

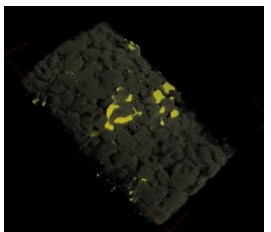


Mineral Deposit Studies Group
36th Annual Winter Meeting
2-4 January 2013



PROGRAMME AND ABSTRACT VOLUME

Delegate list
Venue maps



Hosted by the Department of Geology



**University of
Leicester**



January 2-4 2013
Leicester, UK



Welcome

Happy New Year! Welcome to the MDSG's 36th Annual Winter Meeting, and welcome to Leicester. It is 10 years since MDSG was held in the city, and since then, the meeting has gone from strength to strength, with over 200 delegates now regularly attending. This year we have around 240 delegates from all over the world and with over 40 talks and 50 posters; making it the largest MDSG yet.

As ever, the mix of presentations from academics, industry and postgraduate and Masters students gives the meeting a varied and dynamic feel and plays an essential role in promoting and developing ore deposit and applied research in the UK. This year, we aim to maximise the value that students get from the meeting by allocating dedicated time following each session for students to get feedback on their presentations from the audience. In recent years, undergraduate attendance at the meeting has grown considerably, and this should be welcomed as the next generation of enthusiastic economic geologists find the MDSG community a key source of inspiration, advice and career development opportunities.

This year, we have been able to arrange the talk programme into a number of themed sessions. The first day comprises three sessions on classic ore deposits: gold, Ni-Cu-PGE and porphyry/epithermal systems. The second day is more applied, with sessions on new developments and discoveries in exploration, applied mineralogy, and a session on ore deposit research in progress. In addition, and coinciding with NERC's call for grant proposals, the "Strategic metal supply to the UK" session will involve an open panel discussion.

We have a superb line up of keynote speakers to head up these sessions. Rich Goldfarb will speak on gold metallogeny through time; Tony Naldrett will present on what we know and don't know about PGE in the Bushveld Complex; Jeremy Richards will give an overview talk on porphyry and epithermal systems; Jan Cilliers will give the keynote in the Applied Mineralogy session on novel new experiments related to froth flotation processes, and we welcome the SEG International Exchange Lecturer, Dick Sillitoe, to speak on exploration and discovery for ore deposits in the circum-Pacific region.

Special thanks must, as always, be given to the generosity of our sponsors, without whom, we could not organise a meeting of this size, be able to offer bursaries to students, keep registration costs to a minimum for all delegates, and to attract our keynote speakers.

We hope you enjoy the meeting!

The MDSG 2013 organising committee:

Dave Holwell, Dan Smith, Gawen Jenkin

With thanks to: Gail Andrews, William Bond, Lynsey Bland, Daryl Blanks, Alex Gorman, Shaun Graham, Emily Firth, Helen Ford, Sinead Fenton, Amelia Lees, Jenny Smith, Carl Spence-Jones, Abbie-Jade Sutherland, Hollie Warman, Megan Williams and Ant Wong

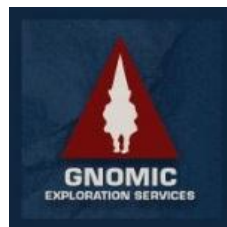
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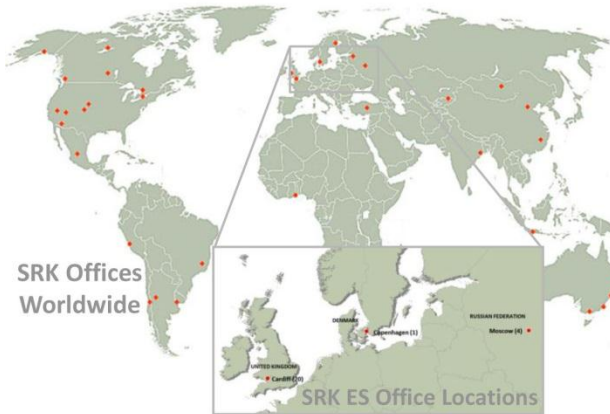
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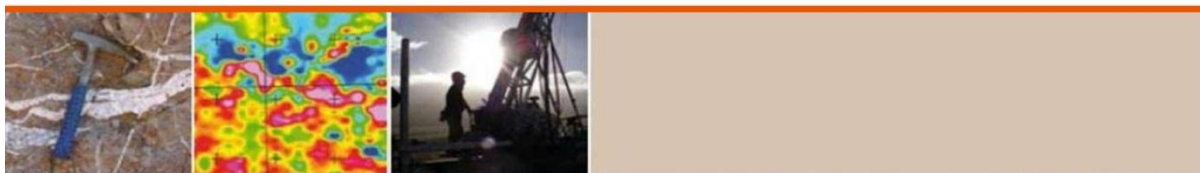


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INNOV-X

PROGRAMME

Thursday 3 January

0800 REGISTRATION (Bennett Foyer) and COFFEE (TA1, SB)

0820 Welcome (Rattray). Dave Holwell (University of Leicester)

SESSION: CRUSTAL TO MICRO-SCALE CONTROLS ON GOLD DEPOSITS (RATTRAY). Chair: Dave Holwell

0830 Keynote: Richard Goldfarb (USGS)

Gold metallogeny and Earth evolution

0915 P Treloar (Kingston University)

The Massawa gold deposit, Eastern Senegal, West Africa: an orogenic gold deposit sourced from magmatically derived fluids?

0930 J Lambert-Smith (Kingston University) STUDENT

Orogenic gold in the Senegal-Mali Shear Zone: fluid sources and potential for IOCG systems in the Birimian of West Africa

0945 B Yardley (University of Leeds)

Pegmatite Fluids as a Source for Gold Mineralisation

1000 N Hill (University of Leicester) STUDENT

Nature and constraints on genesis of newly identified gold targets in the Tyndrum area, Scotland

1015 S Lawther (Dalradian Gold)

Curraghinalt Gold Deposit, Co.Tyrone, N.Ireland

1030 C. Rice (Aberdeen University)

Dating vein-hosted gold deposits in the Caledonides of N. Britain

1045 COFFEE BREAK (TA1, SB), sponsored by Scotgold

SESSION: NI-CU-PGE DEPOSITS (RATTRAY). Chair: Iain McDonald

1115 Keynote: Tony Naldrett (University of the Witwatersrand)

What we know, what we think we know and what we don't know about the concentration of PGE and chromite in the Bushveld

1200 J Smith (University of Leicester) STUDENT

The nature and setting of PGE mineralisation in the Rooipoort area, south of Mokopane, northern Bushveld Complex

1215 W Brownscombe (Natural History Museum) STUDENT

The Sakatti magmatic Ni-Cu-PGE deposit, northern Finland

1230 R Seltmann (Natural History Museum)

Jackpot at the P-T boundary: hot LIPs and giant deposits across Eurasia

1245 LUNCH (TA1, SB), sponsored by Helio Resources. Posters can viewed in TA2 and TA3

SESSION: PORPHYRY/EPITHERMAL SYSTEMS 1 (RATTRAY). Chair: Jamie Wilkinson

1330 Keynote: Jeremy Richards (University of Alberta), sponsored by NERC

Porphyry and epithermal systems in subduction and post-subduction settings

1415 D Smith (University of Leicester)

Lower crustal cumulates and porphyry fertility

1430 S Tapster (University of Leicester) STUDENT

Plateau driven porphyry formation? The geodynamic context of Cu + Au mineralisation in the Solomon Island Arc

1445 COFFEE BREAK (TA1, SB) sponsored by Midland Valley (with demonstration of MOVE software in SB)

Posters can be viewed in TA2 and TA3

SESSION: PORPHYRY/EPITHERMAL SYSTEMS 2 (RATTRAY). Chair: Richard Herrington

1515 M Loader (Imperial College) STUDENT

The evolution of porphyry Cu deposit magmas

1530 E Spencer (Imperial College) STUDENT

The roles of intermediate density fluids, vapours and brines in the formation of Mo-rich porphyries: Evidence from the El Teniente Cu-Mo deposit, Chile

1545 R Harrison (University of Tasmania) STUDENT

Tumpangpitu Porphyry-High Sulfidation Epithermal Deposit, Tujuh Bukit Project, Indonesia – Geology, Alteration and Mineralisation

1600 D Holder (Kingston University) STUDENT

Understanding deposit telescoping and the epithermal-porphyry transition in the Brad-Sacaramb mineral district of western Romania.

1615 J. Naden (BGS)

Alteration, mineralization, and geochemistry of the Viper (Sappes) epithermal Au–Ag–Cu–(Sb–Te–Se) orebody, Thrace, NE Greece

1630-1800 POSTER SESSION (TA2, TA3), sponsored by CSA Global

1920 Drinks reception (Athena)

2000 Conference Banquet, (Athena), sponsored by SRK Consulting and SRK Exploracion Services, including presentation of MDSG project prize and Anglo American Best Student Poster Prize

Friday 4 January**0800 REGISTRATION (Bennett Foyer) and COFFEE (TA1, SB)****SESSION: NEW DEVELOPMENTS AND DISCOVERIES IN EXPLORATION 1 (RATTRAY). Sponsored by Antofagasta. Chair: Lawrence Robb****0845 Keynote: Richard Sillitoe (SEG International Exchange Lecturer)**

Exploration and discovery of base- and precious-metal deposits in the circum-Pacific region

0930 R Chapman (University of Leeds)

The Yukon Gold Project

0945 A Bjorklund (Magnus Minerals)

The relationship between major ore deposits and geochemical provinces in Finland

**1000 COFFEE BREAK (TA1, SB), sponsored by Lonmin
(Demonstration of MOVE software by Midland Valley in SB)
Posters can be viewed in TA2 and TA3**

SESSION: APPLIED MINERALOGY (RATTRAY). Sponsored by the Applied Mineralogy Group. Chair: Bruce Yardley (NOTE PARALLEL SESSION)**1030 Keynote: Jan Cilliers (Imperial College)**

Particles at Interfaces: the effects of shape and contact angle

1115 R Herrington (Natural History Museum)

Mineral-scale studies of acid leaching of nickeliferous goethite ores: implications for large-scale heap leach behaviour

1130 M Boni (Università Federico II)

The "Calamine" and the others: the great family of supergene Nonsulphide Zinc ores

1145 L Santoro (Università Federico II) STUDENT

The Nonsulphide zinc mineralization of Reef Ridge, Alaska

1200 F Molnar (Geological Survey of Finland)

LA MC-ICPMS Spot Analyses of Galena, Altaite and K-Feldspar from the Pampalo Mine, Hattu Schist Belt, Eastern Finland: Lead-isotopic Signatures of Overprinting Proterozoic Events on an Archaean Orogenic Gold Deposit

1215 K Anderson (Camborne School of Mines) STUDENT

Quantitative mineralogical and chemical assessment of the Nkout Iron Ore Deposit, Southern Cameroon

1230 I Baksheev (Moscow State University)

Mineralogy of the Baimka Cu-Au trend, Chukchi Peninsula, Russia

SESSION: ORE DEPOSIT RESEARCH IN PROGRESS (LT1). Chair: Jon Naden (NOTE PARALLEL SESSION)**1030 S Kocher (Imperial College) STUDENT**

Hydrothermal vein formation in the Southern Schwarzwald ore district

1045 B Snook (Camborne School of Mines) STUDENT

Magmatic or hydrothermal? High purity quartz from south Norwegian pegmatites

- 1100 R Williams (University of Brighton) STUDENT**
A study on the structural evolution of karst-associated bauxites of the Parnassos-Ghiona Zone, Central Greece
- 1115 G Boudoire (CRPG-CNRS) STUDENT**
Petrology of melt inclusions bearing xenoliths from the Oldoinyo Lengai, Tanzania
- 1130 M McGloin (Monash University) STUDENT**
How do we get uranium out of crystallised granites? A synchrotron scanning X-ray fluorescence micromapping study of a U-REE deposit source rock
- 1145 K Morgan (University of Leicester) STUDENT**
Constraining a genetic model for mineralisation at the Hana Mining Ltd. Ghanzi copper-silver Project, Botswana: Source and evolution of fluids
- 1200 J Nowecki (University of Southampton) STUDENT**
Stable isotopic evidence of an evolving fluid system within the Zambian Copperbelt.
- 1215 E Firth (University of Leicester) STUDENT**
Base metal-rich, orogenic gold-style mineralisation at Talca, coastal cordillera, Chile
- 1230 R Langdon (Camborne School of Mines) STUDENT**
Structural Controls on Gold Mineralisation along the Dugbe Shear Zone, Eastern Liberia

1245 LUNCH (TA1, SB), sponsored by Olympus InnovX
Posters can be viewed in TA2 and TA3

SESSION: NEW DEVELOPMENTS AND DISCOVERIES IN EXPLORATION 2 (RATTRAY). Chair: Steve Roberts

- 1330 S Jowitt (Monash University)**
Global Cu Resources: Changing trends and endowments
- 1345 G Nicoll (Neftex)**
Using the Neftex Earth Model for mineral exploration
- 1400 E Hill (Carl Zeiss Microscopy)**
MineraLogic - Automated Ore Analysis Solution
- 1415 J Dendle (SRK Consulting)**
Concept to Mineral Resource: Three Dimensional Geological Modelling
- 1430 J Hogg (Micromine)**
The application of computerised 3D modelling software and data capture in mineral exploration and resource development
- 1445 MDSG AGM (RATTRAY) including presentation of Rio Tinto best student prize**

1500 COFFEE BREAK (TA1, SB), sponsored by Micromine
Posters to be taken down

SESSION: CRITICAL METAL SUPPLY TO THE UK (RATTRAY). Chair: Gus Gunn

1530 Session: J Andersen (Camborne School of Mines)

Indium mineralisation in Southwest England

1545 K Goodenough (BGS)

Enrichments in the critical metals: interplay of magmatism, deformation and fluid flow

1600 K Moore (Camborne School of Mines)

The origin of MREE- and HREE-enrichments in carbonatites: evidence from field, petrographic and experimental investigations

1615 L Robb (Oxford University)

New perspectives on the metallogeny of Malaysian tin granites

1630 PANEL SESSION

Including: G Gunn (BGS), R Herrington (Natural History Museum), K Moore (Camborne School of Mines), K Roelich (University of Leeds)

1700 Invited speaker talk (RATTRAY): Graham Brown (Anglo American)

Sustainable Exploration – A Major's Perspective

1730 Close of meeting: Dan Smith

POSTERS

All posters are uniquely numbered, and displayed grouped according to the themes of the meeting. Posters are listed here according to first author. Full lists of authors can be found in the individual abstracts in this volume. Posters will be available to view in TA2 and TA3 (Bennett Building) from lunchtime on Thursday 3rd through to afternoon coffee on Friday 4th. The poster session, where all presenters are required to be by their posters in from 1630 to 1800 on Thursday 3rd.

