we consider both primary and secondary sources as part of the same system, then we can understand the entirety of metal flows and effectively target interventions to improve resource efficiency and reduce negative environmental impacts.

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Rock of the Year – An initiative of German geoscientists

Werner Pälchen and Ulrike Mattig***

Geosciences and the public

Up until the turn of the century, the German public was largely unaware of the geosciences. At most it was disasters, such as earthquakes or volcanic eruptions, and of course the interest in dinosaurs, notably awakened in children through the film "Jurassic Park", that called attention to the field. However, the "Year of Geosciences" proclaimed in 2002 has led to a significant upturn in this relationship. Several major events focused around the themes of air, water, fire and earth, as well as various local events, found a broad resonance among the public, thus creating a much better understanding of and general interest in geological phenomena and their impact on our daily lives. In this context initiatives which are now established as permanent events emerged for the first time. The German Society for Geosciences (DGG) created the "Day of the Geotopes", which has been celebrated nationwide since then each year on the third Sunday in September, with a variety of local field trips, conferences and presentations. The certification of the first German national Geopark also dates from this period.

New approaches

In 2002, the Professional Association of German Geoscientists (BDG) created the „Stein im Brett" Prize, which is awarded on the occasion of the biannual Geology Day. The award winners are public figures, politicians, journalists, writers and institutions that have made, as non-geoscientists, a significant contribution to the popularisation of geoscientific knowledge and contexts.

On the occasion of the declaration of the "International Year of the Planet Earth" (IYPE) for the years 2007 and 2009 by UNESCO, the BDG picked up an idea which has been practiced in the field of nature conservation since several decades, and decided to introduce it in continuation and completion of the above-mentioned activities for the popularisation of geosciences. In 1971, the Association for Nature and Environment (NABU) had proclaimed the peregrine falcon (whose population had been decimated and had therefore been placed under protection) "Bird of the Year". Over the years, more animal and plant species have subsequently been marked with the attribute "Species of the Year". Currently 32 natural beings of the year are included in this list. In addition to representatives from a variety of species of the animal and plant world, complex categories such as soils and landscapes have also been integrated in this listing. The original idea of the exposure to loss and thus the need for protection has gradually faded into the background. The objective now is rather to direct public attention to elements of living nature. So far, geological objects have not been taken into account.

Such exclusion of geo-objects from the whole complex of "nature" is without any doubt unjustified and challenges us to portray the role and function of rocks in the natural environment and in public life and to spread knowledge about them. The declaration of the "Rock of the Year", which took place for the first time in 2007 on the initiative of the Professional Association of German Geoscientists (BDG) and the German Society for Geosciences (DGG), serves this objective.

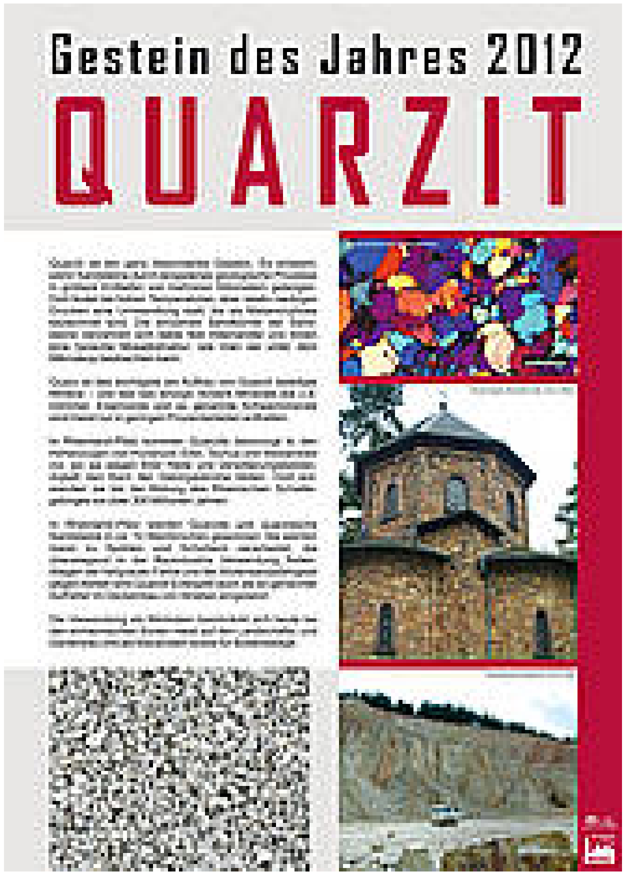

Figure 1: Flyer of the State Office for Geology and Mining Rhineland-Palatinate in Mainz about the "Rock of the Year" 2012 - quartzite (detail).

