| CONTENTS |
|-----------------|  |
| Preface | 3 |
| Organizing committee | 4 |
| Conference details | 5 |
| General information | 7 |
| Conference structure | 11 |
| Program at a glance | 12 |
| Detailed program | 15 |
| Sunday, 5th September, 2021 | 15 |
| Monday, 6th September, 2021 | 16 |
| Tuesday, 7th September, 2021 | 22 |
| Greece Specific Issues | 22 |
| Wednesday, 8th September, 2021 | 29 |
| ITHACA Industrial Workshop | 34 |
| INCO-Piles Round Table | 35 |
| Thursday, 9th September, 2021 | 36 |
| Poster sessions | 37 |
| Platinum Sponsors | 41 |
RawMat2021 is organized by the Technical Chamber of Greece, the School of Mining and Metallurgical Engineering of the National Technical University of Athens and the Greek Raw Materials Innovation Cluster “GRawMat” under the auspices of SEV Hellenic Federation of Enterprises. In addition, RawMat2021 is co-organized by the: Hellenic Ministry of Environment and Energy, Association of Mining Enterprises, Hellenic Survey of Geology and Mineral Exploration, Geotechnical Chamber of Greece, Geological Society of Greece, Scientific Society of the Mineral Wealth Technologists of Greece, School of Mineral Resources Engineering (Technical University of Crete), Department of Mineral Resources Engineering (University of Western Macedonia), Department of Chemistry (Aristotle University of Thessaloniki), Department of Geology and Geo-environment (National and Kapodistrian University of Athens), Department of Geology (University of Patras) and the Materials & Metallurgy Laboratory (University of Patras).

Following the demands and trends of modern society, RawMat2021 shall address a wide range of technological developments and future challenges regarding Raw Materials with emphasis given on Circular Economy aspects. Raw materials and their exploitation are intertwined with the development and prosperity of EU. The European Green Deal adopted by the Member States shows that the future and progress of the EU are highly dependent on mining across the continent, for the benefit of technology, science, economy and sustainability. Similarly, the transition to a circular economy is both an opportunity and a need as the reduction of waste and primary raw materials extraction is promoted to achieve economic and environmental benefits and restrict dependence on non-EU resources.


RawMat2021 shall bring together the Academic community, engineers, early-stage scientists as well as senior scientists, industry executives, stakeholders and policy makers, and other professionals in the field of raw materials for a comprehensive, cross-discipline exchange of knowledge. New tools, methods, research findings, methodological frameworks and hypotheses as well as innovative ideas are going to be presented in its scientific and technical sessions.

We are looking forward to your participation and attendance at the RawMat2021 Conference!

Prof. Anthimos Xenidis
Chair of the Scientific Committee
National Technical University of Athens

Dr. Evangelos Tzamos
President of the Organizing Committee
EcoResources | GRawMat Innovation Cluster
ORGANIZING COMMITTEE

Chairpersons

Prof. Anthimos Xenidis, National Tech. Univ. of Athens/Tech. Chamber of Greece/GRawMat Innovation Cluster, Chair
Prof. Anastasios Zouboulis, Aristotle Univ. of Thessaloniki / GRawMat Innovation Cluster, Co-chair
Prof. Konstantinos Komnitsas, Technical Univ. Crete, Co-chair
Prof. Michail Stamatakis, National and Kapodistrian Univ. of Athens, Co-chair

Members

Alice Corovessi, INZEB
Anastasia Lakasa, GRawMat Innovation Cluster
Angeliki Christogerou, METLAB, Univ. of Patras
Apostolos Kourtis, National Tech. Uni. of Athens/GRawMat Innovation Cluster
Athanasiou Godelitsas, Scientific Society of the Mineral Wealth Technologists of Greece/National and Kapodistrian Univ. of Athens
Christos Kavalopoulos, Greek Mining Enterprises Association
Dimitrios Panias, National Tech. Uni. of Athens
Dionyssios Gkoutis, Geotechnical Chamber of Greece/Hellenic Survey of Geology and Mineral Exploration
Einini Christodoulou, National Tech. Uni. of Athens/GRawMat Innovation Cluster
Evangelos Tzamos, GRawMat Innovation Cluster/Ecoresources, President
Evgenios Kokkinos, Ecoresources
Georgios Banias, CERTH
Georgios Kornelakis, Technical Chamber of Greece
Ioanna Kaneli, GRawMat Innovation Cluster
Ioannis Kapageridis, Univ. of Western Macedonia
Ioannis Zafeiratos, Ministry of Environment and Energy

Kyriaki Makri, National Observatory of Athens/Committee of GEOsciences Didactics GSG
Konstantinos Kontogiannopoulos, Ecoresources
Konstantinos Laskaridis, Hellenic Survey of Geology and Mineral Exploration/Geological Society of Greece
Konstantinos Simeonidis, Ecoresources
Maria Menegaki, National Tech. Uni. of Athens
Michail Galetakis, Technical Univ. of Crete
Nikolaos Xirokostas, Hellenic Survey of Geology and Mineral Exploration/Ministry of Environment and Energy
Nikos Pasadakis, Institute of Petroleum Research, FORTH/IPR
Olga Sykioti, National Observatory of Athens
Panagiotis Kougias, Hellenic Agricultural Organization “DEMEETER”
Petros Kouzovitis, Geological Society of Greece/Univ. of Patras
Petros Tzeferis, Ministry of Environment and Energy
Platon Gamaletsos, Technical Univ. of Crete
Stavros Kalaitzidis, Univ. of Patras
Yiannis Pontikes, KU Leuven, Belgium
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>K. Adam</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>Z. Agioutantis</td>
<td>Univ. of Kentucky, USA</td>
</tr>
<tr>
<td>G. Anastasakis</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>G. Angelopoulos</td>
<td>Univ. of Patras, Greece</td>
</tr>
<tr>
<td>A. Apostolikas</td>
<td>LARCO S.A., Greece</td>
</tr>
<tr>
<td>A. Argyraki</td>
<td>National and Kapodistrian Univ. of Athens, Greece</td>
</tr>
<tr>
<td>N. Arvanitidis</td>
<td>Geological Survey of Sweden, Sweden</td>
</tr>
<tr>
<td>A. Bajcar</td>
<td>Poltegor Institute, Poland</td>
</tr>
<tr>
<td>E. Balomenos</td>
<td>Mytilineos S.A., Greece</td>
</tr>
<tr>
<td>G. Banias</td>
<td>CERTH, Greece</td>
</tr>
<tr>
<td>S. Beaulieu</td>
<td>Aughinish Alumina, Ireland</td>
</tr>
<tr>
<td>P. Benard</td>
<td>Lafarge-Holcim, France</td>
</tr>
<tr>
<td>A. Benardos</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>K. Binnemans</td>
<td>KU Leuven, Belgium</td>
</tr>
<tr>
<td>B. Blanpain</td>
<td>KU Leuven, Belgium</td>
</tr>
<tr>
<td>G. Blengini</td>
<td>TU Turin, Italy</td>
</tr>
<tr>
<td>A. Borst</td>
<td>KU Leuven, Belgium</td>
</tr>
<tr>
<td>P. Brito-Parada</td>
<td>Imperial College, UK</td>
</tr>
<tr>
<td>A. Cavallo</td>
<td>Univ. of Milano-Bicocca, Italy</td>
</tr>
<tr>
<td>A. Chagnes</td>
<td>Univ. of Lorraine, France</td>
</tr>
<tr>
<td>E. Chatzitheodoridis</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>O. Chernoburova</td>
<td>Univ. of Lorraine, France</td>
</tr>
<tr>
<td>D. Damigos</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>E. Deady</td>
<td>British Geological Survey, UK</td>
</tr>
<tr>
<td>N. Demirel</td>
<td>Middle East Technical Univ., Turkey</td>
</tr>
<tr>
<td>G. Demopoulos</td>
<td>McGill Univ., Canada</td>
</tr>
<tr>
<td>S. Diplas</td>
<td>SINTEF, Sweden</td>
</tr>
<tr>
<td>C. Dittrich</td>
<td>MEAB Chemie Technik GmbH, Germany</td>
</tr>
<tr>
<td>C. Drebenstedt</td>
<td>Freiberg Univ. of Mining and Technology, Germany</td>
</tr>
<tr>
<td>A. Ewing Rassios</td>
<td>Hellenic Survey of Geology and Mineral Exploration, Greece</td>
</tr>
<tr>
<td>G. Fermeli</td>
<td>Institute of Education Policy, Greece</td>
</tr>
<tr>
<td>G. Ferrier</td>
<td>Univ. of Hull, UK</td>
</tr>
<tr>
<td>D. Filippou</td>
<td>Rio Tinto, Canada</td>
</tr>
<tr>
<td>A. Finch</td>
<td>St. Andrews Univ., UK</td>
</tr>
<tr>
<td>K. Forsberg</td>
<td>KTH Royal Institute of Technology, Sweden</td>
</tr>
<tr>
<td>B. Friedrich</td>
<td>Aachen Univ., Germany</td>
</tr>
<tr>
<td>K. Fytas</td>
<td>Laval Univ., Canada</td>
</tr>
<tr>
<td>V. Gaganis</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>G. Gaidajis</td>
<td>Democritus Univ. of Thrace, Greece</td>
</tr>
<tr>
<td>P. Gamaletos</td>
<td>Technical Univ. of Crete, Greece</td>
</tr>
<tr>
<td>M. Genovese</td>
<td>EU-China office, China</td>
</tr>
<tr>
<td>T. Gentzis</td>
<td>Core Laboratories LP, USA</td>
</tr>
<tr>
<td>A. Georgiou</td>
<td>TITAN S.A., Greece</td>
</tr>
<tr>
<td>A. Godelitsas</td>
<td>National and Kapodistrian Univ. of Athens, Greece</td>
</tr>
<tr>
<td>K. Goodenough</td>
<td>British Geological Survey, UK</td>
</tr>
<tr>
<td>A. Grammatikopoulos</td>
<td>SGS Canada Inc., Canada</td>
</tr>
<tr>
<td>G. Grieco</td>
<td>Univ. of Milan, Italy</td>
</tr>
<tr>
<td>J. Hadjigeorgiou</td>
<td>Univ. of Toronto, Canada</td>
</tr>
<tr>
<td>E. Hartai</td>
<td>Univ. of Miskolc, Hungary</td>
</tr>
<tr>
<td>J. Hein</td>
<td>U.S. Geological Survey, California, USA</td>
</tr>
<tr>
<td>N. Horsburgh</td>
<td>St. Andrews Univ., UK</td>
</tr>
<tr>
<td>K. Hudson-Edwards</td>
<td>Camborne School of Mines, UK</td>
</tr>
<tr>
<td>J. Hughes</td>
<td>UWS, Glasgow, UK</td>
</tr>
<tr>
<td>I. Iliopoulos</td>
<td>Univ. of Patras, Greece</td>
</tr>
<tr>
<td>P.T. Jones</td>
<td>KU Leuven, Belgium</td>
</tr>
<tr>
<td>L. Jurdziak</td>
<td>Wroclaw Univ. of Technology, Poland</td>
</tr>
<tr>
<td>D. Kaliampakos</td>
<td>National Tech. Univ. Of Athens, Greece</td>
</tr>
<tr>
<td>P. Kalvig</td>
<td>Geological Survey of Denmark and Greenland, Denmark</td>
</tr>
<tr>
<td>A. Karalis</td>
<td>IMERYS S.A., Greece</td>
</tr>
<tr>
<td>S. Kasmaee</td>
<td>Univ. of Bologna, Italy</td>
</tr>
<tr>
<td>W. Kawalec</td>
<td>Wroclaw Univ. of Technology, Poland</td>
</tr>
</tbody>
</table>
V. Kazakidis, Laurentian Univ., Canada
P. Kinnunen, VTT, Finland
A. Korre, Imperial College, UK
N. Koukouzas, CERTH, Greece
D. Krebs, Greenland Minerals and Energy Ltd, Australia
W. Kurylak, IMN, Poland
A. Langella, Università degli Studi del Sannio di Benevento, Italy
M. Lazar, Univ. of Petrosani, Romania
P. Maraboutis, Ecoefficiencia Ltd., Greece
I. Marantos, Hellenic Survey of Geology and Mineral Exploration, Greece
P. Marescotti, Univ. of Genova, Italy
A. Martinez, SINTEF, Norway
M. Mitrakas, Aristotle Univ. of Thessaloniki, Greece
J. Ohta, Chiba Institute of Technology, Japan
D. Oliveira, National Laboratory of Energy and Geology, Portugal
D. Panias, National Tech. Univ. Of Athens, Greece
I. Paspaliaris, National Tech. Univ. Of Athens, Greece
V. Papanastasiou, Univ. of Toronto, Canada
N. Papassipoulou, National Tech. Univ. Of Athens, Greece
N. Pasadakis, Technical Univ. of Crete, Greece
V. Pavlovic, OpenCast Mining Centre, Serbia
L. Perez Villarejo, Univ. of Jaen, Spain
M. Perraki, National Tech. Univ. Of Athens, Greece
Y. Pontikes, KU Leuven, Belgium
M. Pozo, Universidad Autónoma de Madrid, Spain
M. Regueiro, Instituto Geologico y Minero de Espana, Spain
M. Reich, Univ. of Chile, Chile
E. Remoundaki, National Tech. Univ. Of Athens, Greece
S. Roubedakis, Lafarge-Holcim, Greece
C. Roumpos, Public Power Corporation S.A., Greece

J. Safarian, Norwegian Univ. of Science and Technology, Norway
I. Sanoudos, IMERYS S.A., Greece
R. Snellings, Flemish Institute for Technological Research, VITO, Belgium
X. Spiliotis, Univ. of Thessaly, Greece
A. Stalios, European Commission, Belgium
S. Stopic, Aachen Univ., Germany
O. Sykioti, National Observatory of Athens, Greece
F. Tinti, Univ. of Bologna, Italy
A. Tkaczyk, Univ. of Tartu, Estonia
E. Topal, Curtin Univ., Australia
G. Tranell, Norwegian Univ. of Science and Technology, Norway
S. Triantafyllidis, National Tech. Univ. Of Athens, Greece
K. Tsakalakis, National Tech. Univ. Of Athens, Greece
H. Tsikos, Rhodes Univ., South Africa
E. Tzamos, GRawMat Innovation Cluster and Ecoresources, Greece
P. Tzeferis, Ministry of Environment and Energy, Greece
E. Tziritis, ELGO “DEMETER”
A. Vafeidis, Technical Univ. of Crete, Greece
C. Van der Eijk, SINTEF, Norway
L. Yurramendi Sarasola, Tecnalia S.A., Spain
T. Zampetakis, Grecian Magnesite, Greece
E. Zevgolis, National Tech. Univ. Of Athens, Greece
CONFERENCE DETAILS

RawMat2021 is organized by the Technical Chamber of Greece, the School of Mining and Metallurgical Engineering of the National Technical University of Athens and the Greek Raw Materials Innovation Cluster (GRawMat) under the auspices of SEV Hellenic Federation of Enterprises.

TOPICS

- Minerals exploration and resource characterisation: new trends and advances
- Mining: trends and perspectives
- Mineral processing
- Sustainable Metallurgy
- Industrial Minerals
- Environment, Energy and Sustainability
- Reuse-Recycling and Valorisation
- Education
- EU Strategy / Circular economy
- Occupational Health and Safety (OHS)
- Greece-specific issues

PRESENTATION GUIDELINES

Oral contributions

Regular oral presentations will last 15 minutes which include a 12 min speech by the presenting author and another 3 min for questions by the audience. Plenary and keynote presentations will be given a 30 minutes duration (25 min speech and 5 min for discussion).

Poster presentations

All posters will be placed in a special website accessed by all participants. Authors contact details will be visible to allow questions and ideas exchange. The presenting authors with on-site participation should hang their printed posters in the morning of their presentation and remove them at the end of the poster session. The posters from those authors with Virtual attendance will appear in the monitors of the conference hall throughout the poster session. All Presentations should be prepared in English language (official language of the Conference).

AWARDS

The most outstanding presentations during RawMat2021 will receive one of the awards from the following categories:
GRawMat Circular Economy Award. For the presentation best promoting the adoption of circular economy in the raw materials sector. The award is sponsored by the GRawMat Innovation Cluster.

Best Oral Presentation Award. Most distinguished paper combining high scientific quality and presentation significance. The award is sponsored by the journal Minerals MDPI.

Best Poster Award. Dedicated to the best presentation during the poster sessions of the conference.

Young Researcher Award. For the best presentation by a young scientist.

Selected high-impact presentations will get a waiver for full paper submission in the peer-review journals collaborating with RawMat2021.

Presented papers will be evaluated by the Award Committee according to the following criteria: Significance of the paper, Originality, Presentation impact, Young researcher. The winners of RawMat2021 awards will be announced during the closing ceremony of the conference.

PROCEEDINGS

Conference participants may submit a full paper which is oriented to be published in the RawMat2021 Proceedings Volume hosted in Materials Proceedings journal. Publication in the Proceedings Volume is free of charge for all registered participants and the paper will be available as an open access document.

PUBLICATION IN JOURNALS

For selected papers presented RawMat2021, the opportunity to publish a full paper in one of the collaborating peer-review journals will be offered after the end of the conference. Some of the mentioned journals are open access requiring an Article processing charge from the side of the authors. RawMat2021 provides a significant discount of this amount for all participant and a number of waivers for high-quality submissions.

Papers related to metallurgical processes and research aimed at improving the sustainability of metal-producing industries, with an emphasis on materials recovery, reuse, and recycling, will be invited to submit in a Special Issue of the Journal of Sustainable Metallurgy (Impact factor 2.109).

Papers related to mining, processing, metallurgy, industrial minerals and environmental monitoring will have an opportunity to be submitted in the Special Issue entitled “Minerals Study, Applications and Processing: Building the Foundations of a Green Future” of journal Minerals (ISSN 2075-163X – Impact factor 2.644).

Papers related to materials will have the chance to be submitted in the Special issue entitled “Metals Characterization: Novel Methods, Techniques, and Instruments” of journal Materials (ISSN 1996-1944– Impact factor 3.623).

Papers dealing with water treatment focusing on the promotion of sustainable technologies in the field of mining practices which achieve economic viability and competence with minimum
environmental impact will be invited to submit in the Special Issue entitled “Sustainable Approaches in Water Treatment Practices, Presenting Minimum Environmental Impact” of journal Water (ISSN 2073-4441– Impact factor 3.103).

Papers related to circular economy strategies and sustainability in processes will be invited to submit in the Special Issue entitled “Raw Materials and Circular Economy: Concepts and Evidence” of journal Sustainability (ISSN 2071-1050– Impact factor 3.251).

VENUE

RawMat2021 shall take place in Athens, the historical heart of Greece known as the birthplace of democracy and home to some of the most significant philosophers. The Divani Caravel Hotel located in Athens city center, will be the conference venue. The Hotel is the perfect starting point to discover Athens and its many historic monuments, museums and major attractions.

Athens International Airport is about 30 km away from the Hotel (about 50 minutes trip by public transportation of 30 minutes’ drive) and easily accessible. The Hotel is served by a metro station (Evangelismos) located within walking distance (5 minutes) which connects the Hotel to various places in Athens and also to the airport.

DIVANI CARAVEL HOTEL:

2 Vassileos Alexandrou ave., 16121 Athens Greece
Tel. +30 210 7207000
Website: www.divanicaravelhotel.com

EXHIBITION

In the framework of the RawMat2021, a parallel exhibition will be organized where supporting companies and organizations dealing with the raw materials sector are going to provide detailed information on their activities and future plans to the conference participants. The exhibition area is located in the Olympia Hall outside the Olympia Plenary Room.

SOCIAL EVENTS

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Location</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening ceremony</td>
<td>5/9/2021</td>
<td>Olympia Plenary Room</td>
<td>18.30</td>
</tr>
<tr>
<td>Welcome reception</td>
<td>5/9/2021</td>
<td>Thea Pool Bar and Restaurant</td>
<td>21.15</td>
</tr>
<tr>
<td>Gala dinner</td>
<td>7/9/2021</td>
<td>Royal Olympic Hotel-Ioannis Roof Garden</td>
<td>21.00</td>
</tr>
<tr>
<td>All-day visit to Lavrion</td>
<td>9/9/2021</td>
<td>Lavrion Historical Mine</td>
<td></td>
</tr>
</tbody>
</table>

A guided visit to Lavrion Technological and Cultural Park (Mineral processing and Metallurgical plants), Archaeological Sites of Thorikos, Souriza and Poseidon Temple.

All events will follow the applied hygiene protocols valid during that date. Possible occurring restrictions may be
the reason for cancellation in the case of field trips. Info desk is available in the secretary.

PARALLEL EVENTS

- **Greek specific issues**  
  7/9/2021 09.00-13.00  
  Presentations and round tables by companies and government bodies discussing current situation, problems, challenges and future trends in the field of mineral raw materials in Greece. **Event language will be Greek.**

- **ITHACA Industrial Workshop**  
  8/9/2021 10.50-13.05  
  ITHACA Industrial Workshop will be included as a parallel event of the RawMat2021. The workshop will gather experts and stakeholders to illustrate initiatives aiming at reducing the critical raw material content and improve process efficiency and sustainability of materials for aerospace and automotive applications. The event is organized in the frame of ITHACA Project, a Network of experts from all over Europe in the area of Engineering, Chemistry, Materials Science, etc. aiming to understand the current materials’ manufacturing and recycling scene and pump-prime activities to move the sector of automotive and aerospace forward.

- **INCO-Piles round table**  
  8/9/2021 14.30-19.00  
  Second Round Table of the International Consortium to recover CRMs from stockpiles/tailings targeting RIS will be included as a parallel event of the RawMat2021. The Round Table will discuss the "Opportunities for technology transfer to foster the recovery of CRM from mining residues" and will take place at 8th September 2021 in hybrid format.

CERTIFICATE OF ATTENDANCE

All registered participants are eligible to receive a certification of attendance at the end of the conference. The certificate will be available in printed form for on-site participants and will be sent electronically to online participants.

ORGANIZING PARTNER

Giannitson-Santarosa Str. 15-17  
54627 Thessaloniki, Greece  
Tel. +30 2311 823055  
info@ecoresources.gr
# Program Structure

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>21st</td>
<td>RECEPTION</td>
<td>Welcome</td>
</tr>
<tr>
<td>20th-21st</td>
<td>OPENING SESSION</td>
<td>Registration</td>
</tr>
<tr>
<td>19th-20th</td>
<td>PLENARY LECTURES</td>
<td>A7 Mine Planning, Scheduling and Optimization</td>
</tr>
<tr>
<td>19th-20th</td>
<td>A8 Advanced Minerals Exploration and Characterization</td>
<td>Coffee break – Poster session I</td>
</tr>
<tr>
<td>18th-19th</td>
<td>A9 Hydro-, Iono-, Solvometallurgy I</td>
<td>Coffee break – Poster session I</td>
</tr>
<tr>
<td>17th-18th</td>
<td>A4 Mine of the Future and Transition to Industry 4.0</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>16th-17th</td>
<td>A5 Advanced Minerals Exploration and Characterization</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>15th-16th</td>
<td>A6 Novel Metallurgical Methods II</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>14th-15th</td>
<td>A1 EU Strategy- Circular Economy</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>13th-14th</td>
<td>A2 Minerals Exploration-Critical Raw Materials</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>12th-13th</td>
<td>A3 Novel Metallurgical Methods I</td>
<td>Lunch break – Poster session I</td>
</tr>
<tr>
<td>11th-12th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>10th-11th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>9th-10th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>8th-9th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>7th-8th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>6th-7th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>5th-6th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>4th-5th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>3rd-4th</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>2nd-3rd</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>1st-2nd</td>
<td>PLENARY LECTURES</td>
<td>第三人</td>
</tr>
<tr>
<td>31st</td>
<td>21st GALA DINNER</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>30th</td>
<td>30th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>29th</td>
<td>29th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>28th</td>
<td>28th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>27th</td>
<td>27th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>26th</td>
<td>26th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>25th</td>
<td>25th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>24th</td>
<td>24th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>23rd</td>
<td>23rd</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>22nd</td>
<td>22nd</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>21st</td>
<td>21st</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>20th</td>
<td>20th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>19th</td>
<td>19th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>18th</td>
<td>18th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>17th</td>
<td>17th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>16th</td>
<td>16th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>15th</td>
<td>15th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>14th</td>
<td>14th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>13th</td>
<td>13th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>12th</td>
<td>12th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>11th</td>
<td>11th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>10th</td>
<td>10th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>9th</td>
<td>9th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>8th</td>
<td>8th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>7th</td>
<td>7th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>6th</td>
<td>6th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>5th</td>
<td>5th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>4th</td>
<td>4th</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>3rd</td>
<td>3rd</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>2nd</td>
<td>2nd</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>1st</td>
<td>1st</td>
<td>Coffee break – Poster session II</td>
</tr>
<tr>
<td>31st</td>
<td>31st</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>30th</td>
<td>30th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>29th</td>
<td>29th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>28th</td>
<td>28th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>27th</td>
<td>27th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>26th</td>
<td>26th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>25th</td>
<td>25th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>24th</td>
<td>24th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>23rd</td>
<td>23rd</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>22nd</td>
<td>22nd</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>21st</td>
<td>21st</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>20th</td>
<td>20th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>19th</td>
<td>19th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>18th</td>
<td>18th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>17th</td>
<td>17th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>16th</td>
<td>16th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>15th</td>
<td>15th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>14th</td>
<td>14th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>13th</td>
<td>13th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>12th</td>
<td>12th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>11th</td>
<td>11th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>10th</td>
<td>10th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>9th</td>
<td>9th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>8th</td>
<td>8th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>7th</td>
<td>7th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>6th</td>
<td>6th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>5th</td>
<td>5th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>4th</td>
<td>4th</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>3rd</td>
<td>3rd</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>2nd</td>
<td>2nd</td>
<td>Coffee break – Poster session III</td>
</tr>
<tr>
<td>1st</td>
<td>1st</td>
<td>Coffee break – Poster session III</td>
</tr>
</tbody>
</table>

**Monday, 6/9**

- **A7** Mine Planning, Scheduling and Optimization
- **A8** Advanced Minerals Exploration and Characterization
- **A9** Hydro-, Iono-, Solvometallurgy I
- **A10** Minerals Exploration-Ophiolites
- **A11** Waste Valorization-Industrial Symbiosis II
- **A12** Industrial Minerals-Innovative Processes and Applications II
- **A13** Mine Closure/Post Mining
- **A14** Pollution Abatement/ Environmental Performance
- **A15** MINE PLANNING, SCHEDULING AND OPTIMIZATION
- **A16** ADVANCED MINERALS EXPLORATION AND CHARACTERIZATION
- **A17** HYDRO-, IONO-, SOLVOMETALLURGY I
- **A18** MINED MATERIALS EXPLORATION AND CHARACTERIZATION
- **A19** NOVEL METALLURGICAL METHODS II
- **A20** EU STRATEGY- CIRCULAR ECONOMY
- **A21** MINERALS EXPLORATION-CRITICAL RAW MATERIALS
- **A22** NOVEL METALLURGICAL METHODS I
- **A23** GREECE SPECIFIC ISSUES
- **A24** GREECE SPECIFIC ISSUES
- **A25** MINERAL PROCESSING OF ORES AND END-PRODUCTS
- **A26** MINERAL RECOVERY FROM WASTE
- **A27** BASE METALS RECOVERY FROM WASTE
- **A28** SUSTAINABILITY
- **A29** BATTERIES AND MAGNETS RECYCLING

**Tuesday, 7/9**

- **A23** GREECE SPECIFIC ISSUES
- **A24** GREECE SPECIFIC ISSUES
- **A25** MINERAL PROCESSING OF ORES AND END-PRODUCTS
- **A26** MINERAL RECOVERY FROM WASTE
- **A27** BASE METALS RECOVERY FROM WASTE
- **A28** SUSTAINABILITY
- **A29** BATTERIES AND MAGNETS RECYCLING

**Wednesday, 8/9**

- **A23** GREECE SPECIFIC ISSUES
- **A24** GREECE SPECIFIC ISSUES
- **A25** MINERAL PROCESSING OF ORES AND END-PRODUCTS
- **A26** MINERAL RECOVERY FROM WASTE
- **A27** BASE METALS RECOVERY FROM WASTE
- **A28** SUSTAINABILITY
- **A29** BATTERIES AND MAGNETS RECYCLING

**Thursday, 9/9**

- **A23** GREECE SPECIFIC ISSUES
- **A24** GREECE SPECIFIC ISSUES
- **A25** MINERAL PROCESSING OF ORES AND END-PRODUCTS
- **A26** MINERAL RECOVERY FROM WASTE
- **A27** BASE METALS RECOVERY FROM WASTE
- **A28** SUSTAINABILITY
- **A29** BATTERIES AND MAGNETS RECYCLING

**Inco Piles**

**Ithaca**
## PROGRAM AT A GLANCE

### Sunday 5 September 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.30-18.30</td>
<td>Registration</td>
</tr>
<tr>
<td>18.30-19.00</td>
<td>Welcome and brief introduction</td>
</tr>
<tr>
<td>19.00-19.30</td>
<td>Welcome speeches</td>
</tr>
<tr>
<td>19.30-20.15</td>
<td>Sponsors speeches</td>
</tr>
<tr>
<td>20.15-21.15</td>
<td>Plenary lectures</td>
</tr>
<tr>
<td>21.15</td>
<td>Welcome reception</td>
</tr>
</tbody>
</table>

### Monday 6 September 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.00-10.30</td>
<td>Plenary lectures</td>
</tr>
<tr>
<td>10.30-11.00</td>
<td>Coffee break</td>
</tr>
<tr>
<td>11.00-13.00</td>
<td>Parallel sessions</td>
</tr>
<tr>
<td>A1. EU Strategy - Circular economy</td>
<td></td>
</tr>
<tr>
<td>A3. Novel metallurgical methods I</td>
<td></td>
</tr>
<tr>
<td>13.00-14.30</td>
<td>Lunch break</td>
</tr>
<tr>
<td>A4. Mine of the future and transition to Industry 4.0</td>
<td></td>
</tr>
<tr>
<td>A5. Advanced minerals exploration and characterization technologies I</td>
<td></td>
</tr>
<tr>
<td>A6. Novel metallurgical methods II</td>
<td></td>
</tr>
<tr>
<td>16.30-17.00</td>
<td>Coffee break</td>
</tr>
<tr>
<td>17.00-19.00</td>
<td>Parallel sessions</td>
</tr>
<tr>
<td>A7. Mine planning, scheduling and optimization</td>
<td></td>
</tr>
<tr>
<td>A8. Advanced minerals exploration and characterization technologies II</td>
<td></td>
</tr>
<tr>
<td>A9. Hydro-, Iono-, Solvometallurgy I</td>
<td></td>
</tr>
</tbody>
</table>

### Tuesday 7 September 2021

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.00-10.30</td>
<td>Greek specific issues (in Greek)</td>
</tr>
<tr>
<td>09.00-10.30</td>
<td>Parallel sessions</td>
</tr>
<tr>
<td>B1. Education I</td>
<td></td>
</tr>
<tr>
<td>B2. Base metals recovery from waste</td>
<td></td>
</tr>
</tbody>
</table>
10.30-11.00  Coffee break

**OLYMPIA**

11.00-13.00  Greek specific issues (in Greek)
11.00-13.00  Parallel sessions

**VERGINA**

B3. Education II

**ILISSOS**

B4. Critical metals recovery from waste

13.00-14.30  Lunch break

**Poster Session 2 – Exhibition**

14.30-16.30  Parallel sessions

**OLYMPIA**

B5. Hydro-, Iono-, Solvometallurgy II

**VERGINA**

B6. Fossil fuels in the energy transition era

**ILISSOS**

B7. Waste valorization - Industrial Symbiosis I

16.30-17.00  Coffee break

17.00-19.00  Parallel sessions

**OLYMPIA**

B8. Advanced metallurgical processes

**VERGINA**

B9. Minerals exploration - Ophiolites

**ILISSOS**

B10. Waste valorization - Industrial Symbiosis II

21.00  Gala dinner

### Wednesday 8 September 2021

**OLYMPIA**

09.00-10.30  Plenary lectures
10.30-11.00  Coffee break

11.00-13.00  Parallel sessions

**OLYMPIA**

C1. Mineral processing of ores and end-products

**VERGINA**

C2. Sustainability

**ILISSOS**

C3. Batteries and magnets recycling

**PELLA-MYCENAE**

10.50-13.05  ITHACA industrial workshop

13.00-14.30  Lunch break

**Poster Session 3 – Exhibition**

14.30-16.30  Parallel sessions

**OLYMPIA**

C4. Industrial Minerals - Innovative processes and applications I

**VERGINA**

C5. Mine waste / Water management

**ILISSOS**

C6. Recycling / Metals recovery from end products

**PELLA-MYCENAE**

14.30-16.30  INCO-Piles round table

16.30-17.00  Coffee break

17.00-19.00  Parallel sessions
International Conference on Raw Materials and Circular Economy

- **OLYMPIA**
  - C7. Industrial Minerals - Innovative processes and applications II

- **VERGINA**
  - C8. Mine closure / Post mining

- **ILISSOS**
  - C9. Pollution abatement / Environmental performance

- **PELLA-MYCENAE**
  - 17.00-19.00 INCO-Piles round table

  - 19.00 Closing ceremony - Awards

**Thursday 9 September 2021**

- **LAVRION HISTORICAL MINE SITE**
  - 08.30-18.15 Field trip
  - Visit to Lavrion Technological and Cultural Park (Mineral processing and Metallurgical plants), Archaeological Sites of Thorikos, Souriza and Poseidon Temple
Monday 6 September 2021
OLYMPIA

SESSION A1
EU Strategy – Circular economy

Chair: S. Bourg, A. Kladis
In order to secure the sustainable access to primary and secondary raw materials and particularly Critical Raw Materials (CRMs) in the EU, there is a need for an expert advice to better understand the value chains of the raw materials screened in the CRMs assessment. Making this information freely available will support decision-making at the EU level on the CRM strategies. This is the key objective of the European Expert Network on Critical Raw Materials, SCRREEN. Supported by the European initiatives EIT-RawMaterials, Eurogeosurveys, INTRAW, PROMETIA and REIA, SCRREEN develops and strengthens a network covering all the expertise related to the raw materials screened in the European CRM 2020 assessment. The SCRREEN network gathers today expertise on primary and secondary resources; production, including exploration, mining, processing, recycling and refining; substitution of CRM; raw materials markets; future demand and supply; materials flows; socio-economic analysis. It covers also strategic value chains and end-use sectors, including batteries, e-mobility, renewable energy, electronics, defense and aerospace. In order to improve data and knowledge on all screened raw materials, SCRREEN works at updating on a regular basis the raw materials factsheets. It will also publish sector-oriented outlook reports analysing the future supply and demand of raw materials, policy and technology gaps and innovation potential along the raw materials value chains. A work-plan, updated every 6 months allows SCRREEN to flexibly support the European Commission in policy-making related to CRM in general or linked to specific applications or sectors; and to support as well the Commission in the organisation of relevant events. All the information will be made available to the public through the SCRREEN knowledge database and the EC Raw Materials Information System. This presentation will present the network and its first results. It will also the occasion for new experts to join this network.
ERA-MIN3: Raw Materials for the Sustainable Development and the Circular Economy

D. Carrilho¹, J. Sotelo², J. Marchamalo², B. Gómez³

¹FCT - Fundação para a Ciência e a Tecnologia, Portugal
²Fundación Española para la Ciencia y la Tecnología (FECyT)-Agencia Estatal de Investigación (AEI), Spain
³Agencia Estatal de Investigación (AEI), Spain

E-mail: julio.marchamalo@fecyt.es

ERA-MIN3: RAW MATERIALS FOR THE SUSTAINABLE DEVELOPMENT AND THE CIRCULAR ECONOMY (2020-2025) is a global, innovative and flexible pan-European public-public network of 24 research funding organisations, from 18 EU MS countries/regions, one EU Associated Country and province of Québec and South Africa, supported by EU Horizon 2020. ERA-MIN3 aims to support and promote R&I cooperation in Europe and globally, in the area of non-fuel, non-food raw materials (metallic, construction and industrial minerals). This will be achieved through one EU co-funded Joint Transnational call for R&I proposals in 2021 and one additional call in 2023. ERA-MIN3 scope of the joint transnational calls is needs-driven research that clearly demonstrate potential to promote the sustainable and responsible supply, exploration, extraction, processing technologies, resource efficient production, consumption, re-use and low environmental impact recycling of primary and secondary minerals and metals, as well as substitution of critical raw materials, in a circular economy. A crucial challenge is to consider societal impact and public perception, health and safety issues as well as new business models and digital technologies.

ERA-MIN3 is built on the success of ERA-MIN 2, a R&I programme aimed at implementing a European-wide coordination of R&I programmes on raw materials to strengthen the industry competitiveness and the shift to a circular economy. Through three consecutive joint transnational calls (2017, 2018 & 2019) a total of 40 R&I projects were supported that addresses all aspects of the non-energy non-agricultural raw materials life cycle, covering both primary and secondary resources, from the 1) supply of raw materials from exploration and mining, 2) product design and 3) processing, production and remanufacturing to the 4) recycling and re-use of end-of-life products, also targeting the 5) development of new business models, the improvement of methods or data for environmental impact assessment and the social acceptance and trust/public perception of raw materials. Successively, ERA-MIN2 was built on the experience of ERA-MIN (2011-2015) whose aim was to bring together a significant number of funding and programming organisations to support the development of the non-energy mineral raw materials research area in Europe. ERA-MIN counted with another three consecutive transnational calls (2013, 2014 & 2015) which funded a total of 17 R&I projects on exploration, extraction, mine closure and rehabilitation, minerals processing, and metallurgy, secondary resources (recycling) and substitution of critical materials to secure a “Sustainable Supply of Raw Materials in Europe”.
Relating Industrial Symbiosis and Sustainable Development Goals

J. Henriques, J. Azevedo, M. Estrela, R. Dias

Instituto de Soldadura e Qualidade, Portugal

E-mail: jdhenriques@isq.pt

In the last 20 years, the Circular Economy (CE) has gained increasing prominence as a concept that presents solutions to some of the world's most pressing crosscutting sustainable development challenges, for this reason, its various business models such as Industrial Symbiosis (IS) have been pointed out as an important tool to achieve sustainable development (SD). IS is a collaborative approach concerning physical exchanges between industries. By sharing waste, by-products, residues, energy, water, knowledge, and others, the companies involved in this model can achieve environmental, economic, and social benefits. Prior research has created a solid background to understand how the Circular Economy contributes to achieving the SDGs. Nevertheless, there is a limited number of contributions in understanding how Industrial Symbiosis will collaborate to achieve the SDGs. This paper aims to advance in the understanding of how Industrial Symbiosis can contribute to the achievement of the SDGs, having a special focus in identifying which is the relevance of IS for SDGs achievement and which are the critical areas of contribution. A research methodology that integrated a literature review and a matching exercise was designed and performed to accomplish this objective. The main output of this study is a detailed compilation and analysis of industrial symbiosis contributions within the scope of SDGs. The results of this study suggest that the large-scale implementation of industrial symbiosis might collaborate directly with the achievement of 8 SDGs and 24 targets, particularly in goals related to economic growth, industry, clean energy, responsible consumption, and production. IS also will play an important role in the achievement of others 3 SDGs, by indirect contribution.
“Meta-Projects”: Maximizing the value of past EU funded projects in Raw Materials (and not only) sector

A. Kladis, A. Preveniou, K. Papadimitriou, P. Efstathiou

Advanced Minerals and Recycling Industrial Solutions IKE, Greece

E-mail: anastasios.kladis@admiris.eu

During the past 30 years, hundreds of EU funded projects, focusing on innovation across the full value chain of Raw Materials sector, i.e. exploration, mining, mineral processing, metallurgy, physical metallurgy and recycling have been successfully completed. A vivid community of scientists, researchers, and engineers has been incubated and grown around those projects, contributing thus to the sustainable development of the sector. However, few of those projects have managed to create tangible results and bring significant changes in European Industry. The main reasons are, perhaps, that their findings were related to specific (small) parts of the value chain, influencing limited regions, minerals, or applications and producing minimum financial and/or environmental benefits. The thinking evolution of all stakeholders, i.e. researchers, academics, industry, local communities, and mainly EU itself, has promoted a holistic approach and especially a request for simultaneous technical, environmental and financial sustainability for Raw Materials value chains and their relevant operations. As a result, introduction in the recent years of business planning and financial calculations, even at low TRL projects, and of Life Cycle Assessment for all projects has established financial and environmental sustainability as a sine-qua-non condition for a successful project. Last, but not least, Industry 4 with its AI tools, is the latest “horizontal” means to increase the efficiency of every technically innovative idea and should be considered from now on in most projects. Revisiting the results of older and currently ongoing projects, combining them into full value chain solutions and using the above-mentioned tools efficiently, will increase the chances for really game changing, technically, commercially, and environmentally sustainable solutions. In this new generation of “Meta-Projects”, additional skills are required in order to convert a technical/scientific puzzle into a meaningful business proposal. Issues like access to the projects’ deliverables, IP protection, exploitation rights, etc. are challenging and need to be properly addressed. This article will make a deep dive on the approach of “Meta-Projects” and their potential benefits and will present one representative case study of combined several projects highly relevant to one specific raw materials value chain. It is also suggested that EC would create specific calls focusing exclusively on the proposed methodology, since ad-hoc rules would be facilitating this complex endeavor.
A Systematic Evaluation of Commercially Available Corrosion Protection Coatings for NdFeB Magnets with Respect to Performance and Eco-design Under Circular Economy Aspects

C. Burkhardt\textsuperscript{1}, S. Kobe\textsuperscript{2}

\textsuperscript{1}Pforzheim University, Germany
\textsuperscript{2}Jozef Stefan Institute, Slovenia

E-mail: carlo.burkhardt@hs-pforzheim.de

The future cannot be imagined without permanent magnets based on rare-earth elements (REE), which are vital parts of devices for the conversation between electricity and mechanical energy, particularly of electric motors and of electric generators. The fact that Europe has precious little in terms of exploitable REEs, makes them the most important raw materials for integration into the circular economy. Hydrogen assisted recycling (HPMS) is a promising processing route to reprocess End-of-Life (EOL) magnets into sintered materials with large reduction in energy usage and human toxicity compared to the primary production route, exposing the material to hydrogen and disintegrating the magnet into friable, hydrogenated powder, which can be separated mechanically from remaining impurities. Its effectiveness has been proven for single-source scrap sources on a TRL of 7.

To enable a commercially viable circular economy ecosystem for NdFeB magnets based on the HPMS for various scrap sources, it is vital to investigate the influence of different corrosion protection coatings currently employed in the market, as (1) differing penetration characteristics for hydrogen will have a significant influence on the kinetics of the hydration reaction and (2) the quality of the resulting recycling material and thus (3) the magnetic performance of the recycled magnets can be greatly influenced by potential powder contamination caused by coating debris.

To evaluate and classify corrosion protection coatings of NdFeB magnets with respect to performance and recyclability, in a systematic approach 13 commercially available and widely used different corrosion protection coatings for NdFeB magnets were compared. Corrosion and scratch tests on coated magnets were used to compare the initial corrosion protection behaviour of the coatings according to international standards and specifications, the respective layer thicknesses/structure and chemical composition of the magnet coatings were analysed. To test their respective recycling-friendliness, the HPMS behaviour (initiation time and required pressure, resulting grain size distribution) was investigated by means of a tailored lab-scale HPMS reactor that allowed in-situ investigation and real-time video-recording. Contamination of the resulting powders by coatings residues/debris was investigated, as was the ability to separate the coatings from the powders and the behaviour of the coatings during a thermal demagnetization treatment.

The results of these investigation are a vital input for a permanent magnet’s recycling grading and labelling system developed in the framework of the EU-funded projects MaXycle and SUSMAGPRO, which is intended to be introduced on international level to facilitate commercially attractive EOL-magnets recycling on an industrial level.
How the proper management of the extractive waste can support the circular economy

P. Maraboutis, N. Poulimenou, E. Nikolaou

Eco-Efficiency LTD, Greece

E-mail: p.maraboutis@ecoefficiency.gr

The circular economy starts at the very beginning of a product’s life. Both the design phase and production processes have an impact on sourcing, resource use and waste generation throughout a product’s life. The Extractive Waste Directive (2006/21/EC) since 2006 in Article 5.2 (a) & (b) includes the prevention or reduction of waste production and its harmfulness, encouragement the recovery of extractive waste by means of recycling, reusing, or reclaiming such waste, where this is environmentally sound in accordance with existing environmental standards. As a result of the many years of experience with the development of Extractive Waste Management Plans, by the operators, a substantial knowledge base has now been established across the whole of the EU territory, which should enable the identification of best practices that merit a more widespread implementation across the extractive sector. Two years ago, a study elaborated to shed light on the practices that strengthen the spirit of the circular economy in the field of mineral extraction and resulting waste streams, applied technologies, and their environmental impacts. This study was based on exchange of information with the Member States and associations of the field of the extractive industries, as well as contact with EU mining companies to determine the best practices used. This article summarizes eight best practices followed by companies of the extractive sector promoting the circular economy.
Is there a potential for the development of critical raw materials production from primary sources in the European Union?

E. Lewicka, K. Galos, K. Guzik

Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Poland

E-mail: lewicka@min-pan.krakow.pl

Sufficient supplies of raw materials essential in the strategic value chains, especially in rapidly developing green technologies, e.g., Li-ion batteries, wind turbines, photovoltaics, etc., became one of the main economic challenges for the EU. The EU is facing growing import dependency and associated risk of supply disruptions of these raw materials (called critical - CRMs) from third countries. Following especially energy transition processes, an urgent need to ensure sufficient CRMs supplies is one of crucial issues influencing the EU’s economy development. The dependency on some CRMs imports may be reduced by developing their production from the EU’s resources, not only by recycling, but also from primary sources (mineral deposits). Authors tried to evaluate the possibilities of the CRMs supply from the EU’s primary sources in the three-step approach, including an assessment of the CRMs importance for the EU economic growth, their significance in at least two strategic industrial sectors and the potential availability from the EU’s mineral deposits. Authors found that out of 29 critical mineral raw materials indicated in the latest 2020 CRMs List (excluding natural rubber), 16 were important for at least two strategic industrial sectors in the EU. Furthermore, from among the mentioned 16 CRMs, only for 11, i.e.: cobalt, graphite (natural), lithium, magnesium, niobium, PGMs, HREE, LREE, silicon metal, titanium and tungsten, potentially economic primary sources for their production in the EU were reported. The available resources of two of these 11 raw materials, i.e. of silicon metal and magnesium, are considered large enough to meet even the worldwide consumption needs for the next decades provided that certain economic or market conditions will be met (e.g. low electric energy costs). Moreover, although some other CRMs (i.e. gallium, germanium, indium, vanadium) do not form deposits, they are or potentially can be derived as by-products in the course of extraction and processing of major metals. Finally it has been found that only 9 CRMs are significant for at least two strategic industrial sectors and are potentially available from the EU’s mineral deposits, i.e.: cobalt, graphite (natural), lithium, niobium, PGMs, HREEs and LREEs, titanium and tungsten. Especially in the case of deposits of these minerals, in view of the best prospects for the economic viability of their development as well as their economic importance, measures should be taken in the first place to both safeguard and ensure access to their resources within the EU in a sustainable manner.
Monday 6 September 2021
VERGINA

SESSION A2
Minerals exploration – Critical Raw Materials

Chair: A. Finch, C. Bauer
Prospective exploration potential of lithium battery and neodymium magnet minerals in Europe

N. Arvanitidis¹, M. Sadeghi¹, B. Guillaume², D. Oliveira³

¹Geological Survey of Sweden, Sweden
²French Geological Survey, France
³National Laboratory of Energy and Geology, Portugal

E-mail: nikolaos.arvanitidis@sgu.se

There is a broad consensus the demand of mineral resources will continue growing to enable transition to renewable energy and electrification. Lithium batteries and permanent magnets for electric vehicles and wind turbines industrial ecosystems are the biggest factors driving the vast quantities of potential mineral raw materials needed. Supporting the implementation of European Green Deal means we are addressing the twin goal of increasing Europe’s long-term self-sufficiency and resilience of mineral resources as well as to achieving the stated decarbonisation goals. Europe has a great potential of critical minerals, showing mine production and exciting prospects of battery minerals, such as cobalt, lithium, graphite, but also other minerals that are strategic for implementing green transition, such as nickel, copper, or permanent magnet minerals, such as rare earth elements. Having the supply of mineral raw materials from domestic resources secured, the ambition would then be to develop and have full-scale operation of key technology value chains, such as the battery and the permanent magnet ones. Europe’s opportunity to become self-sufficient and sustainable in critical minerals supply from own sources and resources is strongly favored by its geological setting and metallogenetic evolution. Major European mineral belts, such as Fennoscandian, Iberian, Carpathian-Balkan, host highly potential exploration targets challenging new resources and feasible mining prospects. Prospectivity mapping applied to known metallogenetic areas, results in identifying and unlocking new exploration targets challenging the location of an additional mineral resources potential in Europe. This is made possible by gathering available basic geological, economic geology, geochemical and geophysical data, and by conducting efforts towards better understanding of the battery and permanent magnet mineral systems.
Critical minerals in the European seas: The project GeoERA-MINDeSEA

J. Gonzalez¹, I. Zananiri², T. Mediaidea¹, H. Schiellerup³, P. Ferreira⁴, L. Somoza¹, X. Monteys⁵, T. Kuhn⁶, J. Nyberg⁷, I. Melnyk⁸, V. Magalhaes⁹, R. Lunar¹⁰, E. Marino¹⁰, J. R. Hein¹¹, G. Cherkashov¹², Mindesea Team¹

¹Geological Survey of Spain (IGME), Spain
²Hellenic Survey of Geology and Mineral Exploration (HGME), Greece
³Geological Survey of Norway (NGU), Norway
⁴National Laboratory of Energy and Geology (LNEG), Portugal
⁵Geological Survey of Ireland (GSI), Ireland
⁶Federal Institute for Geosciences and Natural Resources (BGR), Germany
⁷Geological Survey of Sweden (SGU), Sweden
⁸SRDE “GeoInform of Ukraine” (GIU), Ukraine
⁹Portuguese Institute for Sea and Atmosphere (IPMA), Portugal
¹⁰Geosciences Institute (IGEO), Spain
¹¹U.S. Geological Survey (USGS), USA
¹²Institute for Geology and Mineral Resources of the Ocean (VNIIOkeangeologia), Russia

E-mail: izanan@igme.gr

The oceans and seas cover more than 70% of the planet, representing a promising new frontier for mineral resources exploration, and an enormous challenge for science and technology. The seabed mineral resources host the largest reserves on Earth for some critical metals like cobalt, tellurium, manganese, and the rare earth elements, critical for Industry. However, seabed geology and ecosystems are widely unexplored and new geological and environmental studies are required to address the impacts of potential mining activities. Moreover, a regulatory framework for minerals extraction and marine spatial planning is necessary for seabed mining sector development. The pan-European seas cover ~15,000,000 km² from shallow waters up to 6000m water depth, in the Arctic and Atlantic oceans, the Mediterranean, Baltic, and Black seas. Spanning a large diversity of environments and resource settings, including high and low temperature hydrothermal deposits, phosphorites, cobalt-rich ferromanganese crusts, and manganese nodules, deep-sea deposits are particularly attractive for their polymetallic nature with high contents of rare and critical metals. Moreover, shallow-water resources, like marine placer deposits, represent another source for many critical metals and gems. The GeoERA-MINDeSEA project [grant agreement No731166 of the EU-Horizon2020 research and innovation programme] is compiling data and genetic models for these deposit types based on extensive pre-existing studies, including geophysical surveys, dredging stations, underwater photography/ROV surveys, and mineralogical, geochemical, and isotopic studies. MINDeSEA results show the potential of the pan-European seas for critical metals, and the enormous information gaps covering vast marine sectors. More than 600 mineral occurrences are reported in the MINDeSEA database. Seamounts and banks in the Macaronesia sector and the Arctic ridges show a high potential for Fe-Mn crusts, rich in energy-critical elements like Co but also Te, REEs, and Mn, accompanied by phosphorites on the seafloor of continental shelves and slopes along the western continental margins. Seafloor polymetallic sulphides and metalliferous sediments are forming today in the Azores
Islands, the Arctic and the Mediterranean volcanic arcs, being among the most important marine resources for Cu, Zn, Ag, and Au. Additionally, hydrothermal deposits may contain economic grades of Co, Sn, Ba, In, Bi, Te, Ga, and Ge. Placer deposits of chemically resistant and durable minerals have been discovered on shallow-water settings (<50m water depth on estuaries, deltas, beaches) linked to the weathering of onshore rocks and ore deposits. Finally, shallow-water concretions and nodules from the Arctic, Baltic, and Black Sea represent potential targets for metals exploration and environmental studies.
The role of Poland in the European Union supply chain of raw materials, including critical raw materials

K. Galos, J. Kamyk, A. Kot-Niewiadomska

Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Poland

E-mail: kgalos@min-pan.krakow.pl

Poland in numerous cases is a crucial link in a supply chain of several raw materials, including critical raw materials for sustainable development of European Union. In some cases, the minerals obtained by the Polish mining industry play an important role in ensuring the Community's minerals security. This applies in particular to coking coal, copper and silver and elemental sulphur. In 2020 the European Commission confirmed the status of coking coal as a critical raw material on the list of 30 critical raw materials for which the risk of supply shortage and its effects on the economy are higher than in the case of other. For years, Poland has been remaining the largest producer of high quality coking coal in the European Union and one of the leading producers and exporters of coke (based on domestic coking coal) used in steel melting belonging to international steel producers. The output of coking coal in Poland constitute almost 80% of total output in the EU countries. Copper (together with silver) and sulphur are the most important of the Polish non-fuel mineral resources that are exploited. The largest in Europe and one of the largest in the world deposits of polymetallic Cu-Ag ores are located in south-western Poland (Lower Silesia). This is the reason why the European supply of mining and refined copper as well as silver are dominated by Polish production. Currently, domestic production accounts for nearly 20% of total refined copper and 44% of total mining copper supply in the EU. Within the EU, Poland is also the clear leader in terms of refined silver production. Some of the world’s largest native sulphur deposits are located near the Tarnobrzeg city in the south-eastern Poland. Moreover, Poland is currently the only country in the world producing elemental sulphur with underground smelting method from native sulfur deposits. Poland's share in total EU sulphur production amounted to about 15% in recent years and it is still leading European producer and exporter of elemental sulphur. Due to intense extraction of good quality minerals, Poland is significant exporter of these raw materials to the European Union as well as world markets. The domestic resources base will enable to maintain strong position of Poland on the international markets especially for analysed in detail raw materials for the next several decades if the demand for this raw materials will be maintained in this time horizon.
Characterization of 3 Metallurgical Bauxite Residue samples with a focus on Rare Earth Elements distribution

P. Angelopoulos¹, M. Georgiou¹, P. Oustadakis¹, M. Taxiarchou¹, H. Karadağ², Y. Eker², G. Dobra³, A. Boiangiu³, G. Demir⁴, S. Arslan⁴, P. Davris⁵, E. Balomenos⁵

¹National Technical University of Athens, Greece
²Necmettin Erbakan University, Turkey
³Alro Slatina, Romania
⁴ETI Aluminium, Turkey
⁵MYTILINEOS S.A., Greece

E-mail: pangelopoulos@metal.ntua.gr

Bauxite Metallurgical Residue (BR) is a highly alkaline and very fine-grained by-product of the Bayer process for alumina production. Its huge global annual production has resulted in BR increasing accumulation, causing deposition problems and serious environmental issues. RM contains oxides and salts of the main elements Fe, Al, Ca, Na, Si, Ti and rare earths - REEs (Sc, Nd, Y, La, Ce, Ds) many of which have been categorised by EU as Critical Metals (CMs). The valorisation of BR as a low-cost secondary raw material and metal resource could be a route for its reduction introducing the waste again in the economic cycle. REEScue (https://reescue.com/) constitutes a research project that aims in the efficient exploitation of European bauxite residues resulting from alumina production from Greece (MYTILINEOS SA), Turkey (ETI Aluminium) and Romania (ALUM SA) containing appreciable concentrations of scandium and REEs, through the development of a number of innovative extraction and separation technologies that can efficiently address the drawbacks of the existing solution. The consortium consists of 3 alumina producers from Greece (MYTILINEOS SA), Turkey (ETI Aluminium) and Romania (ALUM SA), two academic partners from Greece (National Technical University of Athens), and Turkey (Necmettin Erbakan University). We present preliminary characterization results of 3 different BR samples that originate from the 3 aluminium industries, with a focus on chemical and mineralogical analyses combined with microscopy for microstructural observation.
Revisiting public abandoned mine sites in Greece for the assessment of their CRM content and environmental characterization of mining wastes

V. Angelatou, A. Exikis, E. Drosos

Hellenic Survey of Geology and Mineral Exploration - HSGME (former IGME), Greece

E-mail: vasaggelatou@igme.gr

The growing demand for raw materials and more specifically CRMs, moving towards clean energy technologies with low energy demand and minimal environmental footprint of their mining activities, forces all the interested parties to consider every possibility of exploitation and utilization of secondary metal sources. In light of this, in 2016, the EIP Raw Materials launched a “call to arms” to transform the “extractive-waste problem” into a “resource-recovery opportunity”, as “mining waste” still contains valuable and critical metals and answers to perspectives of circular economy.