THEME: CRUSTAL TO MICRO-SCALE CONTROLS ON GOLD DEPOSITS

- 1 P Bird (Kingston University) STUDENT**
'Orogenic Gold' in the Kibali Granite-Greenstone Terrane, NE Democratic Republic of Congo
- 2 K Rubingh (Laurentian University) STUDENT**
A redefined structural architecture for the McLeod Road – Birch Lake thrust panel and implications for gold mineralisation at the New Britannia Mine, Snow Lake, Manitoba, Canada
- 3 A Wong (University of Leicester) STUDENT**
Characterisation of metabasite occurrences in the Dalradian stratigraphy of NE Northern Ireland: an assessment of PGE potential
- 4 A Yuhei (Kyushu University) STUDENT**
Field occurrence and lithology of 2.8 Ga Mistuhe hydrothermal section, Utik Lake greenstone belt, Canada
- 5 M Williams (University of Leicester) STUDENT**
Mineralogical and Fluid Characteristics of 'Monakoff-Style' Iron-Oxide-Copper-Gold (IOCG) Mineralisation in the Cloncurry Area, Queensland
- 6 L Bland (University of Leicester) STUDENT**
Developing Vectors to Mineralisation at Guelb Moghrein, Mauritania
- 7 W Bond (University of Leicester) STUDENT**
Constraining a mineralisation model of the SG Mining Tsagaan Chuluut gold deposit, Mongolia: A petrological and geostatistical study
- 8 N Zimanovskaya (East Kazakhstan State Technical University) STUDENT**
Gold in massive sulfide (base metal) and carbonaceous gold sulfide deposits in Eastern Kazakhstan

THEME: NI-CU-PGE DEPOSITS

- 9 H Carson (Laurentian University) STUDENT**
Komatiite-Associated Cr and Ni-Cu-(PGE) Mineralisation in the Black Thor – Black Label Ultramafic Intrusion, McFaulds Lake Greenstone Belt, Canada
- 10 A Beswick (Laurentian University)**
Some applications of element ratio analysis to understanding the compositional variations displayed by a selection of Fe-Ni-Cu-PGE deposits at Sudbury, Ontario, Canada

- 11 S Graham (University of Leicester) STUDENT**
Characterisation of the newly discovered Cu-Ni-PGE mineralisation at Sron Garbh, Stirlingshire, Scotland
- 12 H Hughes (Cardiff University) STUDENT**
Platinum group element geochemistry of the Scourie Dykes: Parental melt sources and insights into the Lewisian subcontinental lithospheric mantle
- 13 R Knight (Cardiff University) STUDENT**
A follow up study of platinum-group minerals from the Jinchuan intrusion, Gansu province, NW China
- 14 A Sutherland (University of Leicester) STUDENT**
The nature and genesis of PGE-rich sulphide horizons on the farm War Springs, northern Bushveld Complex, South Africa
- 15 A de Joux (University of Edinburgh) STUDENT**
The Comsos greenstone succession; Insights into an Archean volcanic arc, associated with komatiite-hosted nickel sulphide mineralisation, from U-Pb dating, volcanic stratigraphy and geochemistry

THEME: PORPHYRY/EPITHERMAL SYSTEMS

- 16 K Sullivan (University of Southampton) STUDENT**
Investigating the Controls on Critical Metal Distribution in Porphyry Deposits
- 17 L Marushchenko (Moscow State University) STUDENT**
Mineralogy of the Peschanka porphyry copper deposit, Chukchi Peninsula, Russia
- 18 S Fenton (University of Leicester) STUDENT**
Geochemical and mineralogical characteristics of the West Kasulu Cu-Au porphyry prospect, Mongolia: links to Oyu Tolgoi?
- 19 A Dolgoplova (Natural History Museum)**
Isotope systematics of the Hugo Dummett Cu-Au porphyry deposit
- 20 N Shatova (Russian Geological Research Institute) STUDENT**
Petrography, Geochemistry, and Isotopic Dating of Eruptive Breccias of the Ryabinovoe Au-Cu Porphyry Deposit (South Yakutiya)
- 21 J Sidorina (Moscow State University) STUDENT**
Epithermal Au-Ag mineralization of the Baimka Cu-Au trend
- 22 R Knott (University of Leicester) STUDENT**
Petrological Controls on Intrusive Hosted Polymetallic Mineralisation, Tirua Hill, South New Georgia, Solomon Islands

THEME: NEW DEVELOPMENTS AND DISCOVERIES IN EXPLORATION

- 23 T Barrett (Ore Systems Consulting)**
Volcanism and polymetallic mineralization at Parys Mountain, Wales
- 24 R Bartlett (University of Leicester)**
Re-examination of the Broken Hill gossan: applications in exploration for Broken Hill-type mineralisation

- 25 R Bartlett (Barrick)**
Geology and Mineralisation of the Chimiwungu Cu-Co-U Deposit
- 26 M Hutchinson (Trigon Geoservices) STUDENT**
Diamond Exploration in West Greenland – The Qaamasoq Prospect
- 27 J Hughes (University of St Andrews) STUDENT**
Aillikite – an unconventional diamond host rock and its importance in the ‘Greenland-Labrador-(Scotland?) Diamond province’
- 28 P Rourke (Midland Valley)**
Digital Technology for Geological Mapping?

THEME: APPLIED MINERALOGY

- 29 A Azelkhanov (East Kazakhstan State Technical University) STUDENT**
Manrak bentonite used as mineral additive in breeding in East Kazakhstan
- 30 J Chapman (Geological Survey of Canada)**
Anomalous zircon Ce⁴⁺/Ce³⁺ ratios from the Jurassic of Yukon, Canada: implications for exploration applications of a zircon magma redox proxy
- 31 S Hönig (Masaryk University) STUDENT**
Y and HREE residence in A-type granite - Garnet as a major Y and HREE carrier of the rock; An example from the layered anorogenic granite dykes, Cadomian Brno Batholith, Czech Republic
- 32 N Mondillo (Università Federico II, Napoli)**
XRD and QEMSCAN® quantitative mineralogical evaluation of the karst bauxite deposits in Campania (Southern Italy)
- 33 R Norman (Natural History Museum) STUDENT**
Nickel substitution in iron oxyhydroxides: Combining studies of natural and synthetic materials with implications for nickel extraction from goethite-rich laterites
- 34 C Pinto Ward (Imperial College) STUDENT**
Mineralogy, geochemistry and small-scale atmospheric acid leach experiments of the Araguaia Nickel laterite deposit
- 35 A Connelly (University of Liverpool) STUDENT**
Particles at Interfaces: the effects of shape and contact angle
- 36 C Spence-Jones (University of Leicester) STUDENT**
Metallurgical investigation of the ore from Cononish gold deposit, Scotland
- 37 K Torremans (University Leuven)**
Discrete element modelling experiments on the formation of layer-parallel veins in multilayer sequences

THEME: CRITICAL METALS

- 38 A Abdurrahman (Camborne School of Mines) STUDENT**
Geochemistry and Mineral Potential of Rare Metal Pegmatites in the Ijio Area, SW Nigeria

- 39 H Warman (University of Leicester) STUDENT**
Distribution and mineralogy of REE-Zr-Nb-Ta mineralisation within pegmatite sheets at Citadellet, Kangerdlugssuaq Alkaline Intrusion, East Greenland.
- 40 B Thompson (Camborne School of Mines)**
By-product potential of critical metals (Nb/Ta/REE/W) and Sn within IMERYs kaolin operational areas, St Austell Granite, Cornwall
- 41 N Hulsbosch (University Leuven)**
Chemical fractionation of the Nb-Ta-Sn mineralised pegmatites of the Gatumba Area (Rwanda)
- 42 B Simons (Camborne School of Mines) STUDENT**
Distribution of critical metals in biotite and Li mica granite from Cornwall, UK.

THEME: ORE DEPOSIT RESEARCH IN PROGRESS

- 43 F Marks (University College Dublin) STUDENT**
Characterising a geochemical and isotopic halo of the Navan Zn-Pb Irish-type deposit
- 44 A Gorman (University of Leicester) STUDENT**
Developing exploration models for copper-silver mineralisation in the Kalahari Copperbelt, Botswana – A. Mineralogy, geochemistry and structure.
- 45 R Williams (University of Brighton) STUDENT**
Ore genetic –evolutionary features of karst-associated bauxites in the Parnassos-Ghiona Zone, Central Greece
- 46 A Dobrzanski (University of Liverpool) STUDENT**
Initial results of a geochemical reconnaissance study of the Kirk Maughold Haematite Ore Deposit, Isle of Man, foundations of a modern ore deposit model
- 47 B Rakhimbayeva (East Kazakhstan State Technical University) STUDENT**
Ni-Co weathering crust of the Charsk zone in East Kazakhstan

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ABSTRACTS

Abstracts of all talks and posters are arranged in alphabetical order of first author, or, by presenting author if they are not listed as first author.

Geochemistry and Mineral Potential of Rare Metal Pegmatites in the Ijio Area, SW Nigeria

Abdurrahman, A.¹, Andersen J.C.Ø.¹ and Williamson B.J.¹

¹University of Exeter - Camborne School of Mines, Penryn, Cornwall TR10 9EZ, UK

The increasing global focus on strategic rare metals is largely driven by rising demands through the development of high-tech electronics and low-carbon energy production, storage, and emission control. The increase in demand has led to intensified research into their potential hosts, as it is becoming increasingly clear that continuity of supply for many metals cannot be taken for granted. The rare earth elements in particular has become a focus, because of the dominance of production (and export restrictions) of a single supply country. However, many other metals have similar supply issues because of restricted extraction, political or economical constraints, or (as is the case for the "Coltan" minerals) because they are used to fund political conflicts [1].

This study investigates rare metals in granitic pegmatites in the Ijio area of SW Nigeria. The pegmatites occur within the Pan African basement of SW Nigeria. They are believed to have formed around 562-534 Ma [2] and have been the sources of columbite and tantalite since 1912 [3]. More recently, the pegmatites have been mined by artisanal workers for gemstone-quality beryl, tourmaline and garnet. Field relations indicate that the pegmatites form dykes, sills and irregular bodies in their host granites, granodiorites, gneisses and amphibolites.

This investigation aims to establish the lithological and geochemical controls on the pegmatite formation, to explore the mechanisms of fractionation, and to develop a geochemical framework for rare metal exploration in the area. Initial geochemical results suggest that the pegmatites are enriched in High Field Strength (HFSE) and Large Ion Lithophile (LILE) elements, including many strategic/critical metals. Preliminary investigations show that the pegmatites have high concentrations of Li (<1798 ppm), Cs (<377 ppm), Rb (< 2186 ppm), Sn (<259 ppm) and Nb (<324 ppm), but low concentrations of Ta (\leq 52 ppm). The granitic rocks associated with the rare metal enriched pegmatites are highly enriched in LREE and moderately depleted in HREE, with moderately to strongly negative Eu anomalies. A genetic relationship is indicated with the negative Eu anomalies in the muscovites from the pegmatites suggesting common origin with the granites.

References:

- [1] Melcher et al. (2008). SGA News, 23.
- [2] Matheis G & Caen-Vachette M (1983) Journal of African Earth Sciences, 1(1), 35-40.
- [3] Jacobson R & Webb JS (1946) Geological Survey of Nigeria Bulletin pp. 1-61

Indium mineralisation in Southwest England

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Indium is consistently mentioned in metal supply risk lists because of a rapidly growing demand and limited production. The metal is critical in the production of photovoltaic cells and colour liquid crystal displays, and is considered to be of strategic significance to technological developments within the EU and UK [1,2]. Indium is geologically under-explored, as it is only very rarely included in geochemical studies. Consequently the mechanisms leading to enrichment in the crust are poorly understood.

Indium has been reported from granite related mineral veins across SW England in previous presentations to the Mineral Deposit Studies Group [3,4]. Recent research expands the scope for economic indium occurrences to a much wider range of granite-related mineral deposits across the region. Significant indium is found in sulphide-bearing skarns from the northern margin of Dartmoor (the Red-a-Ven mine), the greisen vein systems at Redmoor and Cligga Head, and more than 20 main stage mineral vein systems across the region. The richest occurrences have been identified at Botallack (St Just district); Dolcoath, Wheal Concord and Nangiles (Camborne-Redruth-St Day district), Wheal Charlotte (St Agnes) and Perran St George (Perranporth).

Total indium concentrations are very variable within and between the individual deposits. Whole-rock concentrations locally reach 420 ppm, equivalent to 800 ppm in 100% sulphide + oxide. The indium is distributed between sphalerite (up to 1.2 wt%), chalcopyrite (up to 2200 ppm), stannite (up to 6700 ppm) and cassiterite (up to 1800 ppm). Vein systems that are particularly rich in indium also carry rare, minute grains of roquesite (CuInS₂) that are commonly spatially associated with bornite and chalcocite. While the mineralogical distribution of indium is variable, there is commonly a broad correlation between the concentrations within coexisting host minerals.

Although indium concentrations are highest in sphalerite and stannite, chalcopyrite is the dominant mineral host throughout the area. This raises important questions to the potential for extraction. Most economic operations elsewhere recover indium from sphalerite during smelting by acid leaching and precipitation [5,6]. Although we have failed to find a commercial process for indium recovery from copper concentrates, Ke et al. [7] reported a method to recover indium along with other metals from copper smelter flue dust, which could form a basis for the development of a commercially viable method of extraction.

While indium may never become a main commodity for targeted exploration and extraction in the region, the metal has significant potential to add value to the extraction of tungsten, tin, copper and zinc. Although the metal is considered as a potential by-product by Western United Mines, much more detailed investigations are required to fully understand the timing and nature of indium mineralisation within individual mineral vein systems.

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Quantitative mineralogical and chemical assessment of the Nkout Iron Ore Deposit, Southern Cameroon Using QEMSCAN[®]

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The Nkout deposit is part of an emerging iron ore province in West and Central Africa. It is an oxide facies iron formation comprising fresh magnetite banded iron formation (BIF) at depth which weathers and oxidises towards the surface forming caps of high grade material comprising hematite[1] and martite-goethite ores. The current resource estimate is 1.2Bt at 32.9% Fe indicated, 1.3Bt at 30.3% Fe inferred and this includes high grade caps (50% Fe cut off) totalling 25.1mt at 57.7% Fe indicated and 11.3mt at 53.7% Fe inferred [2]. The mineral species, micro and macro texture, mineral associations, liberation and also the chemical aspects of the mineralogy have been studied using Quantitative Evaluation of Minerals using a scanning electron microscope(QEMSCAN[®]), combined with whole rock analysis, Electron probe micro analysis (EPMA), semi-quantitative X-ray diffraction (XRD) and optical microscopy to determine mineralogical contents, relationships and distribution of deleterious elements such as P, Al, and Si, which need to be known in order to consider processing upgradability and exploitation. This study offers the first detailed predictive process mineralogical look at this deposit, and includes a protocol to discriminate Fe oxides by QEMSCAN[®]. It contributes to the understanding of deposits which have traditionally been considered as separate Direct Shipping Ore (DSO) and Banded Iron Formation (BIF) deposits.