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Figure 2: Presentation of the "Rock of the Year" 2013 - Kaolin - in an open-cast mine close to Oschatz in Saxony (Photo: AKW Amberg).

What should be taught with the initiative "Rock of the Year"?

Rocks cross our way every day, be it as paving stones or road gravel, as a building block in churches, palaces or railway stations, as a sculpture in museums, as a cliff or mountain peak, as boulders in rivers or brooks – raw or processed into various products and objects of daily life. Nevertheless, rocks are often hardly or even not at all noticed. Opening the conscious perception of rocks as a fundamental part of nature and their function as raw material is thus the main concern of the initiative "Rock of the Year". In this respect, especially schools and other educational institutions are the addressees of this action. During the initiative, two main aspects are involved.

Rocks as part of nature: Rocks are the material that forms the solid earth's crust. In conjunction with other factors, the type of rock determines essentially the morphology of landscape. The formation of soils, their composition and structure and the resulting characteristics such as permeability, soil fertility and nutrient potential are significantly affected by the rocks present at the Earth's surface. In this sense, the vegetation is also considerably influenced by the bedrock.

Rocks as raw materials: Since the beginnings of mankind, rocks and minerals have been used for various purposes, at the beginning without changing their structure or composition, merely through external processing: as tools, millstones, abrasives, jewellery, construction material, for sculptures and many other uses. Through the centuries until today, countless sacral and secular buildings of all types, as well as sculptural representations bear witness of this. Crushed hard rocks of all grain sizes and non-cohesive loose rock such as sand and gravel are essential for building mass products in the transport, industrial and residential sectors. After physical or chemical processing, rocks are the starting material for many mass products, including cement, porcelain, ceramics, fertiliser, filler for paper, and rubber and polymer materials, as well as many other applications.

How is this action implemented?

Each year an expert group selects a rock of the year for the following year. The group is composed of competent persons of the two geoscientific associations involved – the Professional Association of German Geoscientists and the German Society for Geosciences – as well as representatives of other associations; the expert group on the Certification of National Geoparks in the GeoUnion Alfred-Wegener Foundation and the network "Stones in the City" ("Steine in der Stadt") is always involved, and in some cases additional experts from other fields. In the early years, widespread and well-known rocks were selected in order to achieve high acceptance among the public. The selected rock is presented with a brief description of the geological contexts and its use in the journal *Geowissenschaftliche Mitteilungen* (GMit) as well as in a press release. In the electronic media the rock of the year may be found at its own website *http://www.gestein-des-jahres.de* and on the homepages of its supporting organisations.

It is a declared purpose of the initiators of the action to proclaim rock types without any specific local context. It is thus possible that local initiatives in different parts of Germany may organise events or field trips in connection with the selected rock.

Most regional geological surveys, but also museums and different educational institutions, have taken up this idea and published flyers or other publications or organised presentations for this occasion (***Fig. 1***). In the past years, a public presentation has been organised several times around concrete objects. The dates where usually scheduled around the "International Earth Day" (22 April) and the "Day of Geotopes" (3rd Sunday of September). Companies that exploit the respective rock as raw material and commercialise it are usually happy to support this campaign in order to gain effective public advertising (***Fig. 2***).

Since the start of the initiative the following rocks have been declared "Rock of the Year": 2007 - Granite, 2008 - Sandstone, 2009 - Basalt, 2010 - Limestone, 2011 - Tuff, 2012 - Quartzite, 2013 - Kaolin, 2014 - Phonolite (***Fig. 3***).

The excellent resonance that the initiative "Rock of the Year" has experienced so far encourages us to proceed further and to carry knowledge about rocks to the general public in a popular way, as well as to communicate on the role and acceptance of geoscientists and their activities in an appropriate way.

Figure 3: The "Rock of the Year" 2014 - phonolite - is "baptized" in the quarry Rupsroth close to Fulda in Hesse (left to right: Managing Director of the company Nüdling; A. Günther Plönes, W. Pälchen, U. Mattig / all BDG; photo: F. - J. Enders).