Critical Raw Materials (CRMs) are those with a particularly high importance to the world economy and, at the same time, with a high risk of supply disruptions. Funded by national structural funds, a project has been designed by HSGME, to revisit and assess the CRM content of mining wastes at public abandoned mines on Greek territory, while at the same time estimating their environmental characterization on a systematic base. Based on screening information from existing es(?), an inventory is prepared and is filled with data (existing and new). The key stages to accomplish the study are: collecting and screening data on site description (information about geology, mining, and processing activities), carrying out site investigation and sampling campaigns to collect representative samples and define the investigating areas, mapping areas of interest (digitized), performing laboratory work on sample characterization and analyses of CRM’s and environmental characterization. 30 mine sites have been visited, 280 samples have been collected and characterized chemically and mineralogically and more than 40 environmental characterization tests have been run. Additionally, preliminary research is being carried out on possible technological treatment of selected wastes (biotechnologically and through conventional beneficiation). The database has been filled with data that give useful information on a systematic basis and maps have been produced so far. Further work needed to cover the aspects of this research is planned.
Mineral raw materials' resource efficiency in selected ESEE countries: Strengths and Challenges

S. Giannakopoulou¹, K. Adam¹, F. Halkiopoulou²

¹School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece
²Department of Mineral Processing, Hellenic Survey of Geology and Mineral Exploration, Greece

E-mail: gianstav@metal.ntua.gr

The mineral raw materials’ resource efficiency is currently recognized in Europe as the way for the future development of the European mining economies. This issue has been addressed in a number of recent EU funded Research projects, e.g. SARMA, RIS-RESTORE, RESEERVE, whose findings evidence that main factors affecting the sustainable exploitation and management of mineral resources in ESEE countries include the prevailing mineral policies, land use planning, permitting procedures and stake holders involvement, exploitation of secondary resources, and geological data management. Recording of geological data and their standardisation was one of the main objectives of the EIT Raw Materials RESEERVE Project, within which significant steps were accomplished towards future development of the mining sector of 6 ESEE countries, i.e. Albania, Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, Serbia. This paper presents the challenges that these countries need to address and the strengths to be exploited in order to achieve mineral raw materials resource efficiency. Key challenges concern harmonisation of reserves classification with international standards, increase of confidence level for resources / reserves classification, integration of state’s mineral policy with spatial planning strategies as well as the upgrading of current processing technologies, capacity building of the Raw Materials workforce and enhancement of the public acceptance of the sector. Examined countries are characterized by the presence of significant mineral resources’ geological potential, long mining tradition, deposits of Secondary Raw Materials and a strategic geographical position, characteristics consisting major strengths of these countries. Moreover, Critical Raw Materials (i.e. Sb, Co, REEs) are reported to be present in a number of raw materials examined, whereas selected secondary mineral resources may present business interest for the recovery of the contained metal values. These opportunities for the sustainable development of the Primary and Secondary Mineral Resources of the 6 ESEE Countries comply with the objectives of the EU Raw Materials Initiative and are expected to contribute in the further enhancement of those economies in transition for the upcoming years.
Monday 6 September 2021
ILISSOS

SESSION A3
Novel metallurgical methods I

Chair: C. Van der Eijk, P. Davris
A look at future metallurgy

D. Panias

National Technical Univesrity of Athens, Greece

E-mail: panias@metal.ntua.gr

Towards achieving the Green Deal targets, Metallurgy has reach at a remarkable bifurcation of its evolution either to follow the route of innovative non-disruptive technological solutions or to follow through breakthroughs the route of totally new disruptive technological approaches to produce the metals. The driving force for both routes are the Decarbonization and Electrification of Metallurgy. This lecture tries to elucidate the future of metallurgy of two basic metals, aluminium, and iron. Although the non-disruptive approaches are always welcome by the industry, the disruptive ones are always welcome by the academia and has in most of the cases higher impact towards achieving energy and environmental optimization in Metallurgy. For this reason, although the former will be mentioned, the latter will be analysed in detail.

In case of Aluminium production, the process of carbothermic alumina reduction will be presented based on the results coming from the EC funded project ENEXAL and its reasonable evolution towards decarbonization by application of hydrogen plasma reactor will be discussed.

In case of primary iron production, the SIDERWIN process, a fully electrified electrochemical pure iron producing technology, will be presented based on the results coming from the EC funded project SIDERWIN.
First industrial scale process concept for the reengineered Pedersen Process within ENSUREAL

D. Konlechner¹, R. Koenig², A. Preveniou³, P. Davris⁴, E. Balomenos⁴

1KON Chemical Solutions e.U., Austria
2Bluemetals GmbH, Germany
3Advanced Minerals and Recycling Industrial Solutions P.C, Greece
4MYTILINEOS S.A., Greece

E-mail: david.konlechner@kon-chem.com

Within the following paper a first process concept for the reengineered Pedersen Process is shown. The design capacity for the investigated case is 500 kt of industrial grade alumina. The present data bases on during the last three and a half years, within the EC funded ENSUREAL project, generated know how. The presented process flow diagram is a preliminary concept developed during ongoing upscaling procedure. It merges lab know how, investigated and understood chemical behavior with industrial scale process equipment and during piloting generated practical experiences. The industrial concept consists of four main sections: Material preparation, thermal treatment, wet treatment and calcination. Within the material preparation bauxite or bauxite residual, limestone, coke and an internal recycled gray mud stream are mixed, milled and formed to pellets. The reason for generation pellets is to have a homogenous feed stream to the hot section and a reduced dust load within the process. During the thermal treatment the pellets are within the preheating kiln dried, hardened and the iron fraction is partly reduced. The hot pellets are afterwards directly transferred to the electrical furnace where at > 1500°C a CaAl-Slag having specific properties and pig iron is generated. The pig iron is the first product of the process and the CaAl-Slag is cooled down at rates that enables formation of leachable crystal phases. Within the wet section the leaching of the CaAl-Slag using a recycled Na₂CO₃ solution takes place. During leaching solid gray mud (CaCO₃) and dissolved NaAlO₂ is formed. This step can be seen as key purification step. The NaAlO₂ solution is in a second step treated with CO₂ so that dissolved Na₂CO₃ and solid Al(OH)₃ is generated. By transferring the Na₂CO₃ solution back to leaching stage the wet cycle is closed. Generated Al(OH)₃ is finally transfers to the calcination step where a proven fluidized bed process produces smelter grade alumina. The advantages of the Perdersen process are flexibility in used raw materials. It’s also a zero-waste process. By execution of a smart CO₂ management within the process it even can become a CO₂ negative process.
Exploitation of kaolin as an alternative source in alumina production

M. Bagani¹, E. Balomenos², D. Panias¹

¹ School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece
² Mytilineos SA-Metallurgy Business Unit, Alumina and Aluminium plant, Greece

E-mail: mariampagani@mail.ntua.gr

The extensive consumption of aluminum combined with the shortage of the existing raw materials, and particularly bauxite, necessitates the exploitation of alternative raw materials necessary for the production of alumina, aluminum’s production first treatment product. The present paper focuses on the possible use of kaolin, as an abundant, cheap and high aluminum content raw material, in alumina production, via the application of the Aranda-Mastin technology in the leaching step. This technology is currently being developed under H2020- AISiCal project, an ambitious and innovative effort for the co-production of three essential raw materials: alumina, silica and precipitated calcium carbonate, using new resources by integrating CO2 capture, aiming a more sustainable and environmentally friendly mineral and metal industry. From this point of view, leaching experiments were conducted on untreated kaolin and thermally treated, metakaolin, applying atmospheric pressure, temperature of 90 °C and with aqueous solution of low HCl concentration, as the leaching agent. Leaching, in the aforementioned conditions, is an industrially applied process, characterized by highly efficient aluminum dissolution in the case of metakaolin with low silicon dissolution at short retention time, but with lower achieved results for untreated kaolin. In order to raise the aluminum dissolution rate from untreated material, temporal and subsequently chemical intercification were applied. The analysis indicated a higher aluminum dissolution rate, up to 70%, with the application of a high acid concentration of leaching agent, performed for a long retention time that could be further improved.
Sustainable Silicon and High Purity Alumina Production from Secondary Silicon and Aluminium Raw Materials through the Innovative SiSal Technology

A. Toli\textsuperscript{1}, G. M. Tsaousi\textsuperscript{1}, E. Balomenos\textsuperscript{2}, D. Panias\textsuperscript{1}, M. Heuer\textsuperscript{3}, J. Safarian\textsuperscript{4}, G. Tranell\textsuperscript{4}

\textsuperscript{1}School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece, \textsuperscript{2}Mytilineos SA-Metallurgy Business Unit, Alumina and Aluminium plant, St Nikolas, Greece \textsuperscript{3}SiQAl UG, Bosestr. 40 12103, Berlin, Germany \textsuperscript{4}Department of Materials Science and Engineering, Norwegian University of Science and Technology Metallurgi, 305, Gløshaugen, Norway

E-mail: katerinatoli@metal.ntua.gr

SiSal-Pilot project is a Horizon 2020 EU funded project that targets the sustainable production of silicon and high purity alumina utilizing secondary silicon and aluminum bearing resources. It demonstrates a patented novel industrial process to produce silicon, enabling a shift from today’s carbothermic Submerged Arc Furnace (SAF) process to a far more environmentally benign and economically viable alternative: an aluminothermic reduction of quartz in slag that utilizes secondary raw materials such as aluminium (Al) scrap and dross, as replacements for carbon reductants used today. An intermediate product of the aluminothermic reduction process is a calcium aluminate slag that represents a proper raw material for the hydrometallurgical production of pure aluminum chloride hexahydrate (ACH) through leaching with hydrochloric acid and subsequent crystallization of ACH by sparging the pregnant liquor with hydrochloric gas. Almost total extraction of Al is achieved with the use of azeotropic HCl acid solution (5,9M) at 80 °C and 1 h retention time. A pregnant liquor with approximately 20 wt% AlCl\textsubscript{3} is produced as a base for ACH crystallization by sparging it with gaseous HCl. The ACH produced is re-dissolved and crystallized 3 to 4 times until the high purity to be achieved. High purity ACH acts as a precursor for producing High Purity Alumina (HPA) through calcination, a high added value material used for instance in LEDs and Lithium-Ion Batteries.
High temperature treatment of selected iron rich bauxite ores to produce calcium aluminate slags

A. Lazou1, C. Van Der Eijk2, E. Balomenos3, L. Kolbeinsen1, J. Safarian1

1Norwegian University of Science and Technology, Norway
2SINTEF, Norway
3Metallurgy Business Unit, Mytilineos S.A, Greece

E-mail: adamantia.lazou@ntnu.no

The Pedersen process is a method to produce alumina from Al-containing sources, traditionally from lateritic bauxites. It is a more material-efficient method than the current commercial Bayer process as the Pedersen process avoids the formation of bauxite residue (red mud). The smelting reduction (SR) part of the Pedersen process yields pig iron and a calcium aluminate slag, and the latter is a feedstock material for alumina extraction via an alkaline leaching step. For the SR treatment lime is used as a flux to ease the process and control the slag chemistry, while carbon is used for the carbothermic reduction of iron oxides. An important aspect is the formation of phases in the slag that are considered leachable such as 12CaO.7Al2O3/5CaO.3Al2O3, CaO.Al2O3 and to less extend 3CaO.Al2O3 to obtain high alumina yields. In the present study, three different bauxite ores (Greek, Turkish and Jamaican) were smelted with lime and the corresponding produced slags were studied. Analytical techniques of XRD and XRF were applied to identify the slag phases and chemical compositions and to discuss their characteristics. According to the obtained results, the slags can have proper characteristics for further alumina recovery. Moreover, it is shown that the amount and distribution of both the leachable and non-leachable phases in the slags depend on the ore chemical composition. In addition, the produced slags are compared based on the potential theoretical alumina recoveries.
A Mathematical and Software Tool to Estimate the Cell Voltage Distribution and Energy Consumption in Aluminium Electrolysis Cells

A. Peppas¹, V. Vassiliadou², M. Taxiarchou¹

¹National Technical University of Athens, Greece
²MYTILINEOS HOLDINGS S.A., Metallurgy Business Unit, Plant Aluminium of Greece

E-mail: vicky.vassiliadou@alhellas.gr

The objective of this work is the development of an appropriate set of mathematical models and a relevant software program to calculate the voltage distribution and energy consumption of a Hall-Héroult reduction cell, as well as a better understanding of the complex physical and chemical phenomena underlying the alumina electrolysis process. The work involves an analysis of the basic principles governing the alumina reduction process, the presentation of the sets of the applied mathematical equations to predict the main electrolysis bath physicochemical properties related to the cell voltage, the mass balance of the main cell material inputs and outputs, the energy consumption of the electrolysis cell and the estimation of the cell voltage distribution along the various cell consisting elements. All the mathematical models have been included in an easy-to-use software to enable the aluminium cell operators and engineers to introduce and retrieve all the necessary cell operational data and study the effect of the key process parameters on the cell energy performance.
Multiscale modeling of the electric submerged arc furnace

K. Karalis¹, A. Xenidis²

¹University of Bern, Switzerland
²National Technical University of Athens, Greece

E-mail: konstantinos.karalis@geo.unibe.ch

A multiscale approach is proposed for the analysis of the operation of a submerged Electric Arc Furnace (EAF) used in ferronickel production. The multiscale modelling involves Computational Fluid Dynamics (CFD) simulations aimed at the study of the mesoscale, while classical molecular dynamics (MD) simulations were employed in the study of the atomic scale. The main data required for the developed CFD model are the properties of the materials with respect to temperature. The most important phase in the EAF process is the slag, for which physical properties (i.e. density, diffusivity, electrical conductivity) were computationally determined by classical MD simulations. The MD simulations in the temperature range 273.15-1773.15K, indicated that the slag density was 3353 – 2966 kg/m³ in excellent agreement with experimental results obtained by a pycnometer and by liquid sample aerodynamic levitation. The CFD analysis revealed that the main slag properties affecting the EAF operation are density, electrical conductivity and viscosity. The low Reynolds numbers suggested that the flow in the slag region is laminar with maximum velocities in the vicinity of the three electrodes.
Monday 6 September 2021
OLYMPIA

SESSION A4
Mine of the future and transition to Industry 4.0

Chair: M. Menegaki, A. Benardos
Managing and utilizing big data in atmospheric monitoring systems for underground coal mines

J. Diaz\textsuperscript{1}, Z. Agioutantis\textsuperscript{1}, S. Schafrik\textsuperscript{1}, D. Hristopulos\textsuperscript{2}

\textsuperscript{1}University of Kentucky, United States
\textsuperscript{2}Technical University of Crete, Greece

E-mail: zach.agioutantis@uky.edu

Underground coal mining Atmospheric Monitoring Systems (AMSs) have been implemented for real-time or near real-time monitoring and evaluation of the mine atmosphere and related parameters such as gas concentration (e.g., CH\textsubscript{4}, CO, O\textsubscript{2}), fan performance (e.g., power, speed), barometric pressure, ambient temperature, humidity, etc. Depending on the sampling frequency, AMSs can collect and manage a tremendous amount of data, which mine operators typically consult for everyday operations as well as long-term planning and more effective management of ventilation systems.

The raw data collected by AMSs need considerable pre-processing and filtering before they can be used for analysis. This paper discusses different challenges related to filtering raw AMS data in order to identify and remove values due to sensor breakdowns, and sensor calibration periods, transient values due to operational considerations, etc., as well as to homogenize time series for different variables. The statistical challenges involve the removal of faulty values and outliers (due to systematic problems) and transient effects, gap-filling (by means of interpolation methods), and homogenization (setting a common time reference and time step) of the respective time series. The objective is to derive representative and synchronous time series values that can subsequently be used to estimate summary statistics of AMS and to infer correlations or nonlinear dependence between different data streams. Identification and modeling of statistical dependencies can be further exploited to develop predictive equations based on time series models.
UNEXUP, a robot-based surveying technology for flooded mines and other underwater structures

M. Tameirão¹, N. Zajzon², B. Bodo¹, L. Lopes¹, S. Henley³, J. Almeida⁴, J. Aaltonen⁵, C. Rossi⁶, G. Žibret⁷

¹La Palma Research Centre SL, Spain
²Institute of Mineralogy and Geology, Faculty of Earth Science and Engineering, University of Miskolc, Hungary
³Resources Computing International Ltd, United Kingdom
⁴INESC TEC, Portugal
⁵Faculty of Engineering and Natural Sciences, Tampere University, Finland
⁶CAR UPM-CSIC, Spain
⁷Department of Mineral Resources and Geochemistry, Geological Survey of Slovenia, Slovenia

E-mail: marcio.tameirao@lapalmacentre.eu

The UNEXUP project is an EIT RawMaterials funded initiative that improves, calibrates, and commercializes a robot-based surveying technology for flooded mines and other underwater structures, which are currently inaccessible without human risks or major costs. This technology was developed and tested in five different sites in Europe during the H2020 UNEXMIN project, its predecessor, with the UX-1 robots, which formed a multi-robotic platform for exploration. The improvements in the robotic system are a result of experiences obtained during the pilot tests of UNEXMIN. Based on these, the technology developers are building two new robots in UNEXUP: UX-1Neo (2020), and UX-2 (2021). These robots are designed to address the needs and requirements from stakeholders and potential customers of the technology. UX-1Neo is an upscaled version of UX-1, with hardware and software improvements that will make it more versatile and effective in the field, resulting in more productive and cost-effective missions. The robot is ellipsoidal (700 x 620 mm), with less than 90 kg, modular, with swappable batteries, over 500m depth capacity (depending on the instrumentation installed), and the autonomy is estimated in more than 8h of operation. The navigation is supported by an IMU and a DVL, for accurate position and depth measurements; a multibeam sonar, which is the mid/long-range sonar for large mine cavities explorations and mapping; 2 scanning sonars, which are for close to mid-range obstacles detection and avoidance; 6 cameras, for the complete perception of the environment and identification of rock types and geological structures; 8 thrusters that allow easier and more efficient motion control; 6 structured light system (SLS) units, for detailed mapping of the environment when turbidity allows; and a mechanical pendulum, for pitch position lock. The geoscientific payload includes a hyperspectral unit, water sampler unit, water chemistry unit (pH, oxygen concentration, EC, temperature, pressure), sub-bottom profiler and a fluxgate magnetometer, which allow the robot to collect valuable spatial and geoscientific data from underwater sites. This innovative technology will perform field missions, and the first tests are scheduled for April and May in 2021, in different environments, such as flooded mines, water well for public supply, as well as other potential opportunities in the EU and overseas. UX-2 will be a vehicle with increased modularity; increased Technology Readiness Level (TRL); higher operational depth, as well as a rock sampling unit, to be able to address even more challenging conditions and requirements in underwater surveying missions.
Planning sustainable deep sea mining

K. Vatalis, S. Platias, G. Charalampidis

University of Western Macedonia, Greece

E-mail: kvatalis@uowm.gr

The increase in world population and the expected global development of the world economy after COVID-19 pandemic will continue to impose unprecedented pressure on securing the supply of minerals. The World Bank report “Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition” finds that the production of minerals such as graphite, lithium and cobalt could increase by nearly 500% by 2050, to meet the growing demand for clean energy technologies. Many of these critical minerals are found in the deep seabed, the only place on earth where mineral resources have not been exploited yet. Three types of resources have been identified in the deep seabed so far: polymetallic sulfides, cobalt rich manganese crusts and polymetallic manganese nodules. There is a strong need to ensure that these critical minerals will be extracted in a sustainable way, verifying the protection of the marine environment and biodiversity. The regulatory, financial and engineering challenges for deep sea mining are considerable, but in fact are not a problem, taking into consideration the remarkable achievements of the International Seabed Authority, the U.N. Convention on the Law of the Sea and the remarkable results of the relative research projects. On the other hand, it is evident that the existing modern ecosystem based management approaches cannot be applied to deep sea areas without detailed knowledge of the individual species and ecosystems; most of the species that live on the deep sea floor remain unknown up to now. Therefore, there is a need for the development of a new environmental management plan for each specific area. The successful procedures of Natura 2000 can be followed and the necessary information on the existing environmental conditions has to be collected separately at every site for a minimum period of 3-5 years. Natura 2000, the world’s largest ecological network united under a single, uniform regulatory framework is regarded as one of the conservation success stories in the global effort to protect biodiversity.
A critical review on evaluation of the marine resources mining versus the land-based ones for REE

K. Papavasileiou

National and Kapodistrian University of Athens, Greece

E-mail: papavas@geol.uoa.gr

Mineral deposits containing Ni, Cu, Co, and REE are plentiful in some parts of the ocean floor, but also their concentration in these critical metals tends to be much higher than is the case on land. These deposits have, in some cases, lower contents of REE, compared to the well-known land deposits, but their size is very extensive, much higher compared to the land-based deposits. So the future use of these marine deposits as an REE source could be an effective alternative to the mounding demand for these strategic elements. To outline the technical and economic viability of these marine deposits for REE, compared to the well-known land REE deposits, two existing case studies from licences granted by ISA are reviewed concerning their exploration pre-feasibility economy technical assessment. Rare earth projects often use a “Basket Price” to value the products they intend to produce. This ideally is the weighted average of the price of the individual elemental components of the intended production basket. A comparison with land-based REE deposits suggests that these deep-sea mineral deposits are usually low-grade mineral deposits with a very high tonnage. In both cases studied, and considering the REO prices for 2014, 2015 and April 2021, the Total Basket Price (TBP) of the polymetallic nodules rich in Ni and Cu, of Fe-Mn Co rich crusts and particularly, some categories of deep-sea sediments, the relative quantities of the more valuable rare earth components such as Nd, Pr, Dy, Sm, Gd and Tb are higher in these deep-sea formations than terrestrial ores of some known and large deposits of REE on land that are currently under exploitation. This results in a nominal TBP that is approximately 20-25% higher than REO products originated from terrestrial deposits. A very sound argument is that while most of the land-based deposits are producing REEs as the primary ore, REE and other critical metals could be extracted from nodules and crusts as a byproduct to the base metal (Ni, Co, Cu, Mn) production of primary commodities. So the costs of mining, transportation, initial ore grinding, and tailings disposal are borne by the four primary target metals. The economic viability for exploiting these marine deposits not only for Co, Ni, Cu, and REE is very promising. However, there are also different views. According to recent reports scientists, are concerned by the lack of enough and detailed research on the possible impacts of deep-sea mining.
Enhancing blockchain traceability with physical tracking technologies: a taxonomy of enabling IoT technologies for supply chains and the circular economy

A. Beckh Bacchetta, E. Cullen, V. Krümpel

Minespider, Germany

E-mail: angela@minespider.com

Blockchain technology guarantees data security by rendering digital assets and information unalterable and transparent. This is due to blockchain’s secure and decentralized architecture. Yet, how can one ensure that the information entered into a blockchain system is accurate, timely and relevant? This paper explores numerous physical tracking technologies and how they effectively capture and collect data that can be recorded in the blockchain. Theoretically, integrating data generated by physical tracking technologies into the blockchain has the potential to revolutionize global supply chains. It could make them more transparent with reliable real-time information.

In practice, physical tracking technologies such as RFID can enable tracing the flow of materials, be it on production sites, or monitoring a shipment throughout the global supply chain, but are still underutilised. In order to illustrate the synergies between these technologies, we provide our interpretation and analysis of the “Internet Of Things” and how they can support blockchain traceability systems. As these IoT devices and tracking technologies generate big data, this can create both new business models within a circular economy, as well as more reliable data flows. Physically tracking the flow of raw materials from mines to smelters, and eventually to end-consumers, in combination with a digital blockchain system, can reshape global supply chains toward more responsible sourcing and enable circular processes. This paper seeks to create a taxonomy of all the key physical tracking technologies that are relevant for the raw materials sector, with examples from minerals as well as other goods. Ranging from barcodes to satellite communications, this research analyzes the benefits, challenges, future trends and best use cases for these tracking tools when linked to the blockchain.

Understanding how the integration of blockchain with tracking technologies can enable more transparent, responsible supply chains and lay the foundations for greater recycling and circularity, is pertinent for both practitioners and policy makers. Furthermore, this study is embedded within a EU-funded research project for the blockchain company, Minespider. This positioning has enabled the authors to generate insights that encompass both the perspective of industry actors, such as mines and smelters, as well as policy makers, NGOs and ecosystem orchestrators, such as Google. Consequently this study contributes to understanding the tools and creating the building blocks for more responsible and transparent supply chains.
Risk Management: An essential “tool” for the extractive sector

P. Maraboutis, N. Poulimenou, E. Nikolaou

Eco-Efficiency LTD, Greece

E-mail: p.maraboutis@ecoefficiency.gr

Integrated risk management is a methodology through which the extractive industry and companies associated with these activities can proactively manage risks (inclusive of potential opportunities and threats) associated with the extraction and initial processing of minerals and metals, the reuse of waste (historic and new), until the closure and rehabilitation of a site (mine/quarry). Risk management as a management technique has developed significantly over the past 20 years with an array of different tools and techniques being increasingly used globally to address risks pertinent to the extractives sector. The sustainability of the extractive sector will be guided by the environmental, occupational health and safety and the societal approval of the extractive operations including the processing plants. Three years ago, the 'Reference Document on Best Available Techniques for Management of Waste from Extractive Industries' (MWEI BREF) draw up 57 different BAT addressing extractive waste management, some of which require appropriate environmental risk and impact assessment to assess their relevance and applicability as an appropriate technique among the techniques listed for each BAT. Risk management of a mine or any other extractive facility is a holistic approach that takes into account all risks resulting from the construction and operation of a facility. This approach results from the need to optimise the overall safety and environmental performance of the facility. The objective of this article is to highlight the advantages of using some of the Risk Management Tools at the extractive sector.
Assessing behavior similarity of mineral raw material prices through a feature-based clustering approach

K. Oikonomou, D. Damigos

National Technical University of Athens, Greece

E-mail: ekonomouk@gmail.com

Mineral raw materials and their products play a crucial role in international trade due to their importance in sectors such as manufacturing, construction, transportation etc. Theoretical and practical research efforts suggest that their prices are affected by macroeconomic factors such as aggregate demand as well as commodity-specific factors like shocks in supply due to unforeseen events. It has been also shown that prices co-move, meaning that some mineral raw materials prices show some degree of similarity in their behavior. The purpose of this study is to determine the level of price behavior similarity of mineral raw material by utilizing unsupervised machine learning methods such as dimensionality reduction and clustering. Specifically, time series of the monthly prices of selected commodities (namely crude oil, coal, aluminium, iron ore, copper, lead, tin, nickel, zinc, gold, platinum, silver and uranium) are examined for the period January 1990 till March of 2021. First, each time series is transformed into a group of global feature variables, able to capture and describe crucial information of the time series characteristics. Then, to extract relevant information deriving from these possibly inter-correlated features, a common dimensionality reduction technique, that is, principal component analysis, is employed. Finally, the k-means clustering algorithm is used to obtain the time series clusters. This clustering approach aims to provide insights into the common underlying dynamics of the mineral raw material prices.
Monday 6 September 2021
VERGINA

SESSION A5
Advanced minerals exploritation and characterization technologies I

Chair: K. Laskaridis, O. Sykioti
Discovering the high potential for critical raw materials in submarine Fe-Mn deposits of the European seas: A GIS multi-criteria analysis based on MINDeSEA database

E. Marino¹, F.J. González¹, L. Somoza¹, T. Medialdea¹, P. Ferreira², T. Kuhn³, A. Lobato¹, V. Magalhães⁴, C. Moniz²

¹Geological Survey of Spain (IGME), Spain
²National Laboratory of Energy and Geology (LNEG), Portugal
³Federal Institute for Geosciences and Natural Resources (BGR), Germany
⁴Portuguese Institute for Sea and Atmosphere (IPMA), Portugal

E-mail: e.marino@igme.es

Marine Fe-Mn crusts and nodules have been studied in the last 40 years due to their polymetallic nature with significant contents in several strategic and critical raw materials essential for the energy transition and the European economy. Submarine ferromanganese deposits grow under the influence of three main genetic processes: hydrogenesis by direct precipitation of Fe-Mn colloids from cold seawaters, diagenesis by precipitation of Fe-Mn minerals from sediment pore waters, and hydrothermal by minerals precipitation from hydrothermal fluids. These mineral deposits are formed essentially by Mn oxides (vernadite, todorokite, asbolane and buserite) and Fe oxyhydroxides (goethite, feroxyhyte, ferrihydrite) with variable contents of detrital and authigenic minerals (quartz, feldspar, calcite and carbonate fluorapatite). Fe-Mn crusts show interesting contents of Mn (up to 20 wt. %), Co, Ni, V, Mo, REYs and Te (average of the global oceans 4500, 3000, 800, 400, 2500 and 45 µg/g respectively). On the other hand, nodules have high contents of Mn (up to 30 wt. %), Ni, Cu, Co, Zn, Mo (in average 1.3 and 1.1 wt.% and 2000, 1300, 500 µg/g respectively).

Fe-Mn crusts and nodules grow in specific morphotectonic environments (e.g., seamounts, plateaus or nodule fields in abyssal planes at depths between 400 and 7000 m or up to 4000 m (depending on the deposit type) and under the action of particular factors as currents, presence and depth of a thick oxygen minimum zone, detrital input and type of substrate. All these factors have been considered in a GIS multi-criteria analysis performed on the given European Seas bathymetry in order to identify the marine sites with the highest likelihood of the presence of these types of deposits. The method allows to generate several polygons that fulfill all the selected parameters and work on them separately.

Finally, the knowledge of the factors that generate known deposits of the MINDeSEA database allows to carry out a geochemical correlation with the obtained polygons in order to evaluate the richest one of the raw materials found.
Machine Learning Based Systems Application to Mineral Resource Estimation and Compliance with Reporting Codes for Mineral Resources

I. Kapageridis, I. Sinatkas, A. Asvesta, A. Iordanidis

University of Western Macedonia, Greece

E-mail: ioannis.kapageridis@gmail.com

Machine learning algorithms have been used in various steps of mineral resource estimation in the last four decades - from regression algorithms in variogram model fitting to implicit geological modelling using radial basis functions, and grade estimation using artificial neural networks. In most cases reported in scientific literature, machine learning algorithms succeeded to some degree in completing a modelling task - part of a mineral resource estimation study, by outperforming conventional methods either in the time taken to complete the task or the accuracy of the produced results. It is a common claim in most machine learning applications in mineral resource estimation, that machine learning algorithms achieve this performance improvement against conventional methods, based on less assumptions on the input data distribution and requiring minimum expertise by those who apply them. The speed of current computing systems, personal or cloud based, has allowed for complex models to be built using machine learning algorithms within minutes, leading to a few commercial implementations becoming available to mineral resource estimation practitioners and gaining their acceptance as reliable systems. In the last decade, several mineral resource estimation reports, part of various levels of study from preliminary economic assessments to feasibility studies, were based on the results of machine learning algorithms application. These reports are commonly released as compliant with one of the internationally acceptable reporting codes, such as JORC or NI 43-101. Therefore, it is important to examine how machine learning algorithms are applied to mineral resource estimation, and how this application complies with the guidelines of international reporting codes for mineral resources, particularly with the requirements for transparency and competence. This paper gives an overview of machine learning algorithms and systems used in mineral resource estimation and discusses possible compliance issues with international reporting codes for mineral resources.
Mapping of FeNi-laterite outcrops through spectral unmixing on Sentinel-2 multispectral data: the case study of Tsouka excavation (Central Greece)

A. Anifadi¹, O. Sykioti², K. Konstantinos², E. Vassilakis³

¹LARCO G.M.M.S.A., NKUA, Greece
²IAASARS/NOA, Greece
³NKUA, Greece

E-mail: alexandra.tragana@gmail.com

Ni-laterites constitute a significant proportion of world nickel reserves. LARCO GMMSA exploits the domestic laterite deposits in Greece during the last 50 years, operating in Locris and Euboea island (Central Greece) as well as in Kastoria area (Northern Greece). Since the late 70’s, the use of remote sensing technology in geological mapping has gained significant attention worldwide. In particular, multispectral/hyperspectral imagery is one of the most widespread and standard source of data for the recognition of spatial and/or spectral patterns in mineral/ore exploration. Towards this direction, the development of suitable state-of-the-art processing algorithms, either at pixel level or at sub-pixel level, is of crucial importance. Spectral unmixing (SU) is currently a very powerful method that allows sub-pixel level processing for assessing spectral information regarding different lithologies that co-exist within a single pixel. The aim of SU is the decomposition of the spectral signatures of mixed pixels onto a space spanned by a set of spectral signatures (represented as vectors) corresponding to pure physical materials (endmembers). The latter are retrieved either from spectral libraries or they are extracted from the image itself by detecting the relatively “purest” pixels via suitable algorithms. The resulting decomposition coefficients are indicative of the degree of each endmember’s presence within each pixel. It should be noted here, that in contrast to other scalar-based approaches (e.g. spectral indices), SU is a vector-based processing that provides higher representational capabilities. The most widely used assumption in SU is that each pixel’s spectral signature can be written as a linear combination of the spectral signatures of its endmembers (linear mixing hypothesis). In this study, we investigate the ability of SU to map FeNi laterite outcrops with high grade of reliability. The study area is the Tsouka laterite excavation in Central Greece, operated by LARCO GMMSA. More specifically, linear SU is applied on a Sentinel-2 satellite image. The dataset is atmospherically corrected, spatially resampled into 10m pixel size. For the needs of SU, two endmembers are used, namely a laterite endmember and a non-laterite endmember. The former corresponds to the average spectral signature of selected pixels of pure laterite composition. The latter represents both the other two existing lithologies, namely Cretaceous limestones and ophiolites. The SU resulting abundance maps show that Sentinel-2 succeeds to map the FeNi-laterite quite satisfactory. The proposed method is fast, low-cost and non-destructive and can contribute to the research of LARCO GMMSA for new exploitable ores.
Resource identification in asteroid & martian meteorite samples via atom probe tomography and correlative nanoscale analyses (SIMS, TEM, EPMA, SEM)

E. Christou1, L. Hallis1, L. Daly1, I. McCarroll2, C. Hayward3, L. Yang2, M. Garbrecht2, M. Lee1, J. Cairney2

1University of Glasgow, United Kingdom
2University of Sydney, Australia
3University of Edinburgh, United Kingdom

E-mail: e.christou.1@research.gla.ac.uk

The exploration and exploitation of mineral resources in the not-so-distant future will be taking place on other planetary bodies of the Solar System. It is still difficult to accurately estimate when extraterrestrial mining will be established (second half of the 21st century or later?) due to socioeconomic factors. Nevertheless, the rapid technological advancements in space engineering and planetary sciences, the imperative necessity for more effective strategies towards environmental sustainability, and the depletion of terrestrial mineral resources, will lead human civilization to establish its mining activities beyond Earth. The importance of identifying mineral resources of other planetary bodies is recognized internationally, as attested by ongoing space exploration projects of agencies and private companies. The first step in this journey of our civilization is to thoroughly study meteorites and returned samples here on Earth to characterize their mineral resources and plan for future space mining missions. We performed atom probe tomography experiments on material from the Itokawa asteroid (RA-QD02_0279) returned to Earth by JAXA’s Hayabusa mission and on the Martian meteorites Nakhla (nakhlite) and Northwest Africa (NWA) 8159 (shergottite) to determine their volatile element and water abundances and to evaluate the exploitability of their environments of origin. Atom probe tomography (APT) is a new technique of nanoscale characterization capable of measuring the concentration of volatile elements, water and OH molecules in 3D. Our results were then validated via correlative Transmission Electron Microscopy (TEM), Secondary Ion Mass Spectrometry (SIMS), Electron Probe Microanalysis (EPMA) and Scanning Electron Microscopy (SEM) techniques. We observed via APT a ~1 atomic % enrichment in water and OH in the solar wind irradiated rim of an olivine grain from our Itokawa sample (Daly et al., in review). Our correlative nano-analyses and numerical experiments also showed that H irradiation of silicate mineral surfaces produces water molecules. Conclusively, regolith from Itokawa could contain 20 liters per m3 of solar wind derived water, implying the origin and amount of water delivered to proto-Earth during accretion. Furthermore, the Martian fluid compositions detected in the water-rock reaction surfaces between olivine and iddingsite in our Martian volcanic rocks (in Nakhla and in the NWA 8159 shergottite) reveal their sources’ volatile composition. Acquired D/H ratios from Martian olivine and apatite grains have provided a further insight into the origin of their water (magmatic, meteoric or impact-induced), the parental melt composition, and the degree of hydration of the Martian mantle and crust.
Rock Image Classification Ore/Waste – Cut Off Identification for Decision Making

A. Mantela

Hellas Gold, Greece

E-mail: katerina.mantela@gmail.com

For the identification complexity of rock image classification, based on a certain cut-off grade, an automatic classification recognition of rock images method is proposed in this dissertation, which is a part of the MSc in Data Science at the International Hellenic University. The main topic of this research was the identification of Rock image Classification through images in order to use the results for further decision making. Basis of specific approach in face mapping images taken by mine geologists for traditional rock-mass characterization. Digital grey image processing of rock face mapping images is used for features extraction. Then features contains the process of knowledge extraction from images in Matlab and furthermore as the classification procedure in Weka, in which different classifiers have been trained and tested in order to classify Ore or Waste. Finally, the model output is the rock image classification. Hellas Gold Company, subsidiary of Eldorado Gold provided a sample of 600 images for the case study. Specifically face mapping images are from Olympias mine located in North-East Chalcidice Prefecture, Greece. For the experiment, the dataset is divided into 300 images as a training dataset in order the algorithm to classify the >15% Ore and 300 images for classify the <15% of Waste. As an outcome the optimum classifier reached 98.5% accuracy for automatic identification of rock face mapping image. Therefore, the proposed method for improving geological pattern is effective and can result in accepted identification performance for rock image classification quickly and accurately. Nevertheless, the target is to reach an autonomous level such that no human intervention will be necessary.
Machine learning is constantly gaining ground in the mining industry. Machine learning based systems take advantage of the computing power of personal, embedded and cloud systems of today to rapidly build models of real processes, something that would have been impossible or extremely time consuming a couple of decades ago. The widespread access to the internet and the availability of cheap and powerful cloud computing systems, led to the development and acceptance of tools to automate resource modelling processes or optimise mine scheduling, using machine learning methodologies. The domain modelling system discussed in this paper, called DomainMCF has been developed by Maptek, using artificial neural network technology. In the application presented in this paper, DomainMCF is used to model the spatial distribution of marble quality categorical parameters, and the results are combined to produce a final marble quality classification using drillhole and quarry face samples from an operational marble quarry in NE Greece. DomainMCF was made available for this study as a cloud processing service through an early access program for individuals or companies who are interested in testing its capabilities and suitability in various modelling scenarios and geological settings. The resulting marble product classifications are compared to those produced by the already established classification system that is based on a more conventional estimation method. The produced results show that DomainMCF can be effectively applied to the modelling of marble quality spatial distribution and similar domaining problems.
Estimation of mineral resources with machine learning techniques

M. Galetakis, A. Vasileiou, A. Rogdaki, V. Deligiorgis, S. Raka

Technical University of Crete, School of Mineral Resources Engineering, Greece

E-mail: galetaki@mred.tuc.gr

Accurate mineral resource estimation is an essential step in evaluating the feasibility of any mining operation. The estimation of reserves and quality of a mineral resource is traditionally developed using a model of selected deposit attributes, created by discretizing them into small blocks. Among these attributes, the thickness and the quality characteristics are the most critical for the mineral reserve estimation. The existing estimation methods include diverse techniques such as inverse distance weighing, kriging and its various versions and stochastic simulations. These methods require an assumption in relation to the spatial correlation between samples to be estimated at non-sampled locations. In many cases due to the complex relationships between the quality distribution and spatial pattern variability, the above-mentioned methods may not give the best estimation results. Machine learning and more specifically Artificial Neural Networks (ANNs) and Adaptive Neuro Fuzzy Inference Systems (ANFIS) have provided a new approach for the estimation of mineral reserves. Since ANNs and ANFIS are not only trainable nonlinear dynamic systems, but also adaptive model-free estimators, no assumption concerning the spatial variation of the deposit attributes need to be made. The basic approach for developing ANNs and ANFIS models for ore reserve estimation is to train them using an existing borehole data set of a mineral deposit and appropriate learning methods. In this study the application of ANNs and ANFIS and the issues involved using them for reserve estimation have been elaborated with the help of a drill-hole dataset of a cooper deposit. The estimation of grade and reserves was conducted by using a feedforward with backpropagation ANN and a Sugeno type ANFIS. To investigate the accuracy and applicability of ANNs and ANFIS for ore reserve estimation and their generalization ability, the resulting cooper concentration maps and tonnage-grade curves were estimated and compared to those obtained by using the geostatistical approach (Krigging).
Monday 6 September 2021
ILISSOS

SESSION A6
Novel metallurgical methods II

Chair: W. Vereycken, D. Panias
The nickel production methods from laterites and the Greek ferronickel production among them

E. Zevgolis¹, K. Daskalakis²

¹National Technical University of Athens, Greece  
²Hellenic Minerals, Greece

E-mail: mmmsez@metal.ntua.gr

Primary world nickel production in 2020 was 2430.7 kt Ni; 69% (1677.7 kt) of them came from oxidized nickel ores (laterites) and 31% from sulfides. Production-wise, 87.7% of the 1677.7 kt came from pyrometallurgical and 12.3% from hydrometallurgical processes. For a long time, Fe-Ni had a 20-40% Ni analysis, but in 2006 a new Fe-Ni quality came into the scene. This is the nickel pig iron (NPI) with 2.5-5.5% Ni that comes from laterite smelting in the blast furnace (B/F). Eventually, the advantages of the R/K-E/F process led to its dispersion in China and Indonesia and resulted in an NPI production with 3-12% Ni. The NPI production in these two countries climbed from zero in 2000, to 1060 kt Ni in 2020 and also stainless steel production from 5.5% to 67.2%, respectively, of the world’s SS production. The integration of Ni industry with SS production, the economy of scale, the low labor cost, the high Ni content of Indonesian laterite, and the loose environmental laws, reduced significantly the NPI production cost. The addition of SS and/or electric energy production units for cost reduction has been adapted from other Fe-Ni producers, as well. Hellenic Minerals in Cyprus after two years of successful industrial tests is in the commissioning state of a Heap Leaching-Solvent Extraction-Crystallizer (HL-SX-CR) unit for NiSO₄·6H₂O production. The high demand for Ni and NiSO₄·6H₂O in the last few years has changed the prospects of Ni laterite hydrometallurgical processing. Regarding the R/K-E/F process used in Greek Fe-Ni, it is characterized by its worldwide acceptance and reliability (more than 77% of world Fe-Ni production comes from this process). Other advantages are the use of all types of laterites and fuels, it has a high metallurgical recovery, and the plant has its own port. However, it is a high energy-consuming process and it does not recover Co. The Greek laterite, in particular, has the lowest Ni% among global Fe-Ni producers and because of this, electric energy (MWh/t Ni) and wages (wages/t Ni) per ton of Ni are high, making Larco’s viability difficult. The only way to overcome the issue with specific electricity consumption is to enrich the local ores by blending them with imported high grade Ni ores. Other negatives were the excessive electric energy price it had to pay to a dominant energy supplier and the very frequent changes of its administration.
Production of sustainable hydrogen and carbon for the metallurgical industry

C. van der Eijk, R. Jensen, A. Waernes

SINTEF, Norway

E-mail: casper.eijk@sintef.no

Hydrogen will presumably become an important substitute for carbon as reductant in the metallurgical industry. Moreover, for the steel industry, this is the most likely way to cut CO₂ emissions. However, not all metals can be reduced using only hydrogen. For example, the production of silicon metal can only take place using carbon as reducing agent. Nevertheless, the challenge to supply enough CO₂ free hydrogen for metallurgical processes has not been resolved yet. The promise of a hydrogen economy to replace fossil fuels is commonly centered on the potential for "green hydrogen," generated via electrolysis of water with carbon-free electricity. But the vast majority of today’s industrial hydrogen production is "grey," made from natural gas via steam methane reforming — a process that emits carbon dioxide but at a low cost that electrolysis will struggle to beat over the coming decades. But natural gas can also be converted to hydrogen without the carbon emissions, via another spectrum of the hydrogen palette. These include "blue hydrogen" (steam methane reforming with carbon capture and storage) or another technique, methane pyrolysis, that had earned the moniker of "turquoise" for merging blue and green. When these latter techniques are run with biomethane produced by anaerobic digestion of organic waste then these hydrogen and carbon produced can be considered CO₂ free. During the last thirty years there has been a development of a plasma based process to produce carbon black and hydrogen from methane at SINTEF. The carbon black can be used as a raw material for the production of silicon carbide and silicon metal. The low level of contamination in the carbon black make it an attractive resource for these two materials. The hydrogen was originally more considered a by-product. With the increased interest in hydrogen, this could become the main product. The plasma based method is at this moment under commercialisation in the US. The paper will review different production technologies for hydrogen and their advantages and drawbacks. Additionally, it will highlight development of plasma technology to produce hydrogen and carbon black that has been going on at SINTEF during the last 30 years.
Σiderwin - A new route for iron production

S. Koutsoupa¹, S. Koutalidi¹, E. Balomenos², D. Panias¹

¹Laboratory of Metallurgy, National Technical University of Athens, Greece
²Mytilineos S.A., Metallurgy Business Unit- Aluminium of Greece, Greece

E-mail: skoutsoupa@mail.ntua.gr

Iron and steel production contribute to ~10 % of global CO₂ emissions. During recent decades different scenarios and low emission pathways have been taken up by steelmaking industries together with universities and research institutes to tackle this problem. One of the most promising novel processes to replace the current steel-making process is the low-temperature electrolysis of iron oxide. This process is currently being developed under the H2020- ΣIDERWIN project; a European project led by ArcelorMittal, the world’s leading steel and mining company. ΣIDERWIN project aims at developing an innovative electrochemical process to transform iron oxide into steel metal plates. This process, based on the ULCOWIN technology developed since 2004, produces steel by electrolysis without direct CO₂ emissions. In this operation, electrical energy and iron oxide are converted into chemical energy consisting of separated iron metal from the oxygen gas. It is a disruptive innovation that entirely shifts the way steel is presently produced. One of the advantages of this process is the fact that in addition to iron oxide (hematite), it is possible to feed this process with other iron-containing raw materials. An alternative raw material which is being studied to be used in this process is Bauxite Residue; the waste material from the Bayer process for alumina production. The Bauxite Residue to metallic iron process is under investigation and insights are showing that it could follow up the electrochemical route for sustainable iron production.
Production of metallic titanium by electrowinning in molten salts of titanium oxycarbide anode

B. Malek¹, J. Serp¹, A. Maitre², M. Miguirditchian¹, F. Doreau¹, Y. Lepetitcorps³, N. Pradeilles²

¹CEA Marcoule, France
²Institute of Research for Ceramics, France
³Laboratory of Thermo Structural Composites, France

E-mail: btissem.malek@cea.fr

The main industrial route for titanium extraction is the Kroll process. Due to its energy consumption, low efficiency, complexity and its high production costs involved at all processing steps, the need for cheaper and more compact processes has encouraged many researches and trials to develop alternative routes. The new methods, categorized into two groups (thermochemical and electrochemical), have been proposed to reduce the number of steps of the Kroll process, to obtain a product of high purity cheap and thus widen its applications. Several electrochemical processes have been developed so far: GTT (Ginatta Titanium Turin), FFC Cambridge (Fray, Farthing et Chen) and MER-process (or the similar Chinuka process and USTB process).

The aim of this work is to study the Chinuka Process. A titanium oxycarbide is used as the consumable anode. The ceramic TiC0.5O0.5 is obtained by carbothermic reduction of titanium dioxide at high temperature and sintered by SPS. Titanium oxycarbide is electrically conductive. During the electrolysis, the titanium present in TiC0.5O0.5 is dissolved as titanium ion which electrodeposited in the cathode, while C and O forms CO without any C or O left in anode.

The main issues for successful development of an electrochemical route for titanium production are associated with the existence of several titanium oxidation states (VI, III and II) in solution which involve multistep processes and lead to disproportionation reactions and low current efficiency. In this study, the salt has been investigated to avoid the formation of Ti2+ and stabilize Ti3+.

In order to understand the mechanism of titanium reduction in the studied molten salt, the first electrowinning attempts were carried out using titanium plate anode. The experimental faradic efficiency is around 85% and the XRD analyzes show the presence of metallic titanium.
High purity magnesia refractories have been tested for their resistance to iron-rich converter slags of ferronickel production. Laboratory tests were performed using crucibles made from magnesia refractories filled with slag at temperatures up to 1700 °C and contact time 1, 2, 4 or 8 hours. SEM observations and microanalyses performed on both refractories and slag mainly close to their contact surface indicated the progressive substitution of Mg in magnesia refractories and production of magnesiowustite ((Mg,Fe)O) resulting in the formation of an affected intermediate zone with depth depending on contact time and temperature. At the most aggressive conditions investigated, i.e. temperature 1700°C and 8 hours contact time, the maximum depth of infiltration zone measured was 1.5 mm. Thermodynamic simulation of the system with FactSage 7.0 involving progressively increasing slag to refractories mass ratio, confirmed the formation of magnesiowustite with progressively higher substitution rates of Mg by Fe that decreases the melting point of (Mg,Fe)O resulting in the progressive corrosion of converters lining.
Development of Complex Concentrated Alloys (CCAs) Utilizing Scrap to preserve critical Raw Materials

S. Chaskis¹, M. Bouzouni³, E. Gavalas³, V. Loukadakis¹, S. Papaefthymiou²

¹NTUA, Greece
²National Technical University of Athens, Greece
³ELKEME S.A., Greece

E-mail: spapaef@metal.ntua.gr

Recently the development of High Entropy Alloys (HEAs) or Complex Concentrated Alloys (CCAs) is facing a tremendous growth potential as the high number of published articles indicates. The researchers focus on the enhanced properties of these alloys. However, so far their potential has not exceeded the laboratory scale. In the frame of our work we focus on the design of CCAs that can find their way in mass production. To meet this challenge not only the processing characteristics (solidification/casting, rolling or additive manufacturing through Selective Laser Melting – SLM 3D printing) are in focus, but also their eco-friendly and sustainable production pathway must be designed and ensured. With a circular economy target, our approach includes the utilization of low-cost, widely available scrap materials for the manufacturing of new lightweight CCAs via induction melting. The implementation of scrap in the production chain can ensure a cost-efficient production and the possibility to surpass major limitation factors in the manufacturing of CCAs in an industrial scale, which are related to the perseverance of critical raw materials. Additionally, avoiding the necessity for super clean input raw materials for the alloy design incorporating scrap, will pave the way for the design of new alloys with advanced properties for existing or more demanding applications. Examples of such an alloy design approach will be presented in this work.
Monday 6 September 2021
OLYMPIA

SESSION A7
Mine planning, scheduling and optimization

Chair: C. Roumpos, D. Damigos
Mining in front of the 21st century challenges

D. Kaliampakos

NATIONAL TECHNICAL UNIVERSITY OF ATHENS, Greece

E-mail: dkal@central.ntua.gr

The 21st century poses dynamic challenges not only to the mining sector but also to the universities that serve it. Environmental mining, the key issue in the context of the deep environmental crisis we are going through, is not just the typical mining activity with an increased level of environmental protection. It is a thorough review of all the involved technologies, in the light of three criteria now, that is, besides the classic criteria of safety and efficiency, the addition of the best possible environmental protection as an equal one. On the other hand, the 4th Industrial Revolution largely redefines a new blend of raw materials, with significant changes in mineral demand. Finally, modern tools such as robotics, machine learning and the exponential growth of biotechnological applications open new frontiers in the understanding and application of mining in the 21st century.

On the ground of these changes, the challenges for the curricula of the mining-metallurgical schools are great. Only by releasing these from the mountains of knowledge that are easily accessible by the new engineer and by decisively shifting the center of gravity of knowledge to critical ability can we win the bet of the new age.
Linking stability conditions and ore dilution in open stope mining

A. Delentas, A. Benardos, P. Nomikos

School of Mining & Metallurgical Engineering (NTUA), Greece

E-mail: andrew_@windowslive.com

In recent decades open stoping underground mining methods have become widespread and used in a variety of mining operations. Nevertheless, besides their ease of use and efficiency in operation characteristics, the external dilution is a major issue to consider which could downgrade the overall quality of the ore and increase final mining and milling cost. In this manner, the estimation of the stability conditions, over-breaks and spalling failures which could inflict potential external dilution is required to ensure the optimal design of the exploitation. Efforts have been made using empirical models and nomograms and relevant methodologies have been proposed so as to provide principal design guidelines, mainly qualitative, with respect to the stope width and the geotechnical conditions expected. On the other hand, numerical models, although complicated and time consuming, can be used to actually depict failure conditions and yielding areas. This paper aims at combining these two approaches and thus linking the extensive experience of the empirical design and the quantitative data derived by numerical analyses. This will assist the engineers to have better insights in the dilution potential and optimize the design of the stopes. To facilitate this, a large number of different geomechanical conditions are modeled and analyzed in the pursuit of obtaining valid and applicable relationships between empirical stability graphs’ approaches and numerical simulation models. The parametric analysis is made to express the stability conditions and the dilution with specific design characteristics, using both Potvin’s and Mathew’s stability graphs while the numerical models were tested using the RS2 software package. The results obtained include direct and easy to use mathematical expressions that can be applied for the initial design of the stoping process, especially for the case of sidewalls (hanging-wall and foot-walls). Furthermore, through the research an initial proposal is made for a dilution-based Stability Graph that could be utilized for the early identification of dilution.
Sub level open stoping (SLOS) is applied to competent ore bodies that are steeply dipping and surrounded by competent host rock in both the hanging wall and the footwall. It has been used in ore bodies with a minimum strength of 50 MPa, a width of 6 m and a dip of 50°. The width of the ore body and the rock mass quality determines the orientation of the stopes. Longitudinal stopes are used in ore bodies of up to 15 m in width, while transverse stopes are used in wider ore bodies with poor to very good rock mass quality. In sublevel stoping with no fill, stopes are contained between support (crown and rib) pillars (that protect the levels and other development headings above) as well as sill pillars (used for protecting the ore collection system). Where used, back filling facilitates the recovery of the support pillars (to increase ore recovery), minimizes subsidence and redistributes mining induced stress, as well as eliminates the use of rib pillars. This paper presents a parametric investigation with respect to the geometry of a SLOS mining project that maximizes ore recovery, while considering safety and operational restrictions. An underground copper mine at the region of southern Africa was chosen as a case study to investigate the characteristics of different layouts. The mine is subject to subsidence constraints because of surface infrastructure that includes buildings, telecommunication networks, high voltage transmission lines and rural roads. The success of SLOS depends on stability of both the stope wall and the support (crown and rib) pillars as well as any backfill used. A software package was implemented to analyze and assess the stability of different SLOS layouts. Numerical results from two- and three-dimensional finite element analyses show the effect of geometry on pillar stability, recovery, as well as compliance with safety, and subsidence targets.
Going underground for ferronickel mining in Greece: Preliminary feasibility and potential benefits

A. Benardos¹, I. Vlachogiannis², C. Stenos³, S. Pappas³, G. Bourmas⁴, S. Koukoumtzis³, N. Koronakis⁵

¹School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece
²Geomine J&K, Greece
³LARCO GMMSA, Greece
⁴Grecian Magnesite SA, Greece
⁵Omikron Kappa Consulting SA, Greece

E-mail: abenardos@metal.ntua.gr

The gradual shift towards underground mining exploitations is a widespread and irreversible trend as the near surface deposits that have been mined through the years are gradually phasing out. Thus, deeper and more complex underground schemes need to be set up so as to provide an efficient and stable supply to meet the demands of modern society. Nickel mining is also experiencing this trend which is coupled with an increased demand as this metal is directly associated with the development of rechargeable batteries, a sector that is anticipating great booming in the next years. In this manner this new and radical approach should be examined and be solidly based on real and accurate data, especially in mining companies like LARCO GMMSA, the sole nickel miner in Greece, which is currently exclusively dependent on open-pit mining and lacking the machinery and experience in adopting underground mining schemes. This paper aims at presenting the results of the feasibility assessment that was undertaken as a significant first step to analyse such prospects of developing underground ferronickel exploitations focusing on LARCO’s deposits in central Evia. Such assessment can be used as an important first step that would allow for the strategic planning of the company and also could be used as the onset for drawing the practical subsequent steps that are required to design and implement the underground ferronickel exploitations. The pros and cons are given and furthermore the framework that will be used to shortlist the most promising deposits to be further evaluated for a subsequent underground mining development is presented in detail. Furthermore, the paper analyses the most favorable and compatible underground mining methods by also taking into consideration the anticipated geomechanical response of the orebody and the hanging wall and outlines the main design principles followed. Finally, the corresponding cost data estimates related to the required capital expenses and operating cost of the underground nickel ore mining exploitation are presented and can be used to assess the potential of the endeavor. According to these findings the transition towards underground mining schemes in Evia seems quite promising in financial terms while could also assist in minimizing the environmental footprint of mining in the area.
Ventilation design modelling and optimization for an underground bauxite mine

M. Karagianni, A. Benardos

National Technical University of Athens, Greece

E-mail: mkaragianni70@gmail.com

Mine ventilation systems is one of the most critical modules of an underground mining project, being responsible for the wellbeing and health of all personnel. Its main goal is to constantly supply fresh air to the mine and successfully disperse gaseous pollutants and control the concentration of airborne particulates. The challenges are often significant and especially in cases where complicated mining works are in place or the selected mining scheme develops difficult airway paths. This is often the case in underground bauxite mining projects, where mine development passes through a series of ore lenses that are scattered around the exploitation area, or utilise previously developed access works to progress and reach the new mining areas. This paper deals with the optimization of an existing ventilation network of an underground bauxite mine that has the above characteristics and also proposes the ventilation design of the future mine expansion project. Initially, the analysis of the current system and existing conditions is carried out in order to model the existing ventilation system its characteristics and the whole 3D mine network airways used in the exploitation. This digital twin of the ventilation system is developed using the Ventsim software and its accuracy is tested and validated by comparing real data of air measurements carried out at the mine and the results obtained by the model. Once this consistency and accuracy is established the optimization of the network is analysed. Moreover, the design and development of the future ventilation system which will support the future expansions of the exploitation is made. Through this model the estimation of the air quality and flow characteristics can be drawn and engineers can use it as a basis to further optimize the whole system, the main and auxiliary fans, the airways and doors as well as the design the progression of mine workings to facilitate a healthy and risk free air-conditioning and reduce the operating costs of the mine. The aforementioned process can be further developed with the implementation of ventilation on demand, with the aim of achieving both a significant upgrade of work safety level and a further reduction in operating costs of ventilation systems.
The role of cutoff grade policy in the financial management of a sedimentary nickel deposit: a case study from Greece

S. Pappas, M. Menegaki

National Technical University of Athens, Greece

E-mail: speris13@mail.ntua.gr

It is well known that cutoff grade policy is one of the critical factors in the design of an exploitation plan affecting its economic viability. However, in many cases, this parameter is not examined thoroughly in order for the exploitation plan to be optimized, especially in cases where the variance of the ore deposit presents small fluctuations. The paper presents the case of the exploitation of a Nickel deposit located at Evia Mines designed to cover the supply needs of a metallurgical plant. The exploitation design that took place in 2009 was based on the NPV and IRR values for a mine life of 10 years without any optimization of cutoff grade. The deposit that is being analyzed is a sedimentary type of Nickel Ore characterized by the low grade and small variance in Ni content. During the implementation of the plan, nickel price and the exchange rates slightly failed resulting in a negative outcome of the investment. As a result, the investment should have halted. Going back with all the data available, a comparison between the estimation data and the produced results of the investment is made, in order to detect the drawbacks of the project and examine if a different approach could result in a different outcome. Analyzing the small variance of Ni grade in the block model and taking into account the production needs and selling prices, we come across a cutoff management scenario, which proves to have a positive economic result that would allow for a viable exploitation plan.
Possibility of using wind and solar sources for electric power generation on Serbian opencast coal mines

N. Pavlovic, D. Ignjatovic, T. Subaranovic

University of Belgrade, Serbia

E-mail: natalija.pavlovic@rgf.rs

The rapid technology advancement and the significant decline of investment costs in wind and solar energy generation over the past two decades has opened up a significant opportunity to build these facilities on closed opencast mines or mines in the phase of closure around the world, where available large areas are almost ideal for such projects. This is a possibility for advanced opencast mine remediation in accordance with the ecological requirements for the best possible use of renewable energy sources. Throughout projected documentation and realized projects of opencast mines in Serbia, the spaces of closed mines have been repurposed for agriculture, tourism, recreation and specific sports activities achieved with recultivation. There are 5 closed mines, 6 larger opencast mines in various operating phases and 2 large opencast mines in the design phase with significant usable areas for the purpose of renewable energy. The end of mining on all mines is planned near 2050. In that sense, it is necessary to give an analysis of the possible application of wind and/or solar energy production, as well as the dynamics of such a generally ambitious and long-term project with conceptual solutions before making individual feasibility studies for investment justification from environmental, social and economic aspects.
Monday 6 September 2021
VERGINA

SESSION A8
Advanced minerals exploration and characterization technologies II

Chair: F. Tinti, I. Kapageridis
Fluid behaviour in the genesis of critical metal deposits

A. Finch¹, K. Sokół¹, A. Borst², N. Horsburgh¹, W. Hutchison¹, E. Stüeken¹

¹University of St Andrews, United Kingdom
²University of Leuven, Belgium

E-mail: aaf1@st-and.ac.uk

Ancient volcanic systems account for most of the world’s reserves in critical metals including Rare Earths, Niobium and Tantalum. The genetic model for such resources suggests that metals are transported in the magma, which crystallises, trapping the metals in magmatic minerals. However, it is known that under certain conditions, metals are soluble in fluids (usually water +/- carbon dioxide) that are exsolved from the magma itself. Recent studies indicate the importance of these processes in modifying the ore, replacing magmatic minerals (relatively easy metallurgy) with intimate nm-scale intergrowths of secondary phases which are difficult to process.