A total of 51 samples were analysed; including samples from 31 drill holes, saprolites, laterites, fresh BIF, grab and outcrop samples. They were divided into 4 main groups based on whole rock Fe content and a weathering index (WI) in which 1 represents fresh itabirite and 6, completely weathered material. The groups are enriched material (EM), weathered magnetite itabirite (WMI), transitional magnetite itabirite (TMI) and magnetite itabirite (MI). The main iron minerals in the enrichment profile are hematite (mainly martite), magnetite and goethite. In the QEMSCAN[®] species identification protocol (SIP), the goethites have been divided into three categories namely goethite (Al), goethite/limonite and goethite (P) and includes goethite pseudomorphs after gangue minerals such as cherts, carbonates and silicates, ochreous goethite or limonite and vitreous goethite [3]. Development of these was based on the knowledge that goethite can contain Al, Si and P in its lattice, but also because EPMA results showed that this is the case for the Nkout samples. There is a rather low but important quantity of P-bearing goethite in the enrichment profile. The aluminium oxides/hydro-oxides (mainly gibbsite) content increases from EM to TMI whilst the quartz content increases from the WMI to the MI. Chamosite occurs in significant quantities from EM to TMI and kaolinite is also present.

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Manrak bentonite used as mineral additive in breeding in East KazakhstanAzekhanov A.¹, Kravchenko M.², Sapargaliyev E.² and Suiekpayev E.²¹East Kazakhstan State Technical University (EKSTU), Ust-Kamenogorsk, Kazakhstan, azelhanovag@mail.ru²LLP "Altai Geologic-Ecologic Institute", Ust-Kamenogorsk, Kazakhstan

The use of nano-dispersive, ion-exchange, slaking, embedded, water-loaded montmorillonite clays from the Tagan deposit in fodder production for agricultural animals and poultry finds increased application in East Kazakhstan [1, 2, 3, 4, 5]. Geological-genetic features of the depositional formation of montmorillonite clays during an oscillative-passive regime of Alpine geotectogenesis is characterized by the hypergene layering of mono-mineral depositions in ancient soil sections (ASS) consisting of the following lithologic horizons: a) soil; b) Cuirasse; c) distillate; d) spotty bentonite; e) mother bentonite [6]. Layering of lithologic horizons is caused by redistribution of chemical elements through percolative and evaporative processes affecting the ASS column under the conditions of tropical savannah Paleo-climate of the Danish age (65-60 Ma back) [6, 7].

Object of geochemical research was the ASS of montmorillonite sections using three open-cast bentonite mines near Ust-Kamenogorsk. The methodology of geochemical research of composition and flow of macro- and microelements is based on comparison of representative analyses from ASS lithologic horizons where molecular and atomic concentrations were assessed against Clarke values of sediments [8]. The following initial indicators are considered: 1 – atomic composition; 2 - substance in % with regards to the accepted basis "e"; 3 - estimation of element mobility relative to the basis "e" in (±) %.

Interpretation of results established the following: 1 - relative dislocation of chemical elements within the ASS column; 2 – concentration levels relative to Clarke values in clays and clay stones; 3 - sharp isolation of lithologic horizons "b - Cuirasse" that are an isolated type of carbonates of organogenic origin, serving as a geochemical barrier; 4 - exfoliation of horizon "a" from continuously embedded clay horizons "c", "d", and "e" which can be used in breeding both in combination and selectively as characterized in the previous work [4].

The geochemical analysis of mineral raw materials for feeding of agricultural livestock will be continued on halloysite-montmorillonite ASS, underlying montmorillonite ASS, on montmorillonite and kaolinite ASS, on Maastrichtian crust of weathering, on ferrimontmorillonite clay of Lower Miocene and illite clay of Late Miocene. As a result it is supposed to draw a full geochemical picture of the given kind of mineral raw materials with estimations of substance levels and distribution of rock-forming, toxic, radioactive, rare and sparse microelements. Simultaneously, geochemical variations of weathering crusts and continental depositions of different age, deposits of Upper Cretaceous, Palaeogene and Neogene of East Kazakhstan will be estimated.

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Mineralogy of the Baimka Cu-Au trend, Chukchi Peninsula, RussiaBaksheev, IA¹, Nikolaev, Yu.N.¹, Nagornaya, E.V.¹, Chitalin, A.F.², Dzhezheya, G.T.¹, Prokof'ev, V.Yu.¹¹Geology Faculty, Moscow State University, Leninskie Gory, Moscow, 119234 Russia, iab_68@mail.ru²Regional Mining Company Ltd, ul. Sadovnicheskaya 4, Moscow, 115035, Russia

The Baimka Cu-Au trend located 200 km South of Bilibino, Chukchi Peninsula, Russia is a part of the Oloi metallogenic zone, where Cu-Au-porphyry systems were formed in arc environment. This trend consists of four ore fields southward Yuryakh, Peschanka (~6 Mt Cu), Nakhodka (~3 Mt Cu) and Omchak discovered in late 1960th to early 1970th and explored in 1972-1986. In 2009, prospecting and exploration were renewed in the Baimka trend. The Baimka trend comprises Upper Jurassic and Lower Cretaceous stratified volcanic and terrigenous sequences intruded by igneous rocks of various composition and age. Cu-Mo-Au-porphyry systems are related to the Early Cretaceous Egdygkich Complex. The emplacement of Early Cretaceous three-phase Egdygkich pluton and monzonite and porphyry quartz monzonite stocks of the Egdygkich Complex (U/Pb zircon age 138-141 Ma) of subsequent hydrothermal activity resulted in Cu-Mo-Au deposits Peschanka, Nakhodka and prospect Top (Yuryakh field). The Rb/Sr age of the early biotite-potassium feldspar (potassic) alteration at Peschanka is ~136 Ma, ~138 Ma at Nakhodka, and ~136 Ma at Top'. In addition to the early potassic alteration, there are propylitic, quartz-sericite (phyllic), and advance argillic alterations at the deposits and prospects of the Baimka trend. Propylite occurs in all locations. Abundance of phyllic alteration increases from the Yuryakh to Nakhodka ore field indicating decreasing erosion level of ore fields. In the Nakhodka field, at the upper and lower level of phyllic bodies occurs phengite and Na-bearing muscovite, respectively, whereas at the Peschanka deposit, only muscovite develops in phyllic alteration. This fact testifies to the shallower erosion level of the Nakhodka field. Advance argillic alteration is sporadic at the locations of the Nakhodka ore field and is absent in Peschanka and Yuryakh.

The ore mineralization within the Baimka trend is divided into three types: (1) mesothermal porphyry, (2) IS-type epithermal, and (3) HS-type epithermal. The mesothermal mineralization spatially related to the potassic and phyllic alterations is present bornite, chalcocopyrite, molybdenite, pyrite, and magnetite elsewhere. The Re/Os age of molybdenite from Nakhodka is 138±11 Ma that is similar to that of the Egdygkich monzonitic rocks. The IS-type mineral assemblage abundant in the Nakhodka ore field is composed of As-rich pyrite, sphalerite, galena, Zn-rich tennantite-tetrahedrite, chalcocopyrite, native gold and electrum, hessite, petzite, and stützite. Due to significant erosion, the HS mineralization related to the advance argillic alteration is sporadic. The ore minerals are As-rich pyrite, enargite, digenite, chalcocopyrite, Zn-poor tennantite, Se and Te minerals (altaite; clausthalite; kurilite; and phases Ag-Te-Se, Pb-Ag-Bi-Te-Se, and Bi-Te-Se), and native gold of high fineness.

The petrography and microthermometry of fluid inclusions from vein quartz indicates three types of inclusions: (1) chloride brines with gas bubble and daughter crystal homogenized at 290-580°C, fluid salinity 37-58 wt % eq NaCl; (2) gas-dominated homogenized at 400-540°C; and (3) aqueous solution with gas bubble homogenized at 120-420°C, fluid salinity 0.4-19.7 wt % eq NaCl. The first and the second inclusion types are related to the formation of potassic alteration; the inclusions of the third type are related to the formation of the phyllic alteration ($T_{\text{hom}} = 240-420^{\circ}\text{C}$) and epithermal mineralization ($T_{\text{hom}} = 120-275^{\circ}\text{C}$).

The sulfur isotopic composition of sulfide minerals from the Baimka trend ranging from -6.4 to +4.8 ‰ is typical of porphyry copper deposits worldwide and indicates magmatic sulfur source. Lead isotope compositions of the sulfides display a narrow range of values ($^{206}\text{Pb}/^{204}\text{Pb} = 18.2-18.5$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.4-15.6$, $^{208}\text{Pb}/^{204}\text{Pb} = 37.5-38.2$) indicating mixed mantle-crust metal source.

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Volcanism and polymetallic mineralization at Parys Mountain, Wales

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At the Parys Mountain deposit in Anglesey, northwestern Wales, three contrasting styles of mineralization are present: massive Zn-Pb-Cu-Ag-Au sulfides of the Engine Zone and Garth Daniel Zone; semi-massive Zn-Pb sulfides + banded quartz of the White Rock Zone; and shale-hosted chalcopyrite-pyrite-quartz veins of the Northern Copper Zone. Total resources in all zones are: Indicated = 2.11 Mt at 0.58 % Cu, 2.18 % Pb, 4.11 % Zn, 46 g/t Ag, 0.5 g/t Au; Inferred = 4.11 Mt at 1.46 % Cu, 1.20 % Pb, 2.40 % Zn, 20 g/t Ag, 0.3 g/t Au (Micon International Co; in Anglesey Mining news release of Nov. 30, 2012). The massive sulfides occur as metre-scale thick lenses at and near the contact between footwall Ordovician shales and an overlying rhyolite complex 100-300 m thick. This style of mineralization was discovered by deep drilling about 1970 and has since been the focus of exploration. The rhyolite complex, which has been dated as Lower Silurian [1], is overlain by Lower Silurian graptolitic shales. The rhyolites and the shale formations strike northeasterly for 2-3 km and dip to the north. Precambrian basement rocks are present to the south and north of the Paleozoic rocks. The overall distribution of rock types is best explained by a regional syncline that is somewhat overturned to the south.

In detail, the polymetallic ores of the Engine and Garth Daniel zones lie within a complex interval of highly altered felsic rocks, shales and minor basalt. Alteration ranges from extreme chloritization to strong silicification to strong carbonatization. Some sulfides have a finely clastic texture, including the distinctive Zn-Pb-rich "bluestone beds", which were probably derived from moderate-temperature seafloor vents. Shale-rich debris flows containing sulfide and white-rock clasts are also present in the polymetallic zones. Locally, chalcopyrite-pyrite-quartz-carbonate stockwork veins are developed in the upper footwall shales. The White Rock Zone, which consists of 10-30 % Zn-Pb sulfides in a matrix of quartz, is interpreted as a relatively low-temperature seafloor deposit.

Several different volcanic chemostratigraphic units were defined at Parys Mountain in the late 1990s based on lithogeochemical analysis of 1000 drill core and outcrop samples [2]. Additional drilling over the 2005-2012 period combined with 500 more analyses has further defined the relations between volcanism and mineralization, including at the recently discovered Garth Daniel Zone, which appears to be stratigraphically equivalent to the Engine Zone but located about 1 km to the east. The use of immobile-element methods is essential at Parys Mountain in order to recognize the precursors of the highly altered rocks and make reliable correlations, and also to quantify the chemical changes due to alteration. Four chemically distinct rhyolite types (A to D) have been identified and mapped out across much the property. The polymetallic sulfides of the Engine Zone and Garth Daniel Zone are associated with a thin unit of highly altered rhyolite B that marks the initiation of volcanism. This was followed by emplacement of a lens of rhyolite C that locally wedged apart the mineralized interval and produced debris flows of sulfide-bearing shale. Rhyolites B and C were then covered by a far more voluminous body of massive rhyolite A. Towards the eastern part of the property, rhyolite A was replaced laterally by rhyolite D, which probably erupted from a separate vent. Rhyolites A and D were then followed by deposition of Lower Silurian shales. Thus the entire phase of volcanism at Parys Mountain must have occurred within the Lower Silurian. This submarine volcanism is notably younger than the much larger-scale, mainly subaerial, bimodal eruptions of Caradoc age that occurred in the Snowdonia region of northwestern Wales [3].

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Geology and Mineralisation of the Chimiwungu Cu-Co-U Deposit

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The recent development of a number of copper deposits in the Domes Region, west of the Zambian Copperbelt, has provided new insights into the potential host and genesis of copper mineralization in the Lufilian Arc. These deposits include the Chimiwungu and Malundwe Cu-Co(-U) deposits at Lumwana within the Mwombezhi Dome, and the Sentinel copper deposit flanking the Kabompo Dome. This new information has reset the prospectivity of a significant portion of the Lufilian Arc.

Following Barrick Gold Corporation's purchase of Equinox Minerals in June 2011, a major 275,000 m combined diamond core and RC resource definition and extension drilling program was completed at Chimiwungu to better define the deposit. This huge increase in the geological and assay data has significantly improved the understanding of this large, strongly metamorphosed, unconventional copper deposit.

The Chimiwungu deposit consists of a tabular, gently south-dipping package of copper mineralised schists and gneisses, varying in thickness from 10 to 200 m. The deposit is dissected by a series of north-west to westerly trending, north-dipping late brittle faults with north-block down movement which has preserved the mineralisation from erosion, placing it at an optimum depth for exploitation. The most recent published Mineral Resource for Chimiwungu is 1.46 Bt @ 0.64% Cu and 0.04% Co plus 2.5 Mt @ 437 ppm U [1].

The hanging-wall to the deposit consists predominantly of pink, feldspar-quartz-biotite-magnetite megacrystic meta-granitoid with subordinate grey quartz-feldspar-biotite gneisses and schists. The ore-bearing package consists of phlogopite-muscovite-quartz±kyanite schists and quartz-biotite gneisses with internal barren quartz-feldspar-biotite gneisses. The mineralized schists typically, but not always, show a down-hole sulphide zonation of pyrite-pyrrhotite, chalcopyrite and bornite. This increasing oxidation zonation towards the base is frequently observed in the Central African Copper Belt (CACB). There is no sharp lithological boundary representing the footwall to the deposit and mineralisation within the schists frequently grades into barren kyanite-porphyroblastic biotite-quartz schists and quartz-feldspar gneisses with interbanded amphibolites. A package of quartzites and talc-kyanite-muscovite-quartz schists below this has been tentatively correlated with the Rokana Evaporites of the Lower Roan in the Zambian Copperbelt.

Two approximate north-south trending thickened zones locally referred to as the Equinox and Roan Shoots are clearly defined by the drilling. These shoots are parallel to a regionally prominent north-south trending stretching mineral lineation. In long-section the shoots have a relatively flat bottomed dome appearance and show a clear thickening of both the mineralised schists and internal barren-gneiss units. However, the thickest part of the shoots does not coincide with the highest grade which is offset by 100 – 200 m to the east.

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Re-examination of the Broken Hill gossan: applications in exploration for Broken Hill-type mineralisation

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The Broken Hill sediment-hosted Pb-Zn-Ag deposit, New South Wales, Australia, is the world's largest Pb deposit, having yielded 28 Mt of Pb metal from 300 Mt ore [1]. It is the type example of the middle-lower Proterozoic Broken Hill type of stratiform base metal mineralisation (BHT), which also includes deposits such as Cannington, Zinkgruvan, Aggeneys-Gamsberg and possibly Sullivan. These deposits typically exhibit high tonnages (30 to >250 Mt) of Pb and Zn rich ore (10-20% Pb+Zn) with high Ag credits (>100 ppm) [2], and as such this deposit type remains an important target for Pb-Zn-Ag exploration.