Book review:

Canadian Professional Engineering and Geoscience Practice and Ethics

*Isabel Manuela Fernández Fuentes**

Canadian Professional Engineering and Geoscience Practice and Ethics (Fifth Edition)
by Gordon C. Andrew, University of Waterloo

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More information: http://www.nelson.com

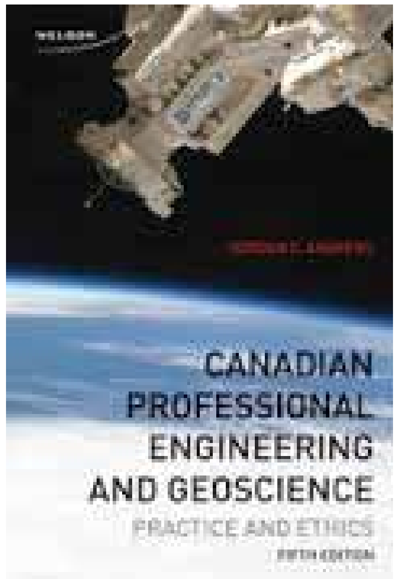
Canadian Professional Engineering and Geoscience Practice and Ethics (Fifth edition) is a textbook for engineers and geoscientists on all aspects of professional practice, and is an important professional resource both for professionals who want to work in Canada and for finding definitions of professional concepts relevant in professional practice worldwide.

This textbook introduces readers to the structure, practice and ethics of the engineering and geoscience professions in Canada. It is a comprehensive reference for practicing professionals such as immigrants who want to practice geoscience in any province of Canada.

The book is divided into five parts: Professional Licensing and Regulation; Professional Practice; Professional Ethics; Environmental Practice and Ethics, and Obtaining and Maintaining Your Professional Status. The five parts of the book cover all practice and ethics topics recommended by engineers and geoscientists in Canada, and advice from the author to help readers become effective professionals.

Geologists from other countries can find information in this book about the academic and experience requirements, the licensing process and the role of associations in professional status. The concepts of Professional Practice and Professional Ethics are described theoretically and with several examples that help the reader to understand the important responsibilities of professional work.

Dr. Gordon C. Andrews, P.Eng., is an emeritus professor at the University of Waterloo. He is a graduate of the Royal Military College (B.Sc), the University of British Columbia (BA.Sc., MA.Sc.), and the University of Waterloo (Ph.D.). He is a licensed Professional Engineer (Ontario),



certified to provide engineering advice to industry. He is the author or co-author of over one hundred publications and two textbooks. Dr. Andrews is a former member of the Academic Requirements Committee of Professional Engineers Ontario (PEO).

PanGeo – Rome (Italy) case history

The PanGeo project is drawing to a close at the end of January 2014, but feedback recently received from Rome illustrates the substantial benefits that can accrue when a Local Authority (LA) and the Geological Survey (GS) combine to form a team that is greater than the sum of its parts.

Representatives of the Rome city authority and the Italian Geological Survey (Il Servizio Geologico dell'ISPRA) combined their expertise to create a PanGeo geohazard product integrating their respective expertise and uniting the different databases to produce a geological mapping hazard product for Rome that could exploit all the available aspects of knowledge. Results from the Rome experience seem to confirm that effective sharing of local resources, special expertise and databases can achieve results not easily produced by the individual entities and have an impact well beyond the initial goal for the benefit of a larger community of users.

This interesting initiative arose from the opportunity provided by PanGeo in linking and networking the two institutions and as such should be regarded a successful example of efficient collaboration which could be promoted and extended to the advantage of other LAs and GSs working for PanGeo in other European cities.

The feedback from the LA representative highlighted the positive stimulus that a project such as PanGeo can provide for developing critical knowledge and practical applications (partly derived from space technologies) for better management of the urban environment. An ongoing programme of collaboration between the two institutions is now envisaged to continue in the future. In order to lead to real success, this type of collaboration needs to integrate a number of different professional competencies. In the specific case of Rome experience, the team members included geologists, urban planners and GIS specialists able to integrate the products.

Figure 1A: Location of the project.