In this study we contrast two volcanic systems in Greenland. One, Illerfissalik, is commercially barren. At Illerfissalik, magma intruded a suite of sandstone and granite country rocks. A fluid associated with the magma altered the country rocks (a process known as ‘fenitisation’). The geochemical evidence shows a magmatic fluid exited the volcanic system carrying with it into the walls of the intrusion a substantial cargo of critical metals, notably Rare Earth Elements (REE). When we reconstruct the mass of metal that carried in this manner, we obtain tonnages equivalent to some of the world’s REE deposits (62 Mt of TREO). In contrast, the nearby Motzfeldt centre is a commercial target, considered to be one of the world’s largest Nb-Ta prospects. Motzfeldt and Illerfissalik show very similar fluid processes, but at Motzfeldt interaction with the roof (not the sides) focussed the mineralisation.

These localities provide insights into how critical metal deposits form in volcanic systems. First, the late-stage fluid stage is a key aspect of magma genesis. At Illerfissalik, fluid transported the metals away from the volcano and thereby dissipated the resource. New secondary REE minerals, such as chevkinite-(Ce) and zircon, formed as nm-scale crystals in country rocks. In contrast, at Motzfeldt, the precipitation of this fluid in a focussed area of the roof created a commercially significant zone of mineralisation. Second, the loss of volatiles, alkalis and high-field strength elements from the magma into the country rocks depleted that magma in those chemical components. Had those elements not been lost, the Illerfissalik magma may have resembled a precursor to metallogenic (sometimes called ‘agpaitic’) magmas such as the economically significant Ilímaussaq Complex and the intrusions of the Kola Peninsula. The behaviour of fluids associated with volcanic systems is crucial in understanding how many of the world’s critical metal deposits formed.
X-Mine project: Sensing technologies and 3D ore deposit modelling methods

J. Paaso1, N. Arvanitidis2, M. Bergqvist3, J. Kolacz4, R. Arvidsson2, S. Sädbom5

1VTT Technical Research Centre of Finland Ltd, Finland
2Geological Survey of Sweden, Sweden
3Orexplore AB, Sweden
4Comex AS, Poland
5Bergskraft Bergslagen AB, Sweden

E-mail: Janne.Paaso@vtt.fi

The X-Mine project is funded by the European Commission Horizon 2020 programme. The project develops X-ray and 3D vision-based sensing technologies and 3D ore deposit modelling methods. The sensing technologies have been integrated in two large-scale prototypes: a drill core analyser and a mineral sorting prototype, which are being demonstrated at the projects four mining. The innovation potential of the X-Mine project relies a lot on the development of new sensing technologies and their integration into prototypes. The X-Mine project developed new on-line capable high-resolution, high-speed X-ray imaging sensors and related software for drill core analysis and mineral sorting. The drill-core analyser measures from a drill core its elements and a tomographic map of structures and minerals with a speed up to 6 m/hour. Analysing the drill core data opens up new possibilities for an extremely fine details down to about 50 microns. The X-Mine has built a container-based pilot sorting prototype to be used as a pre-concentration method after ore crushing. The prototype uses X-ray and 3D sensing technologies to detect valuable ore from waste rock particles and separates them into two fractions (ore and waste) by using pneumatic nozzles. The X-Mine project completed large-scale demonstration of the pilot sorting prototypes and the drill core scanning with 3D geomodelling at the four participating mines. The first two drill core scanner prototypes were installed at the Lovisagruvan, Hellas Gold, Hellenic Copper and Assarel Medet mines and extensively tested and validated with the analysis of conventional and oriented drill cores. The mineral sorting pilots started with the installation of the first mineral sorting prototype at the Lovisagruvan mine and later in Hellas Gold mines aiming at reducing in transportation costs by 20%, through more efficient ore and waste separation, in waste rock by 7% and in energy consumption and CO2 emissions by 10- 30%. In the longer term, the new analysis methods developed in X-Mine could lead to a revolution in the exploration and characterisation of existing and new mineral deposits, enabling the entire value chain of mining operations to be optimised, based on improved insights into mineral grain size, distribution, and other structural, geological, geochemical, and mineralogical information. This would not only make mining more efficient, but would reduce its environmental impact in various ways, and also help in achieving the “social license to operate” for the mining industry.
Dual and Multi Energy XRT and CT analyses applied to copper-molybdenum mineralizations in porphyry deposits

C. Bauer¹, R. Wagner¹, B. Orberger², M. Firsching¹, C. Wagner³, O. Boudouma³, K. Siahcheshm⁴

¹Fraunhofer Institute for Integrated Circuits IIS, Germany
²Catura Geoprojects, France
³Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre Paris, France
⁴University of Tabriz, Iran

E-mail: christine.bauer@iis.fraunhofer.de

Copper porphyries represent complex alteration zones, hosting variable grades of Cu-(Au-Mo), but also Pb, Zn, Te, Bi and Ag. Processing of these ores becomes more difficult and more expensive as metal grades are lower and highly variable. Reducing the operational costs while increasing the resource efficiency at constant production is the challenge for the mining industries. Five samples from the Niaz porphyry copper (Mo)-deposit in northwest Iran, representing each a specific alteration zone were investigated by dual energy (DE) and multi energy (ME) X-ray transmission (XRT) as well as X-ray computed tomography (CT). These non-destructive techniques are powerful tools for locating metal concentrations and evaluating porosities. Two samples come from the potassic phyllic zones: (1) A microgranular quartz-diorite is composed of sericitized albite, chloritized biotite and quartz veinlets. Ore phases are chalcopyrite, Fe-sulfides, galena. Magnetite, barite and Ti-oxides also occur. (2) A granular quartz-monzonite is composed of sericitized feldspars, quartz, amphibole, biotite, chlorite and ankerite. Ore phases are molybdenite and Cu-sulfides. Veins are filled with galena and Cu-Bi-sulfides (+Cd, Sb, As). A coarse-grained diorite composed of feldspars, amphiboles, epidotes, biotite, chlorite and calcite characterizes the propylitic alteration zone. Apatite, zircon, sphene, magnetite and ilmenite are present. Ore phases are molybdenite, galena, pyrite, Te-Bi phases and sphalerite. A microgranular quartz-diorite hosting quartz, feldspars, amphibole, biotite, kaolinite and siderite represents the phyllic-argillic mineralized zone. Ore phases are various Cu-sulfides. Minor barite, monazite, thorite and galena occur. The peripheral part of the porphyry is a coarse-grained skarn composed of chlorite, amphiboles, garnet, epidote, diopside, quartz, calcite and apatite. Ore phases are chalcopyrite, pyrite, Ag-sulfides and Te-Bi clusters attached to galena. Scheelite, magnetite, sphalerite and galena are observed in sulfides. Analysis of reconstructed three-dimensional CT volume data revealed structure information as well as two or three different groups of elements (low, medium and high effective atomic number). With these data, priorly calibrated by SEM, mine-geologists can assign grey values to minerals based on densities. Thus, it is possible to locate rapidly mineralization and evaluate porosities in the alteration zones for unknown samples. With XRT, fractions of heavy and light materials can be revealed in two-dimensional radiographs. While CT is useful for a small selection of samples due to its high time consumption, XRT can be used as a real-time process on conveyor belts. This information contribute to ore body modelling and predicting optimal process parameters like crushing or sorting.
Nanoscale identification of silver in galena ores from Lavrion and Chalkidiki mines (Greece)

M. Samouhos¹, P. Tsakiridis¹, M. Taxiarchou¹, A. Godelitsas²

¹National Technical University of Athens, Greece
²National and Kapodistrian University of Athens, Greece

E-mail: msamouhos@metal.ntua.gr

Lavrion (Attica; near Athens, Greece) Pb-Zn-Ag deposits were extensively exploited for silver (Ag) production since the Classical antiquity - 5th and 4th centuries BC, respectively. Lead sulphide (galena/PbS) is the main Ag-bearing mineral phase in Lavrion (Ag: 449-4070 ppm in bulk according to published data), where an Ag-Pb alloy was produced, since the decade of 70s, through pyrometallurgical processing. According to literature, Ag in Lavrion galena ore exists as solid-solution, while it has been reported -by observations in microscale using optical microscopy and SEM- the presence of native Ag, Ag-chlorides (cerargyrite/AgCl), Ag-sulfides (argentite & acanthite/Ag₂S) and Ag-Sb-(Bi) sulfosalts (miargyrite/AgSbS₂ and matildite/ AgBiS₂). At the same time, the antimony (Sb) content is high (510-8600 ppm), related to a variety of Sb accessory phases. In Chalkidiki peninsula (Kassanda mines; near Thessaloniki, Greece) polymetallic Pb-Zn-Ag±Au massive sulphide deposits, Ag-rich galena (Ag: 941-1556 ppm according to published data) is still exploited and exported as flotation concentrate. In that case, the Sb content is also high (720-11000 ppm) and galena occasionally coexists with Ag-containing Sb-sulphides and -sulfosalts (stibnite/Sb₂S₃ and boulangerite/Pb₅Sb₄S₁₁), whereas there are also significant quantities of Sn (23-131 ppm) and Tl (37 ppm). Despite the extensive study of both mining districts in terms of ore deposit geology, there are still questions concerning the detailed mineralogy and geochemistry of noble (Ag, Au) and critical/strategic elements such as Sb. The current study aims to further investigate the nature of Ag and Sb in selected Lavrion and Chalkidiki pure galena samples, using a combination bulk analytical data (ICP-MS) and, for first time on the literature, microscopic in nanoscale (TEM-EDS) techniques. The bulk data are in general in line with previous studies approving, for both districts, the correlation of Ag with Sb. The TEM-EDS study indicated, for Chalkidiki galena, the general absence of solid impurities in the form of Ag and/or Sb nanophases, implying solid-solutions, despite the fact that -Ag-bearing- stibnite and boulangerite can be observed in macro- and micro-scale into galena. On the other hand, the study of Lavrion galena revealed the existence of Pb-Ag-Sb sulfosalt mineral nanoparticles (<200 nm), particularly diaphorite (Pb₂Ag₃Sb₃S₈) euhedral nanocrystals, and perhaps of even smaller unknown Sb nanominerals. Silver dispersion, according to numerous TEM-EDS analyses, indicates that solid solutions also exist at some extent. All the above support the obvious interplay between Ag and Sb in Ag-rich galena of Greek ore deposits.
Increasing resource efficiency of bauxites using LIBS

J. Meima¹, B. Orberger², C. Garcia Piña³, D. Rammlmair¹, C. Dittrich⁴

¹Bundesanstalt für Geowissenschaften, Germany
²Géosciences Conseils Catura Geoprojects, France
³DMT GmbH & Co. KG, Germany
⁴MEAB, Germany

E-mail: beate.orberger@catura.eu

The EU aluminum production from e.g. bauxite is one of the backbones to support Europe’s green and digital transition. In support of sustainable bauxite exploration and mining, Laser-Induced Breakdown Spectroscopy (LIBS) was used on the major facies of the karst bauxite deposits of SODICAPEI (Southern France). Our results showed, that LIBS is a very promising technology to define the bottom and top layer of bauxite ores and to access critical parameters crucial for bauxite mining and processing. First LIBS tests were made on scandium standards to find appropriate Sc emission lines for future applications.
Contact Profile Analysis of Resource Estimation Domains: A Case Study on a Laterite Nickel Deposit

I. Kapageridis¹, A. Apostolikas², G. Kamaris²

¹University of Western Macedonia, Greece
²LARCO GMMSA, Greece

E-mail: ikapageridis@uowm.gr

Resource estimation of mineral deposits is commonly performed in separate domains, defined using different criteria depending on the type and geometry of the deposit, the mining method and the estimation method applied. The validity of estimation domains can be critical to the quality of produced resource estimates as they control various steps of the estimation process, including sample and block selection. Estimation domains also affect the statistical and geostatistical analysis as they define what estimation practitioners will consider as statistically separate distributions of data. Sometimes samples that are at different estimation domains share similar grade properties close to the contact between the domains, a situation known as a soft boundary. In such cases, it can be useful to include samples from a different domain at short distances from the boundary.

Modelling of multi-domain deposits and analysis of statistical and geostatistical behaviour of samples across domain boundaries has been the subject of extensive research in the past. The Contact Profile Analysis (CPA) technique discussed in this paper, provides useful tools to investigate the behaviour of the transition from one geological unit to another and can be used to improve the use of samples from neighbouring units to estimate the grades of a given geological unit. CPA is a technique that allows measuring the relationship between grades either side of the contact between two estimation domains. Allowing the exchange of samples between neighbouring domains when supported by CPA can help increase the confidence of estimates near their boundary, improve resource classification, and guarantee a smoother transition of estimated grades near their boundary.
Mapping bauxite mining residues using remote sensing techniques

S. Kasmaeyazdi¹, F. Tinti¹, R. Braga², E. Mandanici¹

¹University of Bologna, Department DICAM, Italy
²University of Bologna, Department BIGEA, Italy

E-mail: sara.kasmaeyazdi2@unibo.it

Bauxite residuals from abandoned mining sites are both an environmental challenge and possible source of secondary raw materials. Processing of multispectral and hyperspectral images with the best available techniques can help to produce multiscale spatial maps of elements inside and around the mining sites. Authors propose a procedure for mapping elements concentration using multiple data sets at different scale and resolution. A comparison between multispectral Sentinel-2 images and hyperspectral PRISMA processing is performed over some case studies of bauxite residues in Mediterranean area. Specifically, a case study from Italy is composed by artificial canyons created by past artisanal mining activities and by stockpiles of extracted bauxite. Hyperspectral punctual measurements (Spectroradiometer surveys) were taken in various zones of the bauxite site, where also in-field topsoil samples were taken for X-Ray fluorescence chemical analysis. A final concentration maps was estimated by performing geostatistical techniques.
Monday 6 September 2021
ILISSOS

SESSION A9
Hydro-, Iono-, Solvometallurgy I

Chair: J. Gamarra, N. Papassiopi
Innovative hydrometallurgical processing for sustainable environmental technologies and advanced green energy materials

G. Demopoulos

McGill University, Canada

E-mail: george.demopoulos@mcgill.ca

As we are faced with the climate change threat and the need to meet the growing demand for affordable and clean energy, clean water, and socioeconomic development, the raw materials sector should not only think of economic opportunities but also of how it can be a responsible partner for a sustainable future. In this regard hydrometallurgy (and more generally extractive metallurgy) with proper adaptations of established techniques can provide innovative and sustainable solutions in terms of (a) extraction/refining/supply of critical metals, (b) environmental protection, (c) production of advanced materials for green energy applications, and (d) recycling/reactivation/re-use of end-of-life materials. In this presentation after a brief introduction, we plan to provide an overview of our sustainability-driven hydrometallurgical research in connection to the above four critical areas. An introduction to some of the projects pursued in our HydroMET laboratory to be discussed during the conference presentation will be provided.
Bioleaching of Pyrrhotite Tailings for Nickel and Sulfur Recovery: A Two Stage Remediation Process

H. Shen, V. Papangelakis

Chemical Engineering and Applied Chemistry, University of Toronto, Canada

E-mail: vladimiros.papangelakis@utoronto.ca

Pyrrhotite (Po, Fe7S8) tailings from nickel mining operations in northern Ontario, Canada amount today to more than 100 million metric tonnes (by dry weight). This iron sulfide waste is a potential enormous source of acid mine drainage (AMD), which can mobilize many regulated elements including Cr, Pb, Zn and Cd. Currently, the runoff waters are collected and neutralised whereas different types of covers are applied. The tailings contain 0.8 to 1 wt% Ni and present an opportunity to remediate while recovering the nickel value by bioleaching. Because of the high exothermicity of pyrrhotite oxidation and the need for temperature control we investigate a tank agitated bioleach process. In contrast to classical approaches, we aim at arresting oxidation of sulfur to elemental (S0) to reduce downstream neutralization costs and generate an additional sulfur revenue stream.
CO₂ neutral production of magnesia and silica product by HCl based process route out of serpentine achievable

D. Konlechner¹, G. Kappacher²

¹KON Chemical Solutions e.U., Austria
²Tenova Branch Office, Austria

E-mail: david.konlechner@kon-chem.com

Today the main mineral source for MgO and Mg(OH)₂ products is MgCO₃. The evaluation of molar masses shows that the production of one ton of MgO from MgCO₃ directly results in releasing 1.09 tons of CO₂ in the atmosphere, not considering the process itself yet. By producing MgO from silicate sources the liberation of as carbonate fixed CO₂ will be avoided. The within this paper shown process route explains a possibility of a HCl based zero waste process route for serpentine ores having the capability to produce SiO₂, water glass, precipitated silica, MgO, high purity MgO, Mg(OH)₂ and an iron hydroxide fraction under CO₂ neutral conditions. The process starts with a HCl leaching stage where the dissolvable components, like Mg and Fe, will be separated from the non-dissolvable silica fraction. The generated silica can be mechanically upgraded to a basic grade silica fraction. An alternative route is a caustic leaching procedure by using NaOH to dissolve the amorphous SiO₂ part and generate a high module water glass in the first step. By an additional acid treatment the water glass can be converted to precipitated silica. The liquid phase from HCl leaching process will be purified by pH adjustment, iron and other elements precipitate as hydroxides and pure MgCl₂ solution remains. The mainly iron hydroxides can e.g. be used as an iron source in a steel mill. The pure MgCl₂ solution will be treated in a spray roasting process. Following the chemical reaction below MgO and HCl that is reused for leaching will be generated.

MgCl₂ + H₂O →(~ 500°C)→ MgO + 2HCl

A high purified caustic calcined magnesia (CCM) is able to be produced, if the synthetic MgO is passing a washing and calcination process. As alternative a hydration procedure can be applied to produce Mg(OH)₂ at different, market specific quality levels. Putting the focus to the holistic nature of the approach, the 2nd largest CO₂ producer, the spray roasting process itself, has to be modified in such way, that new energy sources are able to be used. Direct electrical heating or newest Hydrogen burner systems are able to close the loop for a CO₂ free MgO production.
Extraction of REE from Clay and Hard-Rock Ores: The Two Extremes

G. Moldoveanu, V. Papangelakis

Chemical Engineering and Applied Chemistry, University of Toronto, Canada

E-mail: vladimiros.papangelakis@utoronto.ca

Rare earth elements (REE) are characterised as critical materials as they play an important role in the manufacturing of electronics, magnets for electric vehicles, sensors and smart devices to name but a few. Their supply is therefore critical in ensuring smooth growth in many world economies. REE are recovered from natural resources by a variety of chemistries and processes. The Ionic Clays (also known as Weathered Crust Elution-Deposited) are found mostly in topical and sub-tropical zones and constitute the main source of the heavy rare earth elements (HREE). They present the most simple and straightforward case for REE extraction. On the other hand, REE associated with Hard Rock ores are found in temperate zones and are also predominantly rich in HREE. They present the most energy and reagent demanding case. We present a review of the two approaches and a description of the challenges in the process chemistries in each approach.
The effect of the concentration of sodium carbonate on carbonation precipitation of sodium aluminate solutions

D. Marinos, D. Kotsanis, E. Balomenos, D. Panias

National Technical University of Athens, Greece

E-mail: dmarinou@metal.ntua.gr

Alumina hydrate precipitation has been thoroughly investigated in the Bayer and sintering process since they are the dominant ones in the alumina industry. Carbonation precipitation is widely used in the sintering process, applied in poor grade diasporic bauxites in Russia and China and was also used in the Pedersen process in the 1950s. In both processes the pregnant solution to be precipitated carries some sodium carbonate depending on the leaching conditions. The sodium aluminate solution produced, contains free carbonates, which can greatly affect the precipitating phase after carbonation. In this work, synthetic sodium aluminate solutions of stable sodium aluminate, sodium hydroxide and sodium silicate content were prepared varying only the concentration of sodium carbonate. The solutions then, were precipitated through carbonation with pure carbon dioxide gas in atmospheric conditions. The solution was analyzed for aluminum and silicon content in Atomic Absorption Spectroscopy and the precipitates were characterized by X-ray diffraction analysis and Fourier-transform infrared spectroscopy.
Antimony recovery from galena concentrates

R.A. Megaloudi¹, A. Kourtis¹, E. Tzamos², K. Markogiannis³, D. Dimitriadis³, A. Xenidis¹

¹School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece
²Ecoresources P.C., Greece
³Hellas Gold, Greece

E-mail: katerina.248@hotmail.com

Antimony has been included in the EU critical raw materials list considering its economic and strategic importance and high supply risk given that worldwide 75% of total antimony is produced in China. There are several antimony deposits in Greece, however, no one is currently exploited. Antimony is also found in mixed sulphide ores in Kassandra (Olympias and Stratoni) mines, Chalkidiki, North Greece, mainly in the form of mixed lead sulphides, which are collected together with lead in galena concentrate in the sulphide ore beneficiation plants. However, antimony as well as arsenic in galena concentrate are considered as impurities and for this reason penalties are applied by the customer when their concentration exceed certain values. In this study, the recovery of antimony as well as arsenic from Olympias galena concentrate has been investigated using strongly alkaline sodium sulphide solution following a process similar to that applied at former Sunshine Mine company for the treatment of silver containing copper antimony sulphide concentrates. The effect of several parameters including reaction time (15, 30, 60, 120 and 240 min), concentration of sodium sulphide (100, 150, 250 g/l) and sodium hydroxide (30 and 50 g/l) in the leaching solution, pulp density (solid to liquid ratio 0.05, 0.10 and 0.15 kg/l) and reaction temperature (90, 98 and 104 °C) on antimony and arsenic extraction from galena concentrates has been investigated. It has been indicated that 4 hours reaction time is in almost all the cases adequate for obtaining the maximum value of Sb extraction. In general, Sb extraction increases by increasing reaction time, Na₂S concentration and temperature, and decreases with the increase of NaOH concentration and pulp density. High antimony extraction rates approaching 90-100% were obtained at 4 h leaching time. The maximum antimony extraction equal to 99% was achieved using Na₂S concentration 250 g/l at 98°C. Instead, as extraction remained low at all the conditions investigated ranging between 2.5 and 4%, indicating that under these conditions, only certain As containing minerals are dissolved. The process investigated is appropriate for extracting antimony with significant benefits associated with its market value and increased value of galena concentrate.
Recovery of copper from dilute ammoniacal leachates by ion flotation

P. Xanthopoulos, K. Binnemans

KU Leuven- Department of Chemistry, Belgium

E-mail: panagiotis.xanthopoulos@kuleuven.be

Leaching of secondary low grade metal resources, such as metallurgical slags or tailings, could generate dilute aqueous leachates. Solvent extraction is considered as the state-of-the-art method to selectively separate copper from pregnant leaching solutions. Nevertheless, under dilute conditions, solvent extraction might not be an efficient method due to high reagent losses. Ion flotation is an adsorptive bubble separation technique for recovering valuable metals from dilute aqueous solutions. In this process surfactants are added as collectors and compressed air or nitrogen gas is sparged in to generate a mobile gas/ liquid interface (bubbles). The targeted metal ions, also known as colligends, are attached to this interface due to interactions with the collectors’ hydrophilic functional groups and therefore concentrated in a foam phase as the bubbles ascend. The process can be considered as an interesting alternative hydrometallurgical technique for recovering valuable metals from dilute aqueous leachates. Ammoniacal leaching is known to be a very selective method to extract copper and zinc. In this work, the separation of copper over zinc from dilute ammoniacal leachates by ion flotation was investigated. The leachates were generated after leaching of copper- zinc- lead roasted sulfidic tailings of the Iberian Pyrite Belt. The anionic surfactant sodium dodecyl sulfate (SDS) was considered as collector in a series of batch scale experiments. Variables that they tested were: the effect of SDS concentration, flotation time and multiple ion flotation stages. Experimental results showed that 90% of copper was selectively separated over zinc to the foam phase as colloid copper (II) tetraamine dodecylsulfate. These results show great promise for recovering copper by ion flotation from dilute ammoniacal leachates, generated after leaching of low-grade metal resources.
Monday 6 September 2021
FOYER OLYMPIA

POSTER SESSION 1
Mineral exploration and characterization
EU Strategy on Circular economy
Mining trends and perspectives
Waste Valorisation
Technology critical elements (TCE) are key materials for high-tech products such as smartphones, notebooks and monitors. Their demand is expected to increase exponentially due to the shift towards greener economy through the deployment of renewable energy and electro mobility solutions (European Green Deal). This and the lack of TCE production within the EU, puts the market under pressure and leads to increasing prices. The need to secure TCE supply has become even more pressing under the current health crisis and it is a major objective of the Covid-19 Recovery Plan aimed at reinforcing Europe’s resilience and autonomy. A sustainable solution is effective recycling and finally a circular economy. However, the analysis of waste streams is difficult and requires suitable SI traceable analytical solutions to allow for comparability of measurement results throughout the recycling process. The required reference materials (RMs) certified for TCE in the corresponding waste or secondary raw materials and specific documentary standards for TCE to comply with ISO/IEC 17025 requirements, however, are lacking. Furthermore, waste from the so-called “urban mine” is extremely heterogeneous making the estimation of its TCE content difficult. Currently, there is a lack of knowledge at the European level about the TCE stocks and flows in the urban mine. Given the high volume of waste generated and received, fast reliable analytical methods as well as sampling and sample preparation strategies are needed to determine the economic value of the waste and of the final product and to develop and improve recycling procedures. Within this project we focus on TCEs (Co, Ga, Ge, In, Ta, Nd, Pr, Dy, Gd, La, Au, Pt, Pd, Rh), which have been selected from the list of critical elements for Europe established by the EU in 2020. The overall objective of the project is to provide the reliable and SI traceable determination of TCE in urban waste material at µg/g levels to increase the efficiency and accuracy of TCE recycling. This will be realized by developing validated SI-traceable reference methods, developing traceable and validated RMs for the TCEs, validating the use of the routine methods and RMs for real world applications and facilitating the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organizations and end users. This presentation will give an overview of the consortium, the project structure and the planned research. First activities will be presented as well.
For the identification complexity of rock image classification, based on a certain cut-off grade, an automatic classification recognition of rock images method is proposed in this paper. Basis of specific approach in face mapping images taken by mine geologists for traditional rock-mass characterization. Digital grey image processing of rock face mapping images is used for features extraction. Then features are used as inputs to the neural network model. Finally, the model output is the rock image classification. Hellas Gold company, subsidiary of Eldorado Gold provided a sample of 76 images for the case study. Specifically face mapping images are from Olympias mine located in North-East Chalcidice Prefecture, Greece. For the experiment, the dataset is divided into 48 images as a training dataset in order the algorithm to classify the >20% ore and 28 images for classify the <20% of waste. As an outcome the optimum classifier reached 89.5% accuracy for automatic identification! n of rock face mapping image. Therefore, the proposed method for improving geological pattern is effective and can result in accepted identification performance for rock image classification quickly and accurately.
Development and study of MgO-C refractories containing magnesia and SiC nanoparticles

A. Tsetsekou¹, S. Gkiouzel², K. Vasilopoulos², I. Kitsou¹, E. Roussi¹, E. Kagiaras³, M. Karakassides²

¹National Technical University of Athens, Greece
²University of Ioannina, Greece
³Mathios Refractories S.A., Greece

E-mail: sevikgk@gmail.com

In this work, MgO-C refractories were prepared and studied, which contained up to 7wt% magnesia (MgO) and silicon carbide nanoparticles (NPs). The MgO nanoparticles were added as raw materials replacing an equal amount of MgO fine powder, whereas the silicon carbide (SiC) nanoparticles were developed in-situ during the heat treatment process for the production of refractories. Appropriate compositions were prepared by conventional manufacturing techniques of MgO-C refractories using sintering at 1000, 1200, and 1400 °C. Phase identification, microstructure, and physical properties of refractory samples were examined with X-Ray diffraction (PXRD), scanning electron microscopy (SEM) and Archimedes methods, the latter yielding bulk density, apparent porosity and finally water absorption. The mechanical behavior was studied by the cold crushing strength (CCS) of the tempered and coked samples. As a result, it was found that the presence of nano-additives in the magnesia-carbon matrix, improves the sintering process, resulting in refractory samples with higher densities, lower porosities as well as higher cold crushing strengths in comparison to that of conventional compositions.
Ornamental stone cutting processing and sludge production evaluation with the goal of ending waste

L. Zichella, R. Bellopede, P. Marini

Politecnico di Torino – DIATI, Italy

E-mail: rossana.bellopede@polito.it

The Waste Framework Directive (Directive 2008/98/EC) states that a waste shall lose its status if it is submitted to a recovery operation (including recycling, Art. 3 of Waste Framework Directive) and comply with specific eligibility criteria (according to End Of Waste criteria JRC final Report EUR 23990 EN – 2009). In the mining sector, the reduction of landfill material may be obtained not only by finding a suitable recovery of the material as a by-product, but also identifying the best available cutting technique to be used on the basis of the physical, chemical and mechanical characteristics of the stones. The choice of the best cutting technique could lead to high efficiency and performance, high quality of the cut surfaces and a very low environmental impact by reducing energy consumption, decreasing the concentration of heavy metals in the sludge and producing less waste. In this context, an analysis of the procedures for cutting different types of ornamental stones into slabs together with the evaluation of sludge production for the different cutting methods has been carried out. Three types of analysis were conducted in parallel. The first concerns the characterization of the stones and the choice of the type of cutting machine. The analyses carried out were: petrographic analysis, compression strength, flexural strength, apparent density and water absorption. Also ultrasonic pulse velocity and Knoop analyses were performed in order to establish the workability class of the stones, and their classification. The second analysis involves calculating the amount of sludge produced in the three different cutting technologies, taking into account the same block characteristics. The third analysis was carried out on the sludge resulting from the processing of blocks cut into slabs. A comparison was carried out on the quality of the sludge produced, on type and quantity of metals present, taking into account the different cutting technologies. The tests carried out were: chemical analysis, magnetic separation test and SEM analysis of the metal fraction. The study could provide stone producers with a technological, scientific instrument to identify the best cutting techniques for the processing of their stones, in order to obtain a good efficiency process, optimize the recovery process, increase the economic advantages, and evaluate the possible reuse of the sludge through a proactive waste management strategy.
Image analysis and microanalysis of sulfobelite clinkers

M. Kamitsou, E. Vougioukalakis, D. Kanellopoulou, A. Christogerou, G. Angelopoulos

University of Patras, Greece
E-mail: m.kamitsou@gmail.com

Cement/clinker production is among the most important industrial activities worldwide, producing massive CO\textsubscript{2} emissions. For their production they require large amounts of energy, most of which is consumed in clinkering process, at 1450 °C. Sulfobelite cement has been studied as an eco-friendly alternative, as its clinkering temperature is under 1350 °C. Sulfobelite cement clinkers of 27-42% wt. yeelimite, were produced in laboratory scale at 1330 °C resulting in up to 30% reduction of CO\textsubscript{2} emissions according to our calculations (not presented here). Moreover, for the experimental production of the clinker, byproducts were used, such as FGD gypsum and Bauxite Residue (BR), resulting to further reduction of energy demand and of the calculated CO\textsubscript{2} footprint of the process. The so-produced clinkers were analyzed by Q-XRD analysis. In the present study, image analysis was used, for the quantitative analysis of the main phases of the produced sulfobelite clinker, based on the Underwood hypothesis. Following, the results were compared with the corresponding ones of the Q-XRD analysis. Image analysis was performed using the “ImageJ” open-source software, using images taken both by SEM backscatter and optical microscope to determine the most productive method of extracting results from clinker samples. The clinker morphology, the crystal size, color and surface area percentage of C\textsubscript{2}S, C\textsubscript{4}AF, C\textsubscript{4}A\textsubscript{3}S and pores were estimated using the data obtained from the image analysis of optical, and electron microscopy respectively. The results were compared with the corresponding Q-XRD analysis and confirmed that the Underwood hypothesis can be applied for the C\textsubscript{2}S main crystalline phase and the amorphous phase consisting both of C\textsubscript{4}AF and C\textsubscript{4}A\textsubscript{3}S with acceptable results. The Underwood hypothesis states that the surface area analogies of the mineral phases on the surface are equal to those of the overall analogies within the sample. Therefore, image analysis can be used as an indicator for the evaluation of the firing and cooling conditions of the clinker.
Challenges in managing waste from extractive industries during the transition to a circular economy model in Poland

J. Kulczycka, E. Dziobek

MEERI PAS, Poland

E-mail: kulczycka@meeri.pl

Proper waste management is an essential part of the efficient use of natural resources and sustainable economic growth. It has been highlighted in recent years by the introduction of the circular economy concept associated with the increase in demand for raw materials. One of the largest waste streams in the EU, as well as in Poland, is waste from extractive industries. In 2018, the mining and quarrying section generated, respectively, about 24% and 37% of all waste from all types of activities defined and presented in the statistical classification of economic activities in the European Community (NACE) and households (calculated on the basis of Eurostat). Therefore, appropriate treatment of waste generated during exploration, extraction, physical and chemical processing of ores and other minerals should be a priority.

European and Polish waste policy is based on the applicable waste hierarchy. In Poland, the waste framework directive - the Polish Act on Waste introduced a five-step waste hierarchy, in which waste prevention is considered the best procedure at the top. Then there is the possibility of reuse, recycling, other forms of recovery and finally disposal of waste (e.g. by landfilling). The analysis of the data provided by the Central Statistical Office in Poland confirmed the use of the waste management hierarchy. Despite the growing demand for mineral resources, mining and quarrying waste generated in Poland in 2019 at the level of 63.7 million tonnes was 9% lower than in 2015 (Waste from Section B Polish Classification of Activities). At the same time, waste recovery has increased by more than 40%, reaching 25.6 million tonnes and enabling increasingly more useful use of waste by replacing other materials and / or preparing waste to perform this function in the future.

The paper will present the main challenges in the management of waste from the mining industry in Poland, taking into account not only the existing regulations, but also future actions resulting from the Polish Road Map towards the transition to a CE. The roadmap outlined the actions necessary to increase resource efficiency and reduce waste, including the development of indicators measuring the degree of transformation towards a CE, which will be used in practice in shaping national and regional development policies.

This research was funded by the Polish National Agency for Academic Exchange (NAWA) as part of the project “International cooperation for Rational Use of Raw Materials and Circular Economy” (COOPMIN), project no. PPI/APM/2018/1/00003.
Mineralogical and geochemical investigation of nickeliferous lateritic ore of Mamez region (Albania)

A. Stratakis¹, I. Gkikas¹, G. Alevizos¹, A. Apostolikas²

¹Technical University of Crete, Greece  
²GMMSA LARCO, Greece

E-mail: astratak@mred.tuc.gr

The scope of this study is the mineralogical and geochemical investigation of a nickel laterite ore deposit located in the region Mamez, in Northeast Albania. The ore is hosted in a lateritic crust in contact with ultramafic bedrock (Dunite) and covered by Cretaceous Limestones. The lateritic crust as well as the hosting rocks belong to the Mirdita Ophiolite Zone, a large Ophiolitic complex representative of the Hellenic-Dinaric orogenic belt. Nickel-mineralization related to laterization processes that occurred from Early Cretaceous to Eocene in the Mirdita Zone has resulted in the formation of a series of lateritic deposits mainly recorded in three distinct areas; Has-Kukes-Lure region in the North, Pogradec-Librazhd region in the center and Devolli region in the South. The lateritic ore deposit of Mamez belongs to the Has-Kukes-Lure region.

The lateritic crust of Mamez consists of three zones; a pisolitic zone in the top, a clay-Silcrete zone in the middle and a saprolite zone in its base. XRD examination of field samples from all three zones showed presence of hematite, chromite, quartz, willemseite, lizardite and nontronite, while talc and calcite were occasionally observed. A combination of XRD and SEM-EDS microanalyses as well as ore-microscopy investigation, confirmed the presence of willemseite, nontronite and lizardite in a clay rich binder material and hematite, chromite and quartz grains to be scattered in the groundmass. XRF showed an average NiO composition of 1.2% in the pisolitic zone, 0.7% in the clay zone and 1.8% in the saprolite zone.

From a geochemical point of view, main elements of the ore can be divided into two groups corresponding to their respective distribution along the laterite body. Group 1; Fe₂O₃, K₂O, Cr₂O₃, TiO₂, Al₂O₃, MnO, CoO and group 2; SiO₂, MgO, NiO, CaO. Data from the 1st group indicate a positive correlation along group 1 members while maintaining negative correlations with the elements of group 2 and vice versa. The distribution of iron is observed to be opposite to that of silicon, following a trend commonly recorded in Fe-Ni-ores of this type. Nickel is found in the binder material, mainly in the mineral willemseite, while literature suggests that it can also be potentially bound in nontronite.

According to ore-microscopy investigation, mineralogical composition and geochemical distribution of the elements, the nickel lateritic ore of Mamez is described as secondary pseudo-autochthonous deposit, overlying a typical laterite horizon.
Kaoline mapping using ASTER satellite imagery: the case study of Kefalos Peninsula, Kos Island

M. Kokkaliari, C. Kanellopoulos, I. Iliopoulos

University of Patras, Greece

E-mail: kokkaliari_m@upnet.gr

The aim of the present work is to map kaolin occurrences in Kefalos peninsula, SW Kos Island, Greece, through the elaboration of ASTER satellite imagery. Kos island is located in the eastern edge of the Hellenic Volcanic Arc, Aegean Sea, mainly known for two significant magmatic events; the Miocene magmatism accompanied by the intrusion of the I-type pluton at Dikeos Massif, as well as the voluminous Plio-Pleistocene eruption of the Kos Plateau Tuff, the largest Quaternary eruption in the Mediterranean. Kaolin is the product of hydrothermal alteration of the Pliocene volcanic rocks with rhyolitic composition.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data were pre-processed to eliminate atmospheric effects, as well as geometrically and radiometrically calibrated. To better facilitate the process, a vegetation mask was used to exclude the associated pixels representing highly vegetated areas. Visible and Near-Infrared bands of the ASTER multispectral image were merged to one dataset and used to map the spatial distribution of the related hydroxyl-bearing minerals. Characteristic spectra of kaolinite, dickite and kaolinite/smectite from USGS spectral library are used since they represent pure end members for the minerals involved in the kaolinization processes in order to reveal the kaolin occurrences. Mixture-Tuned Matched Filtering Algorithm (MTMF) is employed for the classification process; an advanced spectral unmixing technique focusing on the identification of specific spectral targets.

Our study emphasizes the usefulness of ASTER satellite imagery to detect kaolin-group minerals, either in terms of raw mineral exploitation or even by mapping hydrothermal alteration. Even though there are some limitations using the library spectra because the samples are measured under certain atmospheric conditions, with specific instrumental laboratory equipment and they may not match exactly the spectra acquired from the satellite images, we were able to utilize the MTMF algorithm to estimate their total area of distribution. Image processing techniques in ASTER satellite data can retrieve information about the hydrothermal alteration products or even occurrences of industrial minerals i.e. kaolinite, highlighting prospects for further investigations.
Comparison of static and dynamic Young's modulus of prasinites

D. Kotsanis, P. Nomikos, D. Rozos
National Technical University of Athens, Greece

E-mail: dkotsanis94@gmail.com

Knowledge of the static and dynamic deformational properties of rocks is of vital importance for the characterization of rock masses in many aspects of geoengineering applications. Static methods are destructive and time-consuming; they also require specimens of high quality and expensive experimental configurations. On the other hand, the dynamic methods are passive and based upon the response to the acoustic excitation of the specimen. In most cases, these non-destructive techniques are less expensive and time-consuming.

Therefore considerable attention has been paid in terms of the comparison between the static and the dynamic Young's modulus for various rock types and several empirical equations are quoted in the literature. Despite the derived mathematical formulations, the common trend is that the dynamic modulus is higher than the static one, and this can be attributed to the presence of cracks and cavities within the rock specimen.

This study aims to report the results of a new relation between static and dynamic Young's modulus for prasinites, a metabasic rock type outcropping in Attica Peninsula, Greece. According to the bibliography, this is one of the first efforts on this subject and the proposed equation can be a useful tool for the investigation of these petrological types, either in the study area or in other sites, where prasinites of similar structural characteristics are investigated.
Preliminary feasibility assessment and SWOT analysis of a fast pyrolysis pilot furnace for the management of marine and hazardous waste

A. Malamakis¹, M. Batsioula¹, G. Banias¹, E. Tzamos², G. Palantzas³, K. Triantafyllidis², A. Zoumpoulis³, K. Rekos³

¹Institute for Bio-Economy and Agri-Technology (iBO), Centre for Research and Technology – Hellas (CERTH), Greece
²North Aegean Slops S.A., Greece
³Department of Chemistry, Aristotle University of Thessaloniki, Greece

E-mail: m.batsioula@certh.gr

The management of industrial and hazardous waste is a particularly important problem, on the one hand because of their hazardous nature, and on the other hand due to the lack of methods and infrastructure for their safe treatment. Their mismanagement can be a serious source of pollution for the soil, air, and the environment in general. Towards this direction, and with the aim of sustainable waste management with simultaneous production of energy and value-added products, a fast pyrolysis furnace has been developed. The fast pyrolysis has been adopted as a method of managing specific streams of industrial and hazardous waste, such as marine slops and heavy petroleum products, packaging waste with hazardous substances residues and wood waste containing hazardous substances. The basic aim of this paper is the preliminary assessment of the economic viability and environmental performance of the developed fast pyrolysis furnace on the utilization of specific hazardous waste. More specifically, the main purpose of this paper is to introduce the operational, financial and technical aspects of the proposed method, in order to determine the strengths, weaknesses, opportunities and threats that arise, as well as the resources required for effective and successful its implementation on a larger scale. In this study, most of the data used relate to economic and technical characteristics of the pilot unit implemented. However, due to the limited data available, assumptions were made based on literature references, where the fast pyrolysis process has been used and studied successfully.
Green coatings for the protection of concrete sewer pipes

G. Fytianos, E. Papastergiadis, P. Samaras

International Hellenic University, Greece

E-mail: gfytianos@gmail.com

The deterioration of concrete structures in sewage collection systems has a major impact on environmental health and safety. Microorganisms that produce sulfuric acid accelerate the deterioration of concrete sewer pipes in a process termed Microbiologically Induced Corrosion (MIC) or biocorrosion. The authors have assessed concrete sewer system biocorrosion problems in Greece, and proposed economic and sustainable recommendations to address corrosion issues. Currently, an ongoing national R&D project focuses on the development of an innovative active product based on Mg(OH)$_2$ and MgO, for the coating of the inner surfaces of concrete sewer network pipes with corrosion problems. Before moving to the production of the coating, a corrosion study of concrete samples took place in order to study the deterioration due to sulfuric acid. Most laboratory tests simply include immersion of concrete specimens into acidic solutions. However, the authors conducted experiments under different sulfuric acid flows and concentration due to the fact that real wastewater treatment facilities are exposed to flowing acidic waters. Finally, performance results of the application of a resistant protective coating based on magnesium oxide will be presented.
Dealkalization process of bauxite residue: from laboratory to industrial implementation

G. Flesoura¹, E. Mikeli¹, P. Davris², E. Balomenos², D. Panias¹

¹National Technical University of Greece, Greece
²Mytilineos SA-Metallurgy Business Unit, Greece

E-mail: georgiaflesoura@gmail.com

Global warming and depletion of resources have fueled research towards supplementary cementitious materials (SCMs) for cement and concrete industry. Although bauxite residue (BR), aka red mud, use in SCMs has been reported promising in laboratory scale, its large-scale utilization is inhibited due to its highly alkaline nature. Thus, dealkalization of BR renders to be a prerequisite prior to its sustainable valorization. In the present work, BR neutralization was achieved by a hydrothermal process, in the presence of milk of lime, in which the insoluble alkalis were converted into soluble ones and removed by water washing. By conducting statistical analysis, the effect of processing time, temperature and liquid over solid ratio to sodium removal was underpinned. Dealkalised BR (DBR), free of alkalis, in the order of up to 95 wt% was produced. Preliminary characterization of the DBA product was performed and the exothermal heat flow as part of blended cement after hydration, revealed the potential incorporation in the binder of cement building applications.
Tuesday 7 September 2021
OLYMPIA

PARALLEL EVENT
Greece specific issues

Chair: C. Kavalopoulos, A. Xenidis, P. Tzeferis, E. Tzamos
The lignite phase-out challenge

D. Metikanis

Public Power Corporation SA, Lignite Generation Business Unit, Greece

E-mail: d.metikanis@dei.gr

Considering Greece's National Energy and Climate Plan and the international and local energy trends and changes, including a significant increase in the share of renewable energy sources and natural gas in the energy mix, electricity generation by lignite faces many challenges concerning its competitiveness. In this framework, the planning of lignite phase-out and mine closure need an integrated approach. This work presents the central planning and scheduling steps regarding the lignite phase-out and the corresponding transformation process. The main areas under investigation include the environmental reclamation of the mining and power plants areas, the optimal utilization of the reclaimed land, and new investments, contributing to the local development. Emphasis is placed on the strategic planning of mines and power plants closure concerning environmental reclamation projects and their schedule.
Tuesday 7 September 2021
VERGINA

SESSION B1
Education I

Chair: K. Adam, K. Makri
Innovative teaching and learning pathways for responsible use of resources focusing on the ESEE region

C. Pacher¹, M. Murphy²

¹Graz University of Technology, Austria
²Montanuniversität Leoben, Austria

E-mail: mariaelena.murphy@unileoben.ac.at

In a world depicted by rapid growth and consumerism, where pressing societal issues such as, the critical climate crises, resources exploitation in developing countries and much more, it is essential to educate all citizens about raw materials, their uses and about responsible production and consumption.

Developing life-long learning programmes is an essential tool to educate the population starting with the youngest members of society (pre-school) to adulthood (life-long learning) with a special focus on the life-world orientation from a learners’ perspective. The wider society learning flagship project, ‘Raw MatTers Ambassadors at Schools’ (RM@Schools), is an innovative programme funded by the European Institute of Innovation & Technology (EIT) which promotes science education and careers in the raw materials sector.

Since the projects commencement in 2016, it has gained stronger European representation with a current total of 32 partners from 18 countries. This includes the consortium members from a parallel funded programme, RM@SchoolsESEE. This project aims at extending best practices and diversifying the current portfolio to East and Southeast European countries.

What makes this project so innovative is in the programme and individual learning pathways. Considering a multidisciplinary and cultural perspective, a framework was developed to assist in forming raw materials ambassadors through engaging programmes for school pupils from aged 10 up to 19 years old and through the development of educational hands-on toolkits that range from experiments to game-based tools and much more.

In particular, and as a way to increase impact, the project aims to mentor teenagers from all educational disciplines between the ages of 14-19 years old to become ‘Young RM Ambassadors’. This approach utilises state-of-the-art teaching and learning methods resulting in peer-to-peer knowledge exchange and dissemination. Built into the programme is a continuous feedback loop that involves stakeholders from all sides of the knowledge triangle: educators, pupils, professionals and researchers.
Systematic development of generic skills to enhance innovation capacity of Eastern and Southeastern European universities

S. Borojević Šoštarić, P. Grgasović

University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Croatia

E-mail: sborosos@rgn.hr

According to the preliminary research carried out during 2017 and 2018, technical universities in the Eastern and Southeastern Europe (ESEE) all face similar challenges. Although characterized by excellence in various technical fields, especially the ones related to exploration and processing of raw materials, the level of innovativeness within the higher education systems and their graduates remains modest or moderate in the region. It was recognized that besides the general socio-economic context and the inherited management types, this deficiency stems from a lack of generic skills crucial for increasing the innovation capacity of the universities. TrainESEE project suggests that significant changes should be done already within the applied teaching methodology, but also highlights the importance of developing project development and management skills, innovation and entrepreneurial skills and finally, competences needed to strengthen science to business cooperation. To address the aforementioned challenges, a sound and standardized methodological approach was established and applied to six ESEE universities, resulting primarily in four fully developed training modules for the teaching staff and related acceleration programs to ensure that envisaged changes of the curricula would be implemented and maintained throughout a minimum of three years. The authors will present the TrainESEE methodology and demonstrate its transferability and replication potential. More specifically, the presentation will cover the following: (1) unified approach to identification and prioritization of the universities’ needs; (2) established link between the identified needs and the content and form of the developed modules; (3) expected and achieved objectives and results; (4) actions to ensure midterm sustainability of the TrainESEE results.
“Mineral Resources to Circular Economy”: a new Transdisciplinary Curricular Unit for innovative Raw Materials Master's Programmes

S. Barbosa

NOVA FCT - Nova School of Science and Technology & GeoBioTec, Portugal

E-mail: svtb@fct.unl.pt

“Mineral Resources to Circular Economy” (MRCE) is a recent NOVA-FCT (Nova School of Science and Technology, Lisbon) curricular unit which is integrated in two distinct Master Programmes: “Geological Engineering” and “AMIR Master Programme in Advanced Materials: Innovative Recycling”. With its origins in “Economic Geology and Energy Resources” (EGER), a traditional Curricular Unit included for several years in the Geological Engineering Master Programme of NOVA-FCT, MRCE arose from the need to respond to new challenges in the areas of Primary and Secondary Raw Materials (PRMs and SRMs) in a geological and mining context. The programmatic content of MRCE integrates a significant part of EGER syllabus, but it also considers new challenging and innovative topics such as mine waste recyclability, new value chain evaluation approach (PRM & mining SRMs), new base resource potentialities, innovative responsible mine waste management in mine life cycle. MRCE intends to give students an understanding of the importance of mineral resources in society and in the context of circular economy. It comprises the understand of global geopolitics, its impacts in society and existent policies in the supply and demand of critical and non-critical raw materials within the advent of the 4th Industrial Revolution. MRCE also includes the study of distinct mineral deposits, its geological processes, and metallogenic ore models. Ore as potential multiple sources of critical raw materials, and potentialities of element recovery from waste are key issues. In practical classes, students contact and learn how to identify and characterize distinct types of metallic and non-metallic mineral materials as well as distinct types of mining waste materials. Principles and techniques of metallic ore and waste characterization in a geometallurgical perspective from macroscopic to micrometric scales are explored. One relevent challenge to be pointed is related to the fact that MRCE is for students of very distinct profiles, from geology, mining and material science engineering to economy, policy, and management sciences, among others. The necessity of constant actualization due to the high ratio of knowledge and innovation that are being generated is also a major and permanent concern. MRCE is intendent to be under development through its interdisciplinarity and transdisciplinary potentials, going beyond accepted academic and industrial boundaries and exploring new geological raw material approaches that are necessary in 21st century to promote resource availability for next generations and, as much as possible, more effective green and sustainable economic models.
The significance of SDGs for the Raw Materials sector: A stakeholders’ approach in three ESEE countries

S. Tomazinakis, G. Valakas, A. Gaki, D. Damigos, K. Adam

National Technical University of Athens, Greece

E-mail: s.tomazinakis@gmail.com

The Raw Materials (RM) sector is linked to Sustainable Development Goals (SDGs), having a positive or a negative impact on their implementation depending on practices employed and specific prevailing conditions. These impacts relate throughout the whole RM value chain (e.g., mining, processing, metallurgy, recycling, etc.). This study aims to identify and rank the most significant SDGs for the RM sector, from the perspective of key stakeholders in three East and South-East Europe (ESEE) countries: Poland, Greece, and Slovakia. Within this framework, 423 stakeholders from critical groups involved in the RM sector, i.e., academic staff, students–future engineers, professional engineers, and representatives from the industry, provided their views in a survey with structured questionnaires regarding the significance of SDGs in the RM sector. The survey was conducted in 2020 as a part of the “EnAct-SDGs project” funded by EIT RawMaterials. Based on the survey, a comparative analysis of the ranking results between the stakeholders’ groups and the three ESEE countries is presented. The results at a country level were evaluated taking into account social and economic indicators, such as the perception of the public regarding the social responsibility of the RM sector and the contribution of the sector to the country’s economic production. Overall, the SDGs 9 (Industry, Innovation, and Infrastructure), 8 (Decent Work and Economic Growth), and 7 (Affordable and Clean Energy) were highly ranked by the stakeholders indicating a strong link between these SDGs and the RM sector. However, some measurable differences were also observed, between the examined stakeholders’ groups and their country of origin regarding the significance of some SDGs, especially the ones with a more indirect link to the RM sector. The similarities and the differences observed in the results were then analyzed, based on the characteristics of the stakeholders’ groups and the social and economic indicators regarding the role of the sector in the countries examined.
"Geology in everyday life": Designing educational programmes with students of geology in the Science and Technology Museum (STM) of the University of Patras

P. Theologi-Gouti1, I. Iliopoulos2, M. Kokkaliari3

1 Science and Technology Museum, University of Patras, Greece
2 Department of Geology and Science and Technology Museum, University of Patras, Greece
3 Department of Geology, University of Patras, Greece

E-mail: stmuseum@upatras.gr

The Science and Technology Museum (STM) of Patras University was founded in 2001 as a Laboratory of the School of Natural Sciences and opened to the public in 2009. STM communicates with society and the wider educational community through its permanent exhibition, temporary exhibitions on science, technology, arts and the environment, as well as their relationship, educational programmes on the permanent and temporary exhibitions, different events and seminars, thematic school networks and nationwide contests.

During 2019-2020 the Museum developed and proposed to School of Natural Sciences’ Departments a Pedagogical competence program for fourth year students. The main goals of the program is to help students gain pedagogical experience through innovative non-formal educational programs, discover ways to approach school students at all levels, cultivate their special skills, imagination and creativity and valorization of their knowledge on the science they study, in order to familiarize them with the popularization of science.

The Department of Geology was the first to respond to this challenge. Nine to twelve students have participated to this program every semester since October 2019. One of students’ activities during the programme is to participate in the planning of an educational programme. The topic of the educational program, co-decided by the first group of students who participated during the winter semester from October 2019-February 2020, is “Geology in everyday life”. After discussing the goals of the programme, the topics to be addressed and the general guidelines, the students were divided into working groups that had to deal with one of the following topics: introduction, geology in human life, in house construction, in technology, and environment. The groups have worked separately in close collaboration with the responsible of the Pedagogical competence program and developed fairy tales/stories and presentations.

Their creative work was evaluated and corrected by experts and the fairy tales were illustrated during summer 2020 and given afterwards to groups of students of the winter semester 2020-2021 to enrich them and develop interactive educational activities. After a second evaluation, the educational programme is ready and offers a first insight through the science of geology. It will be added to the list of educational programs the Museum offers for junior high school groups of students.

STM in collaboration with geology students participating in the Pedagogical competence program in spring semester 2020-2021 has started to develop a new educational programme on geology for the 5th and 6th grade of primary education.
Tuesday 7 September 2021
ILISSOS

SESSION B2
Base metals recovery from waste

Chair: O. Chernoburova, K. Karalis
Aluminum recovery from calcium rich Bauxite Residue slags: Lab and Pilot scale experiments

M. Vafeias\textsuperscript{1}, P. Davris\textsuperscript{2}, E. Balomenos\textsuperscript{2}, D. Panias\textsuperscript{1}

\textsuperscript{1}School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece  
\textsuperscript{2}Mytilineos SA-Metallurgy Business Unit, Alumina and Aluminium plant, Greece

E-mail: michalisvafeias@mail.ntua.gr

Leaching of calcium aluminate phases with Na\textsubscript{2}CO\textsubscript{3} solutions for the extraction of aluminium is a hydrometallurgical process known for over a century. In this time, the unquestionable dominance of the Bayer process did not allow for a thorough examination of this technology. Currently, under the pressing demands EU’s Green Deal and the social demands for sustainable industrial policies, the European Aluminium Industry is vividly seeking for technologies that address the issue of Bauxite Residue (BR) management. One of the alternatives under investigation is the metallurgical exploitation of BR. In this technology, a reductive smelting of BR yields metallic Fe and a calcium aluminate slag of modelled composition. Subsequently the slag is leached with a Na\textsubscript{2}CO\textsubscript{3} solution for the extraction of Al and the production of an inert residue, composed mostly by CaCO\textsubscript{3}. The Laboratory of Metallurgy of the National Technical University of Athens (NTUA), in collaboration with Mytilineos Metallurgy Unit (Aluminium of Greece, AoG) have been evaluating the aforementioned technology as a candidate technology for the case of Greek BR. Laboratory tests performed at NTUA revealed the complex leaching mechanism of the calcium aluminate slags and the inherent challenges of this process. Pilot scale tests performed at AoG further highlighted these challenges and highlighted further optimizations that are needed in the process of upscaling.

Funding: “The research leading to these results has received funding from the European Community’s Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 767533. This publication reflects only the author’s view, exempting the Community from any liability”. Project web site: https://www.ensureal.com/
Production of Al-Sc alloy by electrolysis from cryolite melt using secondary feedstock material

A.M. Martinez, S. Senanu, H. Gudbrandsen, K. Osen, A. Støre, Z. Wang

SINTEF, Norway

E-mail: anamaria.martinez@sintef.no

Al-Sc alloys are produced by mixing Sc with overheated liquid Al and subsequent melt crystallization. There are several drawbacks in this method, i.e., high production costs, high price of pure Sc, high material losses during alloy preparation (dross), and difficulties in controlling the cooling process parameters to obtain a uniform alloy crystallization. Therefore, innovative reduction technologies for Sc-Al master alloy production are sought. In this way, savings in process steps with respect to the current process, and the subsequent economic savings could be achieved. In the frame of the H2020-SCALE project, SINTEF has investigated the possibility of modifying the industrially established process for reduction of alumina to aluminium, the so-called Hall-Heroult process, and then apply it for the direct production of Al-Sc alloys using discarded dross material from Al-Sc alloy manufacture. Electrolysis experiments in galvanostatic mode were carried out using a cryolitic melt with NaF/AlF₃ molar ratio CR=2.2 at 980 °C using both primary (synthetic Sc₂O₃ and Al₂O₃) and secondary material (dross) as feed. Small laboratory scale trials allowed to demonstrate the process, as well as to study and optimize the process parameters. Experiments in large-scale electrolysis cells allowed running long-term trials with output material in the order of 1 kg, while on-line monitoring of the cell off-gases (HF, CO/CO₂ and perfluorocarbon compounds), ensured the environmentally benign performance of the process. Analysis of the cathode product obtained showed the presence of the intermetallic Al-Sc compound, Al₃Sc, precipitated all over the Al bulk metal product, and the Sc content varied from 2-2.6 wt%. The metal obtained can be used to prepare master alloys for producing 3D printing powders. The results showed that the developed process has a great potential for valorizing the discarded material from current Al-Sc alloy manufacture and produce high-value Al-Sc master alloy for e.g., aerospace applications. The process can be carried out in current pot-lines for aluminium production, minimising the CAPEX needed to implement the process at industrial scale. Acknowledgement. This work has received funding from the European Union’s Horizon 2020 and Innovation Programme under Grant Agreement No. 730105.
High Temperature Reduction of Bauxite Residue at 1450°C

T. Hidayat, Z. Zulhan, L. Grahita

Institut Teknologi Bandung, Indonesia

E-mail: t.hidayat@itb.ac.id

The present study focuses on the investigation of phases formed during the high temperature reduction of bauxite residue, also known as red mud. A series of reduction experiments of red mud at 1450°C was performed using graphite as reductant. Plastic in the form of linear low-density polyethylene (LLDPE) was tested to partially substitute the reductant material. The experiments were carried out in graphite crucible inside a vertical tube furnace under argon atmosphere. It was found that the iron oxide in the red mud was reduced into metal, leaving behind residual iron oxide of less than 1 wt.%. The LLDPE appeared to vaporize and contributed less to the reduction process.
H$_2$ - based processes for Fe and Al recovery from bauxite residue (red mud): comparing the options

S. Kapelari$^1$, P. Gamaletsos$^2$, Y. Pontikes$^1$, B. Blanpain$^1$

$^1$KU Leuven, Belgium
$^2$Technical University of Crete, Greece

E-mail: stergi.kap@kuleuven.be

Alumina production through the Bayer process generates huge volumes of bauxite residue / BR (red mud) per year. BR is currently mainly disposed. This causes much debate about alumina plants’ storage capacity, and also poses an environmental risk for industry and neighbouring society. Besides, a significant content of base, critical and strategic metals in BR, including Fe and some remaining Al, as well as rare earth elements (REEs), potentially redefine this residue as a promising valuable secondary resource. Therefore, many schemes have been developed towards BR valorisation including metal recovery.