Most BHT deposits have been discovered by prospection of spectacular gossan outcrops and it is likely that most deposits exposed at the surface have been found. However, gossan clasts within the regolith may be a much broader target than the deposit itself and therefore represent an important marker for an unexposed deposit. Gossans form by weathering of various rock types, including ironstones that are fairly abundant in middle-lower Proterozoic sequences; thus it is important to be able to distinguish gossans related to BHT mineralisation from those that are not ("false" gossans). Unfortunately, apart from a number of studies reporting the presence of rare and previously unknown minerals, remarkably little geochemical characterisation of the gossan at Broken Hill has been carried out since early studies [3,4]. This is because most of the gossan has been removed by extensive mining or buried under waste. To circumvent this we have examined sixty-eight gossan clasts collected from beds in a lag deposit near to the main line of lode at Broken Hill. These are material that was once at the surface of the deposit prior to mining and therefore are representative of what an explorationist would find above and adjacent to an unexploited deposit.

The gossan clasts are typically black and unremarkable apart from their high density and could be easily missed by an inexperienced explorationist. The gossan is dominantly composed of an unusually lead-rich coronadite ($\sim\text{Pb}_{1.8}\text{Mn}_{7.3}\text{Fe}_{0.4}\text{O}_{16}\cdot n\text{H}_2\text{O}$; $\sim 32\%$ Pb, 35% Mn) along with lesser goethite, which is unusually Mn, Pb and Zn rich. These occur with subordinate pyrolusite and hinsdalite-corkite group minerals ($\text{Pb}[\text{Al},\text{Fe}]_3[\text{PO}_4,\text{SO}_4](\text{OH})_6$) and minor amounts of pyromorphite and other secondary Pb and Zn minerals.

Whole rock geochemistry by ICP-MS confirms the Pb and Mn-rich and sulphur-poor nature of the gossan, with some enrichment (>20x) relative to bulk continental crust in Zn and Cu, and greater enrichments (>100x) in Sb, As, Cd and Ag. The Ag in the clasts is notably lower than in samples from the in situ gossan [3], suggesting that Ag may have been leached from the clasts during transport or by groundwater.

The mineralogy and geochemistry of the gossan forms a distinctive assemblage that should provide a marker for exploration for BHT mineralisation elsewhere.

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Some applications of element ratio analysis to understanding the compositional variations displayed by a selection of Fe-Ni-Cu-PGE deposits at Sudbury, Ontario, Canada.

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Element ratio analysis techniques, using diagrams such as Ni/S versus Cu/S [1], have been applied to exploration borehole assay data sets for a selection of magmatic-hydrothermal Fe-Ni-Cu-PGE sulfide deposits from around the Sudbury Structure.

In addition to clearly indicating the fractionation paths followed by the parent sulfide melts in these deposits, log- scaled versions of these diagrams reveal several features that have not previously been recognized. These features include the presence of two distinct pyrrhotite fractionation trends as well as indications that sulfide-sulfide liquid immiscibility was involved in the genesis of at least several of these deposits.

These diagrams allow one to identify distinct compositional 'domains' within a deposit that are each dominated by a particular sulfide mineral; low-Ni Po, high-Ni Po, Ccp, Pn, Bn and MI.

These diagrams also allow one to identify and estimate the final, eutectic Fe-Ni-Cu sulfide melt composition and to estimate metal D values between coexisting sulfide melt and each of the main sulfide minerals.

Ratio diagrams involving IPGE indicate their strong enrichment in Po relative to melt while those involving PPGE, Au, Ag, or Co indicate that these elements are strongly enriched in highly disseminated low sulfide mineralization which appears to have been derived from the sulfide melts and transported into the surrounding host rocks by an exsolved super-critical fluid phase.

The spatial aspects of the compositional variations displayed by these deposits indicate the possibility of developing compositional vectors towards 'missing' mineralization.

Information derived from these diagrams, combined with mass balance constraints, can also be used to estimate quantitatively the relative amounts of the different compositional 'domains' within a deposit and potentially to estimate the composition and relative amount of any 'missing' mineralization.

Finally, element ratio analysis indicates that the current approach of recalculating assay data for these deposits to 100% sulfides and examining the recalculated data on diagrams such as Ni₁₀₀ versus Cu₁₀₀ conceals rather than reveals the mass transfer processes controlling compositional variations in these magmatic-hydrothermal sulfide deposits.

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'Orogenic Gold' in the Kibali Granite-Greenstone Terrane, NE Democratic Republic of Congo

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The Kibali 'orogenic' gold project located in NE Democratic Republic of Congo. Current resource estimate is 18.6 Moz with significant upside potential being evaluated. Operations consist of open pit and underground mining, with first gold expected to be poured in 2014. The Kibali mine camp consists of the main Karagba-Chauffeur-Durba (KCD) deposit, and a number of smaller satellite lodes. Ore bodies occur as a series of stacked NE-dipping lodes divided into a series of mineralised 'corridors'. Mineralisation Fine disseminated pyrite, with minor pyrrotite and arsenopyrite, with gold texturally associated with pyrite. Mineralisation is hosted within volcano-sedimentary conglomerates that have been affected by pervasive Quartz-ankerite-siderite-chlorite-sericite alteration events.

The deposit is hosted within the 'Kibali' granite-greenstone terrane, an elongate belt containing volcano-sedimentary conglomerate, banded iron formations, sub aerial basalts and multiple intrusive phases that range from granitic to gabbroic in composition. Metamorphic grade varies from sub-greenschist facies in the west to amphibolite facies in the east. The greenstone belt is bounded to the north by the West Nile Gneiss and to the south by the Upper Zaire Granitic Massif, locally represented by the Watsa Igneous Complex. The structural geology of the belt is characterised by two main structure sets, NW-SE trending NE dipping thrust faults and a series of sub-vertical NE-SW shear structures. The latter are interpreted as transfer faults developed within the thrust system. Regional geology suggests that the West Nile Gneiss was thrust southward over the greenstone belt during the Neo-Archean.

The Kibali deposit differs from many orogenic gold deposits in terms of structural setting. Rather than being linked to a major steeply dipping strike slip fault it is hosted within a thrust stack. The preliminary model being developed is that the ore-forming fluids were produced by metamorphic devolatilisation under upper greenschist facies deep within the thrust wedge. They migrated upward and southward along NE-dipping thrust faults. Mineralisation occurred in dilational sites constrained by intersections between the thrust faults and lateral ramps.

Political instability has restricted geological research into the Kibali granite-greenstone terrane and its gold deposits, with only intermittent exploration carried out since the 1960's. Limited research mainly consisting of classification and dating of the major geological units is restricted to neighbouring greenstone terranes 200km to the east of the Kibali study area. Research in to the origins and characteristics of the gold mineralisation is similarly limited with mining surveys and feasibility studies forming the majority of the current knowledge base. The lack of any modern study has afforded us a remarkable opportunity to examine one of the last unexplored Archean greenstone belts in the world. It provides us with the opportunity to develop the first petrogenetic and ore genetic model for the Kibali gold deposit, in the context of the regional geodynamic evolution of the Kibali granite-greenstone terrane.

The relationship between major ore deposits and geochemical provinces in Finland

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Finland is host to many significant ore bodies including the famous Outokumpu Cu and Ni deposits, where the mines are now closed, and the recently discovered world-class Sakatti Cu-Ni-PGE deposit in Finnish Lapland. Here we examine the relationship between such ore bodies and geochemical anomalies from the reconnaissance to prospect scale using the till-geochemical maps prepared by the Finnish Geological Survey.

Geochemical maps based on the fine fraction of till indicate that all known major ore bodies in Finland are within geochemical provinces, which cut across the mapped bedrock geology. For example the central Finland ore zone which contains the major deposits of Vihanti (Zn), Pyhäsalmi (Zn, Cu) and the Outokumpu deposits (Cu and Ni) is represented on the till-geochemical maps by a marked NW – SE trending anomaly for most chemical elements. The Sakatti Ni-Cu-PGE deposit and the Kevitsa Ni-PGE deposit are in a similar large multi-element geochemical province. Indeed all major Ni deposits in the Fennoscandian Shield are in Ni provinces identified on geochemical maps prepared using the fine fraction of till.

The occurrence of major ore bodies in large cross-cutting multi-element geochemical provinces can be explained using the new fluid flux-centered concept of ore formation [1]. According to this concept ore deposition occurs episodically in anastomosing near-surface structures overlying large fundamental structures at depth. The tendency for such zones to be ore zones or provinces depends on three main components, an underlying lithospheric reservoir of metals, the geological evolution of the zone including magma genesis and channeling, and the large-scale geodynamic setting. According to this model, ore formation involves the fast upward movement of chemical compounds and nanoparticles from large metal-rich saline reservoirs in the lithosphere to the upper crust.

Hence, exploration for major base-metal deposits in Finland should be performed in such geochemical provinces. However, the deposits are frequently found away from the peak geochemical anomalies within the provinces. Moreover, detailed geochemical sampling has shown that fine-fraction till geochemistry is a poor tool for prospect-scale exploration unless the samples are immediately above or close to the sub-cropping ore. Methods based on heavy minerals and lithological studies of coarser fractions of till are better at this scale.

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Developing Vectors to Mineralisation at Guelb Moghrein, Mauritania.

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The Guelb Moghrein Fe-Cu-Au-Co deposit is located at the Western boundary of the West African craton in NW Mauritania [2] and is owned by Mauritanian Copper Mines, a subsidiary of First Quantum Minerals Ltd. The deposit is located close to the town of Akjoujt, approx. 250km NE of Nouakchott, in the Mauritanide orogenic belt [3]. The deposit has a total resource of about 30 Mt at 1.88% Cu and 1.41 gt⁻¹ Au [2]. Commercial production at the open pit commenced in 2006 with a projected annual production of 30,000t of copper and 70,000 ounces of gold [2].

Guelb Moghrein has been classified as an Iron Oxide Copper Gold deposit (IOCG) [3]. IOCG deposits are categorized by the following; 1) Cu with/without Au as economic metals, 2) hydrothermal alteration and strong structural controls, 3) abundant magnetite and haematite and 4) no clear spatial relationship to igneous intrusions [1]. Guelb Moghrein hosts two mineralized ferromagnesian carbonate (FMC) lenses named Occidental and Oriental [3] The FMC host unit is a brecciated mixture of grey to dark grey carbonate [3] which hosts chalcopyrite, pyrrhotite and magnetite. Significant anthophyllite veins are present [3].

This project seeks to enhance near-mine exploration by examining an existing lithogeochemical dataset for drill holes around the mine to vector towards mineralisation, paying particular attention to the changing degrees of hydrothermal alteration around the deposit. The dataset will also include samples collected from sites proximal and distal to the mine. Distal samples will be used in order to try to establish a geochemical baseline in which alteration around the deposit can be referenced.

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Constraining a mineralisation model of the SG Mining Tsagaan Chuluut gold deposit, Mongolia: A petrological and geostatistical study.

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The SG Mining Erdes LLC Tsagaan Chuluut (TC) gold project occurs in north-east Mongolia. The deposit is hosted in Jurassic intrusive diorite, gabbro and granite intruded into Proterozoic meta-sediments [1] and contains 10 t of gold at a cut-off grade of 0.3 ppm. The deposit is delineated in two zones. The northern east-west striking zone, TC1, is 200 x 400 m dipping southwards at 30° and is characterised by pervasive silica, sericite, pyrite and carbonate alteration. The southern zone strikes northwest-southeast and dips at 25° southwest. Exploration work has been carried out on the deposit since 1973 with the most recent work being a 29 hole drilling program carried out by SG Mining in 2012. This project makes use of assay and logging data from this exploration programme and petrography of core samples to constrain a mineralisation model and to identify possible future exploration targets for SG Mining by the creation of an exploration model.

TC has been associated with multiple alteration and mineralisation styles. Pervasive quartz, sericite and carbonate alteration has led to the deposit being described as exhibiting beresite alteration [2]. Low sulphidation epithermal mineralisation was also described which is consistent with Corbett's 2002 classification [3]. Phyllic and propylitic alteration styles have also been described leading to the deposit being classified as a Au-Cu porphyry intrusion related deposit [3]. Fieldwork did not allow the intrusive body responsible for the mineralisation to be constrained as all of the intrusives observed showed evidence of themselves being altered by mineralising fluids. This is suggestive of a fully concealed deep silicic intrusion [2] which could be responsible for other mineralisation in the area.

Multiple stages of veining have been observed in the core samples and preliminary petrography suggests the growth of quartz into open space and a later carbonate rich infill with which the pyrite is associated. There are also occurrences of feldspar-rich granitoid veins that appear to be early stage, but these are far less common. These vein relationships will be studied with reflected and transmitted light microscopy and vein material will be analysed with XRD and SEM to confirm composition. Zoning in quartz and feldspar crystals will also be studied under cathodoluminescence to try and reveal growth stages in these phases. Sulphide mineralisation appears to be almost entirely pyrite and it was suggested in 2005 that the gold mineralisation may occur bound to the pyrite [2]. This will be determined with SEM.

Project work so far has been largely statistical analysis of the assay database, which shows that unlike other deposits in the local area TC is not enriched in copper and the previous classification as an Au-Cu porphyry is incorrect. Gold is approximately 500x enriched. Previously unmentioned in reports on the deposit is the highly enriched nature of tungsten which is approximately 20x enriched relative to bulk continental abundance. This has led us to believe that deposit may be related to a reduced intrusion related gold system (rIRGS).

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The "Calamine" and the others: the great family of supergene Nonsulphide Zinc ores

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Despite the widespread distribution of surficial zinc oxides, economic Nonsulphide ores are much less common than sulphide zinc deposits. "Nonsulphide zinc" is a term, which comprises a series of ore minerals [1] [2]. Nonsulphide minerals of current economic importance are smithsonite, hydrozincite, hemimorphite and willemite, as well as Zn smectite (sauconite). Zinc is also hosted in chlorite like clays [3], in Fe- and Mn-(hydr)oxides and in Zn-rich dolomite. However, the latter concentrations are relatively uneconomic. The high-temperature mineralogical association of franklinite, zincite, and gahnite, occurring in the Franklin Sterling Hill-type deposits in North America [4], is not very common. Willemite-rich ores hosted within Proterozoic/Paleozoic carbonates in Australia, Brazil, Namibia, and Zambia, were also probably deposited in higher temperature conditions as hypogene Nonsulphides [5].

Because the differences in dissolution rates of the zinc minerals present in each deposit may have strong implications for the production strategies and metallurgical requirements, it is advisable to conduct detailed mineralogical and petrographical studies early in the exploration process. The economic value of zinc Nonsulphide ores is thus dependent not only on the geologic setting of each deposit, but also on the nature of the gangue minerals. Host-rock composition also significantly influences the mineralogy (and therefore metallurgy) of Nonsulphide zinc deposits. Those in limestone and dolomite (the "Calamine") tend to be dominated by smithsonite and hydrozincite, due to the interaction of low-pH Zn-rich groundwater fluids with host carbonates, whereas deposits in siliciclastic rocks tend to contain hemimorphite- and sauconite-bearing assemblages. However, even within similar host rocks, the mineralogy can vary substantially: it can be relatively simple (smithsonite, hemimorphite, hydrozincite), as in the oxidation products derived from low-temperature sulphide deposits (Mississippi Valley, carbonate-hosted SEDEX) or far more complex when derived from the weathering of high-temperature ores (VMS, CRD types) [2]. Most "Calamine" deposits have a simple mineralogy, good extraction recovery, and higher grades. Examples are Angouran (Iran) [6], Jabali (Yemen) [7], and Accha (Peru) [8]. Other deposits as Skorpion (Namibia) [9] are mineralogically more complex, but their processing challenges have been successfully overcome [10]. Other similar deposits (Yanque, Peru) may have also a good chance of success.