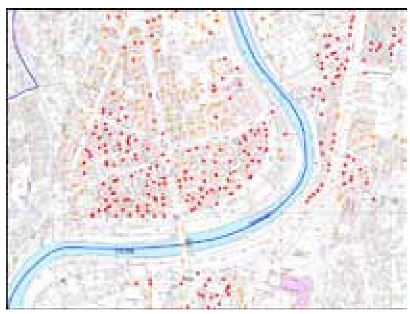


Figure 1B: Location of the project in relation to the evaluation of the maximum carrying capacity of the land, through the analysis of PSI points, highlighted by the movements of the adjacent buildings.

Figure 1C: Location of the project in relation to the Ground Stability Layer information which here indicates compressible ground associated with fluvial deposits.

The Rome LA gave some practical examples of the application of Pangeo. First is an analysis of the area of construction of underground parking (as shown in the figure below). In this instance, the presence of compressible ground and the rates of ground movement that are taking place enable the city planners to optimise the location of the proposed car park development.

The second example presented from Rome is the monitoring of industrial structures producing dangerous material, and therefore an activity classified at high risk within the city limits. The Pangeo data allow checking of the presence of geohazards that could be a cause of movement of some structures in an industrial complex producing dangerous material.

The third case presented relates to the planned monitoring of school buildings.

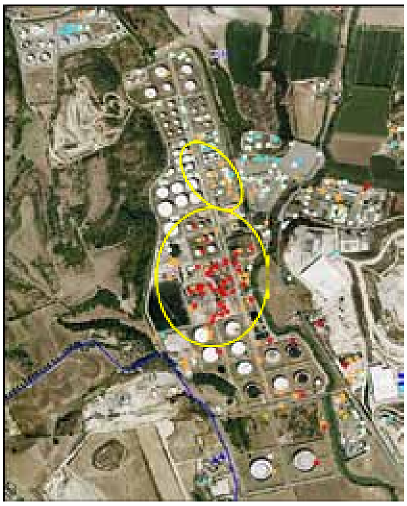


Figure 2A: Location of the project.

Combination of the potential ground hazards and the existing ground movements allowed the LA to review and prioritise the inspection programme for the school buildings.

Given the large number of school buildings within the portfolio it was decided to use the geo-hazard ranking identified by the project PanGeo and their points of PSI to help in prioritising action areas.

Finally, the successful experience of Roma Capitale and its direct involvement in the PanGeo production phase provides an important example of the benefits of close collaboration and the outcome of products that assist in planning use of the urban environment.

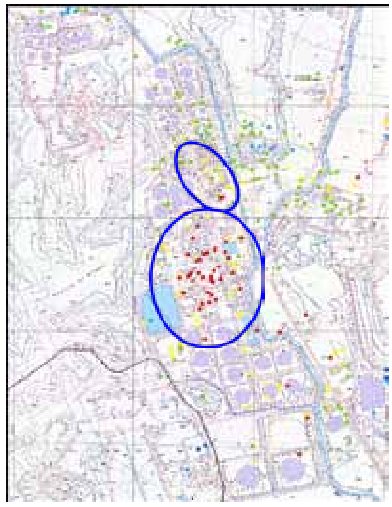


Figure 2B: Location of the project in relation to the evaluation of the maximum carrying capacity of the land, through the analysis of PSI points on adjacent buildings which indicate that potentially significant movements are taking place.

Figure 2C: Location of the project in relation to the Ground Stability Layer, which indicates compressible ground here.