To this purpose, Greek BR was initially mixed with NaOH to produce water soluble Na-aluminates and was roasted under pure H$_2$ gas, in order to reduce the Fe+3 oxide content. Subsequently, three different combinatory H$_2$ -based processes were utilised targeting the recovery of Fe and Al.

The first two H$_2$ - based processes combined water leaching along with magnetic separation and melting, while wet magnetic separation was applied for the third one. The water media resulted in the dissolution of Na-aluminate phases, and the production of Al, Na – ion rich leachates. From these pregnant leaching solutions the recovery of Al and Na could reach approximately 84 and 94 %, respectively. Both the magnetic separation and the melting processes aimed for Fe recovery from the material. A magnetic fraction with a content of 45.5 wt. % Fe was obtained in one case.
Tailings reprocessing technologies: experiences in Lower Silesian copper district, Poland – FLOT-BUD Project

K. Witecki, A. Grotowski, A. Potulska-Bazan

KGHM Cuprum Ltd. - Research and Development Centre, Poland

E-mail: kwitecki@cuprum.wroc.pl

Tailings are the waste product from mineral processing which by definition could not be further utilized for valuable mineral recovery using currently implemented technology. Nevertheless, tailings deposited in old Tailings Storage Facilities (TSF) are the subject of research for the recovery of valuable elements. The recovery from those facilities is possible due to its still high content of valuable minerals locked in tailings from previous processing technologies. The tremendous quantity of produced tailings attracted interest of researchers to other possibilities of tailings utilization such as civil engineering, backfilling etc. Management of a high amount of fine material is the key issue in the development of processing technology, affecting its economy. Since 60’s tailings from old and currently existing copper basin of Lower Silesian, Poland, are considered as a source of valuable material. This paper presents directions of reprocessing techniques tested on tailings from Lower Silesian copper basins and refers them to similar worldwide experiences. Scope of FLOT-BUD project for tailings management technology from current production has been presented.
Tuesday 7 September 2021
VERGINA

SESSION B3
Education II

Chair: E. Yaneva, M. Menegaki
The role of Engineering Education in the achievement of SDGs by the raw materials industries

K. Adam

School of Mining and Metallurgical Engineering, NTUA

E-mail: katadam@metal.ntua.gr

The importance of Education for Sustainable Development (ESD) has been recognized since 1970s and nowadays ESD consists one of the main tools towards the achievement of the Sustainable Development Goals (SDGs) of the UN Agenda 2030. Higher Education Institutes, (HEI’s), are seen as the most important components for “raising awareness of SD among the population” especially within engineering education. Given that the Raw Materials (RM) sector, depending on the performance of its industries, may both positively or adversely impact SD, RM engineers are required to present specific, relevant skills, to enhance the achievement of SDGs in all phases of the RM supply chain.

This article presents the role of HEIs and particularly of the Raw Materials Engineering Education in the development of SD practices, the enhancement of innovation and the formation of strategies to strengthen the capacity in Engineering Education for Sustainable Development. The skills that RM graduates acquire from their education provide the basis to deal with the major environmental and social issues encountered by the sector, while ensuring economic competitiveness. To support the above, major findings of the EIT Raw Materials project “EnAct-SDGs - Enhancing the skills of ESEE RM students towards the achievement of SDGs” are presented. Educational needs and challenges faced by the Raw Materials sector in Greece, Poland, and Slovakia, countries of Eastern and Southeastern Europe (ESEE), defined by extensive surveys and interviews with stake holders from Academia, Industry and Professionals of the sector are summarized.
The mining history of Greece in school textbooks: The case of lignite

K. Makri\textsuperscript{1}, C. Roumpos\textsuperscript{2}, A. Antoniadis\textsuperscript{3}

\textsuperscript{1}National Observatory of Athens, Greece
\textsuperscript{2}Public Power Corporation of Greece, Greece
\textsuperscript{3}Public Power Corporation Renewables, Greece

E-mail: kikimakri@noa.gr

The geological education in Greece is essentially rooted in the second half of the 19th century, since 1836, when Secondary Education was established in Greece. Although Geology is referred to all educational programs, its field was not taught before 1880 due to the lack of competent teachers and suitable books. Geological education in Greece was established as a «necessary» science at the end of the above century, during the opening phase of mining activity in Greece. In particular, the first attempt to exploit lignite deposits began in Aliveri (Evia) in 1873, but the intensive exploitation in Aliveri began after the First World War, reaching an annual production of 23,000 tons by the end of 1927. Respectively, lignite mining began in Ptolemais in the 1950s and Megalopolis in the 1960s.

In the present work, the correlation of the lignite mining activity in Greece for electricity generation with the content of geoscience textbooks is investigated since it is widely accepted that education is directly linked to economic development. The main research question refers to the degree that the knowledge regarding extraction and use of lignite is reflected in the geoscientific textbooks during the period 1900 - 2010. School textbooks often reflect the social and economic needs of a country. In this framework, the method of Content Analysis of the Greek textbooks is applied. Content analysis is often used in conjunction with other methodologies, particularly educational research, where it can be used to code, categorise, and quantify data. The method of content analysis decrypts messages contained in texts. It is a quantitative method for communication, which analyses texts on the presence and frequency of specific terms, narratives or concepts. There are three distinct phases in the quantitative analysis: data collection, coding and data analysis, and presentation of the results.

The proposed survey includes a measurement procedure for counting the occurrence of mining terms related to lignite in the school textbooks of the Greek modern educational system. The statistical analysis is also based on the distinguishing of specific periods regarding lignite mining in Greece. Furthermore, the main characteristics of each period are discussed. The study of the curriculum and the textbooks revealed that they correspond to the social dimensions and characteristics. In this context, it could provide a useful tool for examining related issues.
Women in Stone Sector: Challenges and Opportunities from an educational point of view

M. Maniou, M. Menegaki, M. Perraki, A. Mavrikos

National Technical University of Athens, Greece

E-mail: mmanioy@central.ntua.gr

In the era of Industry 4.0, the deconstruction of the "regime" of gender discrimination does not proceed at a pace commensurate with other development indicators of modern society. As it seems, in terms of values and perceptions, archetypal stereotypes about male superiority are strong and resist change.

Gender discrimination is even more intense in workplaces that are considered to be male-dominated, such as the stone or construction sectors. For instance, in 2019, according to Eurostat, the percentage of women’s employment, in the EU-27, in the mining and quarrying sector was approximately 13.3% and in the construction sector was 9.5%, respectively. Moreover, job positions offered to women are different from the ones offered to men resulting also in lower paying jobs for women.

The main reasons behind this inequality are the level of education (technical training, such as engineering, in particular is typically viewed as reserved for men), the social norms, and the gender stereotypes that dictate the types of employment women and men should seek and for which they are hired.

It is evident that combating gender discrimination in the stone sector is a demanding task that calls for integrated planning and targeted interventions. The paper presents the results of the “Opening Gates for Women in the Stone sector - WINSTONE” Erasmus+ project, which aims at the development of suitable training tools for the integration of women in the stone industry. Based on the main challenges that women have to face, as well as the emerging opportunities in the sector, a training methodology is being developed in order to deal with the actual needs. The suggested methodology follows state-of-the-art approaches in the field of high-level educational materials and tools taking into consideration the particularities of the sector.
Evolution of Health and Safety training needs of the mining sector in Greece and EU

K. Tsichla¹, K. Adam²

¹Greek Mining Enterprises Association, NTUA, Greece
²NTUA, Greece

E-mail: kikitsich@hotmail.com

The aim of this article is to present priority themes covered by the Health and Safety training programs of the Greek and European mining industry during the last decade. Mining is considered as an industry presenting high occupational risks. International Labor Organization (ILO) estimates that 1% of the world’s labor force is engaged in mining, yet mining accounts for 5% of occupational fatalities. Despite the use of advanced technologies in a safer working environment, and the zero harm-zero accidents target” mining accidents’ statistics indicate that despite the gradual decrease in fatality rate, safety performance for the last two decades has reached a safety plateau. In order to further improve this performance, training and promotion of a safety culture through implementation of mine safety plans and enhancement of technical and non-technical skills at all levels of management, consists a prerequisite measure. Training needs of the Mining industry vary over time and may focus in three general areas: organizational needs, job related needs (management and non-management) and individual needs (induction of new employees, update of performance of established employees, job position changes, new equipment and technology). Risk and crisis management, comprise priority themes for training. The risk management process should be conducted throughout the whole mining life cycle, however the greatest effectiveness in controlling risks, is achieved in the early design phase of a mining project. Nowadays, training is increasingly relying on immersive virtual reality to simulate complex operations in potentially dangerous environments. Open-cut or underground mining simulators provide safe, replicable and cost effective environments for miners to be trained and for engineers and managers to test different conditions, new ideas, strategies and scenario outcomes, without exposing employees in real time hazards. High-end training programs have the potential not only to improve workplace safety conditions but also to contribute to a more effective management, and finally to a more sustainable mining industry.
Rethinking education in the raw materials sector through tailor-made teaching methodologies

E. Yaneva¹, S. Papaeftymiou², L. Daling³, S. Borovejić Šoštarić⁴, I. Merta¹

¹Vienna University of Technology (TU Wien), Austria
²National Technical University of Athens, Greece
³RWTH Aachen University, Germany
⁴University of Zagreb, Croatia

E-mail: elena.yaneva@tuwien.ac.at

Bridging the EU research and innovation framework with the education policies and programs through an innovative, entrepreneurial education at the high-education level, is a crucial step for boosting the development of future multi-disciplinary skills, needed in Europe. By practicing lifelong learning, teachers can empower students to adopt a problem-solving attitude towards societal challenges with new, creative ways in teaching/learning. This measure is becoming an ever-greater necessity in order to enable tackling of complex and multifaceted issues, to acquire a competing stimulus and nurture a solution-oriented mindset amongst professionals and individuals in Europe.

The ESEE region is a rapidly developing part of Europe, home to some 180M people, many of which belong to the young generation that very much intends to align with ‘western’ countries, and is a source of tremendous human capital. Despite that, owing to the lasting legacy of former communist times, many ESEE countries show significant delay in economic development with respect to their western-European counterparts. This is also clearly visible in the realm of higher-level education in the raw materials sector. As these countries share many common traits and constitute a distinct educational ‘ecosystem’, it makes great sense to consider them as a group and design a specially tailored approach for the raw material-themed education with the aim to align them with the newest trends in education.

The authors will present the applied methodology to design a tailor-made program for teachers, from teaching assistants to associated and full professors, that addresses these needs with a special focus on the following objectives: introduction of engaging and interactive teaching techniques as well as methods for the teaching staff (in frame of a lifelong learning), improvement of the soft skills of students, enhancement of students’ motivation, digital didactical teaching tools and methods, evaluation skills and assessment of students, practice-oriented learning with real-life case studies.

The EIT Raw Materials Strategic Agenda 2018-2020, the RIS Strategy Document, the EIT Raw Materials Academy Consolidation Action Plan, the ESEE Education Note 2018, the Intermin Deliverable and Competence documents as well as other EU, research and innovation related national and EU documents/directives were used as a basis for aligning the needs of ESEE universities with the research and innovation needs at national and international level.

The expected learning outcomes will be presented next to methods for ensuring a high-quality teaching experience as well as monitoring and evaluation procedures.
Development of lifelong learning course for rising innovativeness of raw materials professionals in Eastern and Southeastern Europe

V. Bohanek, S. Borojević Šoštarić, A. Zrno

University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Croatia

E-mail: vjecislav.bohanek@rgn.unizg.hr

One of the main issues regarding raw materials professionals in the Eastern and Southeastern Europe (ESEE) is their low level of innovativeness and familiarity with advanced tools and methodologies, which is due to lack of lifelong learning courses on raw materials in RIS region and outdated higher education curriculum focused mostly on theory. The analysis conducted by the consortium of Dubrovnik International ESEE Mining school – DIM ESEE project (2016-2020) showed that 60% of all available EIT RM programmes are conducted by only two institutions from Germany and Austria, while other programmes are coordinated by partners from Finland, France, Italy, Netherlands and Sweden. The DIM consortium conducted questionnaire campaign in January-February 2020, titled 100 innovations in the mining industry, in order to establish current status of innovations utilization among companies in the in region. Based on responses from 100 raw materials companies from RIS region, the conclusion was drawn that most of the companies don’t have access to or knowledge for using innovative tools and methods in mining engineering and that mining engineers have need for additional education in some fields. Therefore, DIM consortium developed four annual 3-day workshops within the new project, DIM ESEE-2: Implementing innovations. General topics of DIM ESEE Innovative workshops are:

• Innovation in exploration (2021)
• Innovation in process-oriented orebody characterization (2022)
• Innovation in extraction (2023)
• Innovation in ore processing (2024)

Technical content and subtopics for each year have been carefully chosen based on the outcome of the questionnaire. After every edition of this workshop, spin-off programme will be created for MSc students at ESEE universities to ensure that they are also acquainted with the innovative trends, which will finally ensure the transferability of knowledge and implementation of these courses into the curriculum. In order to evaluate the possibility of self-sustainable workshops after project completion (2025 onwards), the consortium will conduct annual questionnaire campaigns where raw materials professionals will provide their personal experience with and opinion on lifelong learning courses in RM sector. Educational activity will increase level of innovation in the impacted ESEE region, and over the time, overall income of the ESEE mining companies saving jobs in RM sector.
Tuesday 7 September 2021
ILISSOS

SESSION B4
Critical metals recovery from waste

Chair: C. Mori De Oliviera, N. Papassiopi
Viable Scandium Extraction from Bauxite Residue at Pilot Scale

E. Balomenos¹, P. Davris¹, G. Nazari², S. Patkar³, W.-Q. Xu³, Y. Karnachoritis¹

¹Mytilineos SA, Greece
²II-VI Incorporated, Philippines
³II-VI Incorporated, USA

E-mail: efthymios.balomenos-external@alhellas.gr

Scandium extraction from the Greek Bauxite Residue has been demonstrated at an industrial pilot plant at MYTILINEOS. This work comes as the result of the H2020 SCALE collaborative research project. By combining sulfuric acid leaching and II-VI Selective-Ion Recovery (SIR) Technology, a 22 wt% Sc concentrate has been produced from the Greek Bauxite Residue containing 70-100 mg/kg Sc. As detailed in this work, the year-long pilot campaign, achieved low acid consumption, high Sc selectivity over Fe and Ti and high Sc loading capacity of the SIR resin achieved, setting the basis for a viable Sc extraction technology from Bauxite Residue. Furthermore, the neutralized BR from the leaching process, can be used in cement production, enhancing the sustainability of the operation.

The research leading to these results has been performed within the SCALE project (http://scale-project.eu/) and received funding from the European Community's Horizon 2020 Programme (H2020/2014-2020) under grant agreement n° 730105.
The concern of critical raw materials: ITHACA Project and other ongoing EU efforts to face CRMs shortage

M.L. Grilli

ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Casaccia Research Centre, Via Anguillarese 301, 00123 Roma, Italy

E-mail: marialuisa.grilli@enea.it

There is a growing concern about securing access to metals and minerals needed for economic production, especially from import-dependent industrialized countries such as the EU, Japan, and USA, whose high-tech products are strongly dependent from them. Understanding the role of Critical Raw Materials (CRMs) and a careful evaluation of environmental and health impacts are key factors in materials’ substitution, when searching for alternatives able to maintain the performance of components and products. Some of the on-going EU activities in the field of CRMs are described, focusing on the COST INNOVATORS’ GRANT IG15102: Innovative and sustainable TecHnologies for reducing critical raw mAterials dependence for Cleaner transportation Applications - ITHACA, which aims at reducing CRMs in advanced engineering materials for automotive and aerospace applications.
Sustainable supply of Sc for the EU industries from liquid iron chloride based TiO\textsubscript{2} plants

B. Yagmurlu\textsuperscript{1}, G. Croise\textsuperscript{2}, C. Dittrich\textsuperscript{1}, R. Scharfenberg\textsuperscript{1}, E. Balomenos\textsuperscript{3}, D. Panias\textsuperscript{3}, E. Mikili\textsuperscript{3}, C. Maier\textsuperscript{4}, R. Schneider\textsuperscript{1}, B. Friedrich\textsuperscript{4}, B. Orberger\textsuperscript{5}, P. Dräger\textsuperscript{4}, F. Baumgärtner\textsuperscript{4}, K. Sakkas\textsuperscript{6}, M. Schmitz\textsuperscript{4}, P. Letmathe\textsuperscript{4}, C. Georgopoulos\textsuperscript{6}, H. Van den Laan\textsuperscript{7}

\textsuperscript{1}MEAB, Germany
\textsuperscript{2}ORANO Mining, France
\textsuperscript{3}National Technical University of Athens, Greece
\textsuperscript{4}RWTH Aachen University, Germany
\textsuperscript{5}Catura Geoprojects, France
\textsuperscript{6}Enalos, Greece
\textsuperscript{7}Van den Laan International Consultancy BV (V.I.C.BV), Netherlands

E-mail: georges.croise@orano.group

The Sc demand in the EU is expected to rise from 780 kg/a in 2018 to 30 t/a in 2029 due to the increased use for solid oxide fuel cells, heat exchangers and 3D printing. Scandium is a critical metal for the growing EU industries in these sectors, as it is 100 % imported (66 % from China). At present no dedicated production plant exists worldwide.

Chlorine acid residues from the TiO\textsubscript{2} pigment production contain economic contents of Sc, Nb and V (e.g. www.scale-project.eu). In the EU, approximately 0.5 Mt of TiO\textsubscript{2} pigments are produced via the chlorine processing from mainly primary rutile ores. The valuable residual resources for Sc, V and Nb are landfilled or sold as iron chloride solutions to chemical industries.

The H2020 SCALE project developed a process flowsheet to recover Sc from chlorine residues from TiO\textsubscript{2} pigment production. It comprises ion exchange, solvent extraction and antisolvent precipitation followed by thermal decomposition to reach high purity Sc\textsubscript{2}O\textsubscript{3} at technical readiness level of 5-6 demonstrated at pilot scale. The KIC-EIT ScaVanger project (2021-2024), will upscale these technologies to bring high purity Sc\textsubscript{2}O\textsubscript{3} and ScF\textsubscript{3} to the market. At present, the final flowsheet is finetuned. The added value of the ScaVanger process relies in a 10 % increase in the production rate. ScaVanger reaches significant higher purities, thus higher efficiencies, as processing starts with the unique cleaning process to remove the actinides.

ScaVanger is setting the foundation for a sustainable supply for the EU of these critical metals (100 % Sc and about 2 % Nb and V demand), while contributing to the EU’s circular economy action plan. According to initial estimates, the first plant at a major European TiO\textsubscript{2} pigment production site will provide about 30 t/a of Sc\textsubscript{2}O\textsubscript{3} to the EU market.
Recovery of Metal Values from Ni-Cd Cake Waste Residue of an Iranian Zinc Plant by Hydrometallurgical Route

A. Chagnes, S. Kumar Sahu, M. Kargar Razi, M. Beuscher

Georessources Lab, Université de Lorraine, France

E-mail: Alexandre.chagnes@univ-lorraine.fr

This paper concerns the development of an environment-friendly hydrometallurgical flowsheet dedicated to the recovery of zinc and nickel from a waste residue collected from an Iranian zinc plant. In particular, valuable metals from Ni-Cd cake waste generated at this plant were recovered by a simple hydrometallurgical process using minimum acid for leaching, and solvent extraction step was designed such that addition of sodium hydroxide was not required and the effluent generated is safe to dispose off. The waste was leached with a mixture of hydrochloric acid and sulfuric acid in the presence of hydrogen peroxide in order to achieve a good selectivity towards iron and calcium. Afterwards, cementation was performed at pH 5 in order to remove cadmium. Liquid–liquid extraction was then implemented to produce high-purity solutions of zinc and nickel. Zinc-nickel separation was obtained at pH 2 by using a mixture of bis-(2-ethyl-hexyl)-phosphoric acid (HDEHP) and tris-2-ethylhexyl amine (TEHA) diluted in an aliphatic kerosene. TEHA did not directly participate but helped in the extraction of zinc by scavenging the protons released by HDEHP. Therefore, no alkaline solution was necessary for maintaining the equilibrium pH during liquid–liquid extraction. Finally, this flowsheet allowed to recover more than 95% of zinc and nickel from the residue with more than 99% purity.
Sustainable Chelating Surfactants: Synthesis, Surface Activity and Potential for Application in Metal Recovery from Mining Waste

D. Kalebic, K. Binnemans, W. Dehaen

KU Leuven, Belgium

E-mail: demian.kalebi@kuleuven.be

Traditional chemicals used in the mining industry are mostly petroleum derived and bear inherent environmental threats. The heavy environmental load can be relieved by using natural products as starting materials for the synthesis of sustainable mining agents. For example, amino acids and fatty acids are not only readily available and renewable resources, but they can also be obtained from waste streams such as protein lysates and oil waste. As an alternative to amino acids, a-hydroxy acids such as citric and malic acid can be used. By the means of organic synthesis, inherent chelating and hydrophilic properties of amino and alpha-hydroxy acids can be combined with the hydrophobic properties of long-chain fatty acids, yielding compounds named chelating surfactants. The amphiphilic nature of these compounds makes them not only excellent foaming agents, but also enables the extraction of valuable metals from mining residue/waste by selective binding in the solution or at the air-water interface. Such systems avoid usage of any additional ligands and reduce the complexity of the thermodynamic equilibria occurring during the metal extraction process. As a result, that makes them easy to integrate into different metal extraction/recovery set-ups, such as ion or precipitate flotation. Ion flotation, one of the most prominent methods for this process, is a separation technique where metals are bound to a ligand in dilute solutions or at the air-water interface of the bubble, and then sublated into the foam phase. This makes the technique promising in extraction of critical valuable metals (Cu, Zn, Pb) from dilute leachates or removal of contaminant ions (As, Cd) from wastewater. Similarly, precipitate flotation rests on the same principle, but extracts the ligand-metal complex in the form of a precipitate.

In this work, a library of environmentally friendly chelating surfactants derived from amino, alpha-hydroxy and fatty acids was synthesized. To test their potential for application, main surface activity and foaming properties were studied, and the efficiency and selectivity of valuable-metal recovery from aqueous leachates was evaluated by laboratory-scale ion flotation experiments. This was done with the final aim of their employment in remediation of real sulfidic tailings leachates which would aid in turning mining waste, often regarded as a problem, into a solution for resource recovery in a sustainable manner.
Development of Rare Earth Elements separation processes from Coal Fly Ash

A. Tsachouridis, F. Pavloudakis, N. Kiratzis

UNIVERSITY OF WESTERN MACEDONIA, Greece

E-mail: aggtsax@yahoo.gr

The seventeen Rare Earth Elements (REE) constitute a very important family of metals with unique physicochemical properties, whose ever-increasing demand has rendered them as strategic metals, with a huge range of applications and a massive impact on global industry and economy. Recent researches have verified that the Rare Earth Elements exist in important concentrations in coal and its by-products, such as coal fly and bottom ash. Based on the fact that coal fly and bottom ash are by-products found in abundance in the wider territory of Western Macedonia (created by the lignite combustion activity), it is considered vital for the economical, industrial and environmental life of the region that efficient and environmentally benign extraction processes should be developed. In the present contribution, results will be presented on the chemical and mineralogical analysis (XRF, ICP-MS, XRD) of coal fly and bottom ash samples collected from the active thermal power plant of PPC Meliti, Florina, Greece. In addition, characterization of the initial material and the calculation of the REE related indexes has been performed. Examination of these indexes for the fly ash gave a value of an Outlook Coefficient equal to 0.9884 and a Critical Percentage that equals to 36.67% both of which formed a promising basis for further beneficiation. Selection of the beneficiation process is crucial since it will eventually determine the degree of reduction in the quantity of the material under investigation and, therefore, dictate the quantity of the reagents that will be used in the subsequent chemical extraction processes. Accordingly, subsequent size separation via dry sieving was implemented as the first step of the beneficiation process. The size fraction with the higher REE concentration has been identified and the enrichment factor of the process was calculated. Mineralogical analysis has also been performed on the different size fractions and correlations between the mineral phases and the variation of REE concentration in the different fractions has been attempted. Future work includes the examination of the effect of magnetic separation, density separation and selective oil agglomeration on REE enrichment. In addition, the effectiveness of an ionic liquids-based extraction process as well as an electrochemical process based on Solid Oxide Membrane electrolysis will be studied.
The future of scandium recovery from wastes

O. Chernoburova¹, A. Chagnes²

¹Université de Lorraine, GeoRessources laboratory, France
²Université de Lorraine, CNRS, GeoRessources laboratory, France

E-mail: olga.chernoburova@univ-lorraine.fr

With growing demand for renewable and clean energy technologies, the need in rare earth metals is increasing. Scandium, which is often considered as a rare earth element (REE), is a critical metal used in aluminum alloys, for automotive, aerospace, defense and renewable energy industries (European Commission, 2020). The metal’s scarcity is justified by its limited world production that is mostly concentrated in China (66%), Russia (26%) and Ukraine (7%) (Dittrich and Yagmurlu, 2018). Economic concentrations of scandium in primary ores are rare. In order to secure EU supply of the metal it is important to identify its potential alternative sources, as well as the technologies suitable for the metal recovery. According to the study of Gaustad et al. (2021), the most promising scandium-rich residues include: ashes, generated during coal combustion and bauxite residues, containing on average 2.9 and 11.6 times the average concentration of scandium in ores, respectively. For some of these wastes, scandium content is associated with high variability when wastes of different origin are compared, whereas for other wastes such variability manifests to a lesser extent. Nevertheless, despite the attractive concentrations and large available tonnage of the residues, extraction of scandium from these materials presents a technological challenge. An extensive research work has been and is currently being conducted on the extraction of REE from wastes; however, the majority of methods and technologies under development are characterized with low TRL. Another important issue that has to be addressed is the price volatility of scandium and potential influence of an emerging alternative stream of metal on its market price. It is thus important to identify a strategy allowing economically secure recovery of scandium from wastes. In this work, recently developed methods and technologies for scandium extraction from wastes are reviewed and discussed. The major problems associated with scandium production from the above-mentioned wastes are addressed. The review concludes with highlights and perspectives.

References
Dittrich, C., Yagmurlu, B., 2018. SCALE: An emerging project for European scandium supply.
Tuesday 7 September 2021
OLYMPIA

SESSION B5
Hydro-, Iono-, Solvometallurgy II

Chair: D. Konlechner, E. Balomenos
Forward Osmosis - Freeze Crystallization: A Novel Concept for Water Recovery from Industrial Streams

N. Devaere, V. Papangelakis, R. Yuan

Chemical Engineering and Applied Chemistry, University of Toronto, Canada

E-mail: Devaere@utoronto.ca

In many process applications in the mining and metals industry, large amounts of aqueous waste are produced which need energy and chemical intensive technologies to either purify before disposal or to recover water for reuse while concentrating the waste. We present a novel technology that combines a spontaneous membrane process (Forward Osmosis) with a low energy process to recover water for reuse and recycling (Freeze Concentration). Forward Osmosis operates spontaneously and therefore does not consume energy, whereas Freeze Concentration takes advantage of the fact that the latent heat of freezing is seven times less that for water evaporation. This presentation discusses the operating principles of this novel approach and presents an energy comparison between conventional evaporative technology with freeze crystallization.
Separation of rare-earth elements by nonaqueous solvent extraction using the neutral extractant Cyanex 923

B. Dewulf, V. Cool, K. Binnemans

Solvomet Group, Department of Chemistry, KU Leuven, Belgium

E-mail: brecht.dewulf@kuleuven.be

Due to their chemical and physical similarities, the separation and purification of rare-earth elements (REEs) by conventional solvent extraction is a challenging task. The separation factors can be tuned by adjustment of the composition of the two immiscible liquid phases. Besides the development of new extractants and the use of different diluents and modifiers in the less polar (LP) phase, the composition of the more polar (MP) phase, which is commonly an aqueous phase, has received only limited attention. Tuning of the selectivity and extraction efficiency can be achieved by replacing water in the MP phase partly or totally by a polar organic solvent (nonaqueous solvent extraction). Several polar molecular organic solvents were tested, including methanol, ethanol, ethylene glycol, 1,2-propylene glycol, 1,3-propylene glycol, 2-methoxyethanol, triethylene glycol, DMSO, DMF, NMF and formamide. The rare-earth chloride salts of La, Nd, Eu, Dy and Yb (0.01 mol/L each) were added to these solvents to produce the MP phase, with variable concentration of LiCl as salting-out agent. The LP phase consisted out of 1 mol/L Cyanex 923 and 10 vol% 1-decanol as modifier, dissolved in n-dodecane. Already at lower LiCl concentrations, good separation of the REEs was obtained from ethylene glycol and DMSO. Also formamide showed good separation capabilities at high LiCl concentrations, but substantial volume changes were observed. Compared to ethylene glycol, the REE separation factors decreased significantly when using 1,2-propylene glycol or 1,3-propylene glycol, which is remarkable given their similarity in chemical structure. These differences in extraction behaviour can be attributed to a difference in solvation of the rare-earth cations, as well as differences in ion-pair formation, which is investigated by luminescence lifetime of the Eu$^{3+}$ complexes and UV-Vis measurements.

This research contributes to the European Horizon 2020 project NEMO (Grant Agreement No 776846. Website: https://h2020-nemo.eu/), investigating novel techniques for valorization of sulfidic mining waste, for which a new solvent extraction process is being developed for the separation of heavy rare-earth elements (Y, Dy, Ho, Er, Tm, Yb, Lu).
Recovery of tungsten from downstream mineral processing fractions by Deep Eutectic Solvents

L. Yurramendi, J. Nieto, A. Siriwardana
TECNALIA, Basque Research and Technology Alliance (BRTA), Spain
E-mail: lourdes.yurramendi@tecnalia.com

Tungsten (W) is a rare metal with a wide range of applications such as rocket engines, aircrafts, magnetic trains, cutting tools and pacemakers. There are two economically relevant tungsten mineral ores: wolframite, (Fe,Mn)WO₄, and scheelite (CaWO₄). Compared to other metals, the global reserves of tungsten are very low (7 million tonnes), and mostly located in China, that accounts for 80% of the 81100 t global production in 2018. In the same year, the EU production was 3200 t (4% of global production), while its consumption was estimated at about 10000 t per year. Due to the high demand and scarcity of this metal in EU, tungsten was included among the Critical Raw Materials (CRM) since 2011. A strong research effort is being dedicated to reduce the dependence of external countries. In practice, the tungsten grade is expressed as %WO₃. In this way, scheelite and wolframite grades are very low (0.5% WO₃) and they have to be upgraded for further W extraction. Scheelite ores are upgraded by gravity/flotation techniques while wolframite ores, by gravity/magnetic separation due to its paramagnetic properties. By these technologies, the tungsten grade is increased from 0.5% (as WO₃) to 65-70% (as WO₃) tungsten is then produced from concentrates in five steps: (i) Decomposition of tungstates by acid leaching (to H₂WO₄), caustic leaching or alkali roasting (to Na₂WO₄), (ii) Digestion of H₂WO₄ in aqueous ammonia or Na₂WO₄ in water, (iii) Precipitation of tungsten as ammonium paratungstate, (iv) Calcination to WO₃, (v) WO₃ reduction to tungsten in hydrogen. The first step requires toxic acids (HCl/H₂SO₄) or high temperatures (Na₂CO₃ roasting at 800-900°C). In this paper, Deep Eutectic Solvents (DES) are proposed as an environmentally-friendly leaching alternative. Tungsten can be later recovered from the DES leachate by a liquid-liquid extraction process. This work is focused in the DES leaching step. High Grade Scheelite Concentrate (WO₃>60%) from Barruecopardo mine (Spain) was selected as starting material. An exhaustive DES screening showed the best tungsten leaching performance for choline chloride/oxalic acid (ChCl/OA)-based DES. The effect of the leaching variables (temperature, time, solid to liquid ratio, ChCl to OA ratio) was studied. W extraction yields as high as 70% were achieved. By this promising technology, tungsten recovery from lowest grade fractions (tailings, mine wastes WO₃<1%), which are currently stockpiled in mines as residues, will also be explored.
Fe-Mn alloys electroforming process using choline chloride based deep eutectic solvents

V. Sales, G. Kolliopoulos, C. Paternoster, D. Mantovani

Université Laval, Canada

E-mail: vinicius.de-oliveira-fidelis-sales.1@ulaval.ca

Bioresorbable metals are used in clinical applications to produce biomedical implants, such as coronary stents and intraosseous screws, that can fully dissolve in the human body. Recently, Fe-Mn alloys have been suggested as potentially attractive bioresorbable materials due to their intrinsic mechanical and corrosion properties. Electroforming is the ideal process for the fabrication of thin-walled materials with complex shapes and surfaces with high dimensional precision. Aqueous solvents, despite being effective in the electrodeposition of metals with positive reduction potential (e.g., iron), fail to deposit metals with negative reduction potential (e.g., manganese) due to their narrow electrochemical potential window. This characteristic not only prevents the electrodeposition of these metals but also favors water reduction and the consequent evolution of hydrogen gas, which decreases the current efficiency and lowers the quality of the deposit. Deep eutectic solvents (DESs), a class of ionic liquids, are a promising alternative of inexpensive, biodegradable, nontoxic anhydrous solvents that present wide electrochemical potential windows. The present work reports on the potential of three choline chloride (ChCl) based DESs in the electrodeposition of Fe-Mn alloys: 1:2 molar ratio of ChCl/Ethylene glycol (EG), ChCl/Urea and ChCl/Glycerol (Gly). Different concentrations of Fe and Mn chloride salts were dissolved in the aforementioned DESs. The effects of the metal salt concentration and the reduction potential on the obtained alloys were analyzed. The chronoamperometry tests showed that ChCl/EG is the most suitable system for the electroforming process, as it had the highest deposition current values.
Separation of iron, zinc and lead from a choline chloride: ethylene glycol deep eutectic solvent by solvent extraction

S. Spathariotis¹, N. Peeters², K. Ryder¹, A. Abbott¹, S. Riaño²

¹University of Leicester, United Kingdom
²KU Leuven, Belgium

E-mail: nand.peeters@kuleuven.be

In order to reduce the depletion of primary mining sources, secondary sources such as industrial waste streams can be processed. Although the metal concentrations in these wastes are often low, the involved volumes are sufficiently large to secure a secondary source with a metal variety. The recovery of iron(III), zinc(II) and lead(II) is potentially relevant because these metals are common elements in various types of metallurgical wastes. This topic uses deep eutectic solvents (DESs) as an alternative aqueous phase in solvent extraction (SX), introducing the term “non-aqueous SX”. The selective extraction of iron(III) and zinc(II) was studied from a feed of Ethaline 200 (1:2 molar ratio of choline chloride:ethylene glycol, ChCl:EG). A commercial mixture of trialkylphosphine oxides (Cyanex 923, C923) diluted in an aliphatic diluent selectively extracted iron(III) from a feed containing also zinc(II) and lead(II). The subsequent separation of zinc(II) from lead(II) was carried out using the commercially available basic extractant Aliquat 336 (A336). The equilibration time and the extractant concentration were optimized for both systems. Iron(III) and zinc(II) were stripped using 1.2 mol L⁻¹ oxalic acid and 0.5 mol L⁻¹ aqueous ammonia, respectively. An efficient solvometallurgical flowsheet is proposed for the separation and recovery of iron(III), lead(II) and zinc(II) from Ethaline 200 using commercial extractants. Moreover, process upscaling was demonstrated in a countercurrent set-up by using mixer-settler equipment resulting in successful separation and purification.
Separation of precious and base metals with undiluted halide ionic liquids: non-equilibrium solvent extraction in milliflow

W. Vereycken, J. Van Stee, S. Riaño Torres, T. Van Gerven, K. Binnemans

KU Leuven, Belgium

E-mail: willem.vereycken@kuleuven.be

Research on the separation of metals by solvent extraction has focused primarily on conventional extraction media such as sulfates, chlorides and nitrates. In the first part of the presented work, bromide and iodide systems were explored as extraction media and compared with the corresponding chloride system. Changing the applied extraction medium can affect the aqueous metal speciation and hence the observed extraction selectivity. The extraction behavior and thermodynamic separation possibilities of a series of precious and base metal ions using the undiluted ionic liquid Aliquat 336 chloride and its bromide and iodide analogues were evaluated as a function of several variables (halide concentration, phase ratio, stripping characteristics, …). Ionic liquids (ILs) are solvents consisting entirely out of ions and have been studied extensively as green alternatives for volatile molecular solvents due to their negligible vapor pressure and low flammability. Based on these results, a process for the separation of Au(III) and Pd(II) from solutions rich in Fe(III) and Cu(II) – relevant for the recycling of waste electric and electronic equipment – was developed using Aliquat 336 bromide. In the subsequent parts of the presented work, the studied separations were applied in a milliflow reactor i.e. a continuous flow reactor consisting of a millimeter-scale reaction channel. IL-based processes have increasingly been suggested in combination with such reactors as they allow to intensify the use of the IL solvent. Experiments were performed under slug flow conditions where the immiscible phases form a segmented flow of sequential slugs and plugs. Secondary internal vortices are formed due to a shear exerted by the continuous phase on the surface of the plug leading to a more efficient mass transfer and rapid (second-scale) metal extractions despite the high viscosity of the ILs. Additionally, slug flow offers a highly uniform droplet morphology and a narrow residence time distribution. This proved particularly interesting as it allowed the enhancement of the precious/base metal separation through modulation of the contact time between both phases. The extraction rates of Fe(III) and Cu(II) were significantly lower than those of Au(III) and Pd(II) such that their co-extraction could be reduced by working at short contact times. The effect of various parameters (halide and metal concentrations, phase ratio, …) and the hydrodynamics of the slug flow were evaluated and optimized. Under non-equilibrium conditions, decontamination factors could be increased by a factor up to 2 compared to equilibrium separations.
Tuesday 7 September 2021
VERGINA

SESSION B6
Fossil fuels in the energy transition era

Chair: S. Kalaitzidis, N. Pasadakis
The fossil fuel industry in the energy transition era, a vision for Greece

A. Stefatos

Hellenic Hydrocarbon Resource Management SA, Greece

E-mail: a.stefatos@greekhydrocarbons.gr

The global fossil fuel industry is undergoing a transformational period, driven by the fact that the world needs to urgently transition to a more sustainable low-carbon economy. As a result, coal fired power plants are being transformed to gas and biomass fired or being decommissioned while oil and gas companies around the world are expanding and redirecting their strategies, towards renewable and alternative energy sources. Such transformational revisions of strategies are also evidenced in Greece. However, it is important to stress that despite the pressure on coal and oil, natural gas is set to become a much more important component within these companies’ portfolios. This due to critical role of natural gas in the green energy transition as a bridging fuel, that will eventually give way to pure renewable technologies, or new technologies with zero-impact on climate systems. Greece’s National Energy and Climate Plan, for example, foresees an expansion of natural gas consumption of approximately 40% by the end of the decade, an estimation that is more likely to be revised upwards than downwards.

The reason for this is that natural gas can easily substitute coal on existing infrastructure and generates an estimated 50% less CO₂ emissions than coal in electricity production. But natural gas is also set to play a potentially critical role towards a low-carbon “hydrogen economy” as Blue Hydrogen. Blue hydrogen produced from natural gas from which the Carbon dioxide (CO₂) is sequestrated, is a steppingstone towards eventually Green Hydrogen that will be produced solely by renewables. So, natural gas is very important for the global transition towards a low-carbon economy.

This new energy paradigm presents an important opportunity for the Greek state to generate billions of euros in revenues through the development of its upstream natural gas industry, as well as for investors currently active in the country.

Bearing in mind that fossil fuel imports into Greece over the past decade amounted to approximately €150 billion and that, according to our estimates, Greece’s natural gas market could be worth anywhere close to €260 billion, the advancement of the sector could have a transformative impact. Not only would it decrease costly import dependencies, the development of Greece’s natural gas market would enhance security of supply, in addition to potentially generating significant revenue surplus for the national economy and budget – that could be dedicated to tackle climate change – while strengthening the country’s strategic position as a regional and European “energy hub”.
Source Rock Evaluation: Analytical approach, Uncertainties and the Advantages of Organic Petrology

S. Kalaitzidis¹, G. Siavalas², M. Damoulianou¹, K. Christanis¹

¹Section of Earth Materials, Department of Geology, University of Patras, Greece
²Shell Global Solutions International, Netherlands

E-mail: skalait@upatras.gr

The unfolding of a petroleum system requires the understanding of several crucial parts of the puzzle, the most important being - beyond the formation of traps and seals - source rock and reservoir characteristics, migration paths and timing. Among these factors the primary prerequisite for the development of a petroleum system is the potential source rock, the evaluation of which refers to the quantification of the contained organic matter (OM), the identification of its type, and the assessment of its thermal maturity. Most often and easily acquired material from a source rock is when samples are picked up from outcrops, albeit them being weathered in various degrees, and/or contaminated by the current vegetation. Drill cuttings represent the second most often tested material, whereas core samples are sparse, although the latter are actually the most reliable ones. The applicable analytical methods to characterize the source rocks can be distinguished into two main categories, the geochemical and the petrographical ones, with the former focusing on the geochemistry of the soluble phases (bitumens) and/or bulk identification, and the latter being applied on the recognizable particles under the microscope, i.e. macerals and/or solid bitumens.

The overall international experience from source rock studies leads to the realization that integration of organic-petrography examination, including both maceral analysis and reflectance measurements, along with organic geochemical studies are absolutely necessary in order to identify whether a rock is a hydrocarbon source or not and obtain a comprehensive understanding of the petroleum system. Organic petrography remains the absolute tool to visualize the various types of OM, their origin and textural interrelations, and assign the particles to the various HC precursors. The visual determination enables a more confident interpretation of each particular OM component than the results obtained from bulk and advanced geochemical analytical procedures, which are averaging the outcome.

In Greece the majority of the studies on petroleum systems to date have focused mostly on sedimentary features or geochemical data; in few cases only, the organic components were studied by means of organic petrography. This fact shows that while Greece aspires playing an important role on the hydrocarbon production in Eastern Mediterranean, fundamental information on the understanding of the geosystems is either overlooked or incomplete or - at best - remains unpublished.
Evaluation of gas generation potential using thermal maturity modelling; The Katakolo Case: A probable pathway to energy transition

V. Makri¹, G. Panagopoulos², K. Nikolaou³, S. Bellas¹, N. Pasadakis¹

¹Institute of Petroleum Research, Foundation for Research and Technology – Hellas, Greece
²1. Energean, Athens, Greece 2. School of Mineral Resources Engineering, Technical University of Crete, Chania, Greece
³Energean, Athens, Greece

E-mail: vayanna@ipr.forth.gr

Evident is that the increased focus on energy transition, will prolong the demand for oil and especially for gas. The West-Katakolo field is the only oil and gas discovery in Western Greece and it is in the Katakolo offshore area. Operated by Energean, this field consists of Jurassic to Eocene fractured carbonates of the Ionian geotectonic zone, overlaid by a thick Plio-Pleistocene clastic sequence. The field is regarded to be mainly charged by a Triassic source, potentially the same as of the thermogenic gas seepages reported in the surrounding area. The three West-Katakolo wells drilled both oil and gas zones, while onshore exploration wells have penetrated biogenic-gas-saturated Pliocene sands. Given the strong presence indicators of gas prone source rocks within the area, this study assesses the gas generation potential of the local Pliocene and Triassic. Outcrop samples are pyrolyzed and thermal maturity modelling and calibration for both onshore and offshore locations is performed and presented. Overall, the assessment is based on the available legacy data and any data limitations are addressed by running several case-scenarios in a petroleum systems modelling software, to capture the modelling uncertainties. Regarding the biogenic gas in the onshore area, the rapid sedimentation, the low geothermal gradient, and the shallow burial depth of the Pliocene source rocks favour biogenic gas generation and expulsion, which are ongoing based on the modelling. For the oil/gas generation in the offshore area, a Triassic thermogenic-gas source kitchen is identified, with gas generation initiating prior to the Jurassic syn-rift, and gas expulsion occurring in some cases after trap formation (Pliocene). In a nutshell, some case-scenarios suggest the presence of Triassic and Pliocene gas source kitchens within the area, illustrating the importance of maturity modelling in hydrocarbon exploration. In such a project, the Katakolo case might be of prime importance for Greece.
Assessing natural gas versus CO₂ potential underground storage sites in Greece; a pragmatic approach

V. Makri¹, S. Bellas¹, V. Gaganis²

¹Institute of Petroleum Research, Foundation for Research and Technology - Hellas
²Department of Chemical School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece

E-mail: spybellas@gmail.com

Although subsurface traps have been traditionally explored as reservoirs of hydrocarbon production, storage of natural gas and CO₂ has drawn industrial attention during the last two decades thanks to the ever increasing demand for energy resources and contemporaneously the need to mitigate the greenhouse effect. Natural gas underground storage becomes increasingly popular as such reservoirs act as storage buffers which can anticipate seasonality and varying energy demand, as well as increase national energy security. On the other hand, the CO₂ cost determined by the EU emissions trading system is climbing rapidly putting thus a huge overburden on the operational cost of the heavy industry and rendering the need for permanent storage as imperative.

Underground sedimentary formations exhibiting adequate storage capacity, effective porosity and permeability values and are properly overlaid and laterally covered by impermeable rocks and/or seal-faults can be used for storing both types of gas. Depleted hydrocarbon reservoirs, saline aquifers and salt caverns have been the target location for both gas type storage. Since there is a single depleted gas-field (South Kavala) in Greece, only the last two options are worth been investigated. Subsequently, the need for an overall assessment of the existing-recommended ones and for the geological research of new potential locations becomes indispensable.

In this work we discuss the potential of the Greek subsurface for underground natural gas versus CO₂ storage by analyzing the available information of the developed geological models of various locations either recommended so far or new ones. Such potential sites include but are not restricted to (a) the Western Greece Fold and Thrust Belt (FTB), where Triassic evaporites develop interesting closure structures and synorogenetic clastics accumulate in large synclines overlying Eocene carbonates, (b) the Pyrgos-Kyllini Pliocene basins, (c) the north-central Greece where the molassic-type deposits (Mesohellenic basin) developed since the Upper Eocene and (d) the Axios River-Thessaloniki Neogene basin.

We further examine the implementation of underground storage in terms of economic effort and sustainability by considering factors of major importance such as natural gas/CO₂ availability, transportation/interconnection cost, field development procedures and facilities and their compliance to the recently announced National Plan for Energy and Climate.
Physicochemical properties and REE distribution of the Northwest and Central Greece coal deposits

N. Koukouzas¹, S. Kalaitzidis², P. Koutsovitis², A. Bouzinos³, C. Karkalis¹, P. Tyrologou¹, D. Karapanos¹

¹Chemical Process & Energy Resources Institute, Centre for Research & Technology Hellas (CERTH), Greece
²Department of Geology / University of Patras, Greece
³Measured Group Pty Ltd, Brisbane, Australia

E-mail: koukouzas@certh.gr

This paper presents a mineralogical and physicochemical comparison of coal seams located in the regions of Northwest and Central Greece. The present study focuses on the coal occurrences of the following basins, Mesohellenic Trough, Dimitras-Karperos-Grevena, Kastoria, Ptolemais, Amyntaio, Lavas-Servion and Prosillio-Trigoniko from the region of Northwest Greece and the Almyros basin in Central Greece. The comparison extends to the fly ash derivatives from the coal combustion for energy production, in the cases where data are available. In terms of organic petrographic entities the studied coals are dominated by huminite/vitrinite groups, whereas inorganic minerals include mainly quartz, aluminosilicates mostly in the form of clays and feldspars, carbonates and opaque minerals. Coal occurrences from Northwest Greece tend to exhibit higher content of rare earth element (REE) compared to those of Central Greece. Moreover, fly ash products show similar trend in Light-REE compared to their coal parent rocks. The observed REE distribution seems to be correlated with the occurrence of specific minerals such as allanite, monazite, as well as with Fe-contents. The available data of huminite reflectance, as well as O/C and H/C atomic ratios indicate that coals from Northwest Greece are slightly of higher coalification rank compared to that of Almyros basin in Central Greece.
A comparative study of the properties of biomass and coal fuels from Greece

C. Vasilatos\(^1\), D. Cheimarios\(^1\), T. Theodorou\(^1\), C. Stouraiti\(^1\), M. Andreadi\(^1\), N. Koukouzas\(^2\)

National and Kapodistrian University of Athens, Greece
Centre for Research and Technology Hellas, Greece

E-mail: vasilatos@geol.uoa.gr

Biomass has been used as an energy source since prehistoric ages by mankind for heating, cooking and industrial uses, way before the exploitation of fossil fuels. As a matter of fact, biomass provides a renewable fuel source which is carbon neutral and will decrease the carbon footprint by replacing lignite for electrical and thermal energy production. Biomass fuels exhibit high carbon conversion efficiencies due to high volatile matter and low fixed carbon contents. The biomass sometimes contains relatively high moisture content that decreases their heat production efficiency. Biomass can contain alkali phosphorus, silicon, chlorine and sulphur that can contribute to ash bonding and boilers’ corrosion during combustion. Furthermore, chlorine and sulphur may contribute to hazardous gas emissions and solid wastes (fly and bottom ashes).

Three different types of biomass samples from Greece were studied (reed, olive kernel and sawdust) and compared to lignite and xylite samples from Western Macedonia, Greece, coal deposits. These samples were characterized by standard ASTM methods for proximate and ultimate analysis, ash composition, chlorine and sulphur content and heating values. Moreover, PXRD data and SEM images have been used for the mineralogical, morphological and microstructure characterization of their ashes. Mineral chemistry of the ashes was studied by EDX micro-analysis.

All biomass samples exhibit higher calorific values not only from the studied lignite but also from many other Greek coals. Despite of its lower carbon content sawdust sample exhibits the highest calorific values among the biomass samples, probably due to its lower total moisture content. It also exhibits the lower sulphur and chlorine content. As far as the ash content, reed and olive kernel presented higher values than the sawdust. Amorphous phase was detected in all the ashes of the studied samples. Calcite was detected in all the ashes, both from biomass and coal but sylvite was detected only in the biomass ashes. The presence of sylvite in those samples indicates the abundance of potassium in the organic matter that bonds with chlorine and sulphur during combustion. This explains the formation of arcanite that was detected in the reed and the olive kernel ashes. Fairchildite has been detected in olive kernel ash while cristobalite, diopside and gismondite were found in sawdust ash. Clay minerals were determined only in the coal-ash samples. Those differences in the composition of the ashes may lead to different environmental management or potential industrial applications.
The undergoing research on the exploitation of geothermal energy in Greece since late 70’s has indicated various low and high enthalpy reservoirs. Plenty of the former have been identified at the regions of the Central, East Macedonia and Thrace and have been under production during the past decades, mostly exploited for greenhouse heating. However, the latter have not still proved their value in terms of produced renewable energy although the volcanic arc that crosses the Aegean Sea has been shown to have great potential. This can be attributed partially to the unsuccessful operation of the Milos field in the late 80’s as well as to the lack of a large scale governmental plan for the development and utilization of geothermal energy.

Recently, the National Plan for Energy and Climate was presented, constituting the roadmap for the enhancement of renewable resources utilization for energy production and suggesting that within next decade geothermal energy will provide 630 GWh of electric power yearly. Currently, PPC Renewables sA and HELECTOR are planning the development of the Milos high enthalpy field aiming at the construction of a 5 MW power plant by 2025, with Kimolos, Nisiros and Lesvos islands been indicated as potential targets as well. Additionally, the Regulation of Geothermal Exploitation has been recently authored and is ready to dispatch to apply specifications on the development and exploitation of both low and high enthalpy fields.

The recent progress reveals the need for expertise on the setup and utilization of geothermal numerical reservoir simulation models. In this work we examine the capabilities of the two main options, distributed and lumped parameter models, for the mathematical description and eventually the optimization of the geothermal energy resources under development. We investigate their applicability to the high enthalpy fields in Greece in order to handle successfully issues such as reservoir delineation, static modelling, history matching and energy extraction optimization. Eventually, we examine their contribution to the design of the field management program by minimizing the operating cost and the environmental effects, ensuring continuous and constant energy production rate and performing consistently and sustainably so as to meet the requirements of the national energy policy. Furthermore, we discuss the specific requirements that are imposed by the recent national Regulation of Geothermal Exploitation.
Tuesday 7 September 2021
ILISSOS

SESSION B7
Waste valorization – Industrial Symbiosis I

Chair: I. Giannopoulou, K. Tsakalakis
Can the Greek islands set an example on sustainability and autonomy? A proposal

Y. Pontikes
KU Leuven, Belgium

E-mail: yiannis.pontikes@kuleuven.be

It is understandable that communities living in locations not linked to major industrial hubs, harbours or a dense network of infrastructure, are experiencing different, case-specific, challenges. Examples of the above can be communities living in islands, or in less accessible areas, eg in detached, remote and/or mountainous areas. The above challenges can be further intensified during particular months of the year, as a result of touristic activity or particular seasonal activities.

Seeing the challenge as an opportunity, the above examples are very interesting case-studies where new approaches can be embraced. In doing so, innovation, even if it is out of necessity, can become the new paradigm and these communities can become the pioneers. This is the background of this talk, with the focus placed on wastes and ways to transform them into products. The intention is to have local production of end-materials, designed to cover the needs of the locals, by using local raw materials and mobile production units. This versatility allows bespoke, on-time and on-demand production of materials.

One of the ways to do the above is by developing alkali-activated materials. The raw materials can be different clays or industrial by-products and residues, but also glass from the municipal wastes. The source of alkalis can be alkali-hydroxides, -silicates, -carbonates or –sulfates, but also ashes from plants. And the end products, can vary both in microstructure and design. They can be dense for load-bearing applications and porous for heat and sound insulation; they can be boards, tiles or interlocking “dry-stacking” blocks. As for the production itself, this is happening in mobile containers, powered by solar-panels.

