Applied Mineralogist

The bulletin of the Applied Mineralogy Group

Edited by: George Guice
Andrew Dobrzanski
Eva Marquis

Web: http://www.minersoc.org/amg.html
Twitter: @amg_min
Email: amgminsoc@gmail.com

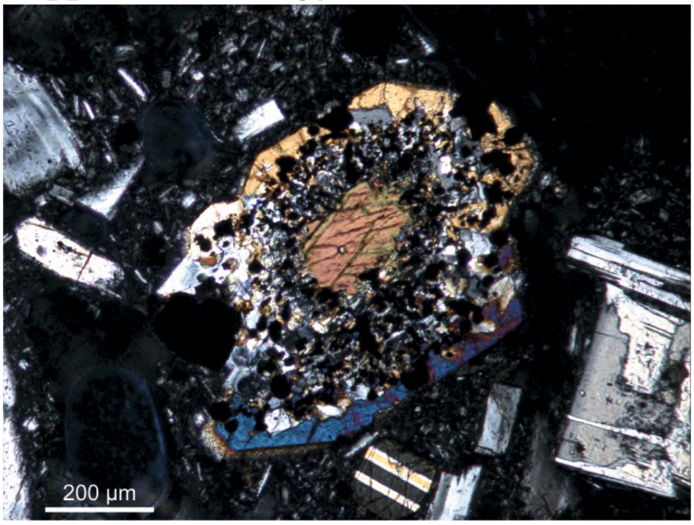
December 2017
Volume 2, Number 4

From the AMG committee

Hello and welcome to the December edition of *Applied Mineralogist*! Additional to two student bursary reports, this edition contains an outstanding special feature about electrowinning of didymium, written by Ksenija Milicevic and Bernd Friedrich. We also have our #Applied Mineralogy winner - Katie Preece's awesome amphibole - and festive mineral application facts.

Before you enjoy this edition, we would like to draw your attention to the Mineral Deposits Studies Group (41st) annual meeting, which is being hosted by the University of Brighton from the 3rd - 5th January 2018. Six keynote speakers will talk on a range of topics encompassing the entire life cycle of mineral deposits, from grassroot discoveries to PGE and Cr in the world's largest igneous intrusion, the use of quantum chemistry in understanding hydrothermal fluids, and mine waste. An exciting program including an icebreaker reception, conference banquet at The Grand Brighton seafront hotel, and two days filled with talks and posters on the most recent advances in mineral deposits research. We look forward to seeing many of you there.

#AppliedMineralogy *@KatieJPreece*



The photomicrograph shows an amphibole (titanian magnesiohastingsite) phenocryst from the 2006 dome eruption of Merapi volcano, Central Java, Indonesia. The amphibole is surrounded by a reaction rim composed of anhydrous minerals: plagioclase, pyroxene and Fe-Ti oxides. These reaction rims form when amphibole leaves its stability field and starts to break down, either through heating, oxidation, or via decompression and H_2O-degassing. The reaction rims thereby often preserve a valuable record of pre-eruptive magma mixing or of the timescales of magma ascent to the surface.

by Katie Preece, SUERC, University of Glasgow, UK.

In this issue:

AMG bursary report: *Lisa Hart*

The SGA bi-annual conference was held in Quebec City (20-23 August 2017). With the help of an AMG bursary, I was able to take part in the post-conference field trip visiting precious and base metal deposits of the southern Abitibi greenstone belt, Superior Province, Canada. The week-long excursion was led by several experts in the geology and metallogeny of the region, including Patrik Mercier-Langevin (GSC-Qc), Jean Goutier (MÉRN), Benoit Dubé (GSC-Qc), K. Howard Poulsen (Consultant), Michel Houlé (GSC-Qc), Stephane de Souza (UQAM) and Pierre Pilote (MÉRN). We visited world class examples of well preserved and exposed komatiite flows at Pyke Hill and Spinifex Ridge, investigated the Cadillac-Larder Lake fault, and discussed its potential as a control of gold mineralisation across the southern Abitibi gold camp. In addition, we visited "volcanic-hosted massive sulphide" (VHMS) deposits characteristic of the area, such as Potter Cu-Zn-Co-Ag Mine, where we looked at the host lapilli stone volcaniclastic unit as it crops out at surface, followed by drill core, where the same unit is mineralised at depth. One of my trip highlights was going underground at the Laronde Au Mine, where we descended 2.9 km below surface to see the high grade VHMS lens *in situ*. On the last day of the trip, we visited the open pit at the low-grade, high tonnage Canadian Malarctic Au Mine. Throughout the week, I collected samples representing the full range of alteration and metamorphic assemblages associated with mineralisation in the district. I plan to compare these

Canadian Malarctic Mine

(continues on page 3)

Special Feature: Electrowinning of didymium

Ksenija Milicevic and Bernd Friedrich (RWTH Aachen University, Germany)

The demand for rare earth metals (REM) has increased significantly due to their use in many modern technologies [1], including those important for reducing our global carbon footprint, such as wind turbines and electric cars. Ironically, although the REMs are utilised in green technologies, their production is environmentally challenging [2], and there remains the issue of secure supply from a Chinese-dominated market for both primary ore and metal production [3]. This concentration of production has resulted in a lack of clarity over the metal production process. Neodymium (Nd) and praseodymium (Pr) are two rare earth elements that have significant applications as magnets, such as those used in wind turbines. These elements have very similar properties, making them very difficult to separate using traditional methods, such as solvent extraction. Therefore, alternative methodologies were investigated under the EU FP7-funded "EURARE" project. The synthesis of neodymium and praseodymium as a metal alloy ("didymium") was achieved at RWTH Aachen, with the electrochemical basis behind this process investigated [4,5].