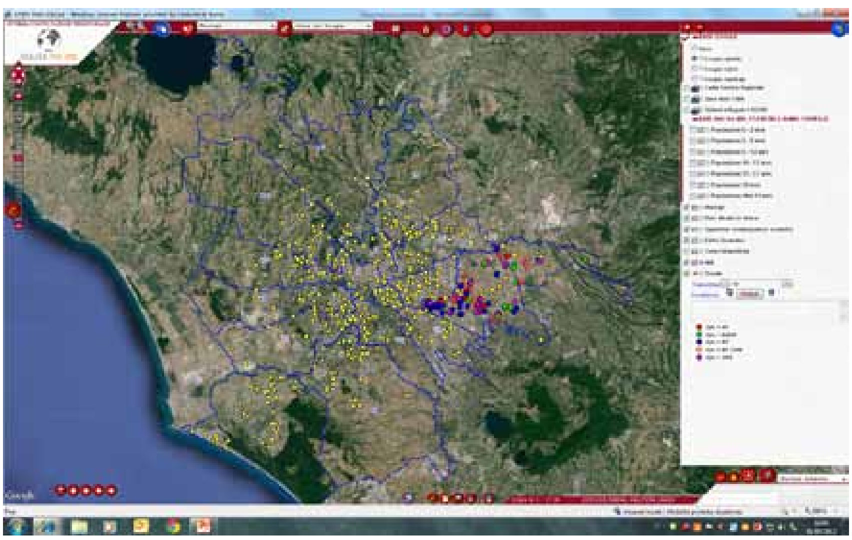


Figure 3: Plan for maintenance of school buildings.

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

UAG new EFG member

Delegates of the Ukrainian Association of Geologists (UAG) attended the November Council meeting of EFG on 23 and 24 November 2013 as observers and expressed their interest in becoming a full member of EFG. Subsequently this request was unanimously approved by the Council and UAG joined EFG as a full member from the 1st of January 2014.

For more information on UAG you may consult the association's website at: *http://www.geolog.org.ua/en*

GEOTRAINET

The statutes of the new GEOTRAINET international not-for-profit association under Belgian law (aisbl) were officially signed on 25 February 2014. The statutes shall be published within the next two to three months in the Belgian Official Journal (Moniteur belge) which will complete its registration as a legal entity.

The official founding members are: EFG - EGEC - ANIG hp (Italy) - RGS (Romania) - BWP (Germany) - GEOPLAT (Spain) - SGC (Sweden) - APG (Portugal) - HHPA (Hungary)

GEOTRAINET is now established as an association which will:

- deliver training and certification programmes in the field of shallow geothermal energy recognised all over Europe,
- 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 design, install and operate efficient systems.

More information: *www.geotrainet.eu*

IUGS Task Group on Global Geoscience Professionalism

Formed by the International Union of Geological Sciences (IUGS) at the 34th International Geological Congress in Brisbane, Australia, in August 2012, the Task Group on Global Geoscience Professionalism ("TG-GGP") provides a single global forum for interchange on professional affairs in geoscience worldwide. Its main purpose is to ensure 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 organisations of this Task Group and backs its activities through administrative support.

Subsequent to the official release of the Task Group's website in November 2013 (*http://tg-ggp.org/*), reported in the last issue of the European Geologist magazine, the Chairs presented the annual report for 2013 to the IUGS which lays out the work plan for 2014. The main tasks will be:

1. To continue to raise awareness of the existence of the new Task Group right across the geoscience community globally and to multiple geoscience communities;
2. To increase direct involvement in the Task Group by professional organisations from additional countries and collaborating organisations;
3. To create a series of working groups focused on specific practice areas in professional affairs, including professional ethics in practice, mineral resources reporting, and human resources capacity; and
4. To support the 36th INTERNATIONAL GEOLOGICAL CONGRESS in South Africa with a workshop or session proposal (or both) on Global Geoscience Professionalism. Plans are to organise the 5th International Professional Geology Conference (held every four years, the last in 2012 in Vancouver) as part of (or at the same time as) 36IPGC in South Africa.
5. To continue to identify, approach and engage additional countries in the Task Group. As well as additional countries, every effort will be made to search out and embrace already existing focus groups within the global geosciences community that are directing attention to different professional and ethical issues impacting both our science and its practitioners, worldwide.

One of the first activities of 2014 was participation in the 67th IUGS Executive meeting in Goa, India (8-10 February 2014) where a presentation was given on the objectives and activities of the Task Group. As stated by the IUGS President, the organisation appreciated the positive cooperation of the two new Affiliated Organisations on ethics - the International Association for Promoting Geoethics (IAPG) and the International Association for Geoethics (IAGETH) - under the guidance of the IUGS Task Group on Professionalism, and recognised the successful symposia these groups held on ethics during several international meetings.