Supergene Nonsulphide deposits have been characterized by stable isotope analyses of their carbonates (smithsonite-cerussite-calcite) [11]. Oxygen isotope variation of the individual carbonate minerals within a deposit is relatively small, indicating constant formation temperatures and a single, meteoric fluid source. The carbon-isotope values are highly variable, suggesting at least two isotopically distinct carbon sources. The isotopically light component can be related to the oxidation of C3 plants (soil derived carbon) and/or microbes that take active part in sulphide oxidation, while the heavy component is derived from the carbonate host rock.

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Petrology of melt inclusions bearing xenoliths from the Oldoinyo Lengai, Tanzania

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Carbonatites are peculiar magmas that are nearly free of silica. These magmas display very high Rare Earth elements (REE) concentrations, represent the main REE-bearing lithology, and are widely exploited worldwide. Oldoinyo Lengai (East African Rift, Tanzania) is the only world volcano where carbonatitic activity has been observed in last decades, it therefore represents an ideal laboratory to study the genesis and evolution of these magmas. Its activity is characterized by an evolution of magma composition from phonolites (Lengai I) in early times of its activity, through combeite-wollastonite nephelinite (Lengai II) more recently, to natrocarbonatites in last decades. Genesis and evolution of these magmas are not well understood and different models are still under debates. Most authors nevertheless consider that an immiscibility stage occurs late, during differentiation within the crustal magma chambers.

In 2007-2008 a major explosive eruption was characterized by return to silicic compositions. Cumulative rocks namely ljolite, and recording magma chamber processes have been ejected as xenoliths during this recent episode. We present here a preliminary detailed study of these samples to decipher on magma chamber processes, and to bring new constraints on carbonatites genesis and evolution. All mineral phases (clinopyroxene, garnet, apatite, nepheline...) contain numerous trapped melt inclusions, that allows us to track the liquid line of descent followed during the crystallization within the magma chamber(s).

Crystallization sequence, minerals, and melt inclusions chemical compositions are presented, and bring new information on Oldoinyo Lengai time evolution. Investigated samples highlight that an advanced differentiation takes place within crustal magma chambers. During crystallization, magma composition varies from phonolites to foidites with an increase of the peralkalinity and a decrease of silica rate. Comparison of the new results with previous experimental works allows us proposing a 15 km deep (500 MPa) magma chamber for the genesis of the studied samples. Carbonatite and silicate melts are observed coexisting early in the sequence, and highlight that immiscibility occurs at Oldoinyo Lengai at largely higher temperatures than previously proposed.

This preliminary study emphasises that carbonatitic melts are present at different stages of magma evolution. Further studies will be performed on these samples, with the objective of constraining the evolution of trace element concentrations (including REE) in minerals and melts during the different steps of differentiation. One objective being to identify the best physical conditions necessary to get the highest critical metals concentrations in carbonatites; such results would be valuable for REE exploration and exploitation..

Sustainable Exploration – A Major’s Perspective

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The Exploration and Discovery business faces three key challenges; improving the declining rate of discovery, reversing the trend of increasing costs and lead time and maintaining our licence to operate. From my perspective as an explorer our business is ultimately all about discovery, delivering value and providing options for growth. Importantly successful exploration and finding new ore deposits are people-driven and a team effort.

However the challenge of maintaining our licence to operate should not be underestimated. In particular how do we as an industry attract and retain people, improve safety and minimize the impact on both the communities and the environments in which we work. In addition to being at the forefront of exploration innovation and technology, we also need to continue to advance our social frontiers if we wish to have continued access to land, resources and talent.

In other words we need to balance risk and reward when selecting the what, where and how to explore. To build a sustainable, competitive business and improve the industry’s discovery track record, we need to continue to push our geography, science, technical and social frontiers. Partnerships on all levels are critical and bringing together communities, industry, academia and government to deliver on the commitment to advancing science and discovery for the benefit of society and our key stakeholders.

The singular most important contribution geoscientists can make to society is the discovery of new deposits. In particular given that the majority of the mining industry’s wealth is captured in a few world-class mines – it is these rare Tier1 deposits that provide the industry with the best opportunity to make a positive and lasting contribution to society.

Successful Exploration and Discovery is a major differentiator in terms of leadership, expertise and value-creation. In the past the priority was finding and building mines whereas today the focus is building partnerships on all levels of society. Key to future success and sustainable exploration requires delivery on advancing exploration frontiers, maintaining access to land, mineral resources and talent and providing options for growth through discovery, acquisition and innovation.

The Sakatti magmatic Ni-Cu-PGE deposit, northern Finland

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The Sakatti deposit is a greenfield discovery in northern Finland. The deposit is both disseminated and massive Cu-Ni sulphide mineralisation, with significant Pt-Group-Elements (PGE), hosted by an olivine cumulate. The cumulate has a conduit-like profile, at least 0.5km in cross section, surrounded by a volcanic footwall and capped by a breccia.

The cumulate appears to consist of several pulses, generally becoming more evolved towards the top of the unit, with the exception of a 'marginal reversal' at the base. This is where the basal 30-40m becomes more evolved towards the footwall, which appears to be due to melting and assimilation of the footwall rock. In addition, the cumulate unit has permeated into the footwall rock itself melting along a pre-existing brecciation.

In magmatic deposits the cause of S saturation is fundamental to the genesis of the deposit. While contamination by S-rich or siliceous footwall rocks is often cited as a cause of S saturation, the footwall volcanic rocks are not S-rich and only contaminate the margins of the cumulate.

However, there are obvious local S-rich sediments that, although not seen in contact with the cumulate unit, could act as a potential S source. To test this, S isotope analysis was undertaken at the SUERC facility and it was found that mineralisation within the deposit consistently has $\delta^{34}\text{S}$ values of between 2‰ and 4‰, while the sediments near the deposit have highly variable values between -24‰ and +20‰. This may indicate that assimilation of the proximal sediments was not involved in the genesis of the deposit, as one might expect values that deviate considerably from a mantle $\delta^{34}\text{S}$ value of $0 \pm 2\%$ [1].

Further evidence that S contamination did not occur through contamination by the local S-rich sediments is present in the cumulate silicate minerals themselves. The olivine has high Ni values of up to 0.4wt%, which implies that the host cumulate itself has formed from a melt that has not been S saturated. This means that the host cumulate is not derived from the parent melt of the sulphide mineralisation, as this would be depleted in Ni. Therefore the host cumulate must have transported a pre-existing immiscible sulphide melt, which would have formed at greater depth.

The trigger for S saturation at greater depth is unclear; however, some insight is offered by the PGE mineralogy. The deposit contains a globally unique magmatic PGE mineral assemblage that is shared only with the Kevitsa Ni-Cu-(PGE) deposit 10km from Sakatti [2]. This similarity suggests that despite the differing styles and host rocks of the two deposits, the mechanism for triggering S saturation and forming the deposits may have been the same. This has important implications for the whole greenstone belt that contains the two deposits.

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Komatiite-Associated Cr and Ni-Cu-(PGE) Mineralisation in the Black Thor – Black Label Ultramafic Intrusion, McFaulds Lake Greenstone Belt, Canada

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The Black Thor – Black Label ultramafic intrusion is part of the regionally-extensive ‘Ring of Fire’ ultramafic-mafic intrusive suite in the Neoproterozoic McFaulds Lake greenstone belt within the James Bay Lowlands of northwestern Ontario [1-2]. The intrusion is ~1.5 km thick and ~2.6 km long, and can be subdivided into three main zones: 1) a *lower zone* of adcumulate-mesocumulate komatiitic dunite locally containing disseminated/semi-massive/massive Ni-Cu-PGE-bearing sulfides, 2) a *middle zone* of chromite-bearing heteradcumulate-mesocumulate dunite/peridotite and heteradcumulate-mesocumulate chromitite, and 3) an *upper zone* of mesocumulate-orthocumulate komatiitic peridotite/pyroxenite. Cr mineralisation occurs in the middle zone and is comprised of lower magmatically brecciated ores (Black Label), and upper thick-laminated to thick-bedded disseminated/net-textured/semi-massive ores (Black Thor). The intrusion locally contains inclusions of underlying granitoids, appears to be younger than overlying metavolcanic rocks, and is cross cut by a pyroxenite that disrupts Black Label. Multiple phases of gabbros and ferrogabbros overlie and locally cross cut the intrusion. All rocks have been metamorphosed to lower greenschist facies, but relict olivine and pyroxene are locally preserved. Chromite grains, regardless of rock texture, are 0.05-0.15 mm and euhedral with almost no evidence of recrystallization. Mineralised material totals 102 Mt averaging ~31% Cr₂O₃ to -400m elevation (open at depth). With mineable thicknesses up to 100m, it is one of the largest, thickest, and richest magmatic chromite deposits in the world.

The genesis of the Ni-Cu-(PGE) mineralisation is not yet clear, but the mineralogy (pyrrhotite-pentlandite-chalcopyrite ± PGMs) and textures suggests that it is magmatic. Minor chalcopyrite-rich veins appear to represent residual sulfide melts derived by fractional crystallisation of Fe-Ni-rich Cu-poor monosulfide solid solution. The occurrence of sulfides along the lower contact of the intrusion and in associated feeder dikes [1] suggests that at least some of the sulfides have been transported into their present locations. The genesis of the Cr mineralisation is even less well constrained at this stage, but we are investigating several models including: physical transportation of slurries of finely-dispersed chromite [3-4] with or without magmatic slumping [5], and in-situ crystallisation associated with oversaturation of chromite with oxidation [6], wallrock contamination [7], and/or magma mixing [8]. The overwhelmingly cumulate nature of the ores and olivine-rich host rocks suggests an open (flow-through) magmatic system similar to most other mineralised komatiitic systems [9].

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Anomalous zircon Ce^{4+}/Ce^{3+} ratios from the Jurassic of Yukon, Canada: implications for exploration applications of a zircon magma redox proxy

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Numerous studies suggest that a genetic link exists between oxidized magmas and porphyry-style Cu ($\pm Au \pm Mo$) mineralization. However, traditional indicators of magmatic redox state can be reset during both hydrothermal alteration and weathering. Zircon ($ZrSiO_4$) is an abundant accessory mineral in granitoid igneous intrusive rocks and is both refractory and resistant to alteration. Trivalent heavy rare earth elements readily substitute for Zr within the zircon crystal lattice, but the degree of substitution decreases markedly with increasing ionic radius. However, Ce shows significant deviations from this model behaviour due to its additional stable +4 oxidation state. Zircon commonly displays a significant positive Ce anomaly, as Ce^{4+} is preferentially incorporated into the zircon lattice over Ce^{3+} due to its identical charge to Zr^{4+} . The magnitude of this anomaly should correlate to the Ce^{4+}/Ce^{3+} ratio in the parent magma, and as such can be used as a qualitative proxy for oxidation state. In this study, we used laser ablation inductively-coupled plasma mass-spectrometry (LA-ICP-MS) microanalysis to determine zircon Ce^{4+}/Ce^{3+} ratios for a suite of Triassic to Jurassic granitoid intrusions from southern and western Yukon, and for various intrusive phases associated with the Cretaceous Casino Cu-Mo-Au deposit.

Results for the Casino samples show that intrusive phases associated with mineralisation conform to established models for Ce systematics within porphyry-style Cu ore-forming settings. The major mineralising intrusive breccia phases have average zircon Ce^{4+}/Ce^{3+} values of 200-350, and peak values approaching 500, in contrast to mid-Cretaceous granitoid host rocks that have average values of 50-100 and peak values <250. Hence, it may be possible to use zircon Ce ratios as a powerful exploration fingerprint and vectoring tool. Although variability within an individual sample appears to be quite high, basing prospectivity thresholds on population statistical parameters may allow the number of individual analyses required to be reduced. More work is needed to establish possible provenance determination protocols, but in time it may be possible that Ce^{4+}/Ce^{3+} ratio determination could be applied to stream and soil sediment samples.

Data from the Triassic/Jurassic suite are more equivocal, however, and seem to indicate that the controls for these rocks are substantially different to those of the Cretaceous. Both the Minto and Carmacks Copper deposits are hosted within Triassic-Jurassic plutonic rocks of the Granite Mountain batholith, part of a regionally extensive suite of plutonic rocks of similar age and composition. Within the Carmacks Copper Belt of south-central Yukon these have been extensively explored for Cu ($\pm Au$) mineralization, and numerous showings have been identified. However, outside the belt few other mineralization targets have been identified. The Triassic-Jurassic suite appears to fall into two distinct groupings: those with modal Ce^{4+}/Ce^{3+} values >700, and those with values <600. However, all are above the values identified by Ballard *et al.* [1] and Liang *et al.* [2] as the threshold for prospective bodies in the Chuquicamata-El Abra district, Chile, and Yulong district, China, respectively. Petrogenetic indicators for this suite suggest that the depth of emplacement was significantly deeper than was the case for the mineralisation associated rocks of the Cretaceous suite. Hence, it may be that the zircon Ce^{4+}/Ce^{3+} ratio in these samples is not dominantly controlled by magma redox. In this case, the technique may be of little use.

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The Yukon Gold Project:

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The Yukon Territory in the northwest of Canada attained international prominence during the Klondike Gold Rush of 1897. Estimates of the amount of placer gold recovered vary between 12 and 20 million ounces, and placer mining is ongoing. The discovery of the Minto (Cu-Au), Casino (Cu-Au-Mo) and Nucleus-Revenue (Au-Ag-Cu-Mo) deposits established the Territory as an exploration target in a mining-friendly administration.

The Dawson Range forms a 250 km belt running southeast to northwest from the south-central Yukon and into Alaska. The area is largely unglaciated, and exposure is typically poor and obscured by permafrost. Systematic soil sampling surveys initiated in the 1990s culminated in two new significant gold discoveries at the 'White Gold' (Kinross) and 'Coffee' (Kaminak Resources) properties which fuelled extensive staking. However, the geology and metallogeny of the Dawson Range is complex, comprising Paleozoic metamorphic rocks with deformed mineralization, together with at least six phases of igneous activity and associated mineralization between Late Permian and Early Tertiary time. Frequently, individual licence areas exhibit elements of this complexity leading to poorly constrained exploration targets.

The Minerals Deposit Research Unit (MDRU) is a collaborative venture between the mining industry and the University of British Columbia (UBC), which designs and manages industry facing research projects. In 2010 MDRU obtained ten industrial sponsors, support from Natural Resources Canada, and matched government funding to run the two-year, C\$1.7m 'Yukon Gold Project' which addressed the metallogeny of the Dawson Range through overarching studies of tectonic and structural setting, magmatic evolution and geochronology, fluid geochemistry and ore genesis. In addition, thematic studies supported by MSc projects focussed on exploration geochemistry and placer-lode gold relationships.