Metal Production

These two metals can be produced separately, or as an alloy (didymium), using an oxy-fluoride molten salt electrolysis process [6]. The technology is similar to aluminum electrolysis, but the setup and size differs. Rare earth oxides (REO) provide the raw material to a fluoride-based electrolyte, which is fed into a closed steel cell operated under an inert argon atmosphere (Fig. 1). The system contains a hollow carbon ring anode and a tungsten (or molybdenum) cathode, and is heated to around 1050 °C. Oxidation occurs on the anode, where oxygen reacts with carbon to produce CO and CO_2 gases. Simultaneously, the reduction reaction occurs on the cathode where the neodymium/didymium metal is produced. The working temperature is slightly above the melting point of the metal/alloy and this allows the liquid metal to drop into the tungsten crucible positioned below the cathode. The "anode effect" occurs when the concentration of REO in the solution drops off and results in the production of perfluorocarbons (PFCs) from the anode, CF_4 and C_2F_6, which have a global warming potential 6.5 and 9.2 times of CO_2, respectively [7]. PFCs production shoots up, current flow is interrupted and metal production is stalled when this occurs (Fig. 2).

As the processes for didymium electrolysis were unknown or the literature difficult to access, the investigations were performed from scratch. FactSage® software was used for thermodynamic calculations and phase diagram construction. Multiple electrochemical techniques (chronoamperometry, linear sweep voltammetry and others) were used in order to determine the process window and recognise the ongoing mechanisms in the system [9,10], in order to produce metal efficiently and prevent PFC production.

Electrolysis trials revealed that alloy composition is directly influenced by electrolyte composition (i.e. the activity concentration is transferred to the composition). An increase in praseodymium content in the electrolyte leads to higher praseodymium content in the alloy, where the obtained alloy had high purity, > 99 %. Investigations of anodic processes during electrolysis of didymium showed that CF_4 can be detected before full anode effect, whereas C_2F_6 is emitted at and after this point. This fact was used for installation of a controller, preventing the system entering full anode effect (i.e. reducing the PFC greenhouse gas production). Emission of these gases depends on oxide concentration and other process parameters, such as potential and current density, which were regulated by an installed controller while a Fourier-transform infrared (FTIR) spectroscope was used to measure off-gases. As soon as the above-mentioned parameters reach critical values and/or the pre-

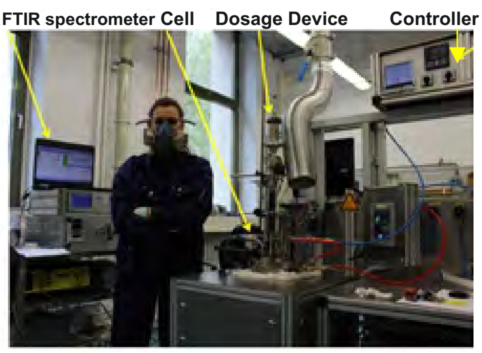


Fig. 1: Setup for modern salt electrolysis of neodymium and didymium at RWTH Aachen.

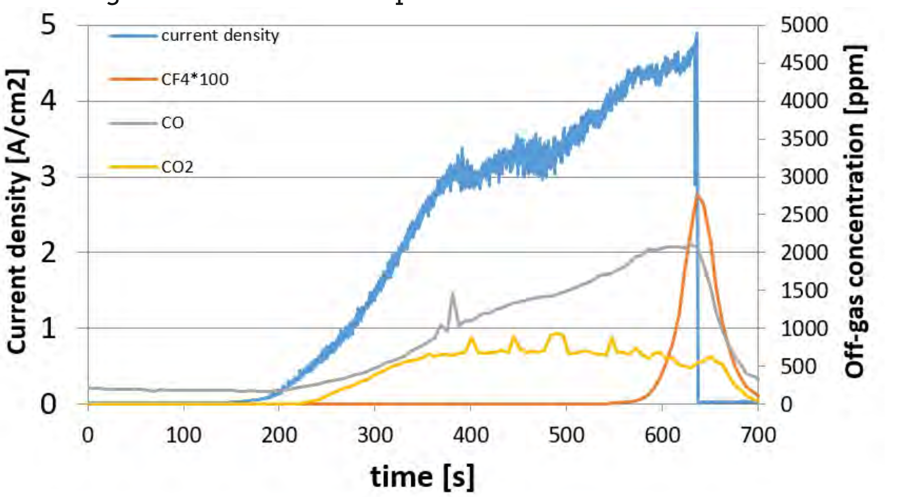


Fig 2: Linear sweep voltammogram of NdF_3-LiF-PrF_3-Nd_2O_3-Pr_6O_{11} system with off-gas concentrations.

set concentration of PFCs is detected, an alarm is sent to controller triggering a dosing of REOs and preventing the full anode effect.