* EFG Office, info.efg@eurogeologists.eu

PERC

The Pan-European Reserves & Resources Reporting Committee, PERC, have participated in several events and publications in Europe and worldwide as follows:

- CRIRSCO Annual General Meeting in Bogota in November 2013. Representing PERC were Eddie Bailey and Steve Henley;
- EPCAT – EFG/PERC Competence Accreditation and Training – Professionalism and Standards for the SIP of the EIP-RM in December 2013;
- MDSG presentation in Oxford, UK by Eddie Bailey and Steve Henley in January 2014;
- Contribution to ERA-MIN MESR in January 2014;
- Participation in the EGRC of the UNFC in Geneva in April 2014.

PERC, represented by Steve Henley, also had a meeting in Brussels with the EFG President Vítor Correia and the Office Executive Isabel Fernandez in order to draw up a memorandum regarding the following topics:

1. Reporting codes and conflict minerals;
2. Standards for secondary sources of raw materials;
3. Establishing a warranty seal to use in public and industry communication;
4. EFG participation in the Pickman project;
5. Interest from the Spanish Association of Mining Engineers to enter PERC;
6. Joint organisation of a conference focused on mineral standards to be held in November 2014 in Brussels.

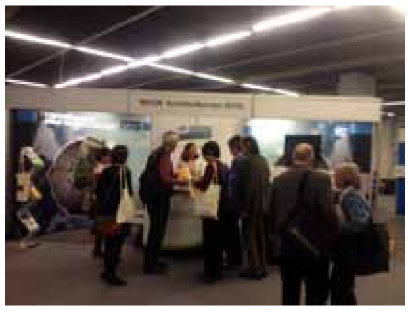
The 2014 Annual General Meeting of PERC was held in Dublin on 29 March in the IGI installations with the presence of representatives from EFG, GSL, IGI, and IOM3. This event was preceded by a Training Workshop entitled: "Best Practice for Assessment and Reporting of Exploration Results, Mineral Resources and Mineral Reserves" with Edmund Sides from AMEC as the instructor.

EFG participation in the European Geosciences Union General Assembly 2014, Vienna, Austria, 27 April – 02 May 2014

For the first time, EFG was present at the EGU General Assembly as an exhibitor. The EGU General Assembly is the most relevant geosciences event in Europe. With 4,829 oral, 9,583 poster, and 483 PICO presentations EGU2014 was a great success. In all, 12,437 scientists from 106 countries attended the conference, of whom 27% were students.

EuroGeoSurveys (EGS) generously invited EFG to join its booth. The booth had a very good position, just next to the main EGU stand. EFG contributed with a banner, the last four issues of the European Geologist magazine, and a Powerpoint presentation. EFG thanks EGS for its generosity and this important opportunity to participate together in the EGU exhibition.

For EFG Executive Director Isabel Fernandez, EGU2014 was also the opportunity to establish closer contacts with EGU Executive Secretary Philippe Courtial. The aim of this meeting was to develop collaboration opportunities between EGU and



EFG. Various interesting possibilities for future collaboration were discussed, such as a common photo contest, and shall be confirmed within the next few months.

EAGE/EFG Photo Contest 2014

After the success of last year, the European Association of Geoscientists and Engineers (EAGE) and the European Federation of Geologists (EFG) are again joining forces for the organisation of the photo contest. As in the past year, the topic is 'Geoscientists at work' and 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 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).

The deadline for submitting photos was 1 April and following the selection by an internal professional jury, a total of 34 pictures is now online for the public voting open to all EAGE and EFG members. On 11 May the voting closes and the 12 most popular photos will be printed and included in a travelling exhibition that will visit several EAGE and EFG events throughout Europe. During the travelling exhibition it will still be possible to cast your vote online for one of the top 12 photos. In October 2014 great prizes will be rewarded to the photographers of the three most popular pictures.

The contest is kindly sponsored by Prospectiuni.

More information and online voting at: *www.houseofgeosciences.org*

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.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout

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

Abstract

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

Main text

- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- 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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Rue Jenner 13, B-1000 Brussels, Belgium.
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Note

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Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organizations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, *www.eurogeologists.eu*
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist Magazine, EFG's biannual magazine. Since 2010, the European Geologist Magazine is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

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

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

Prices for advertisements

EGM	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro

Geonews	**Annual Price**
Ad and regular newsfeed	1000 Euro
EFG Homepage	
Ad and regular newsfeed	1000 Euro
University ad	
Ad for training opportunities in the job area of the homepage	500 Euro
Annual package	
Business card size ad in the EGM, GeoNews and homepage.	3000 Euro