Detailed geochronology of mineralization (e.g. $^{187}\text{Re}/^{187}\text{Os}$ dating) and nearby intrusions (U-Pb, $^{40}\text{Ar}/^{39}\text{Ar}$ dating) has clarified their relationships. In the south, variably reduced intrusions which host porphyry mineralization at Casino, Revenue-Nucleus, and Sonora Gulch yield a common age of ca. 75 Ma. In the north of the area, a genetic link between intrusions and mineralization (e.g. in the Klondike, and at White Gold) has been disproven and orogenic mineralization is believed to be dominant.

Placer gold has been characterized in terms of the alloy composition and suites of opaque inclusions revealed in polished section. Gold from the periphery of the Au-rich porphyry mineralization has a distinctive Bi-Pb-Te \pm Mo signature, whereas gold from orogenic sources exhibits a simple base metal \pm As or \pm Te signature broadly according to host lithology.

The reliance on soil sampling as an exploration technique in areas of poor exposure emphasised the need to understanding surficial processes and their influence on geochemical signatures in the periglacial environment. Regional structural studies are ongoing and make use of new geophysical and geological map compilations spanning the Yukon-Alaska border.

The project provided a cost-efficient mechanism for companies to access a new body of applied research in a timeframe relevant to exploration (two years). The key to overall success was the rapid development and execution of the project, field visits to exploration areas by project staff, and dissemination of results via a program of technical meetings. Results of the project will be published in 2013.

Particles at Interfaces: the effects of shape and contact angle

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There is currently an unprecedented demand for metals, driven by sustained economic growth and infrastructure development, particularly in China. Cost effective exploitation of lower grade ore deposits and the most efficient processing of all mined ore is becoming more and more important.

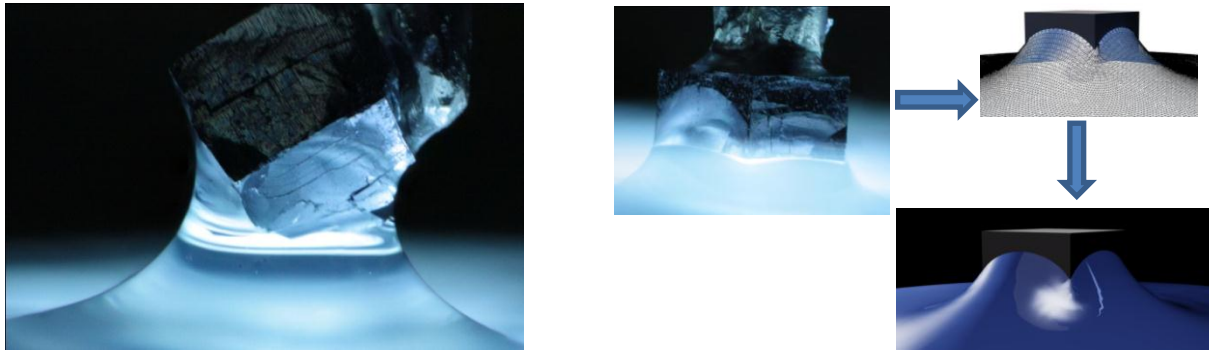
Froth flotation is the key separation and concentration step in the industrial processing of low grade ores. The flotation separation of minerals still relatively poorly understood as it is a dynamic, multi-scale and chemico-physical process. The fundamental interaction required for flotation is between particles and thin liquid films, both for attachment to the bubbles, and the stability of the froth. After comminution to liberate the minerals, the particles being floated are generally in the size range of 10-300 μ m.

The particle shape depends on the specific mineral; for example, galena breaks into an orthorhombic shape, while talc forms flat, plate-like grains. When such particles attach to a bubble they distort the liquid-vapour (LV) interface in a way that depends on both their shape and hydrophobicity. For a given particle, some particle orientations in the LV interface will be more energetically stable than others and will be preferentially adopted¹. For orthorhombic particles there are four stable orientations. It is possible to identify these orientations² and quantify the stability³ using models that minimise the surface energy⁴.

The combination of particle orientation and hydrophobicity also affects the stability of the thin liquid film that forms when two particle coated bubbles come into contact in the froth. By simulating the particles in the film, it is possible to identify which orientations most stabilise the liquid film. The relation between the orientation, particle hydrophobicity and film stability is investigated. It is shown that a particle with a low hydrophobicity will adopt orientations that more stabilise the film than those with a high hydrophobicity.

Dynamic models of particle stabilised liquid films were developed so that the interaction between several particles on the film can be investigated. The agglomeration of spherical particles on a film and the dynamic, self orientation of non-spherical particles will be demonstrated.

While these simulations are extremely useful, experimental results are necessary both to validate the models and to give further insight into the system under investigation. Results closer to flotation systems that investigate bubble coalescence and LV interfacial distortion will be shown and related back to the simulations (shown below).



The figures are an experimental demonstration of the distortion of the liquid-vapour interface around a galena particle at different orientations. On the right an experimental particle orientation and the associated interface shape is simulated and visually rendered.

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Application of EBSD to the microstructural analysis of mineral growth and deformation in gold-bearing sulphide ores

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Orogenic gold and sulphide minerals formed in long-lived crustal scale faults have the potential to preserve textures that record sequences of mineral growth and deformation. Analysis of the textures can thus provide a more complete understanding of mineral parageneses.

Standard methods are easy to apply to silicate minerals because they reveal these textures easily in a polarising microscope, for example. However, sulphide minerals are more problematic as they are typically opaque and often cubic and so reveal less information than silicate minerals when studied with traditional methods. This study uses electron backscatter diffraction (EBSD) and orientation contrast imaging in a scanning electron microscope (SEM) to investigate two orogenic gold deposits in Ethiopia and Sierra Leone. Orientation contrast imaging is a rapid method that shows qualitative variations in crystal lattice orientation, whereas EBSD provides quantified crystal lattice orientation maps of textures. Lattice orientation maps provide evidence for growth and deformation mechanisms that cannot be determined from traditional optical and SEM techniques.

In this study, we use EBSD in conjunction with optical microscopy and SEM with energy-dispersive X-ray spectrometry (EDS) to provide an evaluation of the merits of each technique for resolving mineral parageneses with specific reference to orogenic gold.

Concept to Mineral Resource: Three Dimensional Geological ModellingDendle, JE.¹¹SRK Consulting (UK) Limited, 5th Floor, Churchill House, 17 Churchill Way, Cardiff, CF10 2HH, Wales, UK

Three dimensional (3D) geological modelling is often the first stage in the evaluation of a mineral project and forms the basis for all subsequent technical studies and mining activities. Creating a 3D geological model requires a robust and considered conceptual understanding of mineral deposits; the basis of which is routed in the synthesis of multiple studies that often combine; structural geology, regional and local geology, mineral deposit genesis and mineralogical characterisation. Geological understanding and the degree confidence in the resultant model is of critical importance for the classification and reporting of Mineral Resources in all international minerals reporting codes.

Beyond the macro aspects of modelling deposit geology in 3D, is the distinction between material that is considered to be mineralised and that which, at least from a preliminary economic perspective, is consider un-mineralised. This distinction, combined with accurate and informed modelling is one of the most critical and fundamental aspects of any minerals projects and is usually assessed by a geologist, often at an early stage

In order to embrace these challenges, which vary between deposit types and the quantity of data available, SRK has a large armoury of techniques and approaches that allow geologists to model the geological environment in 3D and produce high-quality models that form the basis for Mineral Resource and Ore Reserve estimates. In recent years, techniques in 3D modelling have progressed markedly, with the development of implicit modelling methods that allow for more rapid, geologically veracious and considered interpretations to be made, with the emphasis moving from the mechanics of the modelling process to the geological interpretation. The aim of this paper is to demonstrate how these technologies can be applied to different styles of mineral deposits and some of the benefits moving into the 3D world can deliver.

Initial results of a geochemical reconnaissance study of the Kirk Maughold Haematite Ore Deposit, Isle of Man, foundations of a modern ore deposit model.Dobrzański, A.¹¹Geology and Geophysics, School of Environmental Sciences, Jane Herdman Laboratories, 4 Brownlow Street, University of Liverpool, Liverpool L69 3GP, UK

The Kirk Maughold haematite deposit is located in Ordovician and Lower Silurian Manx Group in the north of the Isle of Man, and lies at the edge of the East Irish Sea Basin (EISB). There are several haematite deposits around the edge of the EISB with Kirk Maughold forms part of the Northern Haematite Group on the Isle of Man as described by Lamplugh [1]. Kirk Maughold provided a total output of 15,000 tonnes of iron ore during its working history, but there is currently no model for the formation of the mineralization.

Neighbouring haematite deposits of similar style are found on the east side of the basin in Cumbria; these have been extensively studied. Rose and Dunham [2] proposed a model where warm metal rich brines formed within Triassic sandstone aquifer units and then ascended towards the east basin high, subsequently precipitating haematite in limestone formations. Shepherd and Goldring [3] refined the model suggesting brines at 84-121°C, with a salinity of 10-24 wt% originated at depth in Permian and Lower Triassic formations before being expelled towards the Cumbrian high.

To test if this model can be applied to Kirk Maughold, optical, CL and SEM methods have been used to understand textural development and mineral paragenesis, fluid inclusions in quartz have been investigated to provide constraints on temperature and salinity of the mineralizing brines and O-isotope compositions of quartz and haematite have been determined to help constrain the genesis and evolution of the mineralizing fluid as well as any potential mixing.

Initial results indicate a complex paragenetic history for the deposit, with several separate phases of quartz overgrowth on brecciated wall rock followed by sequential botryoidal haematite and specular haematite precipitation, ore dissolution and replacement by syntaxial quartz overgrowths then a return to botryoidal haematite growth indicating fluctuations in the fluid chemistry possibly due to discrete expulsive events. Voids left after the last botryoidal stage are infilled by calcite indicating that meteoric waters possibly flooded the deposit post mineralisation bringing with them dissolved constituents from juxtaposed Carboniferous limestone formations. Further work will allow comparisons with the Cumbrian deposits to be drawn, and the processes of mineralization within the basin to be speculated upon.

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Isotope systematics of the Hugo Dummett Cu-Au porphyry deposit

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The Hugo Dummett copper-gold deposit is a part of the giant Oyu Tolgoi porphyry district in South Gobi of Mongolia. The district is situated within the Central Asian Orogenic Belt (CAOB), one of the largest orogens on Earth [1]. Major and trace element geochemistry including Sr-Nd-Pb-Hf isotopic data are presented for a representative sample suite of Late Devonian to Early Carboniferous plutonic and volcanic rocks from the Hugo Dummett deposit of the giant Oyu Tolgoi porphyry Cu-Au district in the South Gobi, Mongolia.

Whole-rock Sr, Nd, Pb and zircon Hf isotopic compositions were measured in 20 whole-rock samples from Late Devonian to Early Carboniferous intrusions and their volcanic host rocks in order to infer their geotectonic setting, evaluate mechanisms of crustal generation, define the composition of mantle sources, and to estimate the role of juvenile crust in the Oyu Tolgoi and nearby areas.

Sr and Nd isotopes (whole-rock) show restricted ranges of initial compositions, with positive ϵ_{Nd} mainly between +3.4 and +7.4 and $(^{87}\text{Sr}/^{86}\text{Sr})_t$ predominantly between 0.7037 and 0.7045 reflecting magma generation from a relatively uniform juvenile lithophile-element depleted source.

Previously dated zircons from the plutonic rocks exhibit a sample-averaged range of ϵ_{Hf} values of +11.6 to +14.5. Depleted-mantle model ages of 420-830 (Nd) and 320-730 Ma (zircon Hf) limit the involvement of pre-Neoproterozoic crust in the petrogenesis of the intermediate to felsic calc-alkaline magmas to, at most, a minor role.

Pb isotopes (whole-rock) show a narrow range of unradiogenic initial compositions: $^{206}\text{Pb}/^{204}\text{Pb}$ 17.40-17.94, $^{207}\text{Pb}/^{204}\text{Pb}$ 15.43-15.49 and $^{208}\text{Pb}/^{204}\text{Pb}$ 37.25-37.64. Discounting the four samples for which the age corrections are highest, initial $^{206}\text{Pb}/^{204}\text{Pb}$ for the felsic rocks has an even narrower range of 17.64-17.88, and for the basalts an indistinguishable range of 17.67-17.94. These results are in agreement with Sr-Nd-Hf isotopes indicating the dominance of a mantle component.

All four isotopic systems suggest that the magmas from which the large Oyu Tolgoi porphyry system was generated originated predominantly from juvenile material within the subduction-related setting of the Gurvansaihan terrane.

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Geochemical and mineralogical characteristics of the West Kasulu Cu-Au porphyry prospect, Mongolia: links to Oyu Tolgoi?

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The West Kasulu Cu-Au porphyry prospect lies along the copper-gold belt which hosts the world's largest undeveloped copper-gold project - Oyu Tolgoi, which is to start production in early 2013. Located in the southeast of Mongolia, the West Kasulu prospect lies 140 km NE from Oyu Tolgoi, and 40km NW from the Tsagaan Suvarga Cu-Mo porphyry deposit and forms part of Kincora Copper's Bronze Fox Project. Exploration is at an early stage and no well constrained ore genesis models have been developed thus far. However, in such a well-endowed Cu-Au province, it is expected that the West Kasulu prospect may share some characteristics with Oyu Tolgoi and Tsagaan Suvarga.

The Bronze Fox Intrusive Complex (BFIC) is a weakly oxidised, calc-alkaline, intermediate to felsic, slightly elongated intrusive centre, emplaced into sedimentary and volcanic rocks of Carboniferous to Permian age [1]. Based on overprinting relationships observed in the field and through the mineralogical relationships, multiple phases of vein mineralisation and hydrothermal alteration have been recognised (1) pyrite and arsenopyrite which have been cross cut by (2) sheeted quartz-chalcopyrite-sphalerite \pm pyrite and molybdenite veins which are too cross cut and overprinted by (3) chlorite-sericite-carbonate alteration associated with the emplacement of sheeted quartz-carbonate \pm Mo Pb, Sb, Sn, Ag, Te bearing minerals (4) supergene enrichment with elevated copper grades of upto 8%. Gold has been identified within the supergene enrichment zone, and occurs as Au-rich electrum, hosted by malachite, in association with the silver bearing mineral iodargyrite (AgI) and cassiterite. In the primary ore zone, gold has been identified with electrum as infill along fractures within chalcopyrite and within hessite (Ag₂Te) overprinting chalcopyrite.

Geochemical data from the drilling programme was collected using ICP-MS and is being used extensively to define the relationships between the trace metals in the system and to better understand the complex alteration of the area. Zones of propylitic, potassic and argillic alteration have been confirmed through the relationships of immobile Al, Ti and Zr to mobile elements Na, Ca, Mg, K, Mn and Fe. Distinguishing variations in the alteration assemblages will provide insights into the fluids and their migration patterns and styles of mineralisation within the system. 3D models of the alteration zones will be created in MICROMINE which will help to further determine the relationships between the fluids and paragenesis of the ore minerals, with Cu and Au being the primary focus.