The majority of the elements described above is already a reality. You will see the material flow from slurry to a reactive precursor and how to fabricate a range of final building materials. That is taking place in four containers that are continuously being upgraded, with three more in the pipeline. The productivity today is not exceeding 1 ton a day, and there is still plenty of room for improvement. Still, it is a realistic vision that we believe in less than a decade will be fully deployed and operational.
CARBON DIOXIDE: A RAW MATERIAL FOR CEMENTITIOUS MORTAR

A. Fantilli\textsuperscript{1}, R. Calvi\textsuperscript{2}, E. Quieti\textsuperscript{2}

\textsuperscript{1}Politecnico di Torino - DISEG, Italy  
\textsuperscript{2}SIAD s.p.a., Italy

E-mail: alessandro.fantilli@polito.it

The increment of the global concentration of carbon dioxide (CO\textsubscript{2}) in the atmosphere is mainly due to the production of energy, which is largely consumed by the construction sector. Actually, the manufacture of cement is responsible for 7\% of the global anthropogenic CO\textsubscript{2}. Nevertheless, buildings and infrastructures in service can absorb CO\textsubscript{2} from the atmosphere, because of the carbonation process that affects the calcium hydroxide of concrete manuacts. The aim of this research project is to initiate the absorption at casting, by adding dry ice pellets to cement-based mortars. As cement paste can absorb a mass of carbon dioxide equal to 1.5\% that of cement, such content of CO\textsubscript{2} is added to the standard mixtures suggested by UNI EN 196-1. Test results demonstrate that the flexural and compressive strength of the mortars are not modified by this addition. However, due to CO\textsubscript{2}, the standard deviation of strength reduces with respect to that measured in plain mortars. In other words, dry ice pellets can be considered as a common additive of cement-based mortars and, therefore, its addition can generate a sustainable profitable link between the industrial production of gases and the construction market.
Hematite addition to serpentinized by-products of the "Grecian Magnesite SA" mine at Gerakini (Halkidiki) for the production of refractories

K. Kalaitzidou¹, E. Pagona¹, P. Stratigousis¹, X. Ntampou¹, E. Tzamos², V. Zaspalis¹, A. Zouboulis³, M. Mitrakas¹

¹Department of Chemical Engineering, School of Engineering, Aristotle University of Thessaloniki, Greece
²North Aegean Slops SA, R&D department, 26 Oktovriou str., 42, 54627, Thessaloniki, Greece
³Department of Chemistry, School of Sciences, Aristotle University of Thessaloniki, Greece

E-mail: kikalaitz@auth.gr

Nowadays, all processes oriented to sustainability commonly require the reuse and/or recycle of by-products and wastes alongside economic interests, applying the circular economy principles. In the present study, the effects of temperature and time, in order to produce refractory materials from the magnesite-ore mining by-products of the "Grecian Magnesite SA" mine at Gerakini (Chalkidiki, N. Greece), by adding specific amounts of hematite was examined. Moreover, the grounded samples were also examined after the application of simple post-treatment, i.e., the grounded samples were thermally treated at 850 °C (applying the forsterite formation temperature) for 30 min prior to pelletization. The applied thermal treatments were at 1300 °C for 30 and 120 min and at 1600 °C for 60 min. The increase of hematite percentage led to the increase of bulk density from 2.79, 2.60 and 2.72 up to 2.87, 2.86 and 2.82 g/cm³ for the samples W5, W6 and W7, respectively. In addition, better sintering and homogeneity on the surface of the respective samples was observed. The thermally pre-treated samples W5 and W6, compared to the initial samples, both with maghemite addition showed a decrease in fire shrinkage parameter up to 3.0%. However, sample W8 with hematite addition showed opposite results, increasing the firing shrinkage up to 1.0% for the thermally pre-treated samples with maghemite addition. The obtained results showed that the pre-treated samples with hematite addition, although presenting a decrease of water absorption parameter (up to 1.3%) and of apparent porosity parameter (up to 3.0%), indicated significantly lower mechanical strength (in most samples more than 50.0% decrease). The latter issue denotes that thermal pre-treatment is not recommended for these cases. Regarding the applied higher temperature of 1600 °C, the results showed a significant increase in firing shrinkage (in some samples firing shrinkage was doubled), while the mechanical strength was almost zero. In terms of heating time, when the thermal treatment was performed for 120 min at 1300 °C, the samples showed an increase of firing shrinkage up to 3.0% and mechanical strength parameter even doubled in some samples, compared to the thermal treatment for 30 min at 1300 °C, indicating that 120 min heating time is required. Finally, according to the respective XRD diagrams from the pelletized and thermally treated samples the identified phases are forsterite, enstatite and magnesioferrite. In general, hematite addition improves the main parameters of refractory materials, when the thermal treatment at 1300 °C is applied.
Alternative alkali activating solutions in the synthesis of IP binders

L. Kriskova, E. Tatsis, A. Muhammad, Y. Pontikes

KU Leuven, Belgium

E-mail: yiannis.pontikes@kuleuven.be

Inorganic polymers are considered to have much smaller CO$_2$ footprint than traditional Portland cements, with the highest contribution related to the manufacturing of the alkali activating solution. Within this context, the current work discusses the synthesis of inorganic polymers made from Fe-rich precursor and alternative silicate solutions. The obtained results indicate that there is no significant difference between inorganic polymer prepared from alternative and commercially available solutions, which confirms, that the waste glass can be used as alternative raw material in the production of sodium silicate.
Diabase Mud Based Geopolymer Paste: Formulation and Properties

M. Spanou¹, S. Luhar¹, P. Savva², S. Ioannou³, M. Petrou³, D. Nicolaides¹

¹Frederick Research Center, Cyprus
²Latomia Pharmakas, 23 Themistokli Dervi Av., S.T.A.D.Y.L. Building, P.O. Box 23504, Nicosia 1066, Cyprus
³Department of Civil and Environmental Engineering University of Cyprus, Cyprus

E-mail: res.mas@frederick.ac.cy

The concept of sustainability and the utilization of wastes have acquired eminent attention in the European construction industries. Material selection in construction plays a vital role in the manufacturing process of sustainable building construction. The general objective of this research is the transformation of a waste diabase mud into a value-added product. The diabase mud was characterized and a different approach of geopolymerisation was selected by adding small quantities of cement, gypsum as well as metakaolin in the matrix. This paper details analytical research results into a novel geopolymer paste embedded with diabase mud waste material as its precursor, and a combination of sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) as its alkaline activator to form a geopolymer system. The density and compressive strength of the optimum mix sample were found 2059 kg/m³ and 10.0 MPa (72 hrs), respectively. The embedding of a diabase mud into a geopolymer resulted in a viable composite for use in the construction industry.
Potential uses of copper wastes in the building sector: inertization and added value solutions

S. Rosado\textsuperscript{1,2}, L. Gullón\textsuperscript{2}, L.F. Mazadiego Martínez\textsuperscript{1}, J.F. Llamas Borrajo\textsuperscript{1}

\textsuperscript{1}Universidad Politécnica de Madrid, Spain
\textsuperscript{2}Fundación Gómez Pardo, Spain

E-mail: santiago.rosado@fgomezpardo.es

The mining activity is the second producer of wastes in the European Union (EU), so to develop processes that allow the reuse of wastes and the consequent creation of markets for these secondary raw materials are relevant for the desirable transition to the circular economy. The copper wastes such as cakes, tailings, pyrite roasting residues or slags present very different physical characteristics and hazardous. There are two important aspects to consider for the residue hazardous determination and its reuse: the particle size and the leaching behaviour. Also the reactive or non-reactive property of the wastes which depends of their origin is important for the new applications. Based on these parameters (and other specifics for each application), the intention of this paper is to review and study the different applications of the copper residues aiming for new possibilities of cement-based construction materials with added value that allow to economically justify the use of cement.
Morphology and properties of glass-ceramics produced from hospital waste incineration ash and different coal fly ashes

A. Kritikaki¹, G. Bartzas², K. Komnitsas¹

¹Technical University of Crete, Greece
²National Technical University of Athens, Greece

E-mail: komni@mred.tuc.gr

The management of hospital wastes is considered today a challenging problem due to their rapidly increasing amounts and inherent hazardous nature which can cause undesirable effects on the environment and human health. In this context, the present experimental study focuses on the production of porous glass-ceramics using hospital waste incineration ash mixed with two different coal fly ashes of low and high CaO content, respectively. First, vitrification of three mixtures was carried out at 1300 °C. After cooling, the vitrified products were pulverized and then sintered between 800 and 1000 °C for the production of glass-ceramics. Several analytical techniques, namely X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Differential Thermal Analysis (DTA) and Fourier Transform Infrared Spectroscopy (FTIR) were used to determine the microstructure, as well as the mineralogical and chemical composition of the produced glass-ceramics. In addition, the effect of the chemical composition of the initial wastes and the sintering temperature on the properties of the produced glass-ceramics, such as porosity, compressive strength, Vickers hardness and linear thermal expansion coefficient was also determined. The results show that the produced glass-ceramics are characterized by homogeneous structure, high density and mechanical strength as well as almost negligible dissolution rates of hazardous elements, thus they meet the requirements for applications in the wider construction sector.
Tuesday 7 September 2021
OLYMPIA

SESSION B8
Advanced metallurgical processes

Chair: M. Taxiarchou, P. Oustadakis
Heap leaching of Greek low-grade nickel oxide ores by dilute sulphuric acid at a pilot-plant scale

P. Oustadakis¹, S. Agatzini-Leonardou², P. Tsakiridis¹, J. Zafiratos³, D. Dimaki¹, J. Drougas⁴, E. Frogoudakis⁵

¹NTUA, Greece
²Emeritus Professor, NTUA, Greece
³Ministry of Environment, Energy & Climate Change, Greece
⁴Director of I.G.M.E., Greece
⁵Director of Research, LARCO, Greece

E-mail: lina.agatzini@gmail.com

The present paper gives the so far unpublished results of a pilot-scale heap leaching test of a Greek low-grade nickel oxide ore, aiming at verifying, at a large scale, the amenability of Greek laterites to heap leaching by the HELLAS (Heap Leaching LAtersiteS) Method, developed at the National Technical University of Athens for the first time worldwide and patented by some of the authors as early as in 1991. The test was conducted at the site of Aghios Ioannis mine of G.M.M.S.A. LARCO in 2006-2008 and was financed and supervised by the Institute of Geology and Mineral Exploration (I.G.M.E). The ore sample, 800t, was from the “Triada” deposit of LARCO, in Euboea, and contained 0.73% nickel, 0.06% cobalt 35.6% iron and 15% silicon. The ore was ground to -18mm and the leaching agent was 2N(100g/l) sulphuric acid solution. The nickel and cobalt recoveries obtained at the time of termination but not completion of the test, after four leaching cycles and 114 days of irrigation, were 60% and 36%, respectively. The corresponding nickel and cobalt concentrations in the produced leach liquor were 3.4g/l and 0.17g/l, respectively. The value of the ratio Fe/Ni in the leach liquor was 10/1, much lower than the value 45/1 in the ore, thus showing the selectivity of the leaching of nickel over iron in the Greek ores by the above method. The consumption of sulphuric acid was 66Kg H₂SO₄ /Kg Ni recovered. The preliminary feasibility study, that followed the test, confirmed the economic viability of the integrated HELLAS Method for the low-grade nickel oxide ores of Greece.
Reduction of ferric iron in pregnant leaching solution of laterites using Zero Valent Iron

C. Mystrioti, N. Papassiopi, A. Xenidis

National Technical University of Athens, Greece

E-mail: chmistrioti@metal.ntua.gr

Pregnant leaching solutions (PLS) with high iron content are produced by applying atmospheric hydrometallurgical methods for the recovery of valuable metals from laterite ores. The iron is commonly removed from the leaching liquor by chemical precipitation and the addition of a base (NaOH, CaCO3) which increase the solution pH. This process generates a large amount of solid which is difficult, costly to manage and can adsorb valuable metals coexisting in the PLS. The aim of this research is to investigate the separation of iron from the PLS by reducing Fe(III) to Fe(II) in order to inhibit the formation of amorphous ferrihydrite during the pH increase. The ferrous iron ions can be precipitated as a low volume crystalline iron oxyhydroxide, such as goethite, magnetite etc., under controlled oxidation conditions or can be converted to a precursor for the synthesis of high added value materials (e.g. nanomagnetite). Zero valent iron (ZVI) in microscale was used as a reducing agent. The effect of pH (0.5-1.5), reaction time (0 to 60 min) and the type of iron source (ferric chloride and ferric sulphate solutions) in the Fe(III) reduction by ZVI were evaluated by conducting batch tests in an agitated reactor. It was indicated that the reduction of ferric iron to ferrous iron using ZVI can be described by rapid reaction kinetics. The reduction kinetics are faster using ferric sulfate solution as iron source, namely ferric iron can be convert 100% to Fe(II) at pH equal to 0.5 in less than 2 minutes while 60 min are required for the conversion of 90.6% of Fe(III) to Fe(II) using ferric chloride solutions in the same experimental conditions.
How to design the utilization of larger scrap share in aluminum production

S. Papaefthymiou¹, M. Bouzouni²

¹National Technical University of Athens, Greece
²ELKEME S.A., Greece

E-mail: mbouzouni@elkeme.vionet.gr

The share of aluminum (Al) alloys in transportation, food/beverage packaging, automotive and aerospace sectors steadily increases within the last two decades. The high strength to weight ratio and the good formability make aluminium a great engineering material. The enhanced aluminium usage leads to increased scrap streams mainly from two sources: consumption in households and manufacturing operations such as traditional machining. However, the production of Al-alloys is mainly based on electrolytic pure Al alloyed with the necessary other elements, which are added in high purity into the melt pool during smelting processes. This fact is responsible for high costs and emissions during aluminium production. The aluminum industry needs to follow the example of the steel industry and exploit aluminium scrap in its downstream production processes. This will provide multiple benefits since it reduces the overall cost of aluminium production by preserving raw materials (reducing extraction of Al from mineral ores) through a large utilization of scrap streams. This work provides some indicative examples with the aim to propose and demonstrate alternative ways to exploit aluminum waste for the production of aluminum alloys. For this purpose, aluminum alloys found in scrapyards have to be combined to electrolytic Al in order to achieve the chemical composition of the targeted aluminum grades. Theoretical studies using thermodynamic calculations with paradigms of how to use scrap in the remelting process and how to match the new compositions are provided.
Regeneration and synthesis of NMC811 from cathode waste using oxalic acid based deep eutectic solvents

J. Gamarra, R. Younesi

Uppsala University, Sweden

E-mail: jgammarra@gmail.com

As electric vehicles (EV) take a growing share of the automotive market, so does their end-of-life waste take a bigger share of waste management facilities. EV batteries are a great source/consumer of strategic elements and critical raw materials. In this work, we focus on the extraction of metal oxides from LiNi(0.80)Mn(0.10)Co(0.10)O2 (NMC811) using oxalic acid based deep eutectic solvents. The solutions of choline chloride and oxalic acid (1:1 and 1:2 at 30% water content) were tested up to 10 wt% Oxide to solvent ratio. This extraction results in the formation of insoluble mixed oxalates that can be used as precursors for new cathodes [2]. The regenerated NMC was used in new cells and its performance compared against pristine commercial material. Additionally, we explored the use of these deep eutectic solvents from waste stream oxides (LiCoO2, NiO, Mn3O4) as an alternative synthesis method to adapt to the changing chemistries in battery cathodes.

Innovative Recovery Method for Critical Elements from Metallic End-of-Life Products

B. Yagmurlu\textsuperscript{1,2}, C. Dittrich\textsuperscript{1}, G. Dunn\textsuperscript{3}

\textsuperscript{1}MEAB Chemie Technik Gmbh, Germany
\textsuperscript{2}RWTH Aachen, Germany
\textsuperscript{3}Hydromet WA, Australia

E-mail: bengi@meab-mx.com

With the upcoming limitations on gasoline-based vehicles, especially in Europe under the Paris Accord, research on electrical/hydrogen powered vehicles and lightweight alloys for lower CO\textsubscript{2} emissions has peaked. For this purpose, the demand for permanent magnet, metallic 3D printing and battery materials has significantly increased in the last decade. The key elements for the success of these applications: REEs, Sc, Ni, Co and Li, have become critical elements for the future. Due to these reasons, end-of-life materials that contain exploitable amount of the mentioned critical elements have clearly become the focus of research. Magnets that contain REEs, Co and Ni are conventionally treated either with roasting, which requires high temperatures and energy before dissolving the metallic powder in aqueous solution, or hydrometallurgical operations via traditional mineral acid leaching as the first step of the process. However, conventional leaching of electronegative metallic particles and alloys with a strong mineral acid can result in the generation of H\textsubscript{2} gas and an aggressive exothermic reaction. While such a leach process can be made safe at laboratory scale, there are significant challenges at commercial scale from a control and zero harm perspective. Hence, there is a need for greener and sustainable process with easier control, lower chemical use, energy and CO\textsubscript{2} emission without any H\textsubscript{2} gas evolution. Thus, an innovative leaching approach has been applied with a metal salt solution with higher reduction potential to dissolve the metallic powders with cementation of the metal from the leaching solution. Then, the target has been separated and purified from the impurities via refining operations. The flexibility of the end product is another advantage since metal-carbonates, -sulfates, -oxides, and -fluorides could be produced via this processing route. The process is also scaled up and tested in a continuous mini-pilot scale.
Tuesday 7 September 2021
VERGINA

SESSION B9
Minerals exploration - Ophiolites

Chair: E. Tzamos, K. Laskaridis
RAW MATERIALS PROVIDED BY OPHIOLITIC COMPLEXES: From primary metallic ores to alteration of ultramafic rocks

A. Rassios¹, E. Tzamos², M. Bussolesi³

¹IGME, Greece
²ECORESOURCES PC - GRawMat Innovation Cluster, Greece
³Department of Earth and Environmental Sciences, University of Milan-Bicocca, Italy

E-mail: rassannie@gmail.com

Ophiolites are rare on global scale, but provide a unique a petrogenetic source for at least a dozen raw materials. Ophiolites are remnants of oceanic lithosphere emplaced onto continental margins. They originate from the partial melting of the sub-oceanic mantle creating magmatic intrusions responsible for the creation and enlarging of oceanic spreading centers. Magma originates at great depths and may include several melting events that affect the geochemistry of the complex. The raw materials provided by ophiolitic complexes include those that occur within the ultramafic (mantle provenance) peridotite bodies, within mafic crustal sequence rocks, and from the alteration of these assemblages. These Raw Materials comprise:

Primary Ophiolitic Source Ores
a. Chromite Ores: Source of metallic and refractory chrome. Cr-spinel in modal quantities of ~12% - 80% in deposits of ~1 million tons or more are economic targets. These are found within dunite bodies in the mantle section of the ophiolite.
b. Platinum Group Minerals: Rarely in economic quantities. PGE’s can be found in rare sulfide minerals within the mantle section of ophiolites.
c. Copper Ores: associated with ridge crest hydrothermal systems of the uppermost dikes and lavas. Copper sulfides reaching economic quantities are associated with the diabasic dikes and/or pillow lavas of ophiolitic crustal units with origins as metalliferous sediments or within “black smoker” fields.
d. Gold/silver deposition: Rare, but related to ridge crest hydrothermal systems.
e. “Olivinite” industrial grade dunite. These are dunite rocks located within the mantle sequence with essentially no serpentinite alteration.

Secondary Ophiolitic-source Materials
a. Asbestos (chrysotile) within serpentinized peridotite bodies.
b. Gold within listwanitic deposits and their relation to “mother lode” sources.
c. Ni from lateritic deposits derived from weathering of ultramafic rocks.
d. Hydromagnesite (huntite) Mg-rich sediments derived from alteration/weathering of ultramafic sources.
e. Attapulgite clays: From the weathering of ultramafic material.
f. Road building and surfacing material (from diabasic deposits)

Soils within ophiolitic terrains provide another “raw material” derived from ophiolites. The chemistry associated with lavas and dikes (sulphide-bearing) and their textures (including rubbly stones and pebbles) are sought after for production of wine.
Serpentinites: from dimension stones to valuable industrial minerals

A. Cavallo¹, M. Bussolesi¹, G. Grieco²

¹University of Milano-Bicocca, Department of Earth and Environmental Sciences, Italy
²University of Milano, Italy

E-mail: alessandro.cavallo@unimib.it

Serpentinites are used as dimension stones, commercialized as “green marbles” with many different textures and color shades: an excellent example is represented by the Valmalenco area (central Alps, northern Italy). There are two main commercial varieties, depending on texture and microstructures: “schistose” (split in thin slabs) and “massive” (polished, sandblasted, etc.). The main rock-forming minerals are represented by antigorite (60 – 90 wt.%) and olivine (up to 30 wt.%), with smaller amounts of clinopyroxene (diopside), chlorite and magnetite. The very fine grain size and the interpenetrated microstructure confer these materials excellent technical properties (compressive and flexural strength, freeze-thaw resistance). The quarrying and processing waste can be estimated around the 40 - 50 % of the extracted material, and at present time there are no virtuous reuses of the waste materials. However, considering the peculiar chemical and mineralogical composition of serpentinitic rocks, there are many possibilities of reuse in the industrial mineral sector. Finely ground antigorite-rich materials could be used as filler for plastics and rubber (instead of talc), whereas olivine-rich wastes as a reactive fixing carbon dioxide (as carbonates, i.e. magnesite) released during the use of fossil fuels. Recently, research has been funded aimed at serpentine carbonation using microwaves, in order to optimize the process and reduce as much as possible energy consumption. In the ceramic industry, the most promising target is represented by forsterite and/or high-MgO ceramics and forsterite refractories (with periclase addition), but also by cordierite ceramics (adding kaolin) and high-hardness vitroceramics. The real possibility of an industrial use of serpentinitic materials will require much more experimental work, because no relevant previous studies are available. Special care must be taken to avoid chrysotile asbestos contamination, which can be occasionally dispersed in the rock mass.
Mineralogical and isotopic study of magnesite veins in the Evia and Gerakini ultramafites (Greece)

M. Bussolesi
d, G. Grieco2, E. Tzamos3, A. Cavallo1, P. Marescotti4, L. Crispini4, A. Kasinos5, A. Zouboulis6

1University of Milano-Bicocca, Italy
2University of Milan, Italy
3Ecoresources PC, Greece
4University of Genova, Italy
5Grecian Magnesite SA, Greece
6Aristotle University of Thessaloniki, Greece

E-mail: micol.bussolesi@gmail.com

Magnesite ore deposits are the main source of Mg for the industry and are used in the production of various kinds of magnesia. They are closely associated to ophiolite geological contexts, and are usually hosted within variously altered harzburgites and dunites.

Greece hosts exploitable ophiolite-related magnesite deposits in two areas, located in the Evia island and in the Chalkidiki peninsula. In the present contribution we take into consideration magnesite veins at Kymasi (Evia) and Gerakini (Chalkidiki). The Kymasi magnesites are hosted in peridotites in the tectonic unit of the Pelagonian Zone of Northern Evia. Gerakini is located in the Vardar Zone ophiolite belt, and forms the Gerakini-Ormylia ophiolite complex.

Both areas host major magnesite deposits, mainly comprising shallow stockwork-type ores hosted within variably altered dunites and harzburgites locally intruded by pyroxenitic and gabbroic veins.

At Kymasi, field work was focused on a well exposed network of magnesite veins that show the following zoning from core to rim: a thick massive magnesite central portion, a serpentinized hydraulic breccia with magnesite cement and a partially dolomitized peridotite. The host rock is unaltered peridotite. All contacts are irregular and sharp.

At Gerakini sampling was focused on two active open pits, Ugo and Antonium. Magnesite samples show a variety of textures, comprising massive magnesite, cauliflower magnesite, fibrous magnesite and brecciated magnesite. Host rocks are serpentinized dunites.

XRD data show that, differently from Kymasi, at Gerakini magnesite veins contain a variable amount of dolomite up to 16%.

Mineral chemistry data show that, at Kymasi, high-Cr spinels occur in the breccia, while partially dolomitized peridotite and unaltered peridotite spinels are lower in Cr. The isotopic analyses show very similar δ18O and δ13C values in Kymasi and Gerakini, also consistent with other ophiolite-related magnesite mineralizations in the Balkans. The isotopic values suggest that the CO₂ was originated from the decarboxylation of organic matter present in the sediments of the area.

Considering the origin of the CO₂ and the shallow nature of the stockwork mineralization, it can be concluded that both Kymasi and Gerakini magnesites were formed by infiltration of CO₂-rich meteoric waters which interacted with peridotites. The interaction caused the leaching of Mg, which was transported by the fluids through preferential pathways, possibly reactivating older shear zones, and finally deposited in the form of magnesite once it reached saturation at shallow depths.
Investigation of the effects of magnetic separation and thermal treatment combined with additives on the serpentinized peridotites of the Gerakini (Chalkidiki, N. Greece) magnesite mine

D. Papargyriou\textsuperscript{1}, E. Tzamos\textsuperscript{2,3,4}, A. Kasinos\textsuperscript{1}, P. Papageorgiou\textsuperscript{1}, M. Mitrakas\textsuperscript{5}, A. Zouboulis\textsuperscript{6}

\textsuperscript{1}Grecian Magnesite S.A., Greece
\textsuperscript{2}North Aegean Slops S.A., Greece
\textsuperscript{3}Ecoresources P.C., Greece
\textsuperscript{4}Department of Chemistry, Aristotle University of Thessaloniki, Greece
\textsuperscript{5}Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece

E-mail: tzamos@ecoresources.gr

The aim of this work was the study of chemical and mineralogical characteristics of serpentinized peridotites, produced in the magnesite mines of Gerakini (Chalkidiki, Greece), and the impact evaluation of magnetic separation and of thermal treatment with the addition of oxides in specimens of solid wastes left after the mineral enrichment processes. Chemical analysis and mineralogical analysis were conducted with the application of Energy Dispersive X-ray Fluorescence (XRF) and of X-Ray Diffraction Spectroscopy (XRD) methods, respectively. An average chemical analysis of the examined specimen was MgO 42\%, SiO\textsubscript{2} 38\%, Fe\textsubscript{2}O\textsubscript{3} 8.5\% and LOI 8.5\%, whereas the mineralogical phase analysis revealed olivine as the main mineral constituent and secondarily, antigorite and enstatite.

The process of dry magnetic separation, as enrichment method, presented no particular effect in the chemical composition between the separated fractions, although revealed a small increase of olivine, antigorite and enstatite in the non-magnetic fraction. Finally, after firing the specimens of ground peridotite at 1520 °C as received and with the addition of several oxides, showed that the presence of CaO, Al\textsubscript{2}O\textsubscript{3} and SiO\textsubscript{2} showed negative effect on the structure of the specimens, regarding the main refractory properties of them, in contrast to the addition of Cr\textsubscript{2}O\textsubscript{3} and MgO, where an improvement observed, as compared to the raw material.

Acknowledgements
This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T1EDK-03543).
The impact of forefront technology on mine geological methods at Olympias Mine that drive improvements on orebody knowledge through decades

E. Vagkli, G. Gkekas

Hellas Gold, Greece

E-mail: Eleftheria.Vagkli@eldoradogold.com

Since the early 70’s until now, Olympias mine underwent organizational plan changes that impacted the capability of the Mine Geology team to demonstrate efficient orebody knowledge. The running structure engulfed a productivity-orientation, to mitigate the complexity and production volume under the prism of continuously improving technology. A variety of techniques ensured the successful interpretation of the complex geological terrains across the different eras, improving the accuracy constantly. Drilling design, which is the initial major step of geo-modelling, was executed in 2D georeferenced handmade leveled maps, whereas currently the 3D drilling design enables the user to spatially control drillhole’s path and execution. Subsequently to design, assay results were incorporated in the 2D surveyed and georeferenced drillholes on top of handmade maps to ultimately interpret the ore shape along the assay intervals of interest without any QAQCing applied. Assay results nowadays are stored in a well-structured and sophisticated database, whereas the 3D software will then allow the user to interpret georeferenced 3D shapes in a fast and accurate manner. Olympias Geology Team is no exception in adapting to the technological transformation that occurred the recent years. By designing drillholes in CAD based software, Olympias Geology Team controls the key factors for each drillhole’s execution. Following the logging and sampling of the drillholes, assay results’ will then be stored in Acquire Database passing QAQC control. The existing best practice exploits geological domains as a driving factor for a successful grade control. Key components for the referred domains consist among others, up to dated geological mapping, assaying, geological trending, and localized metal predictions. Conclusively those domains will nucleate the estimation ‘space’ (wireframes) for the statistical method that subsequently will be utilized to construct the block-model. During this stage, the ore-contacts’ control will establish a minimum dilution involvement during the mining operation. Wireframes’ modelling passed through 3D explicit defining three-dimensional modelling to implicit modelling. Subsequently, estimation stage, utilizing spatial or descriptive statistics methods such as Ordinary Kriging or Inverse Distance will follow. The implications of the referred procedure resulted to a robust not only quantitively but qualitatively wise approach of modelling in all its aspects. Additionally, the sophisticated 3D software’s development is not restricted in the modelling standpoint but also contributed the most in vital operational processes such as grade reconciliation which establishes model’s performance.
Diagenesis of the sedimentary Fe-Ni deposits of Euboea: Evidence based on phyllosilicate mineralogy

S. Cheliotis-Chatzidimitriou¹, G. Christidis¹, I. Marantos²

¹Technical University of Crete, Greece
²Hellenic Survey of Geology and Mineral Exploration (H.S.G.M.E.), Greece

E-mail: schatzidimitriou@isc.tuc.gr

The sedimentary Fe-Ni deposits of Euboea were formed from lateritic alteration of ultrabasic-basic rocks of Jurassic ophiolites, subsequent erosion of the lateritic mantles and deposition in swallow marine/lagoon environment in the Upper Cretaceous. The deposits have been studied extensively in the past and their mineralogy has been relatively well established regarding the ore minerals and the hosts of Ni. Hence, it is widely accepted that the main hosts of Ni are phyllosilicates, mainly chlorite, serpentine and talc, whereas Fe-oxides and Fe-oxyhydroxides are of minor importance. In contrast, there are contradictory reports about the presence and significance of smectite in the deposits. In this study we report on the phyllosilicate mineralogy of the deposits of Katsikiza, Pagondas, Koutos, Platani, Vrysaki, Rekavetsi and Zygos, Central Euboea, and examine its significance on the evolution in the deposits during diagenesis. The deposits are characterized both by pisolititic and pelitic textures. They consist of complex (peloids, scarce pisoids) and individual grains of hematite with variable sphericity (angular to rounded) as basic component. They also contain angular to rounded quartz, goethite and accessory chromite fragments. The texture of the main phases indicates limited transportation from the sources. Phyllosilicate mineralogy is comparable in all deposits, regardless of the ore texture. The main phases are mixed layer chlorite-smectite (C/S) with 10-20% smectite layers and discrete chlorite. Talc (kerolite-pimelite) is minor phase in all deposits, being a main phase locally in the Vrysaki deposit. Corrensite (Cor) is present in Vrysaki and Platani deposits Smectite was identified as major phase in sectors of the Vrysaki, Koutos and Rekavetsi deposits, and discrete illite in the Zygos deposit. In contrast serpentine is scarcely present in the deposits. The coexistence of mixed layer C/S, Cor, the end-member phases (smectite and chlorite) and the limited abundance or lack of serpentine suggest a) a smectite to chlorite conversion during diagenesis of the ore, b) lack of equilibrium in the smectite-to-chlorite transformation and c) dissolution of serpentine during diagenesis. Therefore, chlorite and mixed layer C/S and Cor phases are rather of diagenetic origin and were not formed during lateritization. It is suggested that the smectite to chlorite transformation and the dissolution of serpentine are related to the mobilization of Ni and other critical elements, such as Co. The presence of Cor and mixed layer C/S may be used for estimation of burial depth and temperature. Further work is in progress on this issue.
Tuesday 7 September 2021
ILISSOS

SESSION B10
Waste valorization – Industrial Symbiosis II

Chair: P. Tsakiridis, D. Panias
Effect of fly ash and other supplementary corrosion inhibitor on the tensile performance of 316L stainless steel concrete reinforcement during accelerated saline corrosion test


Department of Materials Science and Engineering, School of Engineering, University of Ioannina, Greece

E-mail: s.tsouli@uoi.gr

The employment of 316L stainless steel as reinforcement of architectural members in the ancient theatre of Dodona in Greece, as well as in the restoration of other ancient and modern monuments, is common nowadays. However, even 316L is susceptible to localized corrosion in chloride containing environments. Therefore, the partial replacement of Ordinary Portland cement (OPC) with industrial byproducts, like fly ash (FA), could present an effective economical and ecological alternative due to the formation of corrosion resistant pozzolanic reaction products. Following previous works by the authors [1,2] studying the effect of FA on the electrochemical performance and structural integrity of stainless steel concrete rebars in saline and acid rain environments, which manifested a better electrochemical performance of 20 wt.% FA addition compared to lower and higher FA additions, the present study investigates the effect of FA (0-25 wt.%) combined with a liquid corrosion inhibitor (Inhibitor B) on the mechanical degradation of 316L rebars embedded in concrete cubes during 4 m of salt spraying. The degradation of 316L rebars was studied by tensile testing and elastic modulus (E) determination (ultrasound testing). The porosity of reinforced concrete containing FA and Inhibitor B during salt spraying was also measured (ASTM C642-97). Partial replacement of OPC by FA did not significantly affect the tensile properties of the 316L rebar during salt spraying except a slight decrease in E and %elongation with FA increasing that was consistent but within statistical error. The combination of both inhibitors for 20 wt.% FA led to a smaller decrease in all tensile values compared to the sole addition of 20 wt.% FA. The combination of both inhibitors resulted in a smaller decrease in E compared to the sole addition of FA. Both inhibitors, sole or combined, resulted in significant reductions in the porosity of reinforced concrete after 4 m of salt spraying.
Performance of a Fe-rich inorganic polymer in a Na$_2$SO$_4$ solution: role of Mg/(Mg+Ca) in the slag

N. Wen$^{1,2}$, A. Peys$^3$, T. Hertel$^1$, Y. Pontikes$^1$

$^1$KU Leuven, Department of Materials Engineering, 3001 Leuven, Belgium
$^2$SIM vzw, Technologiepark 935, BE-9052 Zwijnaarde, Belgium
$^3$Sustainable Materials Management, VITO, Boeretang 200, 2400 Mol, Belgium

E-mail: yiannis.pontikes@kuleuven.be

To enable the usage of non-ferrous metallurgy slags in alkali activating materials (AAM), the influence of the chemical composition of the slag on durability must be better understood. In this work two slags were synthesized with different MgO/(MgO+CaO) weight ratios to investigate the effect on the sulfate resistance (Na$_2$SO$_4$) of AAMs. Experimental results suggested that a higher MgO/(MgO+CaO) ratio did not lead to higher strength, but the trend of the mass change and compressive strength change of two AAM is quite similar upon Na$_2$SO$_4$ exposure for 24 weeks. The leaching of elements (Na, Al, and Si) during Na$_2$SO$_4$ exposure is more significant at the early stage but slightly less at the late stage, while the leaching of Ca is more obvious in the late stage.
Formation, characterization and SEM microanalysis of yeelimite

M. Kamitsou¹, I. Kostakopoulos¹, D. Kanellopoulou¹, V. Hallet², P. Petrica², A. Christogerou¹, G. Angelopoulos¹

¹University of Patras, Greece
²KU Leuven, Department of Materials Engineering, Kasteelpark Arenberg 44, 3001 Leuven

E-mail: m.kamitsou@gmail.com

Yeelimite is one of the main components of cement. In this study, stoichiometric yeelimite obtained at different temperatures, was characterized by XRD, Q–XRD and SEM-EDS. Moreover, mortars of the synthetic yeelimite, with and without standard sand, were studied in terms of the development of strength over time. The main result is that high yeelimite content samples were prepared by mixing stoichiometric quantities of analytical-grade raw materials at 1330 °C for 3 h soaking time, followed by rapid cooling. Moreover, increase of the so-formed yeelimite results in increased strength values that meet the requirements to be classified at CEM 32.5.
Porous materials from Fe-rich slags: challenges and best practices

R. Murillo Alarcón¹, T. Hertel¹, H. Rahier², Y. Pontikes¹

¹KU Leuven, Belgium
²Department of Materials and Chemistry, Vrije Universiteit Brussel, Brussel, Belgium

E-mail: yiannis.pontikes@kuleuven.be

Fe-rich slags have shown high potential to be used in materials with high-added value. This work summarises the research carried out to valorise Fe-rich slags into lightweight porous materials. A combination of alkali-activation (i.e., dissolution of the solid precursors and further polymerisation within an alkali-medium) and methods to induce porosity (e.g., chemical expansion or mechanical foaming) have been studied in detail for the production of these porous materials. Characterisation of their properties indicates that these materials could be suitable for load-bearing applications, as well as for thermal and sound insulation. Furthermore, a case study of porous materials from modified bauxite residue proved to be suitable adsorbers for pollutants from wastewater.
Bogue equations from thermodynamic modelling for low-carbon ferrite-belite clinkers

R. Roy, T. Hertel, Y. Pontikes
KU Leuven, Belgium
E-mail: rahul.roy@kuleuven.be

In this study, limestone (LS), kaolin (K) and bauxite residue (BR) were considered as potential raw meal ingredients for the preparation of ferrite-belite (cement) clinkers. Forecast of the mineralogical composition for the different clinker composition, based on the major oxides i.e., CaO (C), SiO$_2$ (S), Al$_2$O$_3$ (A) and Fe$_2$O$_3$ (F) was obtained using thermodynamic modelling (FactSage). A phase field schematic representation was established for the three-component raw meal. The data obtained therein were used to compute the Bogue equations for the ferrite-belite cements. Based on this assumption, i.e., only four simultaneous linear equations each containing four different variables (crystalline phases) were used to formulate Bogue type equations. It was established that with increasing LS content from 33 wt% to 64 wt% and BR content decreasing from 66 wt% to 35 wt%, CF was only present at a LS content between 33-47%, followed by gehlenite up to LS content of 53% and rankinite at a LS content of about 55 wt%. Moreover, C3A and lime were present in place of gehlenite and rankinite beyond LS content of 55 wt%. However, the belite and ferrite phases remained present throughout the entire clinker composition. Overall, this study provides the basic understanding required for the development of low carbon ferrite-belite clinkers.
Phosphogypsum-paraffin composites for low temperature thermal energy storage applications

A. Anagnostopoulos¹, H. Navarro¹, Y. Ding¹, G. Gaidajis²

¹University of Birmingham, United Kingdom
²Democritus University of Thrace, Greece

E-mail: argyanag@gmail.com

Phosphogypsum (PG) is an industrial byproduct of the fertilizer industry with an annual production of 300 Mt. PG is typically disposed of, in an occasionally uncontrolled fashion, in the sea, dams or dykes, which presents a significant environmental hazard due to elevated content in radioactive heavy metals. Despite efforts, only 15% is currently utilized. In this work, a novel utilization pathway for PG is proposed, which makes use of the latter, in combination with paraffin (RT90), to formulate composite phase change materials (CPCMs) for thermal energy storage (TES) applications. The formulation is straightforward and involves milling, mixing, shaping, drying, and sintering. Excellent thermal stability of the CPCMs is observed after 96 cycles (25 to 100 ℃) with no variations in the melting point or the latent heat. Maximum latent heat is 75 J/g (60%-40% PG-paraffin content), while the specific heat capacity is up to 1.54 J/gK for the same case. The thermal conductivity is found to be up to 0.46 W/mK; 74.93% higher than pure paraffin. The maximum energy storage density is 237 MJ/m³; only 14.04% lower than the pure paraffin. The melting point and working temperature of this novel CPCM make it ideal for low-temperature TES applications, paving the pathway for a new tangible valorization case for PG.
Tuesday 7 September 2021
FOYER OLYMPIA

POSTER SESSION 2
Recycling
Waste Valorization
Sustainable Metallurgy
Education
An integrated approach for the recovery of used Tin as water adsorbent

E. Kaprara, E. Daskalopoulou, K. Simeonidis, M. Mitrakas

Laboratory of Analytical Chemistry, Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece

E-mail: kaprara@auth.gr

This study aims to establish a non-conventional way of approaching adsorption processes for water purification by designing an infinite operation cycle for the adsorbent according to the principles of circular economy and green chemistry. Regularly, adsorbents used in drinking water treatment are implemented in a through-away basis. Such a practice increases the treatment cost and environmental pollution from disposed wastes. The impact becomes more significant when the used adsorbent consists of elements with relatively high market value.

In this frame, the present research examined a scenario for the recovery of a novel Cr(VI) adsorbent, consisting of Sn₆O₄(OH)₄, after reaching its operational lifetime. To accomplish this target, a sequence of processes involving the spent adsorbent’s decomposition, the separation of Sn/Cr ions and the Sn₆O₄(OH)₄ reconstruction was examined. A combination of analytical and structural characterization techniques was also applied to both spent and recovered adsorbent. The Cr(VI) uptake capacity of the reconstructed adsorbent was validated in extended series of batch adsorption experiments in distilled and natural-like water under 6-8 pH values.

The characterization of the spent adsorbent indicated its oxidation to SnO₂ by simultaneous reduction of Cr(VI) to Cr(III), that was adsorbed up to 19mg per g of adsorbent. The optimization of spent adsorbent’s decomposition process was achieved by dissolution in HCl, at a 10g/L concentration, a solid-to-acid mass proportion of 1:20 and 75°C, resulting in dissolution of more than 95% Sn and 92.5% Cr contained in the spent adsorbent. The subsequent reduction of Sn(IV) to Sn(II) with the addition of (ΝΗ₂)₂ and the gradual increase of pH in the mixture allowed the separation of Cr(III) in a first precipitation stage (pH 3) and the recovery of Sn₆O₄(OH)₄ in a second (pH 7), as confirmed by the characterization of the solid. The percentage of Sn(II) in the recovered adsorbent, an indicator of adsorbent’s reducing capacity towards Cr(VI), was determined 7% higher than in the original one, possibly due to the addition of the reducing agent during reconstruction. The latter significantly improved material’s Cr(VI) removal efficiency and led to a more than 50% increase in Cr(VI) adsorption capacity at residual Cr(VI) concentration of 25 μg/L.

Acknowledgments: This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Reinforcement of Postdoctoral Researchers-2nd Cycle” (MIS-5033021), implemented by the State Scholarships Foundation (IKY).
MAGNESITE ORE WASHING FACILITIES WASTEWATER TREATMENT AND RECOVERED WATER REUSE

I. Tsiloegiorgis\textsuperscript{1}, E. Tzamos\textsuperscript{2}, E. Kokkinos\textsuperscript{3}, A. Zouboulis\textsuperscript{3}.

\textsuperscript{1}R&D Department, Grecian Magnesite S.A., Greece
\textsuperscript{2}R&D Department, EcoResources P.C., Greece
\textsuperscript{3}Department of Chemistry, Aristotle University of Thessaloniki, Greece

E-mail: iason.tsiloegiorgis@gmail.com, evgenios@chem.auth.gr

Grecian Magnesite S.A. (GM) is a magnesite mining company, which produces and commercializes several Mg-based products, such as Caustic Calcined Magnesia (CCM), Dead-Burned Magnesia (DBM), magnesium carbonate (raw magnesite) and basic monolithic refractories. GM’s major deposits and production facilities are in Gerakini, Chalkidiki, N. Greece. In this study, the environmental impact of mining and industrial activities is examined and the water management issues are addressed, as an important part of the overall environmental impact. For the production purposes, water is applied in large quantities for several uses, such as ore washing, road wetting, machinery cooling, tree and plant irrigation etc. The main sources of this water are surface water from precipitation harvesting and surface runoff in “natural” reservoirs, along with groundwater which is utilized for human consumption and irrigation of olive trees at remediate older mining sites. Totally 5x10\textsuperscript{6} - 7x10\textsuperscript{6} m\textsuperscript{3} of wastewater, consisting mainly of muddy water, are produced from the magnesite ore washing facilities each year. This wastewater is appropriately treated in settling tanks (thickeners) in order to remove/separate the solid content and to recover the supernatant water. The water recovery reaches up to 96\% (v/v), whereas the remaining sludge-waste is safely deposited in tailings ponds. Critical water quality parameters are systematically examined to assess its potential for reuse. The recovered water stands for almost 90\% (v/v) of the total water consumption for all uses within the industrial processing and mine activities.

Acknowledgments: This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T1EDK-03543).
A preliminary study on the potential of the LARCO laterite ore tailings as secondary source of cobalt

E. Tzamos¹, G. Grieco², P. Marescotti³, K. Simeonidis¹, A. Zouboulis⁴, A. Xenidis⁵

¹Ecoresources PC, Greece
²University of Milan, Italy
³University of Genoa – DISTAV, Italy
⁴Aristotle University of Thessaloniki, Greece
⁵National Technical University of Athens, Greece

E-mail: tzamos@ecoresources.gr

Low-emission mobility is an essential component of the broader shift to the low-carbon, circular economy needed for Europe to stay competitive and be able to cater to the mobility needs of people and goods. On this frame, a very important component (and the most expensive one) of all kinds of electric vehicles are their batteries; it is projected that until 2025, the EU-based electric cars battery manufacturers will supply ~6,000,000 batteries for electric cars. The uprising demand for these batteries, subsequently rises the demand for specific metals which are used for their manufacturing, namely Ni, Co and Li. Nickel is used as hydroxide or intermetallic compounds in NMC, NCA batteries, lithium as lithium-cobalt oxide (cathode) and as salt (electrolyte) in Li-ion battery and cobalt is used in cathode materials in LCO, NCA and NMC batteries. Li and Co are also included in the 2020 Critical Raw Materials list of EU, meaning that there is a great risk for their supply. EU should speed up the efforts for discovering new sustainable sources for these metals, both primary and secondary.

On this study, the mining tailings of the LARCO laterite ores from Evia were investigated as potential secondary sources of cobalt. A total of 10 tailing samples were analyzed for their chemical composition. The results show that cobalt has an average concentration of 614.70 ppm (median value 644 ppm), with values ranging from 377 to 815 ppm, thus making these tailings as a possible source for this metal. Samples are also particularly rich in Ni (average Ni concentration 9,440 ppm), with the small grain size of the tailings being a negative factor for their use as feed in ferronickel metallurgy at the Larymna plant.
Components’ Characterization of End-of-Life Dishwashers

E. Evangelou¹, G. Anastassakis¹, S. Karamoutsos², A. Stergiou²

¹School of Mining and Metallurgical Engineering, NTUA, Greece
²Ecoreset S.A., Greece

E-mail: eirhnh.ev@gmail.com

The treatment of Wastes of Electric and Electronic Equipment (WEEE) results to a significant sourcing of secondary raw materials. Ferrous and non-ferrous metals, electronic equipment, plastics, are among these materials. The related industries are strongly interested in the recovery of high-purity recycled products, leading to more efficient ways of recycling. Moreover, the environmental benefits will be numerous, such as decreased CO₂ footprint and decrease of raw materials consumption.

One of the most common metals sourced out of WEEE is stainless steel. Stainless steel components contain high percentage in iron; however, other elements such as Nickel (Ni), Manganese (Mn) and Chrome (Cr), which play a significant role in stainless steel properties are of high value and importance and their recovery is highly beneficial.

This project aims at the separation and recovery of stainless steel from dishwashers. The presented processing method results in the recovery of large quantity of stainless steel with minimum, or even free, of impurities.

Following a first size reduction of dishwashers via shredding, the shredded products get through magnetic separator (separation of all magnetic ferrous components), eddy current sensor (separation of all non-ferrous components) and induction sorting sensor (removal of all metallic fractions). This procedure leads to, the following two streams: one with stainless steel, boards and cables and one stream mainly with plastic. In the next stage, the stainless steel stream passes through a high intensity magnetic separator, leading to a magnetic and a non-magnetic stream. Thereafter, hand-sorting is applied to both streams aiming at the increase of recovery from each stream.

Satisfactory results are provided from this separation and recovery procedure. High recovery of stainless steel is achieved under various operational conditions. The chemical analysis in selected stainless steel pieces showed that the purity in many tests exceeded 90%. In addition, SEM analysis indicated that one selected stainless steel sample is austenitic (γ-Fe) and one sample is ferritic (α-Fe).
Valorisation of aluminium salt slag washed residue in the production of portland cement clinker

K. Piperopoulos¹, P. Oustadakis², M. Perraki², P. Tsakiridis²

¹Waste Management, School of Science and Technology, Hellenic Open University, Greece
²School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece,

E-mail: ptsakiri@central.ntua.gr

The presence research work focuses on the utilization of aluminum salt slag washed residue (SSWR) in Portland cement clinkerization. The initial Al salt slag was grinded to “-100μm”, in order to recover the residual metallic Al. The grinded salt slag was subjected to water leaching at various temperatures for the removal of the soluble salts (NaCl, KCl). During the process of washing, about half of the nitrides were also decomposed. Different amounts of the washed residue were introduced in the raw meal before sintering at 1450 °C. The produced clinkers have been characterized by means of chemical analysis, X-ray diffraction (XRD) and scanning electron microscopy (SEM). After co-grinding with suitable amount of gypsum, the produced cements were evaluated by determining setting times, standard consistency, expansibility and compressive strength at 2, 7, 28 and 90 days. XRD and TG/DTG analyses were used in order to determine the hydration evolution. According to the results of the physico-mechanical tests SSWR could be utilized as a raw material in the cement clinker production, presenting a promising alternative to disposal in landfills.
ReActiv: Industrial residue activation for sustainable cement production

P. Benard¹, E. Balomenos²

¹LafargeHolcim Innovation Center, France
²Mytilineos SA, Greece

E-mail: philippe.benard@lafargeholcim.com

ReActiv project will create a novel sustainable symbiotic value chain, linking the by-product of the alumina production industry and the cement production industry. Bauxite residue (BR) is the main by-product of the alumina sector produced at rates of 7 million tons per year in EU, while recycling rates are less than 200 thousand tons per year respectively. In ReActiv modification will be made to both the alumina production and the cement production side of the chain, in order to link them through the new ReActiv technologies. The latter will modify the properties of the industrial residue, transforming into an active material (with pozzolanic or hydraulic activity) suitable for new, low CO₂ footprint, cement products. In this manner ReActiv proposes a win-win scenario for both industrial sectors (reducing wastes and CO₂ emissions respectively).
Adding value to waste marble powder: Utilization as micro/nano-filler of protective epoxy polymer composites

D. Gkiliopoulos¹, K. Simeonidis², D. Efstathiadis³, G. Raska³, I. Polychroniadis³, K. Triantafyllidis¹

¹Department of Chemistry, Aristotle University of Thessaloniki, Greece
²Department of Physics, Aristotle University of Thessaloniki, Greece
³Stone Group International, Greece

E-mail: dgiliopo@chem.auth.gr

The aim of the present work was the valorisation of waste marble powder (WMP). More specifically, the potential use of WMP as polymer additive to produce novel epoxy/WMP polymer composites with improved marble protection action was studied. The benefits of an approach like this are manifold, as WMP, a by-product of marble industry, will be used to improve the properties of the final commercial products of the same industry. This way, economic losses can be reduced, and environmental pollution can be prevented. To achieve this purpose, WMP of Thasos marble was used to produce composite polymers with a reference system of diglycidyl ether of bisphenol-A (DGEBA) epoxy resin and amine curing agent, as well as commercial epoxy formulations that are used for marble protection. The produced composite material was applied to pieces of Thasos marble slabs and its protective properties were tested in comparison with those of the neat epoxy polymer. WMP was used both as it was produced and after particle size reduction/homogenization via ball-milling in various concentrations. Concerning the characterization of WMP, morphology and particle size were examined via scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS), structure and chemical composition were determined via Fourier transform infrared spectroscopy (FTIR) and X-ray powder diffraction (XRD), while thermal properties were determined via thermal gravimetric analysis (TGA). As it concerns the properties of pristine epoxy polymer and WMP composites, dynamic mechanical analysis (DMA) was used to determine the thermomechanical properties, differential scanning calorimetry (DSC) was used to determine the thermal properties, XRD was used to study the structure of the composites, while tensile, flexural, impact and compression tests were used to determine the mechanical properties. Finally, polymer coated marble specimens were exposed to UV light to test their color retention against UV radiation.

Acknowledgment
This research has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation (EPAE) 2014-2020, under the Action “RESEARCH – CREATE – INNOVATE B’ CALL” (project code: T2EDK-02205)
Separation of transition metals and rare earths using ionic liquid-based aqueous biphasic systems

X. Li, J. Van de Ven, K. Binnemans

KU Leuven, Belgium

E-mail: xiaohua.li@kuleuven.be

Solvent extraction is an often used industrial process for recovery of metal ions from aqueous solutions. Ionic liquids (ILs), solvents composed of entirely ions, are generally considered as environmentally friendly solvents, so that they are being applied as alternatives for molecular organic solvents in solvent extraction. However, the drawbacks of ILs, such as high viscosity and high cost, limit that application in industry. By forming ionic-liquid-based aqueous biphasic systems (IL-ABS), the advantage of ILs can be kept and the disadvantages can be mitigated. [1]

In this study, the water-miscible IL tributyltetradecylphosphonium chloride ([P_{444,14}]Cl) was employed for the formation of ABS with aqueous LiCl or NaCl solutions. The IL-salt ABS was then applied for separation of transition-metal and rare-earth metal pairs: Sm/Co, Nd/Fe, and Eu/Zn. After phase separation, the transition metals were extracted to the upper IL-rich phases, and the rare-earth metals stayed at the lower salt-rich phases. The effects of several parameters on the extraction efficiencies of Sm and Co have been investigated, including the concentrations of ILs, NaCl and LiCl. The extraction efficiency of Sm increased with the increasing NaCl concentration. With 3 mol L\(^{-1}\) of NaCl, Sm could be extracted quantitatively, leading to very high selectivity over transition metal ions. The extraction efficiency of Sm reached to 100% when 4 mol L\(^{-1}\) of LiCl was present. However, with the increasing concentration of LiCl, the extraction efficiency of Co gradually decreased and that of Sm increased. Therefore, the extraction efficiency of Co was a bell shape in terms of the chloride concentration. Precipitation stripping of Co from the IL-rich phase was studied using aqueous NaCl solution with addition of Na\(_2\)CO\(_3\) salt. The NaCl solution was required to maintain two phases. Co could be quantitatively stripped in the form of CoCO\(_3\) precipitate at a molar ratio of Co\(^{2+}\) to Na\(_2\)CO\(_3\) of 1:1.2.

IL-based ABS could effectively separate transition-metal and rare-earth metal ions. However, after extraction, the viscosity of the top IL-rich phase was still high, which could make the process difficult at a large scale. Therefore, new systems based on IL with shorter alkyl chain length are being developed.

References:
Development of STEM Educational Application with Easy Java Simulation in Mining and Metallurgical Engineering Educational Procedure. Case Study on Mineral Processing

K. Syrmakezis, K. Tsakalakis

National Technical University of Athens, Greece

E-mail: kcs@metal.ntua.gr

The transition of students, from secondary to tertiary level of education, is accompanied with a change in the followed educational approach. The new approach is characterized by the strong involvement of the learner in the acquisition of new knowledge, during the educational process. This reality highlights the need for the change of the established teacher-based model with the adoption of new didactics approaches, which promote the active participation of learners.

The adoption of STEM educational approach, in universities, is expected to enhance the participation of the students in the educational process, motivating them for further development of their understanding and knowledge in their specialized domains. Especially, for the students of the engineering schools, who use their acquired knowledge to find solutions and elaborate new approaches in engineering problems, the adoption of STEM approach seems promising and challenging.

Seeking to contribute to the limited research activity on the application of innovative educational applications in university education, the current research paper presents the results of the implementation of STEM educational approach in tertiary level education, through the development and use of EJS educational applications, for ‘university level’ engineering studies.

Its implementation was carried out as part of a thesis work for the Master of Science ‘Didactics in STEM’ of School of Pedagogical and Technological Education and focused on the case study of the teaching of “particle size-reduction process of ores”, as it was taught in the 5th semester course ‘Mechanical Preparation and Processing of Minerals and Industrial Minerals I’, at the School of Mining and Metallurgical Engineering of the National Technical University of Athens.

The research has been performed among students, who participated and followed the aforementioned course, during the academic year 2016-2017. During its execution, it was investigated the improvement of students’ performance because of the implementation of educational scenario that is based in a problem-based learning activity and it exploits educational tools and applications developed using Easy Java Simulation.

Analysis of the research results reveals that the application of the scenario selected, as well as the adoption of S.T.E.M. educational approach contributed directly to the students’ performance, especially for those students, who previously presented low performance. The conclusions of the research are aligned with the corresponding research efforts undertaken to other universities and they confirm the significant prospects arising with the use of modern educational approaches, as well as with the use of innovative educational tools, at tertiary level education.
Recovery of scandium as (NH$_4$)$_3$ScF$_6$ by crystallization

E. M. Peters, M. Svärd, K. Forsberg

KTH Royal Institute of Technology, Sweden

E-mail: edwpet@kth.se

Scandium has been classified by the European Commission as a critical raw material due to its increasing demand and limited supply. Due to the scarcity of scandium-bearing ores, it is attractive to recover scandium from waste streams of other mining and metallurgical processes such as the bauxite residue from the alumina industry. This is accomplished in a number of operations including leaching, solvent extraction and stripping, crystallization, calcination and metallothermic reduction. In the present study, we have investigated the recovery of scandium as (NH$_4$)$_3$ScF$_6$, by crystallization from strip liquors containing > 2 g/L scandium and trace impurities such as Fe, Al, Zr, Ti, V, U and Th in a 3 mol/L NH$_4$F solution. Anti-solvent crystallization using alcoholic solvents (methanol and ethanol) is shown to be an attractive and cost-effective method due to the high recoveries possible (> 99.5%) and the possibility to recover the alcohol by distillation for re-use. The crystalline phase obtained was confirmed to be (NH$_4$)$_3$ScF$_6$ with purity > 99.2 %. The solubility of ammonium metal fluorides has also been determined in 3 mol/L NH$_4$F-alcohol mixtures and the incorporation of impurities has been investigated.
Bioleaching is one of several applications within biotechnology. It is generally simple and lower cost to operate and maintain than conventional mineral processing technologies, while it is also more environmentally friendly. Thus, bioleaching is applied to low grade and refractory ores or wastes which cannot be treated effectively economically. The objective of this study was to evaluate the efficiency of the bioleaching of various mining and metallurgical wastes using mixed cultures of chemolitho-autotrophic mesophile microorganisms. The waste samples treated, were collected from the Kirki abandoned public mine, which is located at Prefecture of Evros, Northern Greece. The main minerals are quartz, galena, pyrite, sphalerite, chalcopyrite and anglesite and their chemical composition ranges from 0.09 – 4.8 g/kg As, 3.3 – 170 g/kg Pb, 2.1 – 89 g/kg Zn and 0.25 – 29 g/kg Cu. Experiments were carried out in shaking flasks of 250 mL in a shaking bath at a temperature of 35oC and a shaking rate of 200 rpm using the nutrient medium 9K. Parameters such as pH and Redox potential were recorded daily while the concentrations of solubilized metals such as Fe, Cu, Zn and Pb were analysed also. Results show that, in almost all samples tested, the yield of dissolution of Zn was very high and reached almost 90%, while Cu leaching yields hardly reached the value of 70%. By comparing dissolution data between abiotic (chemical) and biological experimental conditions, the conclusion is that bioleaching is the main dissolution mechanism. Results also reveal that bacterial adaptation procedure is a crucial factor towards process improvement.
Effect of fly ash on the mechanical performance of 316L and 304L stainless steel concrete reinforcement during accelerated saline corrosion tests

S. Tsouli¹, A. Lekatou¹-², S. Kleftakis¹, I. Tragazikis¹, T. Matikas¹

¹University of Ioannina, School of Engineering, Department of Materials Science & Engineering, Greece
²I.M.S.C., URCI, Greece

E-mail: s.tsouli@uoi.gr

The employment of 316L stainless steel as reinforcement of the architectural members in the ancient theatre of Dodona in Greece, as well as in the framework of the restoration of other ancient and modern monuments, is a common practice nowadays. However, even 316L is susceptible to localized corrosion in chloride containing environments. The replacement of 316L, which is an expensive steel reinforcement, with an economical one, such as 304L, combined with a non-expensive and environmentally friendly corrosion inhibitor, such as fly ash (FA), could become a profitable alternative, provided that it is also an equally safe solution. This is attributed to the formation of corrosion resistant pozzolanic reaction products.

Previous works by the authors [1,2] studying the effect of FA on the electrochemical performance and structural integrity of stainless steel concrete rebars in simulating acid rain and saline environments, showed a better corrosion performance of 20 wt.% FA addition compared to lower and higher FA additions. The present study investigates the effect of FA (0-25 wt.%) on the mechanical degradation of 316L and 304L rebars embedded in concrete cubes during 4 m of salt spraying. The degradation of 316L and 304L rebars was studied by tensile testing and ultrasound testing (elastic modulus (E) determination).

Partial replacement of Ordinary Portland Cement (OPC) by FA did not significantly affect the tensile properties of both 316L and 304L rebars during 4 m of salt spraying except a slight decrease in E and %elongation with FA increasing for both steels but within statistical error. 304L can replace 316L stainless steel in critical applications, such as the restoration of ancient and modern monuments and historical buildings, provided that FA has been added to the concrete mixture, even at low contents (10 or 15 wt.%). Visual examination revealed a good surface state for the specimens of both steels after 4 m of salt spraying.

Solar-assisted development of carbonate-derived nanoadsorbents for the hydrogen sulfide capture

P. Kougias1, I. Kellartzis2, D. Karfaridis2, K. Simeonidis2, C. Martinez-Boubeta3, L. Balcells4

1Hellenic Agricultural Organisation DEMETER, Greece
2Aristotle University of Thessaloniki, Greece
3Ecoresources PC, Greece
4ICMAB, Spain

E-mail: p.kougias@swri.gr

Calcium carbonate is a versatile material with high importance for industrial and building applications. In nature, CaCO$_3$ is highly available in dolomites, limestones and marbles depending on the conditions and the environment of sedimentation process. However, there are cases where CaCO$_3$ is considered a solid waste requiring some form of treatment or stabilization to avoid deposition in the environment. Suggestively, marble processing produces extremely large quantities of residual marble dust in the form of aqueous dispersion while mussels or oyster shells and eggshells are another significant source of CaCO$_3$ wastes. The recovery and utilization of such by-products is usually attempted by their incorporation in cements, road asphalts and plastics as replacements of other inert powders. Another set of applications considers the alkaline character of CaCO$_3$, as well as its product CaO, as a way to neutralize acidic sources. This study aims to the development of novel adsorbents with high desulfurization potential through the production of calcium carbonate-based nanoparticles using the solar physical vapor deposition (SPVD) technique, and their evaluation in a laboratory-scale setup. Studied nanopowders were prepared using the simple and low-cost method of SPVD in a Heliotron 2 kW glass chamber. Structural characterization of the produced nanopowders indicate high-crystalline CaO as the major phase appearing in all samples. The presence of MgCO$_3$ in dolomite and marble targets is responsible for the presence of MgO in the corresponding nanopowders. SEM images of the collected samples indicate the nanopowders consist of small nanoparticles with typical dimensions below 40 nm. The preliminary evaluation of nanopowders in the fixed bed reactor indicated an enhancement of adsorption efficiency in comparison to corresponding raw materials. This is mainly attributed to the dramatic increase of specific surface area in the studied nanopowders which enables higher contact times and reaction kinetics. XPS analysis suggests that sulfur capture can be performed through elemental sulfur or HS$^-$ species for H$_2$S.