Within the EURARE project, the fundamentals behind electrolysis of neodymium and didymium were investigated and the optimal process parameters were established. Furthermore, the fully automated process control was installed based on critical potential and current values as well on off-gas concentrations leading to a high efficiency in metal production and reduction of PFC greenhouse gases.

References:

[1] Goodenough, K. M., Wall, F., Merriman, D. 2017. The Rare Earth Elements. Demand, Global Resources, and Challenges for Resourcing Future Generations. *Nat. Res. Research.*

[2] Lee, J.C.K., Wen, Z. 2016. Rare Earths from Mines to Metals. Comparing Environmental Impacts from China's Main Production Pathways. *Journal of Industrial Ecology.*

[3] E.C., 2017. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region on the 2017 list of Critical Raw Materials for the EU

[4] Duan, Y., Milicevic, K. 2015. Reasons and control of carbon impurity in molten salt electrolysis of neodymium. Mini-thesis. RWTH Aachen.

[5] Duan, Y., Milicevic, K., 2015. Setup and optimal process parameters for neodymium electrowinning. Mini-thesis. RWTH Aachen.

[6] Krishnamurthy, N., Gupta, C. 2016. Extractive metallurgy of rare earths. Second edition.

[7] Green, J. A. S. (Hg.), 2007. Aluminum recycling and processing for energy conservation and sustainability. Materials Park, Ohio: ASM International.

[8] Milicevic K., Meyer T., Friedrich B. 2017. Influence of electrolyte composition on molten salt electrolysis of didymium. Presentation at ERES2017 European Rare Earth Resources Conference, 2017.

[9] Meyer, T., Milicevic, K. 2017. Schmelzflusselektrolyse von gemischten Seltenerdoxiden. Master's thesis. RWTH Aachen.

[10]Feldhaus, D., Milicevic, K. 2017. Investigation of anodic processes during molten salt electrolysis of didymium. Master's thesis. RWTH Aachen.

samples to the porphyry alteration styles I have studied in detail during my PhD project. Overall this was an excellent trip, it was extremely well organised and I learnt an incredible amount in only a week. It was a great experience and I am grateful to have been able to attend.

AMG bursary report: *Jessica Hamilton*

The student bursary awarded by the AMG allowed me to attend the Goldschmidt conference in Paris this summer. On the weekend preceding the conference, I attended a workshop on "*Nanoscience in the Earth and Environmental Sciences—Research and Teaching Opportunities*". The workshop had an emphasis on discussion and round table activities, and introduced me to some fantastic resources that I will use throughout my career.

When the conference kicked off, I met with collaborators and made new contacts. I gave an oral presentation, entitled "Optimising Geochemical Treatments to Enhance in situ Carbon Sequestration in Ultramafic Mine Tailings", in session 15j: *The environmental legacy of metal and coal mining: Geochemistry, human health, remediation, resource recovery*. It was well attended and I was pleased to receive positive feedback afterwards. The program was packed with presentations I wanted to see, so each day was meticulously scheduled, and sometimes involved an urgent rush to another room. The highlight presentation was the plenary by Prof. Paul Falkowski on "How Corals Make Rocks". I also enjoyed an exciting presentation by Jennifer Macalady about sampling of microbes in a new glacial cave in Svalbard, Norway. Not only was the intense and daring fieldwork awe-inspiring, the results were very interesting.

Coffee break small-talk: mineral application facts

- The worlds smallest 'snowman' is 3 μm tall and was creating using silica spheres.
- Growing a hectare of commercial Christmas trees can take up to 4 tonnes of mineral-based fertiliser and 2 tonnes of Nitrogen fertiliser.
- Snowflakes (which are minerals) have a hexagonal crystal structure and thus have six sides/arms.
- Tinsel was originaly made of strips of silver, but now is made of PVC coated by a metallic finish by evaporating metals in vacuum conditions which then condenses on the plastic.

Calendar

JAN '18 3 - 5 — MDSG (Mineral Deposit Studies Group) conference, Brighton, UK

JUN '18 16 - 21 — Resourcing Future Generations, Vancouver, Canada.

JUL '18 30 - 6 — Platinum Symposium and Layered Intrusion workshop, Mokopane, South Africa.

JUL '18 10 - 13 — Granulites & granulites, Ullapool, UK

AUG '18 13 - 17 — XXII Meeting of the International Mineralogical Association, Melbourne, Australia.

About Us

Founded in 1963 by Norman F.M. Henry, the AMG is a special interest group of the Mineralogical Society of Great Britain and Ireland. We encourage and promote the study and research of mineralogy applied to ores and related industrial mineral materials. This encompasses: ore microscopy, fluid inclusions, nuclear minerals, coals, refractories, slags, ceramics, building materials, nuclear waste disposal, carbon capture and storage, down-hole borehole alteration, and mineral-related health hazards.