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Base metal-rich, orogenic gold-style mineralisation at Talca, coastal cordillera, Chile.Firth, E. A.¹, Holwell, D. A.¹, Rovardi, M.P.² and N. Oliver³¹Department of Geology, University of Leicester, University Road, Leicester, LE1 7RH, UK University of Leicester
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Orogenic and intrusion-related gold deposits are sub classifications of epigenetic gold deposits in metamorphic terranes. Orogenic gold deposits define deposits that have a genetic affiliation of mineralisation to metamorphic processes of late stage compressional to transpressional regimes of an accreting orogeny [1]. Intrusion-related gold deposits are those which have a genetic affiliation with intermediate to felsic magmas [2], more distal from active convergent plate margins than orogenic gold deposits [1].

Orosur Mining's Mineral de Talca project, situated 375 kilometers north of Santiago in the IV Region, of northern Chile, is a shear-zone associated, quartz-vein hosted gold deposit that has been mined artisanally for over a century [3]. Gold-bearing quartz veins, occasionally with significant Cu-Pb-Zn sulphides, are focussed along regional and local shears associated with the uplift of the coastal cordillera. They are hosted in late Proterozoic-Jurassic metasediments, metavolcanics and granitic intrusions. Until now, no academic work has been undertaken on Mineral de Talca, and whilst it shares many of the characteristics of classic orogenic gold style deposits, the presence of the granitic intrusions in the area, and the high base metal content raise the possibility of an intrusion-related classification.

Initial mineralogical work indicates that the gold can be classified into three distinct styles of mineralisation; (1) nuggety gold in quartz, (2) gold in quartz with Pb-Zn-Cu-Ag-Cd sulphides and (3) gold with arsenopyrite in pyrite in sulfidised wall rock. Mineralisation styles 1 and 2 both have well formed, rounded gold grains with a high Au:Ag ratio (average of 89% wt % Au). Gold grains in style 3 is more irregular in form and has a more varied Au:Ag ratio range, although it averages at 86% Au. The observations are suggestive of several phases of mineralisation, and possible remobilisation of gold and/or base metals into one or more secondary styles. Near surface supergene enrichment is a later stage oxidation process that has caused the alteration of sulphides to bornite and covellite. Fluid inclusion microthermometry is currently testing the indication of several fluid episodes, and S isotope analysis will help to constrain the source of S and the role of the nearby felsic intrusions in the development of mineralisation.

Assessing the role of felsic intrusions on mineralisation at Mineral de Talca has implications for exploration of similar deposits and terranes along the coast, in an area well known for its artisanal mining, but as yet underexplored by modern techniques.

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Gold metallogeny and Earth evolution

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The temporal pattern for different types of gold deposits will vary with evolving global tectonic geodynamics, such that a particular deposit type will tend to have a characteristic time-bound nature (Fig. 1). Factors bearing on the age distribution of a particular type of gold deposit include uneven preservation, data gaps, and long-term secular changes in the Earth System.

The distribution of gold-rich porphyry and epithermal deposits is skewed towards the late Cenozoic. The ores are associated with subvolcanic plutonic complexes and shallower parts of oceanic and continental arcs in the convergent margins of the circum-Pacific and Tethyan of southern Europe. Most deposits that formed in the upper few km of crust before ca. 20-30 Ma, were uplifted and eroded, and thus lost from the geologic record, although significant exceptions date back through all Phanerozoic orogens, and even to the Archean. Carlin-type deposits are only widely recognized in Nevada (Tertiary) and perhaps along the SW edge of the Yangtze craton (Jurassic), so knowledge about these remains too limited to confidently relate the ores to major global tectonic patterns.

Orogenic gold deposit formed in medium-grade metamorphic belts tens of millions of years subsequent to host rock deposition. The deposits in both eastern China and Sonora are hosted in high-grade rocks and provide global anomalies where deposits post-date host rock metamorphism by billions of years, leading to revisions in the ore genesis model. Preserved orogenic gold deposits correlate in time with addition of new oceanic lithosphere to craton margins during supercontinent growth at ca. 2.8-2.55 Ga, 2.1-1.75 Ga, and 650-35 Ma. Major lithospheric instabilities controlling ore formation include thickening by terrane accretion, subduction of a spreading ridge, slab rollback or delamination of subducted oceanic lithosphere, or Precambrian plume events (Fig. 2). The ca. 3.0 Ga timing of stabilization of subcontinental lithospheric mantle (SCLM) below the Kaapvaal craton indicates that the Witwatersrand gold ores cannot be Late Archean orogenic deposits.

The IOCG deposits represent the one group of gold ores in intracratonic settings, typically 100-200 km inland from the craton margins, where extension and anorogenic magmatism occur between areas of Archean and Proterozoic SCLM. The partial melting of metasomatized SCML, either by mantle underplating or plume episodes, leads to IOCG development in buoyant and refractory Precambrian cratons, such that even shallowly formed deposits have been preserved.

Enrichments in the critical metals: interplay of magmatism, deformation and fluid flow

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The critical metals are those metals used in a range of new technologies, for which demand is increasing and there are potential threats to security of supply. At BGS, we are researching the processes by which these metals are concentrated in the crust, using examples in the UK and abroad. We have studied a number of different igneous suites to investigate the importance of magmatic and hydrothermal processes in critical metal mineralisation, specifically studying the REE, Nb and Ta.

A key area of study has been the syenite-dominated alkaline intrusions of the Northwest Highlands of Scotland, particularly the Loch Loyal Complex. These intrusions are enriched in the Light Rare Earth Elements (LREE) relative to other igneous intrusions elsewhere in the UK. Our work has shown that higher total REE contents are found in the more mafic rocks, due to early crystallisation of LREE-bearing minerals, chiefly allanite. At Loch Loyal, hydrothermal activity has caused variable alteration of these more mafic syenites, focused along narrow anastomosing veins. These veins of altered syenite are dominated by biotite, magnetite, allanite and apatite, with whole-rock TREO contents up to 2%, and contain evidence for more than one episode of hydrothermal activity.

Despite being emplaced in a collisional setting, the Northwest Highlands intrusions are chemically more similar to plutons found in extensional rift zones. We have studied rift-related intrusions in Botswana and Greenland, where parental magmas are relatively enriched in the REE. In the Semarule syenite of Botswana, the highest REE contents (approaching 1% TREO) are again found in mafic, allanite- and apatite-bearing syenitic varieties. In the Gardar Province of South-west Greenland, high REE contents occur in more evolved igneous rocks, and hydrothermal alteration has played an important role in increasing REE concentrations.

The Northwest Highlands alkaline intrusions are syn- to post-collisional to the Caledonian Orogeny, but are distinctly more alkaline than post-collisional intrusions in many other orogenic belts. We have studied post-collisional Pan-African granitoids in both Madagascar and Nigeria, and these have relatively low REE concentrations, although it is notable that the highest concentrations are found in more mafic rocks and close to major shear zones. However, pegmatites around these granitoid intrusions have been mined for Ta. In North-east Scotland, enrichment of critical metals such as Li and Ta is also found in post-collisional granitoid intrusions, associated with the Cairngorm granite suite. The highest contents of these critical metals are chiefly found in pegmatites, but also occur in the highly evolved and hydrothermally altered Gairnshiel granite. In this area, very evolved, volatile-rich magmas appear to be the main source of critical metal mineralisation.

In summary, our research shows that a range of geological processes contribute to the enrichment of the REE, Nb and Ta in crustal settings. Parental magmas that have some enrichment in these metals are an important starting point, and critical metal contents are enhanced by crystallisation processes and magma evolution. Although these metals are normally considered to be incompatible, the examples we have studied show that the REE are commonly concentrated in more mafic igneous compositions, whereas Li, Nb and Ta are found in the most evolved compositions. These contrasting behaviours have important implications for exploration. In our studies, post-magmatic hydrothermal processes appear to have played a dominant role in concentrating the critical metals. The presence of shear zones that provide pathways for movement of late fluids may be significant in determining the location of mineralisation.

Developing exploration models for copper-silver mineralisation in the Kalahari Copperbelt, Botswana – A. Mineralogy, geochemistry and structure.

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The Kalahari Copperbelt stretches from central Namibia to north-western Botswana and is similar to the Central African Copperbelt, in both form and potential. North east trending mineralisation is hosted within Neoproterozoic basin metasediments and volcanics, and structurally controlled by the Damaran orogeny [1]. The Ghanzi project, covering 2169 km², is located in north-west Botswana, at the north-west tip of the Central Kalahari Game Reserve and is a potentially viable surface mineable copper – silver deposit.

Hana Mining Ltd. controls 100% of 5 license blocks that make up the Ghanzi property and have recently presented a Preliminary Economic Assessment, with indicated resources of 217.516 kt copper and 10.157 m ounces silver [2]. Discovery Metals have recently opened the Boseto Copper Silver Mine on an adjacent property, producing 36 000 t of copper per annum [3].

Sulphide mineralisation occurs in the lower portions of the cyclic sandstone of the D'Kar Formation and the upper meters of the underlying oxidised Ngwako Pan Formation, with the exact location and form of mineralisation governed by individual stratigraphic zones. Previously, the model for mineralisation was believed to be an early diagenetic origin accompanied by sulfide bearing quartz carbonate veins formed during extensional deformation. However, evidence now points towards mineralisation being stratabound, and is thought to have been emplaced as a result of oxidising fluid pulses, driven by compressional tectonics, metamorphism and basin dewatering during the Damaran orogeny [2].

This MGeol project primarily focuses on constraining a model for the formation of this sediment hosted mineralisation and therefore a strategy for future exploration of deposits of this kind. The economic sediment-hosted sulphide minerals present are bornite, chalcocite and chalcopyrite, which are hosted within laminations, as nodules, in cleavages and in sulphide blebs. Vein hosted mineralisation is explored in detail by Morgan in part B of this project – Fluid Sources [4].

In order to understand the interrelationships of mineralogy, geochemistry and structure within the deposit, detailed core logging and analysis of geochemical data has taken place. On a smaller scale, 2-D microscopy, SEM analysis, CT scanning and other lab based techniques are being used. Detailed petrographic examination, combined with 3d CT scans of hand samples, will provide 3d metallurgical data – the first of its kind for such deposits.

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Characterisation of the newly discovered Cu-Ni-PGE mineralisation at Sron Garbh, Stirlingshire, Scotland

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The Sron Garbh intrusion, located 2.5 km north of Tyndrum, represents an unconventional style of magmatic Cu-Ni-PGE prospect. Mineralisation is hosted within an appinite rim around the margins of, and enclaves within, a monzodiorite-monzonite intrusion. Appinites are located throughout the Scottish Highlands as suites of ultramafic-intermediate intrusions associated with late-post tectonic grainites [1]. The Sron Garbh appinite contains phenocrysts of dark green-green, euhedral hornblendes within a fine-grained green groundmass and large feldspathic segregations. Scotgold assay data from a sulphide bearing appinite rock chip sample contained grades of up to; 1.14 g/t Pt, 0.79 g/t Pd, 0.18 g/t Au, 0.21% Ni and 0.82% Cu.

The Sron Garbh appinite-hosted mineralisation is spatially heterogeneous with two different mineralisation styles: (1) a blebby pyrite-chalcopyrite-hengleinite (Co-bearing bravoite) assemblage, with pyrite blebs up to 3 cm within the groundmass; (2) a fine and more disseminated pyrite-chalcopyrite assemblage is found within interstitial regions in the silicate and as inclusions within the silicates. In addition the monzodiorite-monzonite also contains a finer grained, disseminated pyrite assemblage although assay data illustrates that there are no PGE associated with the monzodiorite-monzonite. Geochemically, the mineralised rocks show consistent Pt/Pd ratios of around 0.8 indicating a well homogenised relatively unaltered sulphide liquid.

A number of platinum-group minerals (PGM) have been identified within the appinitic portions of the intrusion for the first time and appear to be associated with the finer, pyrite-chalcopyrite sulphide assemblage. Textural and compositional data of PGM assemblages can be effectively used as evidence for a variety of syn- and post-magmatic processes associated with mineralisation. The PGM have been grouped as: (1) Pd bismuthide-sulphide; (2) Pd telluride-bismuthide (3) Pd antimony-arsenides; (4) Pd tellurides; (5) Pt arsenides; (6) Ag-Au sulphides; (7) Ag sulphide-selenides; (8) Ag selenides (9) Ag tellurides; (10) Ag sulphides. In total, 96% of the identified PGM are Pd bismuthides, Pd tellurides and Pt arsenides. Furthermore, these PGM are often euhedral and found as isolated inclusions within sulphide and silicates (48% and 26% respectively), along a chalcopyrite vein-pyrite boundaries (13%) or along a sulphide-silicate boundary (13%).

The PGM assemblage appears to indicate a relatively unaltered, primary magmatic assemblage dominated by Pt and Pd bismuthides and/or telluride minerals associated with Cu sulphides [2]. Some minor fluid remobilisation of the PGM may have taken place, but this is only on a very small, micron scale.

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A new time frame for the mineralisation in the Kassandra mine district, N Greece: deposit formation during metamorphic core complex exhumation

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The Kassandra mine district (KMD) in N Greece, hosts different styles of spatially related magmatic-hydrothermal base and precious metal deposits. Mineralisation in the district is related to Oligocene-Miocene magmatism in the metamorphic hinterland of the Hellenic orogen generated during the post-orogenic collapse of the Aegean wedge [1]. The KMD deposits form part of the economically important Serbomacedonian-Rhodope metallogenic province, a tectono-magmatic belt that spans across several tectono-stratigraphic units between Serbia, Greece and Bulgaria. It has total mineable reserves of 7.7 Moz Au, 68.8 Moz Ag, 0.7 Mt Cu and 1.7 Mt Pb + Zn, making the KMD one of Europe's largest base and precious metal resources [2].

Stratoni and Olympias are carbonate-replacement massive sulphide Pb-Zn (Ag-Au) deposits located on the footwall of the Tertiary Stratoni-Varvara fault, which is the southern extension of the main detachment fault of the adjacent Rhodope metamorphic core complex [3]. Both deposits are interpreted to form the proximal and distal part of a fault-controlled exoskarn-type ore system triggered by nearby small-scale intrusions close to the fault system [4-5]. Skouries is a Cu-Au porphyry resource emplaced in a local intrusive belt on the hangingwall of the Stratoni-Varvara fault. Deposit formation in the Serbomacedonian-Rhodope belt is linked to post-collisional Tertiary magmatism in an extensional back-arc setting along the strike of the present-day Hellenic subduction zone [1]. Slab roll-back and subsequent slab-tear and/ or slab-detachment were the trigger for the mineralisation-related magmatism in the belt with decreasing magmatic ages from SE to NW.