The research project was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the “1st Call for H.F.R.I. Research Projects to support Post-Doctoral Researchers” (Project Number: 580 microAD). Authors would like to thank the CNRS-PROMES laboratory, UPR 8521, belonging to the French National Centre for Scientific Research (CNRS) for providing access to its installations, the support of its scientific and technical staff, and the financial support of the SFERA-III project (Grant Agreement No 823802).
Efficient recovery of solid waste units as substitutes for raw materials to produce different types of ceramics

I. Makrygiannis

NTUA, Greece

E-mail: ymakrigiannis@sabo.gr

Ceramic plants for brick and tile industry, constitute energy-intensive production units and their sustainability depends largely on the coverage of their energy demands. Raw material and the additives that compose the product mixture, seem to be a key factor to this direction. Moreover, every product type (solid or perforated brick, tile, porous heat-insulating a.o.), requires different additives to achieve the properties that are postulated by the international standards for every product. For the study, a wide range of additives that were used, has been assorted into three (3) categories: The Inert materials, the lightweight materials, and the industrial remains. Totally, eleven (11) different materials were used as additives into ceramic mass, in different proportions each time. The extrusion of specimens perforated and not, was carried out using the Laboratory’s vacuum press. Firstly, the extrusion of specimens from the original raw material was implemented and secondly extrusion was made on the material mixed with the additives mentioned above. A series of experimental activities was followed in order to determine the variations of the mechanical and physical properties as well as their production environment. Besides the alteration of the mechanical and insulating properties that the additives assign to the final product, in many occasions they contribute to the energy conservation of the ceramic kiln. The energy conservation is obtained by the calorific value of each additive and its proportion to the final mass.
Mechanochemical activation of muscovite mica-rich sulfidic mining waste rock for alkali activation with implication of grinding process simulation

H. Niu¹, L. Adrianto², A. Escobar³, P. Kinnunen¹, M. Illikainen¹

¹University of Oulu, Finland
²ETH Zurich, Switzerland
³Universidade de Lisboa, Portugal

E-mail: he.niu@oulu.fi

Mining operations and mineral processing plants often generate large quantities of waste rock and tailings. Waste rock production in Neves Corvo mine varies depending on types of ore and underground operations, however, 60% of the waste rock is utilized directly as waste backfill. During 2010-2019, the Neves Corvo operation has accumulated 7.3 Mt of waste rock stored at the Cerro do Lobo dam in co-deposition with tailings while 3.1 Mt remained temporarily stocked in stockpiles. It is known how sulfidic mining waste rock gives rise to a heavy eco-burden, such as acid rock drainage, if no remediation strategies would be adopted. In this context, reusage of this large stream with appropriate purpose, which is economically feasible, should be concerned. Alkali-activated material, partially equivalent to inorganic polymers (geopolymers), is a three-dimensional framework of aluminosilicates with alkaline cations charging balance. However, the low chemical reactivity of mineral residues can be a challenge in alkali-activation. In the present study, the reactivity of Neves Corvo waste rock was increased by mechanochemical treatment. X-Ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) analysis were utilized to display the structural alternation of individual minerals. A schematic implication was provided according to the results of transmission electron microscopy (TEM) and scanning electron microscopy (SEM).

To perform robust environmental assessment at industrial scale, an upscaling approach was conducted using a metallurgical process simulator HSC Sim® module developed by Metso Outotec Research Oy. This method allowed for systematic life cycle inventory modelling and parameterizations of the processes, namely the mineralogy of waste rock and particle size distribution. The grinding process model was established based on the parameters, namely the mineralogy of waste rock and particle size distribution.

The results displayed that Neves Corvo waste rock could be a promising secondary raw material for alkali-activation. It is possible to pre-treat such considerable amounts of waste by grinding with less environmental impacts according to process simulation.
A Date Seed-based Carbons for Methane Storage and Carbon Capture and Storage (CCS)

A. Altwala, R. Mokaya

University of Nottingham, United Kingdom

E-mail: Pexaa37@nottingham.ac.uk

This study explores the conversion of a new biomass to activated carbons via a flash carbonisation process at relatively low temperature (>400 °C) that negates the need for hydrothermal carbonisation or pyrolysis. The biomass derives from date seed, which is a by-product of date production, which is very popular in Saudi Arabia. The biomass precursor (date seed) was successfully converted to carbonaceous matter via flash heating for a short period of time (5–10 minutes) under a flow of air. The process is simple, and operates at a lower cost compared to conventional methods. Nonetheless, the formed activated carbons have properties that are similar or superior to analogous carbons prepared via conventional methods. Air carbonisation with KOH as an activating agent generated activated carbons in yields ranging between 46%-64% wt, comparing favourably to yields generally achieved using hydrothermal carbonisation or conventional pyrolysis protocols. The highest surface area and pore volume achieved were 2,738 m²/g and 1.20 cm³/g respectively. The porosity of the carbons can be tailored towards being predominantly microporous, which generates materials that exhibit very attractive CO₂ uptake (up to 4.0 mmol/g) at 1 bar and 25 °C. The activated carbons generated from the flash carbonisation of date seed exhibit unprecedented total gravimetric methane uptake of up to 11.3 mmol/g at 25 °C and 35 bar.
Overview of the ERA MIN2 project "nanoBT: Application of nanobubble technologies to mining industry operations"

K. Komnitsas¹, N. Kalogerakis¹, Q. Botha², G. Kolliopoulos³

¹Technical University Crete, Greece
²Fine Bubble Technologies (Pty) Ltd., South Africa
³University Laval, Canada

E-mail: komni@mred.tuc.gr

The nanoBT project offers a socially acceptable roadmap to revitalize the mining sector in Europe. Building on the principle of sustainability, advances are made towards a future of sustainable metal extraction and zero-waste mining. Key to this green engineering solution is the utilization of nature-based processes and of the highly innovative nanobubble technology.

Québec’s cold winter climate in conjunction with CO2 nanobubbles are used to drive the selective water recovery from effluents in tailings ponds. The technology being developed is based on hydrate based desalination and essentially uses the CO2 gas bubbles at low temperatures to form cages that selectively “trap” and recover pure water in ice-like structures. Using nanobubbles enables the formation of cages at the nm-level, which increases the selectivity as well as the purity of the recovered water. Although the energy for freezing in Québec is free (6 months per year) due to the cold winter, this technology is also appealing worldwide, as the energy for freezing is 7 times less than that of evaporation of water. Furthermore, nanoBT treats the resulting dewatered concentrate with green anhydrous biodegradable deep eutectic solvents to selectively recover valuable metals, which could finance the remediation process. Moreover, these deep eutectic solvents are inexpensive, environmentally benign, and can be fully recovered and recycled, thus leading to a “no new waste” processing route.

Greece’s mild Mediterranean climate results in increased vegetation, thus making phytoremediation processes attractive. Nanobubbles result in increased plant growth and root development. The latter leads to a higher metal removal yield from the soil via phytoextraction. Such techniques are more environmentally friendly, less expensive, and have much lower secondary implications in comparison to others that involve waste transport for additional treatment. Vegetative growth on mine spoils can be sustained by the addition of amendments to mitigate their initial toxicity. Biochar has been selected as an important amendment which works synergistically with the plants to improve soil properties, bacterial and plant growth and finally metal uptake rates. This is actually the main novelty of our “biochar-assisted phytoremediation” approach. The ultimate objective is to increase the efficiency of phytostabilization & phytoextraction technology to remediate toxic metal spoils with the combined use of halophytic plants, biochar, and nanobubbled irrigation water.

The above technologies strengthen and extend our current understanding in the field of environmental remediation of mining wastes, which are viewed as secondary resources for both water and metals.
Distribution of radon concentrations in active and inactive underground mines

K. Asimakou, N. Kallithrakas-Kontos, A. Vafeidis, E. Manoutsoglou

School of Mineral Resources Engineering of the Technical University of Crete, Greece

E-mail: kasimakou@isc.tuc.gr

Radon (Rn), a natural colorless, odorless, noble radioactive gas, with a half-life of 3.8 days, is the most important source of natural ionizing radiation. It comes from the initial concentrations of uranium and its transmuted daughters in rocks, soil and finally waters and tends to be concentrated in closed spaces such as underground mines, caves as well as in underground and mainly ground floor houses. The effects of radon on human health have been investigated for several decades in which more published papers on the subject, record and monitor the values of radon concentrations in all the areas described above and support the need for rules, for the protection of living, working and ordinary visitors to places where radon is highly concentrated. The comparison and evaluation of radon concentration in active and non-active mining sites, the effect of the concentration on human health and the different upper concentration limits applicable by state, are the target of this paper. Data were collected from a total of 82 publications in international journals that have received the most citations in the international literature. The mines studied were categorized into: "uranium mines", "coal mines" and "other mines" (including gold mines, iron mines, copper mines and salt mines). According to the data of the works used, the above works refer to a total of 164 mining sites that are distributed in 29 countries around the world. Out of these sites, 107, i.e. a percentage of 65.24%, refers to active and the rest to inactive mining sites. As far as the inactive mining sites are concerned, 15 of those are already being reused for tourist purposes, while 3 others are about to be used for the same purpose. In the 30 uranium mines under study, radon concentrations were found to range from a few Bq/m$^3$ to some million Bq/m$^3$ (8 - 3,932,920 Bq/m$^3$). In the 71 coal mines under study, concentrations were found from 1.22 to 64,400 Bq/m$^3$. Finally, in the other mines of salt, iron, copper, hematite, etc., the concentrations ranged from a few tens to a few thousand Bq/m$^3$, as also seen in the coal mines. In addition to radon concentrations, the work comments on radiation exposure times as well as the concept of "dose" (equivalent, absorbed, effective) associated with the radiation time of employees, tourists and visitors with emphasis on workplaces, which are priority areas in the guidelines.
Machine learning-assisted selection of elemental composition for refractory high-entropy alloys

B. Postolnyi¹,2, V. Buranich², J.P. Araújo¹, A. Pogrebnjak², V. Rogoz²

¹Institute of Physics for Advanced Materials, Nanotechnology and Photonics, FCUP, University of Porto, Portugal
²Sumy State University, Ukraine

E-mail: b.postolnyi@gmail.com

Refractory metals are in focus of this research, since they separately demonstrate outstanding physical and mechanical properties, such as high melting temperatures, high hardness and wear resistance, which is essential for protective coatings and may give a beneficial synergistic effect in high-entropy alloys matrix.

High-entropy alloys (HEAs) contain at least five metallic components with a molar atomic concentration of each one between 5 and 35%. This gives high values of entropy of mixing, which in a couple with other factors (atomic size difference, mixing enthalpy and other less important ones) leads to the formation of a single-phase material with randomly and uniformly distributed alloying elements [1]. Such materials benefited from HEAs approach exhibit excellent physical and mechanical properties, in particular, high hardness and toughness, superb wear, creep, corrosion and oxidation resistance [2–4]. Properties and stability of HEAs highly depends on their elemental composition. Since there are millions of combinations of elements and their fractions, it is impossible to evaluate each one experimentally. For such purposes various approaches of phase stability, physical and mechanical properties can be applied: density-functional theory (DFT) calculations, thermodynamic calculations, machine learning etc.

In our recent studies we considered various elements from the refractory metal group and established a certain correlation between thermomechanical properties and elemental composition [5]. Alloys composed of Ti, V, Nb, Hf, Ta, and W served the best outcome properties.

References


Acknowledgements:
The research has been partially supported and funded by the Ukrainian state budget via the project Improved Physical and Mechanical Properties of Multilayer Protective Coatings Based on High-Entropy Alloy Nitrides (project number 0120U100475).
Self-assessment tool for OSH Management in SMEs extractive enterprises

P. Maraboutis, N. Poulimenou, E. Nikolaou

Eco-Efficiency LTD, Greece

E-mail: p.maraboutis@ecoefficiency.gr

The extractive industries are considered as of high-risk sectors worldwide. (International Labour Organization (ILO), 2010). The highly variable working conditions in mining and quarrying and other extractive industries’ sites makes the occupational safety and health (OSH) as challenging issues to keep up with. Considering the accident rates from small-scale sites they need assistance to effectively manage OSH in their everyday activities. For this purpose, EUROMINES along with IndustriAll developed a set of tools to build and promote soft skills and competencies for an OSH management system tailored to small, medium, and micro extractive companies. The innovation of this project is the self-assessment tool for OSH that is designed specifically for workers of the extractive sector who wish to improve their performance in key health and safety issues, in collaboration with operators and mining workers from EU member states. The user of the self-assessment tool is called to respond to questions for the key health & safety parameters to identify the necessary skills and the level of knowledge he needs to effectively manage occupational risks in his workplace. Based on the score they achieve per question; the self-assessment tool proposes the worker to review the relative training material that is linked with each section and will remind them to repeat the test after the training. The overall score of their performance will be used to illustrate their individual improvement after the training. Eco-efficiency Consulting and Engineering Ltd prepared the material for the project, which was translated in Bulgarian, Hungarian, Polish, Spanish, and Czech.
Wednesday 8 September 2021
OLYMPIA

PLENARY LECTURES

Chair: D. Panias, A. Zouboulis
Mitigating the European dependency of mineral raw materials: The role of the Mineral Resources Expert Group and GeoERA Raw Materials

Daniel P. S. de Oliveira

Mineral Resources and Geophysics Research Unit (LNEG)
Mineral Resources Expert Group (EuroGeoSurveys)

E-mail: daniel.oliveira@lneg.pt

The European Commission recognises that raw materials are increasingly important for the competitiveness of Europe’s industry, for innovation and for the transition to a low-carbon, more circular economy. Many new enabling technologies rely on materials that are predominantly produced outside of the European Union, such as cobalt for lithium-ion batteries powering low-emission mobility or rare-earth elements for energy-saving electronics. International competition for such raw materials is becoming more intense. The Mineral Resources Expert Group (MREG) of EuroGeoSurveys consists of a group of earth scientists designated by each geological survey member of EuroGeoSurveys that acts upon requests and queries received by member states and the EU Commission. Its mission is to provide the best available mineral expertise and information based on the knowledge of Geological Surveys, for policy, communication, public awareness and education purposes at EU level, focusing mainly on strengthening the position of the European minerals industry towards resource sustainability and competitive growth and is actively involved in contributing to policy- and strategy-making processes aiming to identify, characterize and safeguard a sustainable resource potential, notably on CRM, through research, development and innovation.

GeoERA’s (Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe) main objective of GeoERA is to contribute to the optimal use and management of the subsurface. It started in 2018 with 15 research projects that support a) a more integrated and efficient management and b) more responsible and publicly accepted, exploitation and use of the subsurface. The projects cover the applied geosciences, addressing the following themes: Geo-Energy, Groundwater, Raw Materials and the Information Platform.

The four raw materials projects, namely, FRAME, MINDeSEA, MINTEL4EU and EuroLithos have each come to represent the next innovative milestones in mineral intelligence. FRAME tackling the land-based resources, MINDeSEA the sea-based resources, EuroLithos the ornamental stones and MINTEL4EU placing all the results together in coherent datasets for upload to EGDI (European Geological Data Infrastructure).

Working in conjunction, this two-pronged approach to mineral intelligence forms the backbone of the current research and innovation taking place in Europe. Research is ongoing.
Wednesday 8 September 2021
OLYMPIA

SESSION C1
Mineral processing of ores and end-products

Chair: D. Mesa, G. Anastasakis
Putting the ‘Smart’ into ‘Smart sorting’: Novel methods to identify ore and gangue on run-of-mine

N. Horsburgh, A. Finch

University of St Andrews, United Kingdom

E-mail: njh36@st-and.ac.uk

Novel spectroscopies have potential in ‘smart sorting’ to identify efficiently ore minerals in run-of-mine (ROM). If ore could be sorted into ‘resource-rich’ and ‘resource-poor’ fractions prior to processing, substantial savings in the costs and carbon footprint of mining would be achieved. Of the spectroscopies we have studied one of the most promising is luminescence because ore and/or gangue minerals often have strong characteristic responses. Introducing the practice of luminescence spectroscopy into the cache of smart sorting equipment currently utilising X-Ray and laser technologies has the potential to increase the efficiency and sustainability of Rare Earth Element (REE) ore beneficiation and processing.

Luminescence is invoked by X-Ray techniques, such as X-Ray Fluorescence (XRF) and X-Ray Transmission (XRT), also by excitation with photons from optical sorting operating 3-D lasers, making the coupling of luminescence to other sorting methods practical. Currently diamonds are separated from gangue by X-ray luminescence methods, in principle the same ‘fingerprinting’ can be applied to REE minerals.

REE minerals, such as bastnaesite, catapleiite and monazite can show characteristic luminescence emission lines related to f-f energy cascades in lanthanide (III) ions. Many minerals, however, contain multiple REE, local defects (including chemical substitution) and lattice damage. These features affect the energy cascades and quantum efficiency of REE leading to complex spectra. In most cases it is not possible to assign confidently a single fingerprint to a mineral group but it is possible once ore minerals from a particular locality are characterised as often consistent behaviour is observed.

Comminution of ore in an average mining/processing operation accounts for nearly half of all energy used. Globally comminution is estimated to consume approximately 2% of electricity produced. Optimisation of the ROM at the sorting stage reduces the energy consumption, water usage and processing time by reducing the waste before the ore enters the crushing and concentration, separation stages. With a move to responsible sourcing and increasing global demand for raw materials, new and innovative solutions are required to reduce environmental impacts and improve recovery. Luminescence sorting of ore prior to grinding would significantly reduce energy requirements of processing. This may be by increasing the grade, targeting particular minerals, or from the removal of detrimental minerals at an early stage. Both increase the productivity, result in processing of higher-grade ore and increased overall recovery of target product.
Development and validation of a dynamic model for flotation predictive control incorporating froth physics

P. Quintanilla, S. J. Neethling, P. R. Brito-Parada

Imperial College London, UK

E-mail: p.quintanilla18@imperial.ac.uk

Froth flotation is the largest tonnage separation process in the world, used to separate valuables minerals from the gangue on the basis of surface properties. As froth flotation is a large-scale process, even small improvements in the separation efficiency would translate into important increments in production. Optimising the process to increase metal recovery also increases the sustainability of the operation. One of the most efficient ways to optimise the process is to implement advanced control techniques. Model Predictive Control (MPC), in particular, is widely considered as one of the most efficient strategies to optimise a multivariable process, using an explicit, dynamic model of the process to predict the future behaviour of the most important variables. However, implementing MPC for froth flotation is very challenging, as modelling this process is a difficult task due to the very complex dynamics involved and since it is a multiphase (gas-liquid-solid) system with inherent instability. Models for control purposes must be simple enough - yet robust – to solve the control problem in real-time. Both characteristics conflict with each other; it is thus necessary to find a trade-off between simplicity and robustness.

A dynamic model for MPC purposes has been developed and validated with experimental data. The proposed flotation model differs from the others found in previous studies since, for the first time, the physics of froth is included for control purposes. The importance of including froth physics lies in the fact that the phenomena occurring in the froth – such as bubble coalescence, bubble bursting and particle motion – ultimately determine the separation efficiency and thus the recovery of metals. Having models of the froth phase for MPC will allow detailed predictions and therefore better control strategies to maximise the amount of valuable metal recovered.
Modeling approaches in ball milling of bauxite ores

E. Petrakis, K. Komnitsas

Technical University of Crete, Greece

E-mail: vpetraki@mred.tuc.gr

Comminution is an important operation in mineral processing plants and provides the desired size for separation operations and the liberation of the valuable minerals. Estimations on energy consumption indicate that milling consumes more than 50% of the total energy used in mining operations. Despite the fact that ball milling is an efficient operation, it is energy intensive and its modeling is a great challenge. In the present experimental study, an effort is made to model grinding of bauxite ores and identify the optimum material filling volume in the ball mill. Modeling is based on the characterization of the grinding products obtained after various grinding periods and the description of the particle size distributions using mathematical approaches, i.e. Gates–Gaudin–Schuhmann (GGS), Rosin–Rammler (RR) and logistic distributions. In addition, grinding kinetic models were applied to the experimental data in order to identify if the linear theory of the population balance model is valid during bauxite grinding. The experimental data revealed that the logistic distribution is a slightly better model for representing particle size distributions obtained after grinding, and fits the experimental data better than the GGS and RR models. Regarding grinding kinetics analysis, it was found that grinding exhibits non-first-order behavior and the reduction rate of each size is time dependent.
Retrofit designs for the pulp-froth interface: impacts on air recovery and froth stability

D. Mesa, S. Neethling, P. Brito-Parada

Imperial College London, UK

E-mail: d.mesa16@imperial.ac.uk

The pulp-froth interface is the common name given to the quiescent zone in between the pulp and the froth in a flotation cell, where the bubbles begin to closely pack, leading to the formation of the froth. Ideally, this interface would serve as a flow regime transition zone from the highly turbulent pulp towards a laminar-flowing froth, aiding froth stability and preventing entrainment, to ensure good flotation performance is achieved. While this is true to a certain degree, recent studies have clearly shown that turbulence in the pulp zone can affect the pulp-froth interface, which has been evidenced by swirling and froth instability. Similarly, it has been observed that fast moving flows near the walls of the cell tend to carry more water, generating wetter froth zones near the wall. This higher liquid content near the walls can generate an increase in entrainment, especially for fine particles, which can lead to a destabilization of the froth.

In this work, we study the impact of three pulp-froth interface retrofit design modifications on froth stability, measured in terms of air recovery in a bench-scale flotation tank. The designs assessed correspond to inverted semi-conical funnels of different lengths and geometries, which are installed at the interface to separate the pulp from the froth, with an angle that allows redirecting the pulp flows near the wall towards the centre of the tank to prevent entrainment and the effects of the fast-moving high-liquid content flows. Experiments were carried out with a singles species system at different air flowrates to determine changes in froth stability, and samples were obtained for future assessment of the changes in flotation performance. The findings are discussed with a focus on linking pulp and froth zone phenomena.
From Mineral Processing to Recycling; The case of End-of-Life Printed Circuit Boards Physical Processing

K. Syrmakezis, K. Tsakalakis, I. Sammas

National Technical University of Athens, Greece

E-mail: kcs@metal.ntua.gr

The continuously growing needs of modern societies for large quantity of consumables and raw materials, combined with the existing environmental challenges of raw materials depletion, energy savings highlight the inevitable need of recycling. Research and industrial communities focus their efforts for the development tailormade of new and efficient recycling methods and technologies, tailormade to the specific features of the different generated waste streams. Common attribute of all these methods is the obtainment of maximum recovery of valuable materials, through the application of certain methods of concentration. Nearly all methods of concentration utilised in the recycling industries have been developed from mineral beneficiation technology. One of the waste streams, which treatment presents special interest, is the of End-of-Life Printed Circuit Boards. Their treatment consists a contemporary recycling challenge, with significant environmental, economic and social dimensions. For this reason, instead of being considered a waste stream, End of Life Printed Circuit Boards are considered as a type of ore and, in specific as industrial ores, with significant market value. This reality has attracted the interest for the development of sustainable treatment processes, founded on mineral processing processes. Magnetic, electrostatic, gravity and flotation processes were applied in the treatment of End-of-Life of Printed Circuit Boards, seeking either the pre-treatment of processed waste stream for further processing or refining or for direct recovery of certain metallic elements, such as in case of copper. The outcomes of these endeavours resulted in promising results. In certain cases, high recoveries obtained for valuable materials, such as, for tin (95%), nickel (96%), copper and silver (98%). Seeking to highlight the strong dependency of mineral processing and recycling, the present paper reviews the applications of the conventional mineral processing procedures in the treatment of End-of-Life Printed Circuit Boards waste stream. The analysis of their outcomes is used to highlight their prospects, strengths, weaknesses and limitations in the processing of a valuable waste stream, such as the one of End-of-Life Printed Circuit Boards.
Engineering bio-colloids as sustainable reagents in mineral froth flotation

R. Hartmann, R. Serna-Guerrero

Department of Chemical and Metallurgical Engineering, School of Chemical Engineering, Aalto University, Finland

E-mail: Robert.Hartmann@aalto.fi

The increasing demand of raw materials and the subsequent depletion of mineral resources represent a major challenge on the mining industry. In addition, an increased awareness of the impact of industrial activities demands mineral beneficiation processes that are both more efficient and with a lower environmental footprint. One promising alternative to support the transition to a more sustainable mineral raw material supply is the employment of reagents in flotation processes based on renewable resources, such as cellulose, lignin or chitin. These reagents are bio-colloids, which typically undergo a mechanical and chemical treatment to obtain particles in nano- or micrometre scale. Despite their use in other industries, the use of such bio-colloids has not been systematically explored in the field of mineral processing, although their surface chemistry can be tailored to act as a high-efficient collector, depressant or frother in froth flotation. Indeed, through the incorporation of adequate functional groups, it is expected that bio-colloids will present a selective interaction with specific mineral species to modify their surface wettability. Bio-colloids bear the potential to be more efficient than water-soluble molecules as a result of their spatial dimensions, i.e., a lower mass of bio-colloids leads to a sufficient hydrophobization (as collector) or hydrophilization (as depressant) of mineral particles after adsorption. Therefore, based on the knowledge of currently employed reagents, bio-colloids can be engineered to possess an optimum range of granulometric and surface-chemical properties to replace petroleum-based chemicals. This work presents one such example, namely hexyl-amine cellulose (HAC), a candidate to replace toxic amines for the flotation of silicates. Based on laboratory-scale flotation experiments, HAC presents higher efficiency in recovering quartz (> 80%) at low concentrations (≤0.2 g/t) compared with dodecylamine (> 50%), a reagent commonly used in industry. This work demonstrates that, through the proper understanding of the behaviour of bio-colloids in mineral suspensions, renewable flotation reagents can be engineered for the beneficiation of minerals from primary and secondary resources.
Assessment of desulfurization process of polymetallic ore based on flotation

L. Cisternas¹, Y. Botero¹, M. Benzaazoua²

¹University of Antofagasta, Chile
²University of Quebec, Canada

E-mail: Luis.cisternas@uantof.cl

In a traditional flotation process of sulfide ore, the pyrite ends up in tailings, which can produce acid mine drainage (AMD). Therefore, there is a growing need for cleaner production strategies, with prevention prioritized over waste remediation. The last one is framed in the end-of-pipe technology, which focuses on remediation of AMD. Consequently, the production of tailings with a minimum content of acidifying species such as pyrite should be seriously considered. Nevertheless, methodologies have not been developed that allow AMD's total elimination in the early stages of the concentration process. In this sense, a future practice that could be implemented to prevent AMD would be to identify the source of potential AMD generation in the process and implement methods that allow the separation of acidifying sulfides in an early stage of flotation. This methodology could be called in-process technology following the cleaner production approach.

This work aims to assess the advantage and disadvantages of the tailing’s desulfurization inside and outside of the concentration process. The work presents the desulfurization of polymetallic ore using three design approaches, desulfurization at the end of the process (End of Pipe), desulfurization inside the process using a fractional separation, and desulfurization inside the process using an integrated separation. The design of circuits was carried out based on the advanced optimization design. In the end-of-pipe approach, the design is carried out to obtain the desired product without taking into account the desired properties of the tailing. Then, the tailing is reprocessed for desulfurization. First, a bulk sulfide concentrate is obtained in the fractional design procedure to achieve a tailing with low sulfide content. Then the concentrate is separated following a fractional separation. In the integrated design, the problem is analyzed in an integrated way to search for the best design. The effect of uncertainties on the design is also analyzed, including uncertainties in stage recovery and metal price. The results show that there are advantages in designing the flotation process that considers the desulfurization in the early stages of the design.
Wednesday 8 September 2021
VERGINA

SESSION C2
Sustainability

Chair: K. Adam, G. Gaidajis
MinLand - Mineral Resources in Sustainable Land-Use Planning

R. Arvidsson, N. Arvanitidis

Geological Survey of Sweden, Sweden

E-mail: ronald.arvidsson@sgu.se

The MinLand project focused upon integration of mineral resources policies and land-use planning at different scales and levels. The project is designed to facilitate minerals and land-use policy making by lining the two policy arenas, to strengthen a transparent land use practice, transparency and networking across Europe. MINLAND is composed around the acknowledgement that the call requires a broad and competent consortium with strong links to related projects and activities, a comprehensive and structured data repository, an efficient work flow and strong and broad stakeholder involvement. MINLAND has collected and structured information from member states and EU activities (stocktaking), performing in-depth analyses and industrial and policy case studies on challenges and solutions to safeguarding of mineral, land use solutions and tools, connections between the different involved policies. The project has compiled a comprehensive and practically applicable database concerning legislation, policies, case studies of exploration, mining and related policies. A stakeholder network has been built consisting of authorities, industry and NGO which has been engaged in workshops both at national through European regional scale and at European level for learning, consultations and quality assessment of results.
The dual paradigm of mine waste: “from ecotoxicological sources to potential polymetallic resources” – an example from Iberian Pyrite Belt (Portugal)

S. Barbosa¹, A. Dias², A. Ferraz³, S. Amaro¹, M. Brito¹, J. Almeida¹, S. Pessanha²

¹NOVA FCT - Nova School of Science and Technology & GeoBioTec, Portugal
²NOVA FCT - Nova School of Science and Technology & LIBPHys, Portugal
³NOVA FCT - Nova School of Science and Technology, Portugal

E-mail: svtb@fct.unl.pt

Nowadays, mining waste can be considered an important source of critical raw materials (CRM), such as metals and rare earths. The main goal of this study is to identify the chemical elements present in three types of polymetallic mine waste slags, stored in the old mine site of São Domingos, located in the Iberian Pyrite Belt (IPB), Alentejo, South Region of Portugal. This study involves the characterization of potential resources present in those mining residues, bearing in mind that extraction of CRM can facilitate the environmental remediation and rehabilitation activities which are underway at this site. As some of the most relevant CRM occurs in fine to very fine particle grain size fractions and at micrometric scale, micro-XRF 2D mapping surveys were performed. Univariate, clustering, and multivariate data analysis reveal the distinct patterns and compositions of the studied mining waste. Image processing and clustering analysis allowed the recognition of distinct elemental grain size fractions and its respective spatial distribution patterns. The polymetallic geochemical footprint of the IPB Belt results in the multiple existence of distinct elements per waste. Among others, it is to highlight the occurrence in distinct mineral and concentration conditions of Zn, Cu, Ag, Ag, Pb, Sn, Sb, Se, Al, Mo, Ga, Ge, REE, Sc, In, Ta, Ti, W, Nb, Ba, Be, Bi, Sr, Mg, Cr, Cd, Co, Y and other common mine processing “penalties”, like Fe, Mn, and As. The long mining history of the site explains the variabilities founded in the distinct wastes. In another perspective, environmental impacts and potential toxicological effects generated directly from these wastes are mainly associated to AMD generation and propagation along several km downstream from the mining area. Under these circumstances, static leaching laboratory experiments were also performed. The achieved results allowed to conclude that, despite the polymetallic compositional richness of these mining waste, several elements remain in the material matrix without remobilization or dispersion in environmental natural conditions. Some of these wastes are categorized as archeologic-industrial heritage materials. This fact enhances, therefore, geoethical doubts regarding its remining and exploitability. In this context, an analysis based on geethical criteria was performed under two main possibilities (1) the interest of these waste materials to be reprocessed and (2) the permanence of these wastes at the old mining site, in more environmental controlled conditions, without reprocessing. Advantages and disadvantages of these two opposite actions were balanced according with local and regional conditions.
In a world where the importance of mining for the socioeconomic wellbeing cannot be understated, the growing concern of communities and governments for sustainability issues sets mining industry under the spotlight. Over the past three decades there is an international effort of launching measures for the improvement of the sustainability performance of the sector. Within this framework, the concept of responsible mining has been developed and can be defined as the mining activity carried out in an economic, environmental and social responsible way. Although, initially, responsible mining was related with legal compliance, overtime the mining industry has recognized the necessity of changing this approach and developed several voluntary initiatives that address several sustainability issues related with the environment, the social acceptance and ethics. In this paper we present a review of the associated literature, with a detailed list of voluntary responsible mining initiatives, classified according to their type, objective, addressed topics and target groups. Furthermore, we examine the factors that have motivated mining companies to take on these initiatives, as well as the main characteristics that make these initiatives valuable for ensuring the sustainability of the global mining industry.
MCDM applied to the evaluation of transitional and post-mining conditions – an innovative perspective developed through the EIT ReviRIS project

S. Lourenço Amaro¹, S. Barbosa¹, G. Ammerer², A. Bruno³, J. Guimerà³, I. Orfanoudakis⁴, A. Ostrenga⁵, E. Mylona⁶, M. Hitch⁷, J. Strydom⁸, J. Šinkovič⁵, M. Kaleda⁵

¹NOVA FCT - Nova School of Science and Technology; GeoBioTec, Portugal
²Montanuniversität Leoben, Austria
³Amphos 21, Spain
⁴ECHMES LTD, Greece
⁵AGH University of Science and Technology, Poland
⁶National Technical University of Athens, Greece
⁷WA School of Mines, Curtin University, Bentley, WA, Australia, Australia
⁸Tallinn University of Technology, Estonia

E-mail: s.amaro@fct.unl.pt

In mine closure, the identification of an appropriate Post-Mining Land Use (PMLU) is necessary and crucial to achieve environmental quality, socioeconomic renewal, and social acceptance of mining projects. In this context, Multi-Criteria Decision Methods (MCDM) are applied to support decision-makers and stakeholders involved, identifying the relevant factors and criteria, so that, different available alternatives can be evaluated and compared. This process allows the stakeholders to define a ranking of examined solutions and determine “the best possible alternative” through a documented process. In this research, distinct criteria groups, such as social, environmental, regional, technical (applied engineering), economical, and geoethical, and 15 distinct Transitional Post-Mining Landscape Profiles (TPMLP) are identified and organised for the subsequent decision-making process modelling. The TPMLP are defined in the context of peripheral European countries, through Portuguese, Greek, and Polish case studies, and they refer to the stage of mining operation and revitalisation, as well as ownership. To combine all these concepts, a MCDM toolkit is currently under development, within the ReviRIS project, which is to be supported by two possible evaluation procedures, a MCDM matrix model and an integrated GIS-MCDM model. The decision and modelling procedure are directly dependent on the TPMLP and, to ensure appropriate alternative analysis, characteristic local conditions and regional restrictions are applied. The toolkit methodology involves the integration of the TPMLP selection, the decision matrix with GIS data and experts’ knowledge, to support the input and information generated, and finally, the participatory process of public consultation. Due to the particularities of PMLU process and the many possible scenarios, three MCDM are considered the most suitable methods for the toolkit architecture design and mathematical modelling process, namely TOPSIS (measures the distance of each alternative to positive and negative ideal solutions), SIMUS (combines linear programming with heuristics methods to model complex scenarios), and SMARTER (calculations to include stakeholders’ preferences). At the end of the methodology, a sensitivity analysis procedure will allow the stakeholders to test and verify the strength of their results. The inclusion of geoethical aspects into decision
processes, the definition of transitional post-mining profiles (TPMLP), and the use of several MCDM represent the innovative perspective of this study. This work and its conclusions have been evolving under the EIT KIC Raw Materials funded project “ReviRIS-Revitalising Post-Mining Regions: Problems and Potential in RIS Europe” which focuses on the possible criteria and indicators to be considered in a MCDM process
Novel Techniques for Anticipating the Focus of Visual Attention across different Mining Landscapes

L. Misthos, M. Menegaki

National Technical University of Athens, Greece

E-mail: lmmisthos@metal.ntua.gr

Human vision depends on the gradual integration of small regions of each observed scene into a coherent whole. Visual attention focuses on these small regions in order to reduce the perceived complexity and to further facilitate the processing and interpretation of visual scenes. Thus, anticipating the focus of attention is theoretically interesting and practically useful in many domains. Mining is one of these domains: approximating in advance the behavior of visual attention of potential observers may foster strategies for mitigating visual nuisance from open pit mines.

Saliency models have been developed with an aim to predict the visual attention based on several (low-level) attributes of the stimulus: each feature in a visual scene can be attributed a value of visual saliency depending on its intensity, color, and orientation compared to the respective information of its surrounding features. On the other hand, the actual recording of attention allocation can be obtained through eye tracking techniques.

In this paper, visual nuisance – i.e. subjective impression of landscape disturbance – caused by mining operations is addressed. The fundamental premise was that if the perception of an open pit mine is adequately low, then its visual nuisance is also reduced. By utilizing both saliency models and eye tracking techniques across different mining landscape photographs, useful information for both the anticipated and the actual allocation of attention was collected. In essence, both: i) the saliency maps produced by models and ii) the focus heatmaps resulting from the eye movement analysis of twenty people participating in an appropriately designed eye tracking experiment were examined separately and compared one with each other. As it was shown by the focus heatmaps, the actual focus of attention of the participants while observing the landscape photographs under free-viewing conditions (i.e. without any cognitive task) was allocated very heavily inside the quarries’ excavated areas in almost all cases. Furthermore, the patterns of saliency maps either diverged from or coincided with the patterns of focus heatmaps, depending on the character of each landscape observed. More specifically, for landscapes where the excavated surface dominates upon undifferentiated backgrounds, the saliency maps demonstrated a stunning similarity with the respective focus heatmaps; for other, more complex and semantically rich landscapes, the predicted patterns of attention were not validated by the experimental ones. This selective attention surpassing the sole effect of the low-level attributes indicates the presence of other cognitive factors (e.g. expertise) while free-viewing mining landscapes.
Development of emission factor equations for surface mining activities: the case of a stacker

A. Triantafyllou1, I. Kapageridis1, S. Garas2, Fr. Pavloudakis1

1Department of Mineral Resources Engineering, University of Western Macedonia, Greece
2Department of Chemical Engineering, University of Western Macedonia, Greece

E-mail: atrianta@uowm.gr

A key element of environmental protection in areas where open pit mines operate is addressing problems generated by the fugitive dust emitted from various mining operations. In mine planning, an estimate of dust generation is necessary to check the likely level of air pollution in the mining area due to proposed project activities. Typically, this can be estimated by using emission factors or prediction type equations for the development of emission factors. The latest give better estimation of dust formation in opencast mines. Emission factors are also required as input data in air quality models, which are used in environmental management integrated systems. So, the accurate emission factor estimation is one of the critical problems in forming a strategy to control fugitive dust emissions. The U.S. Environmental protection agency (EPA) published a compilation of air pollution emission factors, usually referred as AP-42, and emission factors equations for open dust sources at western surface coal mines. It has been demonstrated that application of the U.S. emission estimation methods to other regions could lead to results with large uncertainties due to differences in the nature of mining, site practices and mitigation measures, as well as geological and climatic conditions. As a result, experimentally-based derivation of emission factors appropriate to the area and the activities under study is necessary for a reliable calculation of fugitive dust emissions. The Greek Public Power Corporation and specifically the Lignite Center of Western Macedonia (GPPC / LCWM) funded a project named “THEOPHRASTOS” to provide accurate quantification and prediction of mining – related PM10 and PM2.5 emissions and dispersion, which is a key input to environmental impact assessments and regulatory policy decisions. In the frame of this investigation, field measurements were conducted in the four major surface mines of Western Macedonia basin, a lignite-bearing area in NW Greece. By using the Reverse Dispersion Modeling (RDM) method and multiple regression analysis, emission factors were estimated and emission factor equations were developed for selected mining activities. The findings are useful tools in order to predict air pollution before the commencement of any mining activity, and, thus, effective mitigating measures can be designed at the planning stage. The data, method and results related to the stacker, a significant fugitive dust emissions source in mining operations are presented and analyzed here.
The implementation of recycling philosophy in the Greek Fertilizers industry

T. Kouloura

KAVALA FERTILIZERS LTD, Greece

E-mail: th.kouloura@lipasmatakavalas.com

The production of nitrogenous and complex Fertilizers is a complicated process based on the production of all necessary raw materials and following the chemical methods discovered in the lab after their scale up procedure. The Greek fertilizers industrial complex in Nea Karvali Kavala started its operation in 1965 and since then has revamped, up graded, modified and extended its process and equipment several times. This industrial plant is the last one remaining under operation out of four production plants operated in Greece in the middle of sixties. The main and realistic reason to keep the installation in Nea Karvali under operation was the ability of the Plant to incorporate the changes in the international environment and to be modified itself focusing on environmental protection and sustainability rules.

The basic goal for the changes was always the way of the Greek fertilizers sector towards sustainability. Through this way, the wastes and by products from the several industrial procedures are recycled already and there are scientific research projects in progress to reuse the rest of them. This paper presents the recycling methods used in existing situation in the fertilizers sector as well as the future investments on the recycling and reusing materials in order to fulfil the limitations of Fit to 55 package.

More specifically, the industrial complex in Nea Karvali has succeed up to now and between others:

- to reform the emitted SO$_2$ to ammonia sulfate dilution used as raw material for NPK fertilizers production,
- to produce steam from waste heat without using fossil fuel and covering almost 100% of its need for heating and almost 70% of its need for electricity,
- to reuse sea water from the steam turbines’ cooler as scrubbing water and dilution medium

As a next step, the Greek Fertilizers industry is prepared to make a revolution reusing the phosphogypsum in different and prototype uses and at the same time to proceed on blue and green ammonia production.

Both of the new projects need a relative legal framework and the support from the Greek authorities and EU in order to have success in the near future.
Wednesday 8 September 2021
ILISSOS

SESSION C3
Batteries and magnets recycling

Chair: A. Chagnes, E. Balomenos
Upscaling of Permanent Magnet Dismantling and Recycling through VALOMAG project

F. Coelho¹, V. Decottignies², Y. Yang¹, B. Sprecher³, B. Saje⁴, C. Rado⁵, N. Menad⁶, S. Abrahimi³, Z. Li³, K. Bru⁶, T. Marcon⁷

¹Delft University of Technology, Netherlands  
²SUEZ, France  
³Leiden University, Netherlands  
⁴Kolektor Group Vodenje in upravljanje družb d.o.o., Germany  
⁵French Alternative Energies and Atomic Energy Commission, France  
⁶French Geological Survey BRGM, France  
⁷CRM Group

E-mail: f.a.p.coelho-1@tudelft.nl

Neodymium-Iron-Boron (NdFeB) based permanent magnets are indispensable in today’s technology-driven society, and this dependence is likely to increase since they are used in various products such as robotic systems and home appliances. Besides, they are also essential in clean energy applications with wind turbines and cleaner ways of transport such as hybrid/electric vehicles and electric bikes. The VALOMAG project, funded by the EIT Raw Materials, combines different key players (SUEZ, BRGM, CEA, CRM Group, Kolektor, TU Delft and Leiden University) to develop a new value proposition that answers the need of the permanent magnets market. The project develops a technical solution to recover permanent magnets by dismantling end-of-life (EOL) products like computer hard disc drives, electric motors and generators from electric vehicles and wind turbines. It also assesses two short loop recycling technologies, Hydrogen Decrepitation (HD) or Hydrogenation–Disproportionation–Desorption–Recombination (HDDR) and strip-casting, for high and medium quality magnet wastes, and a third alternative route using hydrometallurgical processes for EoL low-quality magnets. Moreover, Life Cycle Assessment (LCA) and Process Integration with Flowsheet simulation tool will integrate the whole recycling value chain (collection, dismantling, physical and chemical treatment options, and re-manufacturing) and assess the environmental impact and the processes efficiency. A market study on the types and expected future quantities for the scrap magnets and the characterisation of the EoL magnets from different sources will be presented as preliminary results. Pre-treatment and sorting of 2.5 tons of NdFeB magnets scraps were carried out, and the two short loop recycling routes (at CEA and KOLEKTOR) and the hydrometallurgical route (at BRGM) were investigated at the lab and pilot scale. The results will be used to develop a process integration and LCA for the three routes.
Recovery of metals from NdFeB magnets using trichloride ionic liquid

X. Li, K. Binnemans

KU Leuven, Belgium

E-mail: xiaohua.li@kuleuven.be

Rare-earth elements (REEs) are essential for various high-tech applications, such as rechargeable batteries and permanent magnets. The supply risk of REEs demands the recycling of these critical metals from secondary resources such as pre-consumer industrial production scrap and end-of-life products. In most cases, a chemical metallurgical route is required for recycling of metals from magnets. In response to the development of new efficient and environmental benign processes for metal recycling, a new branch of extractive metallurgy has been emerging: solvometallurgy, with metal processing in organic solvents without or with only small amounts of water.[1] Previously, we have shown that ionic liquids (ILs) with trichloride anions can be used for oxidative dissolution of elemental metals, such as Au, Ga and Sb.[2] The IL trihexyltetradecylphosphonium trichloride [P_{666,14}][Cl_3] can be applied also for recycling of metals from spent SmCo magnets.[3] Recently, a closed-loop process has been developed for recycling of metals from NdFeB magnets using the same IL [P_{666,14}][Cl_3]. The process includes metal dissolution (leaching), two stripping steps and IL regeneration. NdFeB magnets could be quantitatively dissolved in trichloride IL when the solid-to-liquid ratio was less than a certain threshold value that depended on the volume percentage of [P_{666,14}][Cl_3] in the lixiviant. Higher temperatures did increase the dissolution rate significantly. Addition of an IL with complexing chloride ions to the leaching systems is beneficial for maximizing the dissolution capacity of the trichloride IL. The rare-earth and transition-metal ions could be removed selectively by two sequential stripping steps, using a 3 mol·L^{-1} of NaCl aqueous solution and > 2 mol·L^{-1} of aqueous ammonia solutions, respectively. The regenerated IL [P_{666,14}][Cl_3] showed a similar dissolution efficiency compared with the fresh ionic liquid. In conclusion, the trichloride IL could effectively dissolve NdFeB magnets. Transition metals and rare-earth elements could be separated by two stripping steps. The reusability of the IL supports the sustainability of the process.

References:
Evaluation of graphite separation from metallic oxides by flotation in recycling of Li-ion batteries

J. Yang, A. Torppa, K. Kärenlampi

GTK, Finland

E-mail: jason.yang@gtk.fi

In the developed recycling processes of the Li-ion batteries (LIBs) recovery of graphite is scarce. Because of complex compounds of the LIBs efficient separation of graphite from other components by mechanical methods is very challenging before hydro- and pyrometallurgical steps for recovery of high economic value metals like Co, Ni and Cu etc. In this study a black mass sample of crushed spent Li-ion batteries was divided into two fractions of +250 µm and -250 µm and characterized by using a mineral liberation analyser (MLA). The MLA analysis showed that the main components in the sample are graphite, (Li)-CO-oxide, (Li)-Mn-Ni-Co-oxide, and (Li)-Ni-oxide. Cu and Al are mainly enriched in the coarse fraction +250 µm. Graphite and other carbon-containing components are evenly distributed in the coarse and fine size fractions. The separation of graphite and other carbon-containing components from the metallic oxides was evaluated by flotation after classification by sieving and treatment of roasting. Cu and Al as a mixture with the mass yield of 16%wt were clearly separated by sieving and flotation and other two products of (Li)-Co-Ni-Mn, one low carbon (C <15%) with the mass yield of 17%wt and one high carbon (C >54%) with the mass yield of 58%wt, were obtained. The mechanisms of separation of graphite and other carbon-containing components from the phases of (Li)-CO-oxide, (Li)-Mn-Ni-Co-oxide and (Li)-Ni-oxide were discussed.
Resource recovery from lithium-ion batteries - challenges and opportunities for precipitation and crystallization processes

K. Forsberg, Y. Ma, M. Svärd, X. Xiao, S. Ashoka Sahadevan, J. M. Gardner, R. T. Olsson

KTH Royal Institute of Technology, Sweden

E-mail: kerstino@kth.se

In keeping with international goals to reduce carbon emissions and mitigate global warming, production of electric vehicles worldwide is dramatically expanding. The electric vehicle boom could potentially leave our societies with 11 million tons of spent lithium-ion batteries (LIB) given a warranted lifetime of about 8 years. It is also apparent that increasing battery demands will require new global strategies for providing battery factories with a sufficient supply of materials. In this scenario, battery recycling must be able to serve as an important source for these raw materials. Many of the electric vehicles are equipped with lithium-ion NMC (nickel-manganese-cobalt oxide) batteries. Both lithium and cobalt are listed as critical raw materials for the EU. Various salts can serve as starting materials for the production of LIB. Research efforts for recycling LIB have increased steadily over the last 10 years. Current industrial processes have been reviewed, but the details of these processes are proprietary. However, from publicly available sources it is known that the batteries can be first mechanically pre-treated, followed by hydrometallurgical processes involving acid leaching and recovery of the main elements by combinations of solvent extraction and crystallization. In hydrometallurgy, crystallization and precipitation are important unit operations. Precipitation is mainly used for impurity removal and preliminary production, while controlled crystallization can be applied to produce a pure product. There is still room for applying novel techniques for these operations. This contribution focuses on challenges and opportunities for precipitation and crystallization processes for recycling of LIB and the production of metal salts for LIB materials. The application of novel and promising precipitation and crystallization techniques, including eutectic freeze crystallization, antisolvent crystallization, and precipitation in a fluidised bed will be discussed.
A sustainable process for the recovery of valuable metals from spent lithium ion batteries by deep eutectic solvents leaching

L. Yurramendi, J. Hidalgo, A. Siriwardana

TECNALIA, Basque Research and Technology Alliance (BRTA), Spain

E-mail: lourdes.yurramendi@tecnalia.com

Recycling of lithium ion batteries (LIBs) is a demanded process due to the necessity of recovering critical resources such as lithium and cobalt. Current recycling treatments involve dismantling, size reduction and thermal pre-treatments to obtain a metal containing black-mass (BM) which is subject to hydrometallurgical processes involving leaching with strong mineral acids (HCl, H₂SO₄). These lixiviants pose environmental challenges that could be mitigated using organic leaching media like Deep Eutectic Solvents (DES). In the framework of the European H2020 CROCODILE Project, the technical feasibility of using lower environmental impact leaching media to recover valuable metals contained in BM from various types of LIBs (consumer mixed LIBs, electric vehicle LIBs, etc.), have been evaluated. Several DES, for example, the binary formulation choline chloride-citric acid and the ternary formulation choline chloride-citric acid-lactic acid, were used as leaching reagents in the presence of different type of additives (i.e. H₂O₂). BMs were characterized before and after the leaching step by ICP, SEM-EDS and X-ray diffraction. The optimization of the Co recovery yield was carried out by investigating the several operating conditions such as reaction time, temperature, solid (BM) to liquid (DES) ratio and additive type and concentration. Leaching with selected DES at 55 °C achieved more than 95% of Co extraction. The leaching mechanism likely begins with the dissolution of the active material in the BM followed by chelation of Co(II) with the DES. The results obtained confirm that those leaching media are an eco-friendly alternative to the strong inorganic acids used nowadays.
Microstructure-efficiency relationship in liquid-liquid extraction

A. El Maangar\textsuperscript{1}, M. Špadina\textsuperscript{1}, J. Duhamet\textsuperscript{2}, J. Gabriel\textsuperscript{2}, T. Zemb\textsuperscript{1}

\textsuperscript{1}INSTITUTE FOR SEPARATION CHEMISTRY IN MARCOULE (ICSM), France
\textsuperscript{2}CEA, France

E-mail: y.asmae.elmaangar.t@gmail.com

It is a matter of strategic independence for Europe to urgently find processes taking account of environmental and economic issues, when mining and recycling rare earth elements. Separation and recycling of rare earths from electronic waste is important for the success of present and future carbon-free technologies. Hydrometallurgical separation based on nanoscience is one of the first technologies allowing the take-off of circular economy. Liquid-liquid extraction is a promising method for retrieving rare earths from electronic waste. However, an optimized process on an industrial scale has not been established. One major reason is the lack of fundamental knowledge, therefore designing a cost-efficient, adaptive and predictive formulation is still out of scope of possibilities. Emulsification and demulsification processes in extraction devices are only efficient when the coexisting phases are located between binodal tie-lines in the Winsor II regime. Most extraction processes are based on the combination of an extractant with a diluent. The main disadvantage of these processes is the formation of viscous emulsions known as third phase accident. This occurs when processes are intensified by increasing solute and extractant concentration. Our objective is to develop the fundamental understanding involved in the process’ complex fluids (experimental and theoretical) concerning liquid-liquid extraction of REE and furthermore to use it to design new, cost-effective and environment-friendly recycling processes. A new and promising approach has been recently proposed using Ultra Flexible MicroEmulsions (UFME) which are characterized by an Ornstein-Zernike scattering often observed for weak extractants. These surfactant-free self-assembly is based on the usage of hydrotropic co-solvents instead of the classical extractant/diluent couple. Co-solvents as well as hydrotropes quench the formation of third phases. A systematic comparison of the extracting power of a given formulation by the classical solvent-based, modifier enhanced co-solvent based and the new possible UFME route is now necessary. This requires measuring with enough precision the free energy of transfer of ions along the lines in the quaternary phase diagram. This is only achievable by using a newly developed liquid-liquid extraction microfluidic device coupled to X-ray fluorescence microanalysis. Our contribution towards a more complete understanding in this matter is the analysis and comparison of the phase behavior, extracting efficiency and selectivity of such systems as well as the correlation of these findings with the “ienamics” approach by identifying the molecular driving forces favoring or quenching the transfer.
Sulphuric acid leaching of spent nickel metal hydride car batteries

E. Polychronopoulou, P. Oustadakis, P. Tsakiridis, K. Betsis, A. Xenidis

NTUA, Greece

E-mail: ellidp@hotmail.gr

The treatment of spent nickel metal hydride batteries (NiMHs) of Lexus vehicles to recover nickel (Ni) and cobalt (Co) as well as rare earth elements (REEs) including La, Ce, Nd and Y was investigated. Co-extraction of Al, Fe, Cr and Cu has been also examined. Following batteries manual dismantling to remove metallic cases, outer plastics and current collectors, the remaining parts including cathodes of black coloured nickel (oxy)hydroxides, anodes consisting of a nickel-containing alloy (AB5 mischmetal type), and separators was simultaneously ground down to -5mm using a hammer mill equipped with sieves. The fine (-1 mm) fraction of this product was further subjected to sulphuric acid leaching to recover the high value elements contained. Acid consumption of 14 mol H₂SO₄ per kg of this fraction was found to be sufficient to decrease pH to less than 1 value. Leaching experiments were performed using 0.5, 1 and 2 M sulphuric acid solution at 5% pulp density and temperature 50, 75 or 95°C. The optimum conditions for the extraction of all elements were 2M H₂SO₄ concentration and temperature of 75°C with the exception of Ni extraction, which reached its highest value at 2M H₂SO₄ concentration and 95°C. It was indicated that 93.34 of Ni, 99.03 of Co and 100% of REEs were extracted at these conditions.
Wednesday 8 September 2021
OLYMPIA

SESSION C4
Industrial Minerals
Innovative processes and applications I

Chair: M. Taxiarchou, C. Vasilatos
The 20th century world was made of industrial minerals; disruptive and sustainable mineral solutions are required for the 21st century world

T. Karalis

Imerys S.A, Greece

E-mail: thanasis.karalis@imerys.com

The cities we live in, the clean water we drink, the food we eat, the personal care formulations and the drugs in our daily life, the electronic devices we use, the cars we drive, the trains and the airplanes we fly with, are to great extent based on mined, beneficiated, physically and chemically modified industrial minerals. At the heart of European Economy there are more than 100,000 jobs directly depending on mineral raw materials and approximately 4,000,000 millions jobs indirectly depending on minerals derivative products and formulations. It is practically impossible to imagine the future of European Economy and civilization without the industrial minerals, and their physical and chemical derivatives as well as without the end products where those minerals are incorporated.

On the other hand, new successive waves of technological products and novel formulations increase the demand for raw materials of new specific properties, which the traditional minerals and chemicals cannot provide or, they can provide, but at high environmental or hygienic cost. Conventional solutions originating from the industrial sectors of industrial minerals and the primary chemicals are very often not approved by various consumer products sectors and the search for alternative sustainable solutions is very intensive. In this framework Imerys is promoting innovation along the entire value chain: i.e. the raw materials knowledge base, exploration, licencing, extraction, physical and chemical processing, refining, recycling, and substitution involving the relevant upstream and downstream sectors. For Imerys innovation is an engine for growth and Science & Technology Division (R&D) is at its heart. The focus of Imerys S&T is rather the disruptive innovation than the step wise improvement of existing mineral based solutions. Three examples of innovative materials which Imerys has developed for the huge FLS market (Filtration & Life Sciences) are presented and analyzed: a) bentonite clays for aflatoxin absorption from animal feedstuff, b) perlite and diatomaceous earth for controlled release fertilizers, and c) TiO₂-free toothpastes(kaolin) and personal care ethical and sustainable formulations (mica).
Comparative study of acid activated nontronite and montmorillonite in oxalic acid of various concentrations

D. Tsakiri, I. Douni, M. Taxiarchou

National Technical University of Athens, Greece

E-mail: dtsakiri@metal.ntua.gr

Acid activation is a chemical modification of minerals and mainly smectites, in order to enhance their surface properties and reinforce their adsorption capacity for specific ions. Acid activated clays and more specifically inorganic acid activated calcium montmorillonites are usually used in the bleaching process of vegetable oils, holding the 3rd place in world food consumption after cereals and rice, in order to remove chlorophyll and other undesirable substances from the oils. This study proposes the use of oxalic acid for the acid activation of smectites, in order to modify their surface so as to create good quality bleaching earths. In particular, two different types of smectite (a montmorillonite and a nontronite) are treated in oxalic acid of 0.5, 0.7 and 1M and the structural modifications in the materials after treatment are observed through FT-IR analysis, combined with the observation of the main structural metals’ extraction from the smectites. The results showed that nontronite is more susceptible to oxalic acid activation. The final product has developed vacant spaces in its structure to absorb other ions, although it retains the structure of smectite. Oxalic acid concentration of 0.5M is sufficient for this result. The materials produced through the oxalic acid activation are also compared with inorganic acid activated smectites originating from the same deposits.
Physical mechanical properties and producing areas of Greek dimension stones

K. Laskaridis, A. Arapakou, M. Patronis, I. Kouseris

Hellenic Survey of Geology and Mineral Exploration (HSGME), Greece

E-mail: laskaridis@igme.gr

Quarrying is a significant factor for Greek economic activity, as dimension stones are widely and increasingly used both in big scale structural works and specific applications. The most important Greek ornamental stone types are marbles (calcitic and dolomitic), limestones, dolomites, schists, travertines and sandstones. Since ancient times, marble production has been connected to the history of civilisation, due to the unique properties of the Greek stones. White “Pentelikon” marble is famous for being employed in the construction of historic monuments of art, such as the Parthenon on Athens Acropolis. Modern Greek marble industry is a dynamic sector, being classified among the top world producers of dimension stones, concerning both the volume of production and exports. The current status of the major ornamental stone producing areas in Greece is described in this paper. Quarrying companies are scattered almost all over Greece, offering a wide variety of materials with different technical and aesthetic characteristics appropriate for every use. In order to assess the overall quality of each stone it is important to determine its physical mechanical properties and its petrographic characteristics, since they affect its behaviour and define its proper use. Typical average values for various physical mechanical properties of Greek ornamental stones, having been determined according to the relevant EN Standards in LITHOS laboratory during its 20-year active life in quality control testing, are also presented in this paper.
Thermal activation of kaolin: effect of kaolin mineralogy on the activation process

D. Kosmidi, C. Panagiotopoulou, P. Angelopoulos, M. Taxiarchou

School of Mining and Metallurgical Engineering, National Technical University of Athens (NTUA), Greece

E-mail: dkosmidi@metal.ntua.gr

Kaolin is an industrial mineral used in a wide variety of applications due to its crystalline structure, mineral and elemental composition. After kaolin undergoes heat treatment in a specific temperature range forms a product called metakaolin which exhibits strong pozzolanic reaction. This paper examines the effect of different kaolin qualities in the thermal activation process for the metakaolin production. The qualities of kaolin depend on the impurities they contain, such as mica, feldspar and quartz. In this study four different samples of kaolin are investigated. Each sample is heat treated in a lab scale rotary kiln in order to study the chemical, structural and morphological changes that occurred and the influence on the pozzolanic activity. The parameters being considered in the experimental process are the temperature and the duration of the treatment. Thus, the calcination process for each of the four kaolin types is carried out at 600, 650 and 700°C for 3h. The occurred changes are monitored using XRD, FTIR and TG-DTA analysis. Additionally, the reactivity of all the samples, raw materials and thermally treated samples, is evaluated based on Chapelle test. The results show the less the contained impurities the easier the transformation of the material to metakaolin. The optimum result is the metakaolin which originates from the purest quality of kaolin and it is comparative with the commercial product. Finally, the pozzolanic activity of the thermally activated samples also depends on the purity of the kaolin quality.
CO$_2$-mineralised nesquehonite: a new ‘‘Green’’ building material

V. Skliros, A. Kastrinakis, P. Tsakiridis, M. Perraki

School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece

E-mail: sklirosbill@metal.ntua.gr

Synthetic nesquehonite with a Mg(HCO$_3$)OH·2H$_2$O chemical formula is a solid product of CO$_2$ mineralization with cementitious properties. It constitutes an “MHCH” (magnesium hydroxy-carbonate hydrate) phase and along with dypingite and hydromagnesite they are considered to be a promising permanent and safe solution for CO$_2$ storage with potential utilization as supplementary materials in “green” building materials. In this work, synthetic nesquehonite-based mortars were evaluated in terms of their compressive strengths. Nesquehonite was synthesized by CO$_2$ mineralization under ambient conditions (25°C and 1 atm). A saturated Mg$^{2+}$ solution was used at a pH of 9.3. During the reaction, a continuous input of a high concentration NH$_3$ solution (35%) maintained the pH alkaline. The NH$_3$ solution did not react with the products and was easily separated using a vacuum pump. The synthesized nesquehonite was subsequently studied by means of optical microscopy, X-ray diffraction (XRD) and scanning electron microscopy (SEM). Impurity-free nesquehonite forms elongated fibers, often around a centerpiece creating a rosette-like structure. The synthesized nesquehonite was mixed with reactive magnesia, natural pozzolan, standard aggregate sand and water to create a mortar. The mortar was cast into 5x5x5 silicone mold and cured in water for 28 days. Compressive strength of up to 22 MPa was achieved. X-ray diffraction study of the cured mortars revealed the formation of brucite as the new major mineral phase. Carbon dioxide mineralized nesquehonite is a very promising “green” building material with competitive properties that might prove to be an essential part of the circular economy industrial approach.
MASTERFLOOR: The new application of pumice stone as lightweight floor filling material

M. Nomikou¹, C. Galmpenis¹, V. Kaloidas², G. Tzouvalas¹

¹HERACLES Group, Greece  
²Self employed, Greece

E-mail: maria.nomikou@lafargeholcim.com

Pumice quarried by LAVA MINING & QUARRYING SA from Yali island, Dodecanese, is used in domestic and foreign markets mainly as concrete lightweight aggregate, masonry units constituent, road substrate and loose soil stabilization. It is a porous natural volcanic rock with low density, low thermal and noise transmission and the higher strength among all the natural or artificial lightweight materials of mineral origin. Nowadays, pumice is of additional interest as it has a reduced CO₂ footprint because thermal energy is not needed for its expansion compared with the artificial lightweight aggregates.

In this context HERACLES GROUP is launching a new product in the market under the brand name MASTERFLOOR, a commercial bagged product for lightweight floor fillings with lightweight and insulating properties.
Wednesday 8 September 2021
VERGINA

SESSION C5
Mine water/waste management

Chair: G. Grieco, E. Gazea
The technology of dry stack tailings and the implementation in Kassandra mines

D. Dimitriadis, E. Zachareas, E. Gazea

Hellas Gold, Greece

E-mail: eystratios.zachareas@eldoradogold.com

In every mine in the world, the result of the process is a slurry material called tailings. Today, more than ever before, the Mining industry is looking for technical solutions to dewater mine tailings to eliminate the risk of tailings dam failures. Among other modern methods of tailings dewatering, the removal of excess water with the use of filter presses prior the placement, results to a soil-like or “wet cake” material (solid content by weight >80%) called dry stack tailings. These filtered tailings are normally transported by conveyor or truck, deposited, spread, and compacted. The “Dry-stacking” tailings methodology is beneficial for the environment due to the less disturbed footprint for the disposal area, is increasing the physical stability of the tailings disposal and thus the construction of retention embankments could be avoided, simplifies the overall water management and recovery, and provides complete restoration opportunities due to the direct access on the tailings surface.

In the Kassandra Mines at NE Chalkidiki, the Kokkinolakas Tailings Management Facility (KTMF) is currently in operation as “dry stack” disposal area, by incorporating materials generated from the removal, cleaning, and rehabilitation of every old, non-operating tailings areas from the extended past mining activities (1960-1995) as well as the tailings and wastes produced from the operations of Olympias and Stratoni mines. Recently, the Kassandra Mines was also permitted to use the same “dry-stack” technology at the Skouries project, providing the huge benefit for the environment of the full release of the Lotsaniko valley.
Implementation of a procedure for buffering Acid Mine Drainage waters from pyrite-rich tailings at Fushë Arrëz copper enrichment flotation plant

G. Cocomazzi¹, G. Grieco¹, A. Sinojmeri², A. Cavallo³, M. Bussolesi³

¹University of Milan, Italy
²University of Tirana, Albania
³University of Milan-Bicocca, Italy

E-mail: giuseppe.cocomazzi@unimi.it

The extraction process from metal deposits has the inevitable consequence to generate enormous amounts of waste (close to mines and enrichment plants) mainly solid and in the form or accumulation of sterile minerals or tailings deriving from the processes of concentration and refinement. These waste materials, if not properly treated, constitute a considerable environmental risk. Some of them can be very rich in sulfides, hence the capacity of inducing the formation of high acidic waters rich in Potentially Toxic Elements (PTE).

The present work is focused on the copper enrichment plant of Fushë Arrëz (Northern Albania copper mining district) where a change in tailings environmental impact, due to the transition from double flotation, with separation of pyrite as a by-product, and single flotation, without pyrite separation has been documented. Pyrite, due to its abundance, high reactivity and high S to metal ratio is the main responsible of Acid Mine Drainage (AMD).

The aim here was to define the most suitable procedures for the buffering of leached samples and natural waters from sulfur-enriched mining tailings, through the evaluation of samples chemical parameters and assessment of major, minor and trace elements distribution.

The buffering of the leached products and natural waters was carried out by adding to the solutions fine-grained calcium carbonate supplied by UNICALCE company.

The results show an important reduction in the concentrations of the metals in solution. The metal removal efficiency obtained through this procedure turned out to be excellent and even higher than 90% for most of the PTE considered. In terms of absolute amounts, moreover, almost all the concentrations detected after the buffered remain below the legal limits envisaged for Albanian industrial water discharges. The precipitate produced takes over all the PTE in high concentrations and therefore will require a specific purification or storage treatment.

In order to better understand the buffering process of acid solutions rich in heavy metals and improve their application, two insights are suggested for next steps:
• perform MP-AES analyses at each buffering step allowing, in addition to validating the buffering model created, to yield buffering curves for each ion considered as a function of pH
• perform tests with different buffering materials and subsequently compare the costs and the buffering performance
Rational and sustainable water resources management in the Ptolemais lignite basin using remotely sensed data

G. Louloudis¹, C. Roumpos¹, E. Mertiri¹, G. Kasfikis¹, F. Pavloudakis²

¹Public Power Corporation of Greece, Greece
²Public Power Corporation SA, Greece

E-mail: G.Louloudis@dei.com.gr

Greece is committed to the European Commission’s long-term strategic vision to achieve technological neutrality to CO₂ emissions by using renewable energies. In the context of the early closure of coal mines, the strategic planning for the repurposing of the mining area includes, among others, the development of agricultural activities and the adoption of Renewable Energy Sources (RES) technology. As a result, multi-level planning is critical for implementing effective strategies, examining repurposing options, and making decisions about post-mining future and economic transitions. Planning should also include water management issues. They may refer to the new demands of water, the spatiotemporal development of water inside the mined-out pits, the effect of the planned end uses, the hydraulic protection of the new RES, the needs in water for successful end uses as well as to specific other related projects (e.g. the application of pumped hydro storage technology in the abandoned mines).

During the operation period in lignite mines, surface water and groundwater control measures are adopted (dewatering wells, pumping stations) to reduce the groundwater influx in the mine pits by pumping water from the aquifer and modifying surface runoff. The application of RES or other projects in the phasing-out mining area will demand new water management strategies.

The main objective of this research is to provide a methodology to identify areas where the application of hydraulic protection is imperative, to estimate the design water inflow risk and the feasibility of hydraulic protection works via remotely sensed data from satellites (satellite images, DEM etc.). Several factors and indices were selected to examine the status of the hydrological conditions, including the Topographic Wetness Index (TWI), the Power Stream Index (SPI), the Slope length and Steepness factor (LS-factor), the Normalized Difference Water Index (NDWI), the Modified Normalized Difference Water Index (MNDWI), the Normalized Difference Vegetation Index (NDVI), the Modified Normalized Difference Vegetation Index (MNDVI), the slope of the riverbed, the Horton index and the accumulation index. Satellite images in different bands and Digital Elevation Models (DEM) of the Ptolemais basin were processed. As a result, the factors mentioned above were defined and evaluated, leading to a more accurate estimation of the runoff ratio for the catchment area, the percolation ratio, the Field Capacity and the potential of groundwater supply. In addition, the zones of potential artificial groundwater recharge and zones where appropriate hydraulic protection measures are necessary (trenches, lakes etc.) can be determined.
Bathymetry surveys of post mining pit lakes formed after exploitation of lignite

A. Bajcar, J. Szczepiński, B. Rogosz

“Poltegor – Instytut” Instytut Górnictwa Odkrywkowego, Poland

E-mail: adam.bajcar@igo.wroc.pl

Flooding of post mining voids is one of the most common methods of post mining areas reclamation. The article presents selected post-mining lakes investigated within the research project "Risk assessment of final pits during flooding" (RAFF) cofinanced by the Research Fund of Coal and Steel and the Polish Ministry of Education and Science. The main objectives of the project are focused on the development of comprehensive models that can be used for risk assessment purposes. Innovative outcomes of the project will help to elaborate methodologies and guidelines to improve the safety, security of flooding of post mining open pits and sustainable management of environment. In the paper results of bathymetry surveys carried out on pit lake Lubstów belonging to the PAK Konin Lignite Mine SA. has been presented.
Long-term slope stability of abandoned mine lake – numerical modelling and risk assessment

V. Renaud\(^1\), M. Al Heib\(^1\), R. Muller\(^1\), J. Burda\(^2\)

\(^1\)Ineris, France
\(^2\)VUHU, Czech Republik

E-mail: vincent.renaud@ineris.fr

Almost all post exploitation open pit voids in the world are shaped as a final reservoir intended to be filled with water. In Europe, the creation of water lakes is the most common way of reclaiming post open pit mines. The safety and the security of mine lakes is one of the mine regions priorities. A risk assessment methodology was developed for mine lakes. The main mining hazards and risks were identified and discussed. One of the main hazards identified is the ground movement and more precisely the slope stability of the banks around the lake. The methodology was applied on lake Most which is one of the largest mining lakes in Europe (Czech Republic). Additionally, a slope stability study of the lake area was carried out where a large-scale numerical model was built, based on the site observations, large LiDAR data and geotechnical data.

A large LiDAR campaign was carried out in August 2019. The final data point cloud was used to create the digital terrain model to build the 3D volumetric mesh (geometric model). This step was done using the Rhino (v6) software together with its Griddle (Itasca) add-on developed for generating homogeneous meshes that are compatible with the Flac3D numerical modelling software.

In order to develop a reliability methodology for assessing the long-term stability of flooded open pit mines, a large-scale numerical model of the lake was carried out with Flac3D, the model integrated the complex geology of the mine and the dump. The results of the numerical modelling were analysed as large scale by calculating a global and local safety factors and the effects due to the variation of water level of the lake. The results highlighted the reliability of the methodology to combine the geometric model with the geologic model to create a large-scale numerical model, and to identify local potentially instable zones.
Assessment of advantages and limitations of installing PV on abandoned dumps

M. Al Heib, A. Cherkaoui

Ineris, France

E-mail: marwan.alheib@ineris.fr

The aim of this paper is to address the fundamental question concerning the best potential post-mining usages for waste dumps. This contribution is a part of the European research project named “Sustainable Use of Mining Waste Dumps”.

The feedback of international practice shown that the installation of photovoltaic (PV) parc on the dumps is one of the best solutions to minimize the negative impacts of mining industry and to maximize the benefit regarding the energy transition and the circular economy development. The installation of photovoltaic panels on dumps response the challenge of the increasing the renewable energy production in European countries.

The photovoltaic installation on dumps and heaps presents an attractive opportunity for vitalization large number of dumps through the Europe. The paper discussed the site selection criteria for the installation of solar power plants, more specifically the installation of solar panels on existing spoil and dump lands.

However, the coal dumps are unfortunately characterized by several mining hazards: ground movement, fire, pollution, flooding. For installing the PV, different environmental, technical and economic criteria should be respected for ensuring the stability and the production of the energy for years. The installation of the photovoltaic panels on dumps depends on the level of mining hazards and the PV installation requirement. The slope of the dumps appears as the main constraint and limitation for the installation of photovoltaic panels. The suitable slope angle should be less than 15°. In addition, specific foundation system should be considered to ensure long-terms safety and security due to the settlement hazard. Furthermore, the potential for renewable energy installation on the spoil sites depend on the location, mine design and other power sourcing options.

The paper presents several examples of installation of photovoltaic panels on coal-lignite dumps in France. The number of projects is still very limited comparing to the identified potential.
Hydrogeochemical and environmental evaluation of mining water from Chalkidiki area, Northern Greece

K. Sachsamanoglou¹, E. Tziritis¹, E. Tzamos², D. Ballas³, E. Gazea³, A. Xenidis⁴, A. Zouboulis²

¹Hellenic Agricultural Organization, Soil and Water Resources Institute, Greece
²Department of Chemistry, Aristotle University of Thessaloniki, Greece
³Hellas GOLD S.A., Greece
⁴National Technical University of Athens, Greece

E-mail: e.tziritis@swri.gr

This study evaluates the overall hydrogeochemical and environmental conditions of mining waters from 3 active mines (Skouries, Stratoni, Olympiada) located in Chalkidiki area. The assessments are based on the records of 31 sampling points of surface water, which constitute part of the environmental monitoring network for water resources of the Hellas Gold Corporate. The measured parameters included main physicochemical properties, major and minor ions, and trace elements. The environmental characterization is performed with the use of PoS index, which constitutes a robust tool for evaluating environmental status and changes, can flag potential threats or trends, and identifies the dominant factors that control the respective water chemistry issues. The combined results may be used in compliance with specific aspects of examined sites (i.e. land use, geology, hydrological and hydrogeological regime etc.) for environmental control, in line with legislative oriented environmental monitoring purposes, and ultimately for strategic planning in water resources management.
Wednesday 8 September 2021
ILISSOS

SESSION C6
Recycling / Metals recovery from end products

Chair: L. Yurramendi, E. Kaklamanos
Study of metal recovery from printed circuit boards by physical-mechanical treatment processes

C. Mori De Oliviera¹, R. Bellopede¹, A. Tori², P. Marini¹

¹Politecnico di Torino – DIATI, Italy
²OSAI Automation System S.p.A, Italy

E-mail: rossana.bellopede@polito.it

The acceleration of the global production and consumption of electronics device and the concerns related to waste electrical and electronic equipment (WEEE) motivated this research. Printed circuit board (PCB) can be found in almost all type of electronic devices, making it an important component of WEEE. It has a heterogeneous composition made of polymers, ceramic material, and metals. It contains heavy metals that can cause environmental impacts due to improper disposal. But on the other hand, there are elements with added value, such as copper, gold, silver, iron, aluminum and critical raw materials, such tantalum that can be recovered, making PCB scrap an economically attractive for recycling. The metal recovery can conserve natural resources, since it prevents new minerals from being extracted and it is a great contribution to the circular economy, removing the waste from its disposal and reinserts in the production cycle. The mechanical recycling of PCBs was studied through different operations, with the following sequence, comminution, granulometric classification, magnetic separation, gravity separation and electrostatic separation. The goal is to concentrate metals, especially copper, identifying the main elements obtained through cheaper processes to recycle e-waste. The PCB composition was initially carried out through the scanning electron microscope analysis. Then, it was shredded in a cutting mill and classified according to their grain size by sieving. Afterwards, a magnetic separation has been performed together with gravity and electrostatic separation of the non-magnetic fraction. The products obtained were observed with the macroscope to qualitatively assess the metallic content. The results obtained allowed to conclude that physical-mechanical techniques have high potential to produce a concentrate product with high added value. The application of magnetic separation proved to be efficient, as it enabled the recovery of high percentage of iron. In gravity separation, the metal recovery was satisfactory for the particle size -0.6 + 0.3 mm and for the particle size -1.18 + 0.6mm. In the recovery of metals by electrostatic separation the efficiencies obtained was really high the lower particle size (-0.3mm).
Delamination of waste printed circuit boards using microwave-assisted organic swelling

L. Martelo¹, B. Monteiro¹, P. Sousa¹, M. Bastos², H. Soares¹

¹REQUIMTE/LAQV, Department of Chemical Engineering, Faculty of Engineering, University of Porto, Portugal
²LEPABE, Department of Chemical Engineering, Faculty of Engineering, University of Porto, Portugal

E-mail: lmartelo@fe.up.pt

Circular economy and its potential application to electronic waste (e-waste) has emerged as an important subject in current environmental research. Nowadays, our lifestyle requests more electronics products, and this rapid development generated an increase in the amount of improper e-waste management. Waste printed circuit boards (WPCBs) are components in all electronic devices and responsible for a high percentage (approximately 5 million tons annually [1]) of the total weight of the e-waste generated worldwide. WPCBs are composed of fiberglass reinforced epoxy composites and additives. The critical step in recycling and recovery of the high-value metals of WPCBs is to separate the non-metallic and metallic components by removing the epoxy resins through an efficient and friendly environmental process. Here, we propose a novel process to separate the several layers of the multi-structured WPCBs using organic solvents under microwave conditions [2]. Our studies firstly focused on the appropriate choice of several solvents capable of dissolving the brominated epoxy resin from WPCBs. For that purpose, we based our rationalization on the calculation of Hansen solubility parameters. All chosen solvents were tested by microwave and then compared with methods previously described in the literature (thermostatic and ultrasonic baths) for its performance. Microwave-assisted swelling showed to be the most efficient, energy cost and rapid method. The best conditions obtained were for WPCBs dimensions of 225 mm² using N-methylpyrrolidone (S/L ratio of 300g/L) at 200 ºC with 2 cycles of 10 min 2. This method showed to be an efficient, fast and eco-friendly choice over the technologies available for delaminating totally WPCBs into metallic and non-metallic components.

REFERENCES

ACKNOWLEDGMENTS
This work was financially supported by Project PTDC/EAMMIN/31041/2017 - POCI-01–0145-FEDER-031041 - funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) and with financial support of FCT/MCTES through national funds (PIDDAC).
A hydrometallurgical process for Cu recovery from waste printed circuit boards

D. Vlasopoulos, E. Remoundaki, P. Oustadakis, P. Tsakiridis, S. Agatzini-Leonardou

National Technical University of Athens, Greece

E-mail: dimvls@metal.ntua.gr

The current study presents an effort to develop a sustainable hydrometallurgical process for the recovery of copper from waste printed circuit boards (PCBs) to be applied at local, small to medium, industrial units. The process aims to separate and recover copper from a filter dust, produced during the crushing of PCBs using a hammer mill, in a recycling facility. Due to the high plastic content in the dust (approximately 30% w/w), the metal fraction was separated gravimetrically and the material originated consisted of Cu (23.8%), Fe (17.8%), Sn (12.7%), Pb (6.3%), Zn (3.4%), Al (3.3%), Mn (1.6%) and Ni (1.5%). Prior to copper recovery, the dust was leached with HCl, as a pretreatment step. During this step, more than 80% of iron, zinc and tin were leached out. The resulting solid consisted mainly of Cu (37.6%) and Fe (10.7%), leading to a copper condensation of around 60% in the powder. The leaching of copper was conducted in a two-step process using H$_2$SO$_4$ as leaching agent with the addition of H$_2$O$_2$ as oxidizing agent. The experimental conditions were of low energy needs (no heating or agitation needed). The leaching of Cu reached 98%. Despite the pretreatment step, the leachate’s content in other metals (Fe, Zn, Ni) were high to proceed to electrowinning. Therefore, the organic solvent ACORGA M5640, was selected for the extraction of copper from the leachate. The extraction was conducted in two stages at equilibrium pH 1.5 and the loaded organic phase was stripped with HCl in two steps. The strip liquor was suitable for electrowinning.
Recovery of gold from waste printed circuit boards using sustainable technologies

P. Sousa¹, L. Martelo¹, M. Bastos², A. Marques³, H. Soares¹

¹REQUIMTE/LAQV, Department of Chemical Engineering, Faculty of Engineering, University of Porto, Portugal
²LEPABE, Department of Chemical Engineering, Faculty of Engineering, University of Porto, Portugal
³LAETA, Department of Mechanical Engineering, Faculty of Engineering, University of Porto, Portugal

E-mail: hsoares@fe.up.pt

A large fraction of e-waste generated worldwide is waste printed circuit boards (WPCBs), approximately 6-10% [1]. This stream contains a wide range of valuable metals (such as gold, copper, silver, etc.), ceramics and polymers. The variety and the economical value of these materials has made the recycling and recovery of WPCBs an interesting and important topic of research. Recycling WPCBs is a complex problem worldwide and sustainable technologies are required since the current ones are not adequate to address this global issue in a sustainable way. In this work, we aim to offer a novel (an European patent was submitted [2]) and more environmentally friendly solution to recover gold, which is the high-value material present in WPCBs. This novel process includes the following steps: (i) cutting the connecting terminals of WPCBs containing gold fingers using a mechanical tool (such as, a guillotine), (ii) swelling the cut WPCBs pieces (64 mm²) in an appropriate organic solvent inside a low-pressure reactor (with stirring and temperature control), (iii) recovering the gold fingers from a mixture of copper foils and fiberglass using a magnetic separation process followed by sieving [2]. Subsequently, gold (and copper) were recovered from the gold fingers using microwave-assisted acid leaching with nitric acid to leach copper. This process allowed recovering gold, as a solid metal, with high yield (99.9%) and a purity grade of 74%. Finally, copper was recovered from the acid leachate by alkaline precipitation (pH around 8.8), as a solid of copper hydroxide, with high yield (99.9%) and a purity grade of 87%. Additionally, an economic assessment of the overall process was performed and evidenced to be highly competitive. This fact together with the sustainability (no generation of dusts and wastewaters) of the recycling process constitute important advantages for a future implementation in industry.

REFERENCES

ACKNOWLEDGMENTS
This work was financially supported by: Project PTDC/EAMMIN/31041/2017 - POCI-01-0145-FEDER-031041 - funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI) and with financial support of FCT/MCTES through national funds (PIDDAC).
Green Zero-Waste Metal Extraction and Recycling from Printed Circuit Boards

H. Askari Sabzkoohi, G. Kolliopoulos

Université Laval, Canada

E-mail: halimeh.askari-sabzkoohi.1@ulaval.ca

The vast amount of electronic waste generated from our modern tech-heavy societies is a significant challenge facing the world nowadays. In fact, waste electrical and electronic equipment (WEEE) is one of the fastest growing waste streams and represents a valuable secondary resource for strategic, critical, and precious metals. With increasing environmental awareness, recycling has become significantly important worldwide, thus making metal recovery and recycling from WEEE both environmentally and economically attractive. In this work, we report on an innovative green non-aqueous metal extraction process for the recovery and recycling of metals from WEEE. Specifically, our process is based on a promising class of sustainable green solvents, namely deep eutectic solvents (DESs). DESs are eco-friendly, biodegradable, low-cost, and easy to prepare anhydrous solvents of tunable properties. They are mixtures of recoverable salts, which, due to hydrogen bonding, result in lower melting point compared to their discrete components. Therefore, DESs could substitute water in processing, minimize waste generation as well as water and acid consumption, and maintain or improve the selectivity in metal extraction and recovery. We shall present our findings on the effectiveness of choline chloride based DESs on metal extraction and recycling from printed circuit boards. Our proposed solvometallurgical approach generates a strong potential to attain a truly circular economy via sustainable zero-waste green urban mining.
Hydrometallurgical treatment for the separation and recovery of Indium and Gallium from end-of-life CIGS photovoltaic panels

M. Theocharis¹, E. Remoundaki¹, P. Tsakiridis¹, P. Kousi¹, A. Hatzikioseyian¹, I. Zarkadas², G. Lyberatos¹

¹National Technical University of Athens, Greece ²Polyeco S.A, Greece

E-mail: minasteo@yahoo.com

Solar energy production is expected to reach 40GW/year in the coming decade. Europe holds about 70% of the total installed capacity of photovoltaic panels (PV). Although silicon remains the most common solar cell material, other types of PV materials gain increasing part in the market. In thin film solar cells, the semiconductor material is much less than that required in conventional solar cells making this type of technology more economic. End of Life (EoL) PV panels, classified as WEEE, should follow recycling practices and technologies in line with circular economy principles. Indium and Gallium are classified as critical raw materials due to their scarcity and their wide use in electronic products. Their separation and recovery from EoL PV attracted particular interest during the last decade.

This study presents experimental results from the development of a process treating EoL CIGS (CuGa₁₋ₓInₓSe₂) panels for the recovery of Indium and Gallium. The process consists of a primary thermal treatment of the wafers, followed by a hydrometallurgical treatment, where quantitative leaching of In, Ga, Cu and Mo is achieved. The elements may be then separated from the resulting solution by precipitation and solvent extraction. Representative samples of CIGS wastes have been used for the experimental development of the process. The thin film of Mo (metal base electrode), sputtered on the supporting soda-lime glass, is covered by the thin film containing In, Ga, Cu and Se (1 μm) as detected by SEM EDS in polished sections. The thermal treatment at 550°C for 15 min, in excess of air, led to the successful disintegration of ethyl vinyl acetate (EVA) and delamination of the wafer from the front protective glass. The glass fragments coated by the thin film contain Se: 0.03-0.05%, In: 0.02%, Cu: 0.05%, Ga: 0.004-0.006%, Mo: 0.04%. Following thermal treatment, glass fragments of about 1.5 cm x 1.5 cm were used in acid leaching experiments using HNO₃, HCl and H₂SO₄. Quantitative leaching of Cu, Ga, In and Mo was obtained by HNO₃ at ambient temperature. The roles of pulp density and acid concentration on the efficiency of metals leaching were investigated. Part of Se was evaporated during the thermal treatment. The rest is insoluble and is separated from the solution by filtration. Finally, options of elements separation via successive precipitation of Ga(OH)₃ and In(OH)₃ as well as via solvent extraction by D2EHPA (Di-2-ethylhexyl phosphoric acid) are presented and discussed.
DES-based solution for Regenerating the catalyzed-Diesel Particulate Filters of Euro 5/6 diesel vehicles

H. Papadopoulou¹, I. Yakoumis¹, S. Papagianni¹, A. Moschovi¹, K. Sakkas²

¹Monolithos Catalysts & Recycling Ltd., Greece  
²YS Cypriot Catalysts Ltd., Cyprus

E-mail: harapap4@gmail.com

According to the European emission legislation standard Euro 5, one of the mandatory parts of the aftertreatment system of diesel vehicles is the Diesel Particulate Filter (DPF), from 2008 onwards, or the catalyzed-Diesel Particulate Filter (c-DPF), from 2014 onwards. The main function of DPF is to remove diesel particulate matter (PM) and soot from the incomplete combustion of diesel engine vehicles. Over time, particles are trapped and accumulated into the channels of the filter, without being oxidized/burnt. Thus, the porous walls of DPF are plugged and the exhaust gas flow is blocked through the filter resulting to extremely high back pressure effect. The specific mechanical blockage of the DPF is very usual (every two years) in light diesel vehicle due to the low velocities in city roads, making successful regeneration processes critical since the cost of the DPF/catalytic system for Euro 6 Diesel Cars has been estimated as half of the car engine (in most case more than 2,000Euros per part).

Nowadays, organic based solvents are used for washing and regenerating filters, which however are revealing toxicity. During the specific research from, YS Cypriot Catalysts Ltd, an innovative environmental friendly and low-cost alternative solvent is proposed. The main characteristic of the eco-friendly washing solution is the selective dissolution/removal of ash and soot (organic compounds) from blocked-DFPs, without dissolving platinum group metals (PGMs) and rare earth elements (REEs). The latter are essential for the functionality and reuse of the DPF.

The studied reagents are Citric Acid (C.A.), Deep Eutectic Solvent (DES) of Choline Chloride (Ch. Chl.) Lactic Acid (L.A.), the surfactant Sodium dodecyl-benzene sulfonate (SDBS) and Sodium hypochlorite (NaOCl), as an antimicrobial factor. The optimized solution concentration was found to be: Ch. Chl. 10% w/v, L.A. 5% v/v, C.A. 2% w/v, SDBS 0.1% w/v and NaOCl 1% v/v.

By the proposed novel regenerating method, we were able to dissolve up to 90% of organic compounds from DPFs and c-DFPs. At the same time, the dissolution of the critical elements of the DPFs was less than 10%, driving to a successful reuse/retrofitting of the DPFs on the vehicle, since the proposed method is not destructive (no cutting/welding of the part is required). The proposed method has proven its efficiency in full scale, since real DPFs were regenerated using a commercial automotive part’s washing machine, with very satisfactory back pressure results.
Opportunities of AI and ICME in Metals Recycling, Production and Processing

S. Papaefthymiou¹, M. Bouzouni², V. Loukadakis³

¹National Technical University of Athens, Greece
²ELKEME S.A., Greece
³NTUA, Greece

E-mail: spapaef@metal.ntua.gr

The rapid penetration of Artificial Intelligence (AI) and all related developments of the 4th industrial revolution in the metals recycling, metals production and processing sector surprises even the field experts. The deep learning opportunities, the data analyses and the interconnection of level 3 systems in steel, aluminium and copper producing plants are paving the way for a more sophisticated production sequence that strives to ensure higher quality, lower emissions and lower costs. Additionally, the digital transformation, the urge for preserving critical raw materials, the integration of renewable energy sources into industrial production, the reduction of Carbon from the steelmaking process and its substitution by Hydrogen as a reduction agent and many other measures that are taken already by large corporations indicate that the transformation of the metals sector in the near future is going to be massive. This work reviews and discusses these developments and correlates them as well with state–of–the–art changes in Materials Engineering. We highlight penetration paradigms of modern computation tools, e.g. the creation of Digital Twins or Industrial Intelligent Twins in the metals processing industry. These technologies, sound very promising in terms of maximizing the production efficiency of modern industries and, thus, minimizing the required energy input, the greenhouse gases emissions leading the way to a more eco–friendly economy. Are their benefits as promising as they sound and what are their limitations? Digital Twins fall under the big data and AI categories and are programs that simulate the production line of a factory and how each one of the parameters will affect the final properties of the product and the overall efficiency of the facility. On the other hand, according to the Integrated Computational Material Engineering (ICME) approach detailed simulations of processes and materials to enhance the output of the materials design, reduce the cost, accelerate the process/materials development time and couple manufacturing processes in various scale levels providing insights on how various parameter changes affect the microstructure–properties relationships of advanced materials.
Wednesday 8 September 2021
OLYMPIA

SESSION C7
Industrial Minerals
Innovative processes and applications II

Chair: G. Anastasakis, A. Peppas
GUNITECH: An innovative pumice based dry shotcrete application

G. Tzouvalas¹, C. Galmpenis¹, M. Nomikou¹, V. Kaloidas²,³, N. Anagnostopoulos⁴

¹HERACLES Group, Greece
²Self employed, Greece
³Chemical Engineer NTUA, Greece
⁴SIKA HELLAS ABEE, Greece

E-mail: george.tzouvalas@lafargeholcim.com

Pumice quarried by LAVA MINING ANG QUARRYING SA from Yali island, Dodecanese, is used in domestic and abroad markets mainly as concrete lightweight aggregate, masonry units constituent, road substrate and loose soil stabilization. It is a porous natural volcanic rock with low density, low thermal and noise transmission and the higher strength among all the natural or artificial lightweight materials of mineral origin. Nowadays, pumice is of additional interest as it has a reduced CO₂ footprint because thermal energy is not needed for its expansion compared with the artificial lightweight aggregates.

In this context HERACLES GROUP in collaboration with SIKA HELLAS have launched a new product containing pumice stone, under the brand name GUNITECH. GUNITECH is an innovative spraying lightweight bagged concrete, certified as EN 1504-3 for building repairs with lightweight, mechanical and usage quality properties (as very low rebound)
Development of high added values products from industrial minerals for hybrid energy storage

A. Peppas¹, C. Politi

National Technical University of Athens, Greece

E-mail: Peppas@metal.ntua.gr

Industrial minerals are at the forefront of innovation and play an essential role in many high-tech applications. Their functionalities and properties make them very versatile materials which are essential to many industries. A combination of properties like heat capacity, density, price, availability, and eco-friendliness is exceptional and crucially advantageous of industrial minerals utilisation as thermal energy storage systems (TES). This technology stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. In this context, the utilisation of industrial minerals as carriers for encapsulating phase change materials (PCM) aims to overcome the issues and barriers in maximising the TES capacity of buildings and deliver more comfortable and healthier buildings with limited energy import dependency. However, the most recent publications study PCM-enhanced building components from the material point of view rather than focusing on the building component scale. Therefore, this study is focused on the industrial minerals-PCM application as part of the internal building fabric components, aiming to determine the benefits for buildings in terms of thermal energy performance and renewable energy penetration based on real data, harvested by an intelligent monitored building in Lavrion Technological and Cultural Park operated solely for research activities. All things considered, TES is a technology that can solve the existing mismatch of energy supply and demand and improve buildings’ system performance by smoothing temperature fluctuations, as well as improving the reliability of the heating and/or cooling source. Therefore, the use of industrial minerals in conjunction with PCMs have the greatest potential to optimise TES and lead to a decrease in CO₂ emissions and to economic and energy savings.
Modification of the Color Properties of Natural Hydraulic and Air lime Binders using Pyroclastic Rocks as Natural Pigments

G. Triantafyllou¹, O. Kalagri¹, G. Christidis¹, I. Marantos²

¹Technical University of Crete, School of Mineral Resources Engineering, Greece
²University of Crete, School of Mineral Resources Engineering, Greece

E-mail: gtriant@mred.tuc.gr

The use of naturally occurring pozzolanic materials, such as many pyroclastic rocks, as additives in various binders in order to enhance the properties of mortars used in a series of construction applications, is well established. In particular, binders designed for preservation and restoration works are evaluated not only for their physical and mechanical properties but also for their aesthetical characteristics. The addition of coloring substances like pigments in mortars is a practice that enhances this demand. In this research, pyroclastic rocks from the island of Santorini were used as natural inorganic pigments, to study their influence in the modification of the color properties of three commercial lime-based binders, consisting of an eminently hydraulic, a moderately hydraulic, and a calcium lime (CL 90 type), respectively. Petrographic, mineralogical, and chemical analyses of the rocks samples collected from various pyroclastic deposits in Santorini showed that they consist of pumice and scoria falls, following a basaltic-andesitic to dacitic series, and a composition range from 59.52 to 65.21 wt. % in SiO₂. Their amorphous content varies between 62 to 92%. Regarding their color, they present shades of grey, brown, red and black, while their L* and ΔE*ab values range from 85.25 to 59.65 and 15.00 to 40.58, respectively. Eight selected samples were initially extensively grounded to achieve a granulometry less than 63 μm and then a large number of experimental mixtures were prepared by partial weight replacement of the three binders, with five different ratios of the fine powdered pyroclastic materials (2.5, 5, 10, 15, and 20 wt.%, respectively). The modification of the color properties of the reference binders samples was examined using a spectrophotometer and by determining the chromatic parameters on the green-red (a*) and blue-yellow (b*) axes, the lightness (L*), and the deviation from the perfect white diffuser (ΔE*ab) in the resulted mixtures, according to the CIE color space measurement system. A significant effect of the Fe₂O₃ content in the pyroclastic materials, on the variation of their L* and ΔE*ab values, was observed. The addition of different percentages of pigments in the blended binders is accompanied by a gradual decrease of lightness and a corresponding increase in the deviation from the perfect white diffuser. The chromatic parameters of redness-greenness (a*) and yellowness-blueness (b*) are also modified. A rich color chart resulted by converting all measured chromatic parameters of the mixes, into different color standards similar to a variety of commercial color products.
Perspectives of lithium mining in Quebec, potential and advantages of integration into a local battery production chain for electric vehicles

S. Ibarra-Gutiérrez¹, J. Bouchard¹, M. Laflamme², K. Fytas¹

¹Université Laval, Canada
²InnovExplo, Canada

E-mail: seiba@ulaval.ca

This paper presents a discussion on Quebec’s pegmatite lithium resources and potential markets. It also evaluates the opportunities of lithium battery production for electric vehicles (EV) in the province while reducing greenhouse gas emissions. The paper shows that mining Quebec’s lithium ore deposits would be sufficient to satisfy the province’s lithium demand and also for exporting abroad lithium-ion batteries. By considering only the projects whose final product is LMH or LCE, Quebec would be able to produce between 10 and 21 million lithium-ion batteries for electric vehicles with a greenhouse gas emissions footprint of only 43% of the international average value due to Quebec’s hydro power. Finally, considering Quebec’s lithium mining project economics, the increased future demand for lithium would render Quebec’s lithium pegmatite projects competitive compared with those reported for brine projects.
Quantitative analysis of Portland cement clinker with Rietveld refinement: Implications of the amorphous matter

G. Christidis¹, M. Dimitriadi¹, G. Triantafyllou¹, C. Tsoumeleas²

¹Technical University of Crete, Greece
²Titan Cement co SA, Greece

E-mail: christid@mred.tuc.gr

Fine-grained industrial minerals and synthetic materials often contain variable amounts of amorphous or poorly crystalline phases, which are not easily detectable by the conventional X-ray diffraction (XRD) methods. The quantification of amorphous matter in industrial rocks is important for thorough characterization of the raw materials and assists to interpret their reactivity. Rietveld refinement is among the most reliable methods used for quantification of amorphous matter and recently it has been utilized for quantitative analysis of Portland cement. In this contribution we present the results of quantitative analyses with Rietveld refinement of a series of 6 grey and one white Portland cement clinkers supplied by TITAN cement Co, corresponding to industrial products of different production days and different cement plants (Kamari, Patra and Thessaloniki). ZnO was used as internal standard to determine the amorphous matter content. The particle size analysis and the chemical composition of the clinker were determined by laser diffraction and X-ray fluorescence (XRF) spectroscopy respectively. The grey clinkers consist mainly of tricalcium silicate (C3S, 57-61.5%) and calcium aluminate ferrite (C4AF, 12.7-17.4%) with dicalcium silicate (C2S, 3.2-7.6%) and tricalcium aluminate (C3A, 2.2-4.4%) being minor phases. The white clinker is free of C4AF, the C3S is present in lower amounts (50.5%) and the C2S in higher amounts (14.6%) than its grey counterparts. Finally, most samples contain traces of lime (0-4.5%) and periclase (0-2%). The 6 grey clinkers have a relatively constant amorphous matter content (13.6-15.4%), suggesting relatively controlled composition of the blend and constant firing conditions. By contrast, the white clinker has a considerably higher amorphous content (27.6%). There is not clear evidence for the presence of amorphous matter (e.g. hump in the range 15-30°2Θ). The mean particle size of the grey clinkers varied between 10 and 16.5 μm, were that of the white clinker was 15.4 μm. The theoretical Bogue composition of the grey clinkers is characterized by higher contents of the 4 crystalline phases, because it does not take into consideration amorphous matter. The Bogue composition of the white clinker yielded higher C3S and C3A contents but lower C2S content than Rietveld. The mineralogical composition of all clinkers by Rietveld refinement, without considering the amorphous matter, is comparable to the composition provided by Titan cement Co. These results strongly suggest that determination of amorphous matter is vital for accurate analysis of the cement clinkers, rendering the use of Rietveld analysis a valuable tool in this aspect.
The Italian zeolite tuffs used in the construction industry

M. Stamatakis, C. Vasilatos, I. Stamataki

National and Kapodistrian University of Athens, Greece

E-mail: stamatakis@geol.uoa.gr

Zeolitized tuffs used as construction materials had been sampled in south-central Italy near Naples, Rome, and Viterbo-Oevietto-Pitigliano-Sorano. Those areas are considered to belong to three different volcanic districts, those of Naples, Vico and Bolsena. The Napolitanean Yellow Tuff (NYT–Campanian Ignimbrite) in Naples volcanic district is extended north and west of the city of Naples. The formation is thinning towards to the north exhibiting a yellow to brown-red colour. Vico volcanic complex, Rome area, yields some red-brown zeolitic tuffs. Some quarries located in Riano and Nepi contain black scoriae (pumice) randomly distributed in a red-brown or grey groundmass. The volcanic Complex of Bolsena area contains zeolitized tuffs overlaying a volcanic conglomerate formation, grey glassy tuffs and marlstone. Small pumice or scoriae fragments are randomly scattered in a fine-grained porous groundmass. In Bolsena area occur the major deposits and active quarries of zeolitic rocks in Italy; the Piantorena Quarry, located near to Sorano, hosts a zeolitic succession of more than 40m thickness, developed for several Km2. The quarries studied have an average size of some 500x300x30m. The samples collected were analysed by XRD, XRF and SEM/EDS techniques. All tuff samples studied contain zeolites, mainly chabazite and/or phillipsite, and rarely analcite. The zeolite content of the NYT is up to 75%, comparable to those from Rome area, whereas the Sorano-Pitigliano tuffs have zeolite content up to 90%. In the zeolitized tuffs of Naples, phillipsite predominates, whereas Bolsena and Rome zeolitized tuffs are rich in both chabazite and phillipsite. SEM analysis revealed that there is an extensive replacement of the volcanic glass by subhedral zeolite crystals, whereas in pore spaces and fissures, euhedral zeolite crystals occur. Two different types of chabazite have been identified according to their XRD patterns; a Ca-rich and a Ca,Mg,K,Na-rich, both accompanying K- & Na-rich phillipsite. This could be attributed to the chemistry of the original volcanic glass, but also to the presence of alkali & alkaline earths-rich pore fluids. According to their bulk chemistry, all tuffs studied exhibit shoshonitic affinity and trachytic composition. Their comparison with zeolite tuffs from the Balkans suggested that the chemistry of the original volcanic glass phases and the parent magma plays an important role to the kind of the zeolites formed. The Italian zeolitized tuffs studied present a characteristic model for an early zeolite diagenesis of the volcanic glass in open hydrological systems.
Petrographic, mineralogical and geochemical characterization of Greek Triassic gypsum-anhydrite deposits and their industrial applications

I. Badouna¹, S. Neokosmidis², M. Stamatakis³, C. Karkalis¹, N. Koukouzas¹

¹Centre for Research and Technology Hellas (CERTH), Greece
²Hellenic Public Properties Company (HPPC) S.A., Greece
³Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, Greece

E-mail: badouna@certh.gr

Greece is considered as one of the most common producers of gypsum-anhydrite in Europe. The low content of impurities of these evaporite minerals, their big reserves and the low cost of logistics costs makes them exploitable and applicable for a range of industrial uses, such as in the building, pharmaceutical and agricultural sectors. The current study endeavors to present the petrographic, mineralogical, geochemical and qualitative features of evaporite samples from seven selected localities of western Greece and Crete Island. The deposits studied are those of Skopos (Zakynthos Island), Filliates (Thesprotia region), Etoliko (Etoloakarnania region), Katouna (Etoloakarnania region), Kastro (Kyllini region), Stomio (west Crete Island) and Altsi (east Crete Island). The studied evaporitic rocks are classified as a mixture of gypsum and anhydrite, where gypsum predominates. Other minerals present in minor amounts include celestite ± calcite ± dolomite ± magnesite ± sanidine and quartz. Samples of Skopos (Sk1-3, 5) Altsi (Alt1), Stomio (St1-2) Kastro (Kas1-3) and Filiates (Fil3) exhibit the higher content of gypsum. Celestite (SrSO₄) is a secondary mineral phase that was detected in all studied samples in the form of radical prismatic aggregates, fracture-filling mineral or as part of the evaporite groundmass. Its formation is most probably attributed to the effect of dissolution processes on sub-areal gypsum and/or the release of Sr amounts during the anhydrite → gypsum transformation. The main global supplier of strontium is Spain with a market share of 31%, exploiting 2 mines of celestite, and consists the sole supplier in Europe. In Cyprus also, there is a temporarily exploited celestite deposit which is associated with gypsum deposits of Messinian age. The investigation for Sr recovery (even from non-pure celestite ores) presents high interest, since Sr is included in the list of critical raw materials. The highest celestite value (13.5%), corresponds to the region of Filiates, indicating that this deposit is prosperous for further research and potential Sr exploitation. Significant focus is also given on the assessment of the evaporite whiteness with respect to their mineralogical and geochemical composition. Their average whiteness is ranging between 68.98% to 95.58% and it is substantially affected by the presence of mineral impurities, i.e. dark colored dolomite. The highest whiteness values (>93.6%) are presented in samples of Skopos (Sk1-5), Altsi (Alt1) and Stomio (St2, 3). The aforementioned data aim to serve the dynamic Greek calcium sulphate industry by enhancing the evaporites’ prospects of industrial use, providing potential applications for those not already exploited.
Wednesday 8 September 2021
VERGINA

SESSION C8
Mine closure / Post mining

Chair: C. Roumpos, A. Antoniadis
Introducing the IDEF0 Methodology in the Strategic Planning of Projects for the Surface Mine Land Reclamation and Repurposing

P. Spanidis¹, C. Roumpos², F. Pavloudakis²

¹ASPROFOS Engineering, Greece  
²Public Power Corporation of Greece, Greece

E-mail: pspani@asprofos.gr

Surface mines are long term and capital intensive industrial systems of high complexity, generating considerable environmental and social impacts to the communities and ecosystems located in the vicinity of the mining operations. When a surface mine enters steadily to the closure phase, several strategic questions and critical decisions related to land reclamation and post-mining activities planning with high impact in terms of sustainability, performance and cost-effectiveness are coming into the front. For this reason, a properly organized and well-functioning framework for the mine land reclamation and repurposing to an upgraded and sustainable complex of land uses with beneficial returns to society, environment and economy is required. The objective of the present paper is (a) to provide an overview of the essential mine-closure problems and their critical role for the sustainable transformation of post-mining sites and (b) to propose a methodology through which the analysis and design of the repurposing activities can be carried out, in a view to constitute a functional basis for the planning of an integrated, sustainable and large scale strategy of new land uses with reasonable perspective(s) of implementation. Based on the literature review, the IDEF0 (Integrated DEFinition Function modelling) functional analysis and activity-oriented method of visualization is demonstrated and recommended as a low cost and easy development tool appropriate for the situational analysis and planning of a generic strategic framework applicable in typical projects for post lignite mining and repurposing. The proposed methodology enables an empirical and knowledge-based interpretation and workflow mapping of the post-mining projects as multidisciplinary business process models/entities decomposable to four (4) discrete sub-processes: (A1) “Setting-up the Strategic context”, (A2) “Geo-Environmental Data Collection and Situational Analysis”, (A3) “Selection of the Reclamation Strategy” and, (A4) “Perform the Reclamation Project Execution Plan”. The identification of the sub-processes and the priorities and interrelations among them along with the main inputs (I), outputs (O), controls (C) and mechanisms (M) are structured in a functional model in accordance with the IDEF0 ontological and syntax requirements. The methodology was tested in a case study for a reclamation project in a Greek lignite mine entering to closure phase. A discussion on the advantages and disadvantages of the IDEF0 method is presented, along with recommendations and proposals for further research.
Restoration of Old Olympias arsenopyrite concentrate storage area (former METBA plot)

E. Gazea, D. Dimitriadis, A. Galatsianou

Hellas Gold, Greece

E-mail: emmy.gazea@eldoradogold.com

The area of the old arsenopyrite concentrate disposal site is located in the Olympias Mining Facilities and specifically within the boundaries of the flotation plant. The area was formed in the 80's by the mining owner at the time Hellenic Chemicals & Fertilizers Co. S.A. as a temporary storage area of the produced concentrate of gold-bearing arsenopyrite of Olympias. The concentrate had to be stored because it was not possible to place it on the market as it was non-merchantable at that time and its planned future use for the recovery of the gold content. In the late 90’s, the concentrate was removed from the site in order to establish the then-planned gold metallurgical plant by the “Metallurgical Industries of Aegean (METBA)”. The total area is 110 acres. Arsenopyrite concentrate pockets as well as oxidized residues from the removed pile, which remained on the deforested surface were major sources of pollution of the surface and groundwater of the wider area. The environmental impact of this area was extremely high, especially during periods of heavy rainfall with acid mine drainage (AMD) to the adjacent Mavrolakkas creek.

The remediation and restoration works of this area initiated by Hellas Gold as a priority immediately after taking over the Kassandra Mines property. The measures implemented for the restoration of the area included the removal of the contaminated soil (remediation), the addition of calcium carbonate as soil additive and the addition of healthy soil material to restore the morphological characteristics to the previous condition before the mining activity. Immediately after the restoration of the area, a nursery installed with more than 1,000,000 plants. The nursery produces 320 different species of forest and ornamental plants and covers the needs of plants with species of local flora for all the restoration projects of Hellas Gold but also for the support of local stakeholders. In the context of maximizing the recycling and sustainable operation of the Olympias Mining Facilities, the irrigation of the nursery plants is performed exclusively with the Olympias mine water from after treatment. At the same time, about 20 new jobs were created, increasing the economic activity of the region. In summary, the rehabilitation of the “former Metallurgical Industries of Aegean (METBA)” plot of an old arsenopyrites concentrate storage site in Olympias contributed to the upgrade and protection of the environment along with its utilization for the creation of a new productive activity.
Lignite deposits in the post-coal era: alternative utilization in the agriculture and horticulture sectors

S. Kalaitzidis, K. Christianis, A. Giannouli, A. Rizos, K. Perleros

Section of Earth Materials, Department of Geology, University of Patras, 265.04 Patras, Greece

E-mail: skalait@upatras.gr

The main substance controlling the soil health and fertility is the content and the type of the organic matter (OM), particularly of humus. The contained OM affects the nutrient supply, the water retention and drainage, the erosion resistance and the plant resistance to parasites and diseases. The main constituents of humus are the humic compounds, which are quite resistant to further decomposition. The most common and effective practice for preserving, restoring or even improving the physical, chemical and biological properties of soils is the use of soil amendments and/or organic fertilizers. The use of peat and lignite as raw materials for manufacturing products capable of improving the functionality of soils, is mainly based on their high humic-compound content.

The objectives of the study include the determination of the physicochemical properties of several lignite deposits across Greece. Emphasizing is given on the composition of their organic fraction, including the humic substances, in order to assess their applicability in the agricultural/horticultural sector as soil amendments and/or for the manufacture of organic fertilizers. The ultimate goal is to contribute to the promotion of non-electrical and environmental-friendly technological applications of coal.

The main advantageous features of several Greek lignite deposits positioning them to be suitable for the manufacture of humic components are the low rank, lying between peaty lignite to soft lignite, as well as the predominant matrix lithotype, and the pH value between slightly acidic to slightly alkaline. The obtained results show that the characteristics making Greek lignite a poor fuel, are exactly these benefiting the manufacturing of humic substances and/or soil amendments. Numerous small deposits in Greece, as well as specific layers from the main Florina-Ptolemais-Kozani and Megalopolis deposits can be exploited towards this direction in order to offer an alternative option in the coal industry of the country in the onset of the post-lignite era.
Geotechnical engineering perspectives: challenges and solutions in the transition to a post-lignite era

I. Zevgolis¹, A. Theocharis², N. Koukouzas²

¹National Technical University of Athens, Greece  
²Centre for Research & Technology Hellas (CERTH), Greece

E-mail: izevgolis@metal.ntua.gr

For many decades, coal and lignite mining has been a vital industry based on extracting non-renewable coal resources from the ground. However, the transition to cleaner forms of energy has led to mine closures in several regions across Europe and globally. With this shift in the energy mix and the groundbreaking changes in the economy’s structure, the economic and social impact in many coal regions should not be ignored. Decarbonisation of these areas will leave vast areas of closed mines and waste dumps that will burden local and national communities unless suitably reclaimed. Coal regions are searching for ways to reinvent themselves, being on the verge of the post-coal and post-lignite era. For this transition, several solutions have been proposed, and some have been implemented, including reclamation of coal areas by renewable energy systems (e.g. wind farms and solar parks) and development of recreational areas with open-pit lakes and green zones. These plans pose geotechnical challenges that relate to the safety and cost-efficiency of the proposed solutions. Furthermore, climate changes should be considered towards this new era, as temperature, rainfall, and wind speed changes might crucially affect the areas’ safety.

In this work, three issues are analysed regarding geotechnical engineering’s role in the reclamation of lignite mines and adjacent waste dumps. Firstly, the slope stability of lignite excavations is examined when flooding the excavation to create an open-pit lake. During the flooding procedure, the safety factor decreases to reach a minimum value when the lake height is about 20%-40% of the slope’s height. Then it increases again, and at the end of the flooding, the safety factor becomes higher than the initial one. Secondly, the potential reclamation of a waste dump is investigated. Different scenarios are analysed, such as the foundation of a highway, a railroad, or a building, based on the waste material’s average soil properties. Finally, rainfall changes’ effect is studied on the slope stability of abandoned lignite mines. Specifically, the change in rainfall characteristics is incorporated in numerical analysis to examine its influence on the safety factor of partially saturated slopes of a lignite excavation.

Overall, the importance of geotechnical engineering in the transition to a post-lignite era is underlined. Each of the three cases presents a different aspect ranging from reclamation of lignite excavations with open-pit lakes to the reclamation of waste dumps and the safety of the areas due to the effect of climate change.
Correlation of ambient air quality with the sudden reduction of mining activity in a complex of lignite mines

C. Sachanidis, F. Pavloudakis, C. Roumpos

Public Power Corporation SA, Greece

E-mail: f.pavloudakis@gmail.com

The elimination of fossil solid fuels share in the energy mix is a priority of EU energy policy. In this context, many European power utilities have already started to implement programmes to gradually reduce the use of coal and lignite, turning either to natural gas, as a transitional fuel, or directly to renewable energy sources. With regard in particular to the exploitation of the lignite deposits of the Ptolemais basin, the plans until recently provided for the operation of mines and steam power stations until 2042. However, under the pressure of competition largely shaped by the high price of carbon dioxide emission allowances, lignite production has been dramatically reduced in recent years while the definitive closure of mining activity has been rescheduled for 2028. This development, in addition to the obvious negative impacts, affects positively the ambient air quality of the greater lignite mine area, as evidenced by the data presented in the present study, which has been collected by a network of ten monitoring stations. These figures are correlated with the main production parameters of the mines. Conclusions are being drawn both for the entire basin of Ptolemais and for some of its parts, which were selected to be investigated thoroughly, taking into consideration the spatial distribution of various activities that have already ceased operations. Based on the above analysis, a prediction is made as to what the contribution of the mines will be to the release of particulate pollutants after the phase out of mining activity. This contribution will mainly be due to diffuse sources, such as excavation sites and, predominantly, dumps of wasted rocks and ash. The acceleration of the closure of the mines results in the sudden release from the production process of thousands of acres of surfaces with limited vegetation, which will be potential sources of air pollution. These surfaces should be gradually restored, over a period of at least a decade, provided that required resources will be available by the mining operator and local authorities. For this reason, the conclusions and information to be highlighted in this paper should contribute, inter alia, to the selection and spatial distribution of appropriate land reclamation methods and land uses to be developed in the post-lignite era.
Planning RES projects in exhausted surface lignite mines. Challenges and solutions

A. Antoniadis¹, C. Roumpos², P. Anagnostopoulos¹, N. Paraskevis²

¹Public Power Corporation Renewables, Greece
²Public Power Corporation of Greece, Greece

E-mail: aantoniadis@ppcr.gr

In the context of the complete phase-out of the lignite-fired power plants and the corresponding surface mines of Greece by 2028, as reflected in the National Energy and Climate Plan forecasts, the central priority is to ensure a fair development transition for the lignite mining areas. In this context, a strategic plan considering a mixture of interventions and measures of economic diversification is an essential part of the transition from lignite mining to other uses of mine land.

According to the current environmental legislation and the appropriate scientific approach, mining land reclamation gradually follows the completed mining works during the surface mining operations. It is required not only for environmental but also for geotechnical reasons, ensuring the suitable landscape architecture and the geotechnical and geochemical stability of mining landforms. This mining reclamation is described, among others, in the Environmental Impact Assessment for the mining operations and the respective Decision of the Approved Environmental Terms. The related projects need strategic planning, also taking into account the future land uses.

In the framework of the development of RES projects in the surface lignite mines of Western Macedonia, the challenges mainly refer to the optimal utilisation of mining land concerning the topography and the technical characteristics of mining land, the current mining activities or the alternative land uses. This paper aims to analyse the challenges for developing photovoltaic projects in areas of different characteristics and propose solutions for selecting suitable areas based on corresponding analysis.

The investigated parameters include (a) the current land use/cover, (b) the time of the exhaustion of mining works, (c) the slope and orientation of the mining land, (d) the distance from settlements, villages and populated areas, (e) the proximity to transmission lines and road network, (f) the geotechnical stability, (g) the hydrogeological conditions, (h) the existing infrastructure and (i) the archaeological areas.

Considering that the Photovoltaic stations are planned to be developed in the mining landfills, the reclamation of mining land is crucial to minimise the subsidence risk, while the levelling will increase the installed power density of the Photovoltaic Stations. In addition, the simultaneous operation of Lignite Power Plants and Mines and their respective infrastructures, the parallel mining reclamation and the development of Photovoltaic Stations in areas of different characteristics constitutes an original approach and a technical and licensing challenge. The results prove in practice the transition to green energy generation concerning circular economy and sustainable development.
Examination of the potential utilization of phosphogypsum as an alternative material for the reclamation of mines and quarries

G. Gaidajis

Democritus University of Thrace, Greece

E-mail: geogai@pme.duth.gr

Phosphogypsum is an industrial waste of the phosphate fertilizer industry, produced during the production of phosphoric acid. Typically, 4-6 tonnes of phosphogypsum are produced per ton of fertilizer. Presently, annual phosphogypsum production is estimated to be in the range of 100-280Mt. The majority of the produced phosphogypsum is usually disposed within a confined lined or unlined area, exposed to weathering processes and causing environmental problems. In Greece, large quantities in the order of 15 Mt are stockpiled in certain areas in Northern Greece. Given the massive quantities stockpiled and the existence of exhausted quarries in the vicinity of the disposal area, a potential promising use of the specific material could be as an alternative material in reclamation projects of quarries. In order to examine the environmental suitability of phosphogypsum as a reclamation material, its environmental characteristics were studied through laboratory and large-scale pilot scale experiments. In the laboratory experiments, the material and mixtures are placed in lysimeters and the leachate is monitored continuously in terms of quantity, pH and conductivity, and periodically in terms of its chemical composition. Similarly, in the pilot-scale experiments, the emanating leachates from four lysimeters with dimensions of 10mX10m are monitored periodically. The initial results indicate that in general terms the leachates satisfy the environmental limits for discharge in natural receivers, however the long-term behavior of the material is necessary to be determined.
Risk assessment methodology for pit lakes instabilities

M. Galetakis¹, V. Deligiorgis¹, E. Steiakakis¹, S. Raka¹, M. Al Heib²

¹Technical University of Crete, School of Mineral Resources Engineering, Greece
²Institut national de l'environnement industriel et des risques, France

E-mail: galetaki@mred.tuc.gr

One of the most common uses of pit voids left by large scale mining operations, such as the surface lignite mining, is the formation of pit lakes by flooding pit voids after mine closure. Pit lakes offer the opportunity to enhance the recreational or ecological benefits by re-landscaping and re-vegetating the shoreline, by creating aquatic life, and maintaining water quality. Pit voids are filled by artificially flooding or allowing the pit voids to fill naturally through hydrological processes such as precipitation or ground water infiltration. Pit flooding, which is the most popular type of reclamation for open pits, induces groundwater rebound with short and long time consequences, such as soil instabilities causing landslides and subsidence. To ensure safe use of pit lakes by public, it is necessary to assess the risk of instability of these areas. The main aim of this study is to develop a probabilistic risk assessment methodology to evaluate the risks associated with flooding process of the pit and particularly on slopes failure. The proposed methodology consists of two distinct phases. Initially the risk analysis and the risk assessment are performed, while in the second phase the spatial analysis of risk and the creation of the related maps are implemented. In the first phase the bow-tie analysis is used to analyze the critical unwanted event (slope failure) and the systemic risk assessment method to estimate the risk for the population, the environment and the infrastructure. The spatial analysis of the risk included the discretization of the area under study into squares, the estimation of the risk in each one and the creation of the corresponding risk maps by using appropriate spatial interpolation techniques. The developed methodology was applied in the area of pit lake Most in Czech Republic.
Wednesday 8 September 2021
ILISSOS

SESSION C9:
Pollution abatement/Environmental performance

Chair: M. Menegaki, S. Kalaitzidis
Following the Paris Agreement, the EU has established an ambitious plan for decarbonization of the economy until 2050 based on circular economy and resource efficiency. However, new technologies should be adopted and implemented to achieve the sustainability goals set by the EU in respect to net-zero greenhouse emissions. An emerging technology that could potentially contribute to reducing the level of CO₂ is attributed to the in-situ mineral sequestration (long-term geological storage) and/or the ex-situ mineral sequestration (controlled industrial reactors) of CO₂. In this study, coal combustion fly-ash containing ≈39 wt.% of lime (CaO) is subjected to carbonation experiments by applying an innovative and fully controlled autoclave reactor to assess the aqueous carbon sequestration. The effect of pressure (1-15 bar) and temperature (25-200°C) was studied. A combination of wet-chemical procedures as well as microscopic (SEM/EDS), spectroscopic techniques (FTIR) and differential thermal analysis are used. Based on the experimental results, the optimum conditions for the CO₂ sequestration by fly-ash correspond to treatment at T=100°C and P=15 bar, which indicated that the carbon content was increased by 23% compared to the experiment with the lower carbon content. The qualitative comparison of reactants and products revealed a complete CaO–CaCO₃ conversion. Thus, this study demonstrates that 1 ton of fly-ash could sequester up to 162 kg of CO₂.
Simulating the use of a smelter off-gas in the precipitation stage of the Pedersen process

A. Manataki\textsuperscript{1}, J. Mwase\textsuperscript{2}, C. van der Eijk\textsuperscript{1}

\textsuperscript{1}SINTEF Industry, Norway
\textsuperscript{2}Norwegian University of Science and Technology, Norway

E-mail: any1m@yahoo.com

The Pedersen process is an alumina production process which combines pyrometallurgical and hydrometallurgical methods. In the pyrometallurgical stage, limestone is calcined and CO\textsubscript{2} is generated. This off-gas can be captured with a high CO\textsubscript{2} concentration. At the end of the hydrometallurgical process, aluminum hydroxides, like bayerite are precipitated using CO\textsubscript{2}. In this paper, experimental work on precipitation of aluminum hydroxides through the addition of a mixture of CO\textsubscript{2}, O\textsubscript{2} and N\textsubscript{2} is presented. The parameters varied, were the percentages of each gas and the temperature. The indicators measured were the time till the beginning of precipitation and the time that precipitation lasts. These tests simulate the use of a smelter furnace off-gas in the precipitation stage of the Pedersen process and have shown promising results.
Valorization of bottom oil sludge in red ceramics – Inertization of the contained heavy metals in the ceramic matrix

X. Spiliotis¹, D. Kasiteropoulou¹, D. Kaffe¹, D. Chistodoulou¹, G. Papapolymerou¹, G. Banias²

¹University of Thessaly, Greece
²CERTH/iBO, Greece

E-mail: spil@uth.gr

Refineries generate large amounts of waste. Among the solid wastes, special attention is paid to the oily sludge that accumulates at the bottom of crude oil storage tanks and oily sludge generated at different steps in the treatment of oil containing process water and stormwater. Co-processing is a proven sustainable development concept that reduces: demands on natural resources, pollution and landfill space and environmental footprint. Potentially useful industrial secondary resources, co-processed with clay mixtures can lead to the manufacturing of novel ceramic building products. The expected advantages, resulting to industrial symbiosis, are: combustible parts of the sludge replace fossil fuels, exploitation of the contained water in the sludge, significant GHG emissions reduction, elimination of wastes for refineries, replacing raw materials by non-combustible parts of the waste, inclusion of ashes and residual metals from the wastes within the ceramic structure, complete destruction of organic compounds found in the oily sludge (high residence time >5 sec in oxygen rich atmosphere). The residence time, temperature, and turbulent environment in a ceramic kiln's combustion chamber is ideal for the degradation of organic components, whereas inorganic components are bound up in the ceramic microstructure of the product coming out of a kiln. The leaching tests conducted on the ceramic products containing 5% and 10% of the waste in question, do not have an adverse impact on the environment or human health.
Investigation of the freezing-thawing effect on the slip resistance of natural stones

K. Laskaridis, A. Arapakou, M. Patronis, I. Kouseris

Hellenic Survey of Geology & Mineral Exploration (HSGME), Greece

E-mail: laskaridis@igme.gr

The main objective of this paper was to investigate the effect of freeze-thaw cycling (EN 12371) on the slip resistance of natural stones used as flooring materials. For this purpose, specimens from limestones, granites, calcitic and dolomitic marbles were selected and studied in order to determine their slip resistance (EN 14231) before and after freeze-thaw action. Slip resistance was determined through the pendulum tester in dry and wet conditions, and frost resistance was assessed through controlled freeze in the air – thaw in water repeated cycles within a temperature range between +17°C and -12°C. Test results under dry conditions indicated that slip resistance of the unpolished surfaces was positively affected by freeze-thaw action, mainly as far as granites and marbles were concerned, while in wet environments slip resistance values presented slight to negligible decrease. Furthermore, slip resistance of the polished surfaces under both dry and wet conditions remained almost unchanged even after 100 freeze-thaw cycles. It is obvious that surface processing techniques, as well as wet or dry environments play important roles in the slip resistance values determined. As SEM analysis indicated, in the case of unpolished specimens the widely distributed surface anomalies result in making these surfaces more susceptible to wear caused by freeze-thaw action, allowing for the increase of their roughness and rendering them more slip-resistant. On the other hand, the observed homogeneity of the polished surfaces prevents slip resistance of the relevant specimens from being significantly affected.
The industrial application of nanomaterials focusing on the development of “green” products aiming to face urban pollution constitutes a trend of modern era bringing together scientists from different scientific fields such as toxicology, materials’ science and engineering. Air pollution over urban areas constitutes a major problem posing adverse effects to human health to large population groups. Under these circumstances, there is a need to develop a “green” tile along with the application of nanomaterials able to face urban pollution. The addition of nanomaterials onto the surface of the tile would provide to the final product extra properties capable of breaking down atmospheric pollutants and reflecting the sunlight. Titanium dioxide (TiO$_2$) is well known for its photocatalytic activity, its zero toxicity and its ability to degrade organic pollutants. This research aims to develop a new bioclimatic product with photoreflective and photocatalytic properties for subsequent use in cool roofs. Due to its white colour and high refractive index, titanium dioxide is an ideal material for this purpose. Aqueous suspensions of TiO$_2$ nanoparticles and PEG (polyethylene glycol) were developed as surface-active material and sprayed in the form of a photocatalytic active suspension onto the surface of fired clay roofing tiles. Characterization techniques were carried out and determination of the sample composition phases was performed by XRD analysis. The diffraction patterns exhibited strong peaks corresponding to the anatase and rutile phases. Textural characteristics (BET analysis) of the TiO$_2$ suspensions indicated that temperature and PEG addition can change the surface area of the final product. The hydrophilicity of the surfaces of all samples was determined by contact angle measurements, monitoring the change in glycerine contact angle with UV-irradiation time. The photocatalytic activity of all samples was determined by monitoring the decomposition/decrease of volatile organic pollutants and NO pollutants. The results showed that the TiO$_2$ photocatalytic coating-samples exhibited great photocatalytic activity and high hydrophilicity. This research was conducted as part of the research project “Green Tile Development-KERAMI” in collaboration with “KEBE-Northern Greece Ceramics” and was funded by the Operational Programme Competitiveness, Entrepreneurship and Innovation 2014-2020 (EPAnEK) of the Hellenic Ministry of Economy and Development.
LCA and LCC of Emerging and Incumbent Technologies on Energy Harvesters

A. Malagnino\textsuperscript{1}, M. Rostagno\textsuperscript{2}, G. Amaro\textsuperscript{1}, A. Vlysidis\textsuperscript{3}, A. Gkika\textsuperscript{3}, E. Koumoulos\textsuperscript{3}, Y. Qin\textsuperscript{4}

\textsuperscript{1}GAe Engineering, Italy
\textsuperscript{2}DIAD Group, Italy
\textsuperscript{3}IRES - Innovation in Research & Engineering Solutions, Belgium
\textsuperscript{4}University of Strathclyde, Belgium

E-mail: a.malagnino@gae-engineering.com

Interest in energy harvesters is growing rapidly the last decades. However, the majority of the materials used in energy harvesting devices have high dependence on rare elements. Current obstacles to the large-scale introduction of energy harvesters that use materials with less rare-element dependence and/or are toxic-free are associated largely with inadequate material performance and reliability, high manufacturing cost, and inadequately developed product design strategy addressing needs for sustainable development. The introduction of nano-structured smart materials and component manufacturing for energy harvesting applications is expected to offer improved quality and structural reliability whilst reducing overall resources and operational costs through shortening the process chains and improving material processing efficiency. In this study, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are performed to assess and evaluate PE and TE materials enabling to identify current lowest environmental impact as well as trade-offs across the supply chain of a product, providing insights into designing for recycling towards circularity. The life cycle inventories of the incumbent technologies are compiled based on literature and LCA and LCC results are extracted and evaluated. This study will serve as a basis for comparing current PE and TE based energy harvesters with lead-free PE and Hf-free half-Heusler TE materials that will be developed within the FAST SMART project. This European project aims at increasing the performance of current energy harvesters while reducing at the same time: the use of rare elements and toxic substances; resources and energy consumption; environmental impact and costs; paving the way for the adoption of new and more environmental-friendly systems for Energy Harvesting.
Correlation between physical mechanical properties of Greek dimension stones

A. Arapakou, K. Laskaridis, M. Patronis, I. Kouseris

Hellenic Survey of Geology & Mineral Exploration (HSGME), Greece

E-mail: arapakou@igme.gr

The objective of the present study was to investigate possible relations in physical mechanical properties of Greek natural stones used widely either as structural materials or in the decorative art. The study focuses particularly on flexural strength, durability in environmental conditions and water absorption of stones quarried from various places in Greece and differing in composition, structure and textural properties, i.e. limestones, marbles, sandstones and schists. Specimens were appropriately prepared in order to perform the relevant laboratory tests according to the applicable EN Standards. Namely, they have undergone tests for determining flexural strength (EN 12372, EN 13161), frost resistance assessed through controlled freeze in the air – thaw in water repeated cycles (EN 12371), open porosity (EN 1936) and water absorption at atmospheric pressure (EN 13755). Overall and “by individual stone type” correlation equations were established between the corresponding flexural strength under concentrated load values without (FS3) and either after freeze-thaw cycling (FTFS3) or after thermal shock action (TSFS3). Results suggested a linear relationship between (FS3) and (FTFS3) values, i.e. (FS3)=a*(FTFS3)+b, and a power one between (FS3) and (TSFS3), i.e. (FS3)=c*(TSFS3)^d. Furthermore, a significant correlation via a power function was found to hold between flexural strength under concentrated load values (FS3) and those of flexural strength under constant moment (FS4). Results have also shown that generally water absorption, a property playing an important role on mechanical behaviour of stones affecting structural safety and on their aesthetic characteristics, increases linearly with the increase in open porosity.
Project risk management adaptations of infrastructures in the Greek context

G. Demertzis¹, K. Vatalis²

¹Hellenic Open University, Greece
²University of Western Macedonia, Greece

E-mail: std131594@ac.eap.gr

Last years in Greece there has been an increase in the number of “Small and Medium Enterprises, SMEs” active in the construction of infrastructures and specifically in the telecommunications sector. Large companies, for both operational and financial reasons, prefer to outsource projects and services related to their network infrastructure to third companies rather than using their own resources. SMEs undertake to implement many of these services. They are more flexible in terms of operation but also adapt faster to the requirements of the projects they undertake. However, unlike large companies, they lack in procedures and have limited administrative resources. This makes them more vulnerable to the risks presented in the various phases of the projects they undertake. The research methodology was done with an appropriate questionnaire which is addressed mainly to construction companies. Risk Management, as a process, includes the identification of risks, the prediction of the probability of occurrence and its consequences and finally proposes solutions to treat them. This research investigates the current situation regarding risk management by Greek SMEs and highlights the usefulness of the process and finally propose according to International Standards, the risk management plan for a specific project that SMEs could implement as internal process.
Wednesday 8 September 2021
FOYER OLYMPIA

POSTER SESSION 3
Environment, Energy and Sustainability
Industrial Minerals
Catalytic action of zeolite in micropollutants’ ozonation. Application in a continuous flow pre-industrial unit

E. Kaprara¹, S. Psaltou², M. Salapasidou³, P. Palasantza³, P. Diamantopoulos³, A. Zouboulis², M. Mitrakas¹

¹Laboratory of Analytical Chemistry, Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece
²Laboratory of Chemical and Environmental Technology, Department of Chemistry, Aristotle University of Thessaloniki, Greece
³AKTOR S.A., Wastewater Treatment Plant of Touristic Area of Thessaloniki “AINEIA”, N. Michaniona, Thessaloniki, Greece

E-mail: kaprara@auth.gr

The aim of this study was to evaluate the potential of zeolite to act as catalyst to the ozonation of micropollutants through a continuous flow system used for their removal from wastewater. For this purpose, a pre-industrial level unit was designed, constructed and operated at AINEIA’s municipal wastewater treatment plant (established in N. Michaniona-Thessaloniki, Northern Greece). The unit comprised of a column packed with sand for the filtration of suspended solids, a custom-made porous PTFE hollow fiber membrane (provided by Markel Corporation, PA, USA) for the dilution of ozone gas to water, a column packed with zeolite that served the catalytic ozonation of micropollutants and another sand/activated carbon column for the final biological stabilization of treated wastewater. The secondary effluent of the wastewater treatment plant was introduced to the pilot unit at a flow rate of 200L/h while target micropollutants (benzotriazole, caffeine, paracetamol and p-CBA) were added to the system after the filtration column to a concentration of 2μM. Ozone gas supply to the pre-industrial unit was provided by an existing to the plant generator that produced 190 grO3/Nm3. Gas flowrates tested at the experiments were 7, 16, 30, 40 and 50 L/h.

As experimental results revealed the introduction of zeolite to the system significantly enhanced the removal of micropollutants. In the case of p-CBA and for an ozone gas flowrate of 7L/h the catalytic action of zeolite improved the degradation of micropollutant by more than 1.5 times, leading to a total removal, after the biological stabilization, of 63%. This presentence increased with greater ozone gas flowrates reaching 78% for 50L/h. Zeolite’s contribution in benzotriazole ozonation was higher since for an ozone gas flowrate of 7L/h almost 70% was removed while for 30L/h and above complete degradation of benzotriazole was achieved. Regarding caffeine, more than 85% was removed with 7L/h ozone gas flowrate and no residual concentration was determined for greater ozone supplies. Paracetamole was completely removed at any conditions tested in the pre-industrial unit.

Acknowledgments: This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEACH-CREATE- INNOVATE (project code: T1EDK-02397).
Synthesis and Characterization of Magnesium Silicide formed by thermochemical diffusion process

D. Stathokostopoulos, A. Teknetzi, K. Chrissafis, D. Karfaridis, G. Vourlias

Aristotle University of Thessaloniki, Greece

E-mail: dstat@physics.auth.gr

In last few decades, considerable research effort has been concentrated to develop material which can be used to transform heat into electric power. These materials have been considered as a potential environment-friendly high performance thermoelectric material. Metal silicides are promising thermoelectric materials and characterized by low resistance, high thermoelectric figure of merit $ZT$, low density, high melting point, thermal stability, low toxicity and fabrication cost. A variety of techniques have been used to prepare silicides, as ball milling, solid state reaction, sputtering, reactive deposition epitaxy. Here, a new environmental friendly, low cost and simple technique, thermochemical diffusion process (pack cementation) was used to synthesize Magnesium silicide ($Mg_2Si$). Magnesium silicide is a prospective narrow gap semiconductor for thermoelectric energy conversion at high temperatures. The current study focuses on the fabrication of new thermoelectric materials, aiming towards the development of compounds with advanced thermoelectric properties. For this process a powder mixture which contains Si powder Mg (donor material), and a halide salt which is the chemical activator are packed and sealed in a ceramic. The sealed crucible is then heated in an electric furnace under Ar atmosphere. A series of experiments were carried out at temperatures ranging from 450°C to 650°C at different durations from 120 min to 240 min to compose $Mg_2Si$, thermoelectric powders. The morphology and the chemical composition were determined by SEM equipped with EDS analyzer, the phase identification was performed using XRD analysis, the chemical state was identified via XPS and the oxidation resistance of silicides was investigated by TGA.

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Reinforcement of Postdoctoral Researchers - 2nd Cycle” (MIS-5033021), implemented by the State Scholarships Foundation (IKY).
Uptake of high-valent heavy metals from water by magnetite nanoparticles

E. Chioti, K. Kalaitzidou, T. Asimakidou, K. Simeonidis, M. Mitrakas

Analytical Chemistry Laboratory, Aristotle University of Thessaloniki, Greece

E-mail: ksime@physics.auth.gr

The presence of heavy metals in aquatic environments is considered as a major worldwide problem related to many harmful effects on the health of humans and other life forms. Long-term exposure to water with high concentrations of heavy metals is implicated with chronic diseases, cancer development, organ damage and increased human mortality. According to their chemistry, such pollutants are classified in divalent cations (Pb, Cd, Ni, Hg), high-valent ions (Cr, Mo, Se, U) and oxy-ionic species (metalloids As, Sb). High-valent metal pollutants pose a very serious risk due to their toxicity, which is clearly defined by both high mobility and elevated oxidation state. Among them, hexavalent chromium is by far the most discussed form in this category of heavy metal species as defined by the extended debate on its toxicity by the drinking water consumption path in combination with the recently applied regulation limit of 25 μg/L. Several removal methods have been tested to capture aqueous forms of Cr(VI) or other high-valent metals but only few of them were proven sufficient to operate in consistence to the drinking water requirements. Adsorption is considered as a very promising method because metal-loaded adsorbents are more compact and generally stronger bonded. The recent conjunction of nanoparticles synthesis and modern water treatment technology describe a rather challenging field for the development of novel adsorbents beyond the current state of the art. In this study, magnetite nanoparticles, known for their high reducing potential, were synthesized by transferring a well-known green aqueous precipitation method in a continuous-flow setup. Particularly, green rust was formed by the addition of FeSO₄, NaNO₃ and NaOH in a stirring reactor under nitrogen bubbling and the oxidizing ageing of the mixture at temperatures above 70 °C for several hours. Depending on the reagent ratios, the reaction pH, the bath temperature and the ageing time, obtained nanoparticles were optimized to provide efficient reduction and capture of Cr(VI) at concentrations below 25 μg/L.

The research project was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the “2nd Call for H.F.R.I. Research Projects to support Post-Doctoral Researchers” (Project Number: 00046 MagnoSorb).
Retention of Pb using thermally-treated palygorskite under dynamic sorption conditions

M. Gatou¹, Z. Kypritidou², A. Argyraki², E. Pavlatou¹

¹NATIONAL TECHNICAL UNIVERSITY OF ATHENS, Greece
²NATIONAL & KAPODISTRIAN UNIVERSITY OF ATHENS, Greece

E-mail: mgatou2@mail.ntua.gr

Palygorskite-rich clays are known for their exquisite sorption properties regarding potentially toxic elements, such as Pb, Cu, Cr, As, Cd, etc. due to their high surface area, permanent surface charge and fibrous texture. Their sorption capacity can be further increased by thermal treatment, which induces an increase in microporosity. The present study aims to compare the sorption capacity of raw and thermally-treated palygorskite-rich clay samples regarding Pb ions from mono-elemental aqueous solutions under dynamic sorption conditions.

A commercial clay sample (Pal0) was supplied by Geohellas S.A. and heated at 200°C (Pal200) and 400°C (Pal400) respectively, in a muffle for 6 hours. P-XRD analysis of the samples prior to and after the thermal treatment, showed that the raw sample (Pal0) consists mainly of palygorskite and smectite. After heating at 200°C (Pal200), smectite phase was destroyed, whereas the main intensity peak of palygorskite significantly decreased. At 400°C (Pal400), only a small peak of the palygorskite phase remained.

Additionally, the specific surface area (SSA, m²/g) of the samples decreased in the order Pal0 (198)>Pal200 (153)>Pal400 (112), whereas the pore diameter (in nm) increased as Pal400(9.1)>Pal200(7.3)>Pal0(5.6).

Dynamic sorption experiments were carried out in fixed-bed columns containing mixtures of palygorskite clay and quartz sand at a 1:7 ratio. The retention efficiency of the tested palygorskite samples was assessed by plotting the respective breakthrough curves (C/C0 vs t) at flow rates of Q=0.35 and 0.7 mL/min, initial solution pH=3.5 and 5.5 and initial Pb concentrations C0=50 and 100 mg/L Pb. The maximum amount of Pb sorbed by the beds (qmax, mg/g) was observed for initial concentration C0=100 mg/L at pH=5.5 and Q=0.7 mL/min as follows: Pal400(46)>Pal200(42)>Pal0(31). The amount of Pb retained by the quartz sand was <1mg/g.

The obtained results demonstrated that thermal treatment of palygorskite can readily improve its sorption capacity regarding Pb. Heating induces the folding palygorskite’s structure and increases its microporosity enabling the diffusion of Pb ions further within the clay mass. The experimental approach used, showed that dynamic sorption experiments can accurately describe the sorption behavior of non-expandable clays, such as palygorskite, under flow through conditions, similar to those that take place in natural systems.
Determination of the slagging and fouling tendency of the ashes from North Greece lignites, based on their chemical and mineralogical composition

A. Stratakis, G. Kostakis

Technical University of Crete, Greece

E-mail: astratak@mred.tuc.gr

The aim of this study is to predict the slagging or/and fouling tendency by the combustion of lignite in the power plants of Agios Dimitrios, Kardia, LIPTOL, Ptolemais and Amyntaio from West Macedonia, Greece. For this purpose, an extensive number of samples of lignite and fly ashes were investigated. Both kinds of samples, fly ashes and lignite, were selected simultaneous in each power plant during a time period of 12 months. The lignite samples were collected from the mill feeders of the power plants and then in a laboratory kiln burned to produce laboratory high-temperature ashes. The fly ashes were captured from the electrostatic precipitators. Both kinds of ashes were mineralogical and chemical quantitative analyzed by XRD and XRF, respectively. Using a heating microscope, the ash fusion temperatures (initial deformation, softening, hemisphere and fluid or flow temperatures) of the ashes were investigated. The mineralogical composition showed that all ashes were rich in calcareous minerals and amorphous phase.

By using indices reported in the literature based on the chemical composition, so as on the determined ash fusion temperatures, a qualitative prediction of the slagging or/and fouling tendency is achieved. The indicated tendency of slagging or/and fouling has been found to be medium to high. Further on, there were performed correlations using either linear or multiple regression analysis between the quantitative mineralogical composition and the ash fusion temperatures. The adjusted regression coefficients were around 0.92, while the accuracy according to relative root mean square error was less than 2% or 30 °C. These correlations using the mineralogical composition, allowed the establishment of quantitative relationships for the determination of ash fusion temperatures, especially hemisphere temperature, as well as of the approximate softening and flow temperatures of the ashes. Likewise, it was shown that especially the calcareous phases gehlenite, brownmillerite, lime, calcite, so as quartz and amorphous content are relevant for the determination of the ash fusion temperatures.
Proposed methodology to evaluate innovative Phosphogypsum processing routes through LCA, ESIA Impact Matrix and Global Geoethical Balance

S. Barbosa¹, S. Lourenço Amaro¹, M. Silva², J. Do Rosário¹, J. Almeida¹, J. Kullberg¹

¹NOVA FCT - Nova School of Science and Technology (Lisbon); GeoBioTec, Portugal
²Institute of Earth Sciences - University of Évora, Portugal

E-mail: s.amaro@fct.unl.pt

A Global Geoethical Balance (GGB) methodology is proposed with the aim of verifying the reliability, potentialities, advantages, and disadvantages that may came from the implementation of distinct possible phosphogypsum (PG) processing routes. Four idealistic commodity recovery flow paths that considers separated and integrated-shared routes for PG tailings processing were evaluated under the proposed methodology. Potentialities and benefits of multi-resource recovery when shared and integrated PG processing systems are applied were balanced. PG is a TENORM and cannot be directly applied in the industry although its processing potentialities and necessities. The investigated flow paths follow relevant results from already performed laboratory scale tests, published by distinct authors, which consider mainly REE concentration, CO2 mineralization and possibilities of inert PG re-use in distinct industries, like fertilizer and concrete production. These tested PG processing methods leads to REE sorting and other components recovery, but very few considered the evaluation of its associated costs and the potential environmental and toxicological risks derived from the utilization of distinct by-products and co-products that may contain some metals and/ or radiological ionization effects. Following this main concern, and other relevant identified factors, the proposed GGB methodology integrates environmental, socio-economic and geoethical impact factors. ESIA Impact Matrix was previously established and its respective integration in a GGB was studied given particular attention to possible toxicological and radiological effects that may be present in distinct stages of the processing flow paths. In this context, a set of specific measures and actions are suggested to be included in future project implementation as “Geoethical Implementation Plan”. With this, it is expected to increase the management procedures related with PG tailings processing from the ethical point of view, ensuring increased safety public health conditions, and environmental and eco-toxicological controlled actions. The GGB methodology also integrates the expected impacts generated in distinct value chains due to the introduction of new co-products and by-products. This possibility is achieved through the integration of preliminary qualitative and semi-quantitative LCA matrix results into the GGB evaluation procedure. Quantification and algorithm estimation is under investigation being important to notice that most, if not all, PG processing methods have only been tested on a lab-scale, meaning that their efficiency is yet unknown at an industry-scale. Reliable verification of the proposed GGB methodology through parameter quantification is presently necessary but it is also dependent on the implementation of in-situ and operational up-scaling tests in a short to medium term.
Novel age - estimation model for petroleum middle distillate release in the environment

K. Selekou¹, E. Chamilaki², N. Pasadakis¹

¹Institute of Petroleum Research, Foundation for Research and Technology – Hellas, Greece
²School of Mineral Resources Engineering Department, Technical University of Crete, Greece

E-mail: kselekou@ipr.forth.gr

Petroleum products, during transport, storage and use, may be accidentally released in soil and groundwater, causing significant environmental impact. The knowledge of the release time is appropriate for the determination of legal and financial responsibilities. Since the 2008’s several models have been developed to estimate the time a middle distillate fuel (mainly diesel) release in the environment occurred. This time can be estimated under specific environmental conditions using (1) the Christensen – Larsen method, (2) the middle distillate degradation model (MDD) or (3) the zero-order approximation of the Monod model. The first two models are based on the linear correlation between the time of diesel fuel release and the ratio of n-C17/Pr, taking into account that the models require knowledge of the initial ratio value. On the other hand, the third model is a general model that can be used for estimating release ages of middle distillate fuels with different initial values, ((n-C17)o/Pro). The above models cannot be applied to all middle distillate products, (e.g. kerosene), because the ratio n-C17/Pr cannot be calculated. Additionally, the value of the initial n-C17/Pr ratio of the oil fractions shows wide variation, due to the origin of the crude oil. Finally, the available models are based only on two specific compounds, making the models less robust. In this work a novel model is presented for the estimation of the age of middle distillates’ releases in the environment, using an alternative ratio of n-alkanes and isoparaffins. This ratio is calculated using the sum of n-alkanes from n-C9 to n-C19 over the sum of the respective 2-methyl-, 3-methyl- and 4-methyl- isoparaffins and found to be strongly correlated with age of the oil release. The new model was verified with gas chromatographic analytical data from a series of samples, obtained from fuels released in the environment, and found to estimate accurately their age.
Research and innovation in exploration and mining of raw materials: The ROBOMINERS project

E. Koutsopoulou1,2, A. Servou3, G. Aggelopoulos1,4, K. Laskaridis2

1Association of Greek Geologists, Greece
2Hellenic Survey of Geology and Mineral Exploration, Greece
3University of Patras, Greece
4Geotechnical Chamber of Greece

E-mail: ekoutsop@upatras.gr

ROBOMINERS (Resilient Bio-inspired Modular Robotic Miner) is a new project funded under the European Union’s Research and Innovation Programme Horizon 2020 which aims at employing a bio-inspired robot, focused on the prospect of mineral exploration and extraction within Europe. The project introduces robotization and miniaturization technologies (robotic autonomous explorers & miners) which allow localization and mapping of an orebody, extraction planning, optimization of extraction, and real-time selective mineralogy. The project targets mineral deposits that are generally considered “non-economical” either because they are not accessible anymore for conventional mining techniques, or they have been formerly explored but exploitation was considered uneconomic (abandoned, small, ultra-depth deposits). The Association of Greek Geologists (AGG) is participating as an EFG (European Federation of Geologists) Linked Third Party in the project aiming at the collection of publicly available data on mineral deposits which are potential targets for the advanced mining technology, and the creation of a European database of suitable ore deposits for the utilization of ROBOMINERS technology.

The establishment of a European database is crucial for the design of exploration and exploitation applying the ROBOMINERS innovative approach. The AGG contributed in the building of a database at a national level, of the major and most important mineral deposits, focused on the project requirements. A number of ore deposits in which ROBOMINERS advanced technology may provide a unique solution include porphyry and epithermal deposits and especially vein-like types, but volcanogenic massive sulphide (VMS-type) and lense-like or layered orthomagmatic deposits can also be important. From the above mentioned ore deposits the most abundant in Greece are epithermal, deposits in hydrothermal veins, porphyry copper, as well as chromites in ophiolite complexes. Regarding the spatial distribution, vein-type or metasomatic deposits are located mostly in Northern Greece (Western Macedonia and Thrace regions) while significant variable-mineralization deposits are related with the Attico-Cycladic belt volcanism (mainly Lavrion, Evia, and islands in the Aegean Sea). Finally, PGE bearing chromite deposits and bauxite deposits, located mainly in Central Greece, may also be significant for the project.

The development of a common European ROBOMINERS database is of great importance for the advancement of the project since it will provide essential information on the deposit type and commodities, the host rock, and the spatial distribution of the targeted ore deposits. Furthermore, it will produce valuable knowledge for the future planning of the exploration and exploitation of the targeted deposits from the ROBOMINERS advanced technology approach.
Targets and indicators for the mining industry with a focus on mine tailings to achieve the sustainable development goals

N. Araya¹, A. Kraslawski², L. Cisternas³

¹LUT University, Chile
²LUT University, Finland
³Universidad de Antofagasta, Chile

E-mail: natalia.araya.gomez@gmail.com

Sustainable development is a concept that resonates since 1987, its first definition is “Society must live and meet their needs without compromising the ability of future generations to meet their own needs” developed in the Brundtland Report in 1987. To achieve sustainable development, society must work on preserving the environment and natural resources and improving social and economic equity. The United Nations Environment Programme (UNEP) launched the 2030 agenda for Sustainable Development. This agenda includes 17 Sustainable Development Goals (SDGs) and 169 targets, as well as 241 indicators to measure the progress towards achieving this agenda.

Minerals and metals are important to the economic and social development of our society, and they are essential to modern life. The continuous exploitation of mineral resources has led to a large amount of waste which has a large impact on the environment. Mining waste, known as mine tailings, is produced at a rate of anywhere from five to fourteen billion tons per year. Mine tailings need to be properly managed and treated to reduce their impact on the environment, if it is possible mine tailings could be re-processed, reused, and recycled.

The mining industry must enhance its contribution to achieving sustainable development by incorporating SDGs into its operations to achieve sustainable development goals. The objective of this article is to define targets and indicators for mine tailings management and valorization of tailings to achieve the SDGs, defined in the 2030 Agenda for Sustainable Development by the United Nations. The result of this study is a collection of indicators proposed to measure the progress of mine tailings management and valorization towards sustainable development.
A Review about the sustainability of pit lakes as a Rehabilitation factor after Mine closure

C. Sakellari¹, C. Roumpos², G. Louloudis², E. Vasileiou¹

¹National Technical University of Athens, Greece
²Public Power Corporation, Greece

E-mail: xarasak@gmail.com

At the end of surface mining activities, the remnant voids are of great concern regarding the rehabilitation of the final open pits. The creation of remnant lakes is usually an aesthetically attractive and practical solution if it is planned and implemented correctly to minimize the environmental risk. Pit lakes are permanent forms in mostly large and deep voids that remain after the mine closure. Their size and depth vary depending on the surface excavations. They are considered as very small catchments with unique characteristics. The final depth of the pit lake is strongly associated with the water balance between inflows and outflows, and its stabilization time may range from a few years to many decades.

The investigation of pit lakes sustainability in post-mining regions is a challenging research problem. One of the most crucial environmental issues after creating pit lakes is related to their water quality. The role of geological, hydrogeological, hydrological and geochemical conditions in the mining areas as principal components for predicting the water chemistry and the sustainability of pit lakes needs to be analyzed in correlation with climate changes.

This paper aims to highlight the effectiveness of the pit lakes as a rehabilitation factor. In this framework, several cases from Central German (lignite mining district), Western Australia (copper & iron mines), Western Australia (Collie coal basin), and United States (open-pit copper mine) were examined in detail and evaluated. In Greece, the created pit lakes are limited: a) in central Euboea (Ferro-Nickel mining area where ended in 1991), b) in Northern Euboea (Magnesite mine in Mantoudi ended in 1980), c) in Southern Euboea (lignite mine in Aliveri ended in 1990) and d) in Peloponnese (lignite mine of Kyparissia in Megalopolis mining area ended in 2009). The advantages and the risks of the pit lakes as environmental and aesthetic solutions are analyzed for each case study, and the crucial factors of their formation and preservation are pointed out.

The results indicate that mine pit lakes must be evaluated as dynamic systems, natural or artificial, which demand rational mine water management to ensure their sustainability. The formation and maintenance of pit lakes as a rehabilitation factor is globally qualified and emphasized as an efficient environmental solution in order to minimize the long term impacts of surface mining activities. Specifically in Greece, it is of great importance during the transition to the Post Lignite Era.
Using expanded perlite as additive in ceramic mass of a brick and tile industry to study the reduction of density on the final products

I. Makrygiannis, A. Tsetsekou

NTUA, Greece

E-mail: ymakrigiannis@sabo.gr

Thermal insulation is an efficient solution to reduce energy consumption by preventing heat gain or loss through the building envelope. This reduction of unwanted temperature changes decreases the energy demand of heating and cooling systems. A great way to reduce the energy consumption of a building is the use of thermal insulation bricks which provide excellent earthquake behavior and fire resistance, significant acoustic capacity and certainly, a remarkable thermal capacity make them a unique building material for energy efficient building. In this study, two (2) different grain size of expanded perlite were used as additive in a ceramic mass. Brick solid samples were produced from three (3) different mixtures with different ratios of expanded perlite in the mass. From every mixture three (3) different vacuum values were used. The constructed brick samples were dried and fired in the same conditions and their mechanical properties were gathered. The thermal insulation coefficient of every constructed mixture was calculated according to EN1745. A real drawing of a thermal insulation ceramic block provided by the factory XALKIS was used and by using computational fluid dynamics (CFD) simulations the thermal insulation of the brick was calculated for every mixture.
Low-temperature synthesis of SiC worm-like nanoparticles and their catalytic activity for reduction of hexavalent chromium

A. Tsetsekou\textsuperscript{1}, S. Gkiouzel\textsuperscript{2}, G. Asimakopoulos\textsuperscript{2}, G. Vasilopoulos\textsuperscript{2}, I. Kitsou\textsuperscript{1}, E. Roussi\textsuperscript{1}, E. Kagiaras\textsuperscript{3}, M. Karakassides\textsuperscript{2}

\textsuperscript{1}National Technical University of Athens, Greece
\textsuperscript{2}University of Ioannina, Greece
\textsuperscript{3}Mathios Refractories S.A., Greece

E-mail: athtse@metal.ntua.gr

In this work, silicon carbide worm-like nanoparticles (SiC, NPs) have been synthesized at low temperatures via a microwave heating process, using a mixture of expanded graphite and silicon powder. The SiC nanoparticles were prepared by direct solid-state reaction in a 2.45 GHz microwave field in nitrogen atmosphere. The structural, textural and surface properties of as derived nanoparticles were investigated by means of spectroscopic, microscopy and surface physicochemical methods. β-SiC appeared as the only phase in the x-ray diffraction pattern for SiC nanoparticles formed by using 30 min of heating time. Raman and Infrared data showed that after decarbonization at 800oC for 2 h and leaching overnight with an acid solution of hydrochloric and hydrofluoric acid, no traces of unreacted silica and graphite were observed. Transmission electron microscopy (TEM) images showed a nanoparticle morphology, composed out of worm-like tangle structures, where each worm has a width of 10 nm, while the whole tangle has an average size of 150 nm. Batch experiments were conducted on contaminated water to determine the rate and extent of Cr\textsuperscript{6+} removal and its immobilization by the SiC nanoparticles. The kinetic studies showed a rapid removal of Cr\textsuperscript{6+} ions from the water in the presence of the SiC NPs.
Comparative Life Cycle Assessment of Green Sand Casting and Low Pressure Die Casting for the production of self-cleaning AlMg₃-TiO₂ metal matrix composite

M. Santiago-Herrera

ICCRAM - Universidad de Burgos, Spain

E-mail: msantiago@ubu.es

The growth in the use of new materials, as is the case of the Metal Matrix Composites, is improving the production process, longing for different functional characteristics of the final products, such as less weight, more strength and hardness; and could also minimize environmental impacts, depending on the casting process used.

This paper provides a comparative Life Cycle Assessment of two different manufacturing technologies, Green Sand Casting and Low Pressure Die Casting, for the case study of a self-cleaning doorknob, produced by an aluminium alloy reinforced with TiO₂ nanoparticles, that confers special characteristics. Large information, with regard on the materials needed, the energy requirements, wastes produced and environmental impacts, is provided by the study, which can be used for further analysis.

Different impact categories were analysed, and the results showed a slight difference between both technologies, for instance with just a 3.16% variation in terms of kg CO₂ eq. emitted, where the GSC emissions are 13,098 kg whereas 12,684 kg are released from the LPDC.
Minerals as potential catalysts in heterogeneous catalytic ozonation: A kinetic study of p-CBA degradation in aqueous solutions at pH 7

S. Psaltou, E. Kaprara, M. Mitrakas, A. Zouboulis

Aristotle University of Thessaloniki, Greece

E-mail: spsaltou@chem.auth.gr

Catalytic ozonation is an Advanced Oxidation Process (AOP) capable of removing micropollutants from aquatic ecosystems. In the present study small concentrations of p-CBA (4 μM) examined to be removed by ozonation systems in the presence of 19 solid materials, belonging to the category of minerals. The solids were used as raw materials or after modification (thermal treatment). The pH of the solutions was adjusted to 7 to simulate the actual conditions in waters and municipal wastewater effluents. p-CBA was used as a probe compound, because it can practically only be removed by hydroxyl radicals (•OH), which are a by-product of ozone decomposition reactions. The results of heterogeneous catalytic ozonation were compared to that of single ozonation to differentiate the catalytic materials from the non-catalytic ones. The optimum minerals for the removal of p-CBA by heterogeneous catalytic ozonation were zeolite, calcite, dolomite and thermally treated talc. By studying the kinetics of the ozonation systems, it was observed that ozone decomposition followed a first-order kinetic model in all the ozonation systems, while the kinetic model of p-CBA removal was different, depending on the materials that were used. The catalytic degradation of p-CBA followed a second order kinetic model, while in the presence of materials with no catalytic activity the p-CBA abatement was in best agreement with the pseudo-second order kinetic model, as in the system of single ozonation.
Study of magnesium hydroxide protective coating against corrosion applied on poly(methyl methacrylate) plates, by using the sulfuric acid attack acceleration test

M. Merachtsaki, E. Tsardaka, E. Anastasiou, A. Zouboulis

Aristotle University of Thessaloniki, Greece

E-mail: meradomn@chem.auth.gr

The microbiologically induced corrosion (MIC) of concrete sewer pipes can be mitigated by using magnesium hydroxide coatings. During MIC, microorganisms can produce biogenic sulfuric acid under the influence of specific conditions, which in turn can react with the cement paste of concrete. This phenomenon initiates the degradation of concrete pipes, due to the formation of gypsum, which weakens the overall construction system. Magnesium hydroxide powders, produced from raw caustic calcined magnesia, may protect the concrete surface by maintaining alkaline pH values in the concrete surface, hence blocking the development of the acidophilic sulphur oxidizing bacteria, or by neutralizing the produced biogenic sulfuric acid in the case that the bacteria may eventually be developed. The study of the reaction between magnesium hydroxide coatings and sulfuric acid solution can lead to important conclusions, regarding the coating consumption (and the duration of protection), as well as the ability to maintain the required alkaline surface pH values. An accelerated acid spraying test, in a custom-made spraying chamber, was used to examine the consumption of magnesium hydroxide coating. In order to perform the respective spraying tests, the duration of procedure was selected to be 4 days, by using 0.2 M sulfuric acid. The magnesium hydroxide coating was examined, by applying it on poly (methyl methacrylate) plates, with dimensions 50 mm x 50 mm x 5 mm, instead of applying on concrete substrates, in order to eliminate the influence of concrete substrate (i.e. the formation of gypsum) and to study only the neutralization/consumption mechanism of protective coating under the influence of acid attack. In this case the substrate mass can be considered as constant during the experiment, because the poly (methyl methacrylate) cannot react with the sulfuric acid spray. In that way, only the magnesium hydroxide coating can interact with the acid and be consumed. Surface pH measurements, as well as mass changes were daily conducted, during the four day accelerated sulfuric acid spraying test. Additionally, the mineralogical phases existing before the test, or produced after the test, were determined by using X-ray Diffraction (XRD) measurements, in order to examine the potential change in the mineral phases of used coating.
The contribution of geological mapping to industrial scale design

E. Manoutsoglou¹, N. Papageorgiou², E. Georgiou³

¹School of Mineral Resources Engineering of the Technical University of Crete, Greece
²Environmental and Quarries Manager at Titan Cement Company S.A., Greece
³Raw Materials Manager at TITAN Cement Company S.A., Greece

E-mail: emanout@mred.tuc.gr

The purpose of the study was to locate a new potential quarry site that fulfills all the necessary pre-conditions & restrictions in order to supply with low alkali aluminosilicates raw materials, the existing cement production line of the "TITAN CEMENT Company S.A." in Achaia, Greece. For the development of a new quarry, the materials to be mined must meet specific requirements, mainly: acceptable quality, adequate reserves, environmental restrictions and economic viability. A search without criteria for targeting a new location, would lead to the collection of several hundred samples from the wider area and different lithologies formations. The quality of raw materials needed, is directly related to the chemistry and homogeneity of rocks in adequate quantities. The procedure's starting point is the adequate and detailed knowledge of the raw materials to be sought after, in order to sufficiently restrict the number of the geological formations that would potentially supply the raw materials in need. These different litho-stratigraphic formations which appear at an acceptable distance from the cement factory, are groups of rocks, of different ages, different stratigraphic and tectonic evolution, which belong to more than one geotectonic zones and appear with different lithological and mineralogical composition, all of which, ultimately, delimit and determine also their chemistry. By using as a background info the existing geological maps of the wider area and among dozens of outcrops investigated, a group of ten areas of potential interest were identified and focused on. From these ten Focus Areas, the first sampling was performed, in order to characterize the chemistry of the host-rocks. Then, a detailed geological mapping of the outcropping structural formations was performed, in the most promising three areas of interest. Finally, based on the collected data, a spatial valuation, and an initial reserves evaluation was performed aiming in a preliminary design of a new quarry in the most promising area. The calculation and the targeting was conducted with respect to the expected needs in aluminosilicate raw materials for the next few decades by the Cement Factory, in such a way that a low alkali cement can be produced without any scarcity of raw materials. Geological mapping was effectively and systematically applied in order to address the long-term planning needs of "TITAN CEMENT S.A." Cement Factory in Drepano, Patras. The end result was a final proposal of a new quarry site, with sufficient reserves in low alkali aluminosilicates and of in-specs quality.
Assessment of the suitability of clayey raw materials from the argillic alteration zones from Sappes area, Thrace, Northern Greece in ceramic production

E. Koutsopoulou¹, I. Marantos, V. Xanthopoulou, N. Xirokostas, I. Iliopoulos

¹Hellenic Survey of Geology and Mineral Exploration, Greece
²University of Patras, Greece

E-mail: ekoutsop@upatras.gr

The Sappes area is located at the border of Essimi - Kirki and Sappes - Komotini Tertiary basins. The studied area is covered by volcaniclastic rocks and lavas of intermediate composition, sub volcanic intrusive rocks (dacites - andesites) and plutonic rocks (quartz monzodiorite). The above formations have been strongly altered as a result of intense hydrothermal activity. Based on mineralogical and geochemical results the following alteration zones have been identified: a) siliceous zone, b) alunite zone, c) sericite/argillic zone, d) kaolinite zone, and e) pyrophyllite zone. In the present contribution extended petrographic, mineralogical and geochemical studies have led to the detailed description of the mineral assemblages as well as the spatial distribution of the "argillic" alteration zones. By the term "argillic" we include the sericite zone, which is the most prevalent type of alteration in the studied area, the transitional sericite-kaolinite zone which is found either as sericite-rich or kaolinite-rich assemblages and the pyrophyllite-rich altered rocks. The collected samples were also examined for their technological ceramic properties. The Atterberg limits (liquid limit, LL and plastic limit, PL) were determined using the Casagrande apparatus, while the plasticity index was calculated by the numerical difference between liquid and plastic limit. Particle size distribution was assessed by laser diffraction. Experimental briquettes were also produced from the studied raw materials and fired at 1200°C under oxidizing conditions and the microstructure and consistency of the samples after firing was examined with Scanning Electron Microscopy (SEM). Preliminary results showed that after processing, the clayey raw material from the alteration zones could be used in the ceramic industry.
Natural Hydraulic Lime Masonry Mortars: effect of Pozzolan addition and Aggregate type on their Mechanical Properties

G. Triantafyllou, A. Samiotaki, M. Galetakis, G. Alevizos

Technical University of Crete, School of Mineral Resources Engineering, Greece

E-mail: gtriant@mred.tuc.gr

Natural hydraulic lime (NHL) conforms as a building lime binder with both air-setting and hydraulic properties. NHL mortars are widely used for restoration and conservation works since they exhibit important properties like workability, flexibility and compatibility with the building substances of historic structures. Furthermore, an increasing interest is noticed, in the utilization of these binders as environmental sustainable alternatives to cement for masonry and other construction applications. The classification of natural hydraulic limes depends on physical and chemical requirements mainly focusing on the characteristic values of compressive strength at 28 days, and their content in available lime, respectively. The latest version of EN standard 459-1 has introduced the term of formulated lime, which is a binder with hydraulic properties mainly consisting of air lime and/or natural hydraulic lime with added hydraulic and/or pozzolanic material. In this study, the effect of both pozzolan addition and the type of aggregates used in natural hydraulic lime mortars, in their mechanical properties is evaluated. Two commercial products were used as a binder and as a pozzolanic additive, consisting of a moderately natural hydraulic lime (NHL 3.5) and a natural pozzolan deriving from the island of Milos in Greece, respectively. The mineralogy and chemistry of the raw materials were determined by X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) analyses. According to their source, three different types of aggregates were used in the mortar mixes. Two crushed rock aggregates consisting of a calcareous limestone, and a mafic subvolcanic rock (diabase), and natural quartz sand. The granulometry of the used aggregates followed the particle size distribution of the CEN reference sand. Two recipes of mortars were prepared. One reference mix using only NHL 3.5 as the binding agent and another with the addition of natural pozzolan, as 20% partial replacement of the binder. The binder/aggregate ratios were 1:3 by mass proportions in all mixtures. Compressive and flexural strengths of the specimens were determined according to the curing time, up to 180 days. Polished surfaces of the mortar samples were prepared for microscopy observation and their water adsorption capacity was also measured. The resulting mortars are classified as M5 and M10 masonry mortars, according to EN 998-2: 2003. The results indicate that the addition of pozzolanic material increases significantly the strength parameters of the NHL mortars. Moreover, the use of siliceous aggregates (diabase and quartz sand) results in higher values of compressive and flexural strength than limestone aggregates.
A palygorskite-smectite specialty clay from Vентzia Basin, Western Macedonia, Greece, showing enhanced metal sorption capacity

A. Argyraki¹, Z. Kypritidou¹, G. Chryssikos², M. Stamatakis¹

¹National and Kapodistrian University of Athens, Greece
²National Hellenic Research Foundation, Greece

E-mail: argyraki@geol.uoa.gr

Palygorskite and smectite clays are well-known for their sorptive properties regarding organic and inorganic contaminants. The textural and structural characteristics of these minerals define their relative effectiveness and subsequent potential use in environmental applications. In this study, we provide evidence of a synergistic effect in the retention of metal ions, such as Pb in aqueous solutions, when the natural clay sample contains both palygorskite and Fe-Mg-smectite. A natural mixed material (MCM) from Vентzia Basin in northern Greece, has been characterized regarding its grain morphology, mineralogy and physicochemical properties (SSA, PZC, CEC) and compared to palygorskite-rich (PCM) and smectite-rich (SCM) clays from the same region. Batch sorption studies regarding Pb retention by the studied clays, revealed higher sorption capacity (q_max, mg/g) of MCM (66 mg/g Pb) compared to SCM (47 mg/g Pb) and PCM (45 mg/g Pb).

 Tested bulk samples are rich in Fe₂O₃ and MgO, reaching 9.9 %wt and 27.5%wt, respectively, in the MCM, due to their origin as alteration products of ultramafic rocks. The relative amount of palygorskite phase is 70% in PCM and 20% in MCM samples, whereas the respective amount of Fe-smectite is 20% in PCM, 70% in SCM and 40% in MCM. Variability on the dioctahedral/trioctahedral character of clay mineral components is observed among the samples. The specific surface area (BET-N₂, m²/g) of the samples increases as PCM (180)>MCM(170)>SCM(110), and their micropore area (BET-CO₂, m²/g) is PCM(130)>MCM(100)>SCM(74). The respective cation exchange capacity of the samples (CEC, meq/100g) is SCM(62)>MCM(29)>PCM(27). All samples exhibit a high point of zero charge (PZC=9). Increased proportion of palygorskite phase in the samples induces variable charge of the clay surface (due to the high surface area), whereas the presence of smectite phase accounts for the permanent charge that arises from substitutions in the clay structure.

Scanning electron microscopy revealed characteristics of three morphological types: (a) fibrous particles of palygorskite phase in PCM, (b) platy particles of smectite phase in SCM, and (c) a combination of the above in MCM sample. The MCM sample presented a more complex morphology where palygorskite fibers grow in parallel arrangement and are connected to the underlying smectite flakes. This morphology has been interpreted as palygorskite originating from the transformation of smectite, in alkaline Mg-rich environments. It is concluded that the genetic coexistence of palygorskite and Fe-Mg-smectite clay phases in the MCM sample is adding to its value as an effective sorbent material.
Bionanocomposites as a market potential from Greek bentonite resources: Preparation of Chitosan-Clay Bio-Nanocomposites

E. Koutsopoulou¹, I. Marantos¹, G. Christidis², N. Xirokostas¹

¹Hellenic Survey of Geology and Mineral Exploration, Greece
²Technical University of Crete, Greece

E-mail: ekoutsop@upatras.gr

Bentonites are smectite-rich industrial clays which find a number of applications in a wide range of markets including traditional industrial usages as well as advanced technological applications. Smectites are 2:1 layer silicates with unique intrinsic properties such as high cation exchange capacity, swelling behavior, adsorption properties and large surface area. Strategic adsorption of functional biomolecules (i.e. biopolymers) by smectites has led to the formation of new organic-inorganic materials which present significantly improved properties that stem from both types of components. Chitosan is a natural linear polysaccharide and is considered one of the most promising biomaterials for the production of chitosan/clay nanocomposites. Functional chitosan/clay nanocomposites have improved thermal stability and mechanical properties and exhibit excellent properties in drug delivery and biomedicine related applications. In the present study the moderate-low grade bentonite deposits from the islands of Chios and Samos, eastern Aegean and from areas of Thrace (Skaloma, Feres, Sappes), NE Greece have been assessed for their mineralogical and geochemical characteristics and for their potential use in advanced technological applications. Chitosan-clay bionanocomposites were prepared from chitosan biopolymer solutions and four different smectites (Chios and Samos montmorillonites, and Thracian montmorillonites and Fe-rich beidellites). The intercalation of the chitosan in the homoionic Na⁺-smectite samples showed that all samples produced a series of chitosan-smectite nanocomposites even at the lowest chitosan-clay ratios. The intercalation of chitosan in the smectite interlayer was monitored by the migration of the 001 diffraction maximum towards lower angles and was characterized by a decrease in the intensity of the basal reflections. With increasing concentration of the biopolymer (i.e. increased chitosan loadings), the basal reflection migrated towards lower angles. The results of the present study show that these moderate-low grade bentonite deposits could be used in the production of high added-value functional chitosan-based nanocomposites with advanced technological applications.
Shaping a sustainable future made of aluminium and copper.

A global leader in the aluminium and copper processing industry, with an 84-year history, ElvalHalcor excels in 100 countries by developing sustainable and high value-added products and solutions that meet the requirements of the most demanding customers.

Executing a long term programme of technologically advanced strategic investments in parallel with extensive Research and Development, ElvalHalcor seizes the opportunities created in rapidly developing markets fueled by global megatrends, the transition to climate neutrality, the circular economy and the growth of renewable energy and e-mobility.

With the long experience and expertise of our people coupled with our continuous efforts on ESG, we are shaping a sustainable tomorrow for the planet and the future generations.

www.elvalhalcor.com
JOINING THE NATIONAL AND GLOBAL EFFORTS FOR A FUTURE OF SUSTAINABLE EXCELLENCE.

In MYTILINEOS we believe that our collective future depends on sustainable growth. It is the only way to address crucial challenges such as climate change, while at the same time strengthening growth, performance and value creation.

That’s why, today, we are taking action. We are fully embracing ESG principles for Environment, Society and Governance, putting them at the centre of our strategy. We are committed to achieve a 30% reduction of CO₂ emissions across our entire business activity by 2030 and become a Net Zero industry by 2050. By raising our commitment and further integrating sustainability into the core of our business model, we pave the way to a new era of sustainable excellence.

New, ambitious CO₂ emission reduction targets

<table>
<thead>
<tr>
<th>Overall</th>
<th>-30% Minimum reduction in total emissions</th>
<th>2030</th>
<th>Net Zero</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>by Business Unit:</td>
<td>Net zero by 2030</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sustainable Engineering Solutions and Renewables & Storage Development BUS:

Power & Gas BU:

- ~50% of emissions / MWh generated by 2030

Metallurgy BU:

- -65% of absolute emissions
- -75% of emissions / ton of Al produced

Sustainability. Our DNA for the future.

Further Integrating the concept of sustainability into our organization’s DNA.

Adopting ESG as a core part of our strategy, decisions and operation.

Constant Monitoring & Transparent Reporting through performance management forums, public reports & website.
PROMETIA is an international non-profit association promoting innovation in mineral processing and extractive metallurgy for mining and recycling of raw materials, with the mission of making raw materials accessible for European industries and citizens.

PROMETIA contributes to:

- Developing innovative technological solutions to optimise raw materials & waste treatment
- Enhancing EU skills in mineral processing and extractive metallurgy of ores and industrial residues
- In the longer term, boosting the innovation capacity of the EU raw materials related sectors

PROMETIA association gathers industries, SMEs, research organisations and academia covering all the skills and Technology Readiness Levels (TRLs) from the mineral processing to the extractive metallurgy (hydro and pyro) domains.

CONTACT US

PROMETIA

www.prometia.eu

contact@prometia.eu