A detailed geochronological study on the Tertiary intrusives and the carbonate-replacement deposits in the KMD indicate a genetic link to the exhumation of the nearby Rhodope metamorphic core complex. A suite of barren and mineralised sub-alkaline to alkaline, high-K calc-alkaline volcanic arc/ syn-collisional plutonites intruded the crystalline basement (Mesozoic or older) within a short magmatic interval between 30 and 20 Ma. These emplacement ages are diachronous compared to the subduction-related, orogenic plutonites in the region (40-57 Ma) and are synchronous with the granitic intrusions linked to core complex exhumation in the Greek Rhodopes (ca. 21-24 Ma, [6-8]). The granite, diorite and gabbro stocks were emplaced in a narrow (<10 km) intrusive belt within a local dilatational jog between two normal faults [3]. With an intrusion age of 20.56±0.48 Ma (LA-ICP-MS single grain zircon U-Pb) and a mineralisation age of 19.9±0.9 Ma (Ar-Ar biotite, potassic core) the Skouries Cu-Au porphyry represents a late-stage, evolved member of this magmatic suite. Furthermore, an arsenopyrite Re-Os isochron age of 26.1±5.3 Ma from the Olympias deposit is the first ever in-situ mineralisation age for the carbonate-replacement deposits in the KMD and links the deposit formation to tectono-magmatic processes related to the core complex exhumation rather than post-subduction processes [8].

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Tumpangpitu Porphyry-High Sulfidation Epithermal Deposit, Tujuh Bukit Project, Indonesia – Geology, Alteration and Mineralisation

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The Tumpangpitu porphyry Cu-Au-Mo and high sulfidation epithermal Cu-Au-Ag deposit is part of the Tujuh Bukit Project, located on SE Java, Indonesia. A number of Au ± Ag epithermal and Cu-Au porphyry deposits have been discovered along the Sunda Banda magmatic arc, including Batu Hijau and Elang in Sumbawa. Tumpangpitu is the most recent discovery and it currently stands at 1.9 billion tonnes @ 0.45% Cu and 0.45 g/t Au containing 28 Moz Au and 19 billion lbs of Cu, making it one of the largest, undeveloped porphyry deposits in the world.

Tumpangpitu is located along a NW-SE striking structural corridor covering an area of 12 x 5km. This structural corridor hosts several Cu-Au-Mo mineralised tonalitic porphyries, each with varying degrees of metal enrichment. We have constructed type sections through Tumpangpitu based on intrusive and breccia cross-cutting relationships, supported by radiometric dating. This work has provided the first comprehensive geological model for the deposit.

Tumpangpitu exhibits a large, classic example of telescoped Au-Ag (oxide) and Au-Ag-Cu (unoxidised high sulfidation mineralisation and associated advanced argillic alteration (part of a district-scale lithocap) overprinting the top of a Cu-Au-Mo porphyry. Mineralisation extends from the present-day surface to depths below 1200m (current drilling capacity). High sulfidation mineralization is hosted by three main NW-trending quartz ledges known as Zone A, Zone B and Zone C, containing oxide ore close to surface with transitional and sulphide ore at depth. Porphyry mineralisation extends from an upper level of 200m to depths of over 1200m and the 0.2% Cu shell extends 1km laterally around the tonalite intrusive complex. Spectral data has been used extensively as a vital aid in creating an alteration model for determining high temperature acid clay species. Zonations are evident whereby quartz - alunite - dickite are dominant at higher levels in the epithermal system and pyrophyllite ± diaspore ± topaz at deeper levels. Fluids channelled along structures formed vuggy quartz ledges that zone out to advanced argillic envelopes with dickite-kaolinite and decreasing quartz content. Argillic zones developed distal to the system with illite-smectite neutral clays and propylitised margins (chlorite-calcite ± epidote). The highest grade porphyry mineralisation occurred in highly magnetic, potassic altered rock. This has allowed airborne magnetics to be used in conjunction with mapping and soil molybdenum responses as successful, direct exploration targeting techniques which lead to the discovery of the deep porphyry system.

Epithermal mineralisation grades from high-sulfidation, fault-controlled enargite ± covellite ± bornite at surface to intermediate sulfidation (tetrahedrite-tennantite dominant ± bornite) at depth, where the epithermal features have overprinted porphyry mineralisation (bornite, chalcopyrite, digenite, covellite and molybdenite) with complex sulphide overprinting relationships at the interface.

The overlying high sulfidation epithermal mineralization at Tumpangpitu contains 2.1 Moz Au and 72.9 Moz of silver. The presence of HS ore is a significant difference between Tumpangpitu and other porphyry systems along the Sunda-Banda arc.

Mineral-scale studies of acid leaching of nickeliferous goethite ores: implications for large-scale heap leach behaviour

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More than 70% of land-based global Ni resources are locked in laterites yet only 40% of current production is sourced from them. Various technologies are used in the processing of nickel laterites ranging from pyrometallurgy to hydrometallurgy, largely dependent on the mineralogy of the particular deposit. Ambient acid heap leach extraction potentially offers a low-carbon footprint, low energy consumption, low capex cost route to production of Ni, Co and other elements including Sc from oxide-dominated laterite profiles which may offer advantages as compared with alternative high pressure acid leaching (HPAL) or bioleaching methods. Utilisation of this ambient leach process has been shown to be variably effective in testwork to date, which is likely to be in part due to an oversimplification of the mineralogy of the ore treated, which in some cases has led to unexpected products and residues forming during the leach process.

A recent EU-funded Marie Curie Industry-Acadamic Partnership Project 'Nical' developed between the Natural History Museum and Çaldağ Nikel in Turkey has focused on investigating atmospheric heap leaching of goethitic nickel ores at arrange of scales in order to improve both recoveries and process efficiencies. Small scale column coupled with bottle-roll experiments of ambient-temperature leaching of goethite-dominated ores from a range of deposits in the Mediterranean region and the Philippines have been carried out. This has included detailed mineralogical characterisation of the fresh ore, investigation of partially leached material together with transient-formed mineral phases, and finally the leached residues. This study has resulted in a better understanding of the mineral-scale reactions that relate to the release of nickel and other components, formation of transient reprecipitation products during leaching and full characterisation of the nature of the final residues. This leads to a more predictive modelling of the leaching process at the mineral scale from samples collected at the exploration and evaluation stages of projects. These results yield important information for predicting leach behaviour in any scaled-up mining operations and identifying any potential adverse reactions.

The results from the investigation of material from three goethite-rich nickel laterites from Turkey, Albania and the Philippines during the course of the Nical project will be presented.

MineraLogic - Automated Ore Analysis Solution

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Use of the scanning electron microscope (SEM) to characterize ores provides process mineralogists and metallurgists with invaluable information for the enhancement of value added products and the extraction of metals. Manually obtaining relevant information such as, for example, mineral coatings that may interfere with flotation, mineral separations, the location of the values, and mineralogical reasons for low recovery can be exhausting and time consuming. For this reason Carl Zeiss has devised an automated analytical process resulting in improved productivity and reduced subjectivity. Automating the analysis and reporting of results, releases the mineralogists and metallurgists to concentrate on the interpretation of results and implementation of solutions.

The automated analysis of ores, feeds, concentrates and tailings is performed by MineraLogic with its associated Mining plug-in software. MineraLogic provides a platform independent solution to the extractive industry, therefore specialised software plug-ins such as the Mining plug-in can be used on any ZEISS SEM. This includes our laboratory platform (EVO), research platform (ΣIGMA), 3D FIB-SEM platform (AURIGA), and our portable and rugged platform (ParticleSCAN). The flexibility of MineraLogic solutions means that end users are not limited by capability or resolution.

The user interface of the Mining plug-in presents the operator with a simple workflow and full flexibility in selecting the desired parameters for an analysis. The workflow guides the user through the different stages required to create a recipe. At each stage the operator has full control over the analysis parameters required e.g. particle size discrimination, image resolution, stop criteria by number of frames or number of particles, dwell time, EDX settings, self-calibration check interval etc. Once a recipe has been created, it is stored and can be used repeatedly. In this way, non-experienced users can perform routine analysis by choosing the adequate recipe from a menu of previously created recipes. The aim is to provide a total turn-key solution that allows for commonly executed analysis routines to be available instantly without the need to set up on every occasion.

When a recipe is activated, the Mining plug-in automates SEM functionality and starts the gun, aligns the beam, calibrates the detectors, moves the stage to the sample position, obtains and analyses the image, identifies particles of interest, collects EDX data, determines the compositional information and then matches the composition to a mineral library, thus allowing for the quantification, description and classification of the phases present. The physical and chemical parameters obtained provide information on key aspects such as assay, grade, particle size distribution and make possible the generation of outputs such as cumulative liberation curves and grade recovery curves.

Following analysis of a sample the data may be reviewed in situ or remotely using MineraLogic Explorer; a stand-alone application that allows data visualisation and retrospective analysis of databases. The ability to study the data remotely frees SEM time and allows future reclassification without the need to re-analyse the sample.

At the end of each sample analysis, or at a future date, the results can be automatically reported using MineraLogic Reporter. The reports are available as operator customizable templates with a wide range of text, tables and charting options. Reporter is also a stand-alone application which may be used away from the SEM hence freeing valuable SEM time.

MineraLogic with the Mining plug-in represents an automated solution that provides process mineralogists and metallurgist with key measurements and statistics to aid in the processing of ores and extraction of metals.

Nature and constraints on genesis of newly identified gold targets in the Tyndrum area, Scotland

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In recent years increasing gold prices have rejuvenated interest in Dalradian vein-hosted gold mineralisation. The Cononish deposit, near Tyndrum, is a structurally-controlled quartz vein hosting a resource, reported in accordance with the JORC 2004 code, of 169,200 oz Au and 631,300 oz Ag in the Measured, Indicated and Inferred categories. Cononish will be Scotland's first modern gold mine when it goes into production in early-2014. Work in conjunction with Scotgold Resources Ltd has identified a number of new gold targets and mineralisation types in the Tyndrum area. This work aims to understand the mineralising system geometry and to improve exploration targeting. The study also aims to assess the potential of local meta-sedimentary and igneous rocks as a sulphur source.

Gold, as electrum, is related to sulphides across all mineralisation types observed in the study area. The sulphide assemblage is dominated by pyrite and galena, with sporadic chalcopyrite, sphalerite and arsenopyrite. Two phases of gold are observed; gold 1 is closely associated with early galena as inclusions in pyrite. Gold 2 is accompanied with a late void-filling galena and sphalerite stage. Molybdenite veins with minor pyrite pre-date gold mineralisation.

Pyrite $\delta^{34}\text{S}$ values obtained for newly identified gold targets and mineralisation types show wide variation; from -2 to +12‰. The majority of gold-bearing quartz veins have $\delta^{34}\text{S}$ values between +5 and +11‰, broadly comparable to published data for Cononish [1]. Molybdenite-bearing veins have $\delta^{34}\text{S}$ values between +3 and +7‰, with breccia pipes exhibiting slightly lighter $\delta^{34}\text{S}$ values, +1 to +6‰.

Pyrite $\delta^{34}\text{S}$ analysis of local (this study) and regional meta-sedimentary sulphides indicates variable but largely positive (> +8‰) values within the stratigraphic sequence [2]. The lower Dalradian is sulphur-poor and no data is available for the Grampian group or Lochaber sub-group. $\delta^{34}\text{S}$ values from this study for local small-scale igneous bodies indicates the magmatic signature in the area is comparable to data for sulphides in mineralisation associated with plutonic deep-seated intrusions across the SW Highlands, average $\delta^{34}\text{S}$ +2.6 ± 1.8‰ [2].

The heavy $\delta^{34}\text{S}$ values for gold-bearing quartz veins support a sedimentary origin for the sulphur as advocated by Curtis et al. [1]. However, the lower $\delta^{34}\text{S}$ values observed at Cononish may indicate a magmatic component. The range of values for all mineralisation types suggests mixing of two sources in the system. The veins show increasingly heavy $\delta^{34}\text{S}$ values through time. This supports evolution of the system through time from a magmatic- to sedimentary-dominated source of sulphur.

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The application of computerised 3D modelling software and data capture in mineral exploration and resource development

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For more than 20 years computerised data capture, 3D presentation and analysis has been an essential tool in the exploration, evaluation, development and exploitation of mineral resources. In recent years with new advances in hardware capabilities, both in the office and in mobile computing, MICROMINE's software solutions have adapted to push new frontiers in line with hardware capabilities.

In this short presentation we will demonstrate how software can be used to aid exploration programs from the desk study, through "first boots on the ground" stage of exploration programs, feasibility study and operation stages.

Efficient and secure data capture and storage in the field using solutions such as Geobank Mobile is proven to improve efficiency and eliminate data validation issues which cost time and money further into project life cycle. The Geobank Mobile solution has many applications ranging from reconnaissance sampling through to core logging and grade control sampling. This can be coupled with powerful GIS displays to aid real time mapping and interpretation in the field.

We also aim to showcase recent developments in MICROMINE's software, including true 3D visualisation reminiscent of viewing stereoscopic photographs. In recent years Micromine has also been successfully applied in academic teaching environments at the University of Leicester and in research projects. In the future MICROMINE hopes to aid the teaching and understanding off all stages of the project lifecycle.

We hope to demonstrate the power of these tools in academia and industry.

Understanding deposit telescoping and the epithermal-porphyry transition in the Brad-Sacaramb mineral district of western Romania.

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Telescoping between epithermal-porphyry systems is understood to be the result of rapid unroofing (1-3 kmMyrs⁻¹) of a system by high denudation rates, volcanic related sector collapse and mass movement [1], and has the potential to develop giant ore deposits..

The 'Golden Quadrilateral' of Romania, is a rich mineralized magmatic province with high base and precious metal potential. Magmatism and subsequent mineralisation is controlled by a series of NW-SE trending transtensional pull-part basins (e.g. Brad-Sacaramb and Zlatna-Stanija). These basins were developed as a result of the opposite sense rotation of the Alcapa and Tisza microcontinents during the late Miocene that facilitated extension-related calc-alkaline magmatism [2]. The 900 km² quadrilateral hosts over 64 Cu-Au porphyry and related epithermal Au deposits [3]. This includes the world-class Rosia Poieni porphyry (350 Mt Cu [3]) and epithermal vein-breccia deposit of Rosia Montana (14.6 Moz Au [4]).

The Brad-Sacaramb basin displays a well-preserved cross section through a telescoped hydrothermal ore system. The numerous epithermal deposits are characterised by telluride-rich polymetallic veins (Au-Pb-Zn) and rare sulphide disseminations. The presence of ~200-300°C, low salinity (<10 wt. % NaCl equiv.) fluid inclusions indicate formation from predominately meteoric waters. However $\delta^{18}\text{O}_{\text{fluid}}$ (6.8 to +9.9‰) and $\delta^{18}\text{D}$ (δD -76 to -29‰) data [5] suggest a magmatic source atypical of low sulphidation style deposits. This epithermal mineralisation and alteration is observed overprinting earlier, high-temperature porphyry-style ore assemblages. The spatial relationship between porphyry-Cu, epithermal and surficial (silica sinters) deposits provide a unique opportunity to investigate the role of unroofing and thermal collapse in the generation of ore telescoping.

Preliminary U-Pb data indicate that the epithermal mineralisation closely followed magma emplacement (12-10Ma). However, apatites from unmineralized stocks display few fission tracks, suggesting a thermal event approximately 5Ma. This may correlate with the propylitic alteration observed and therefore indicate a time gap (~5Myrs) between magmatism and mineralisation.

Correlation of U-Pb ages and stable isotope data from the porphyry and epithermal mineralisation with fluid inclusions and apatite fission track geochronology will characterise the spatial and temporal evolution of the hydrothermal ore system and the role played by denudation in the development of telescoped ore bodies.

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Y and HREE residence in A-type granite - Garnet as a major Y and HREE carrier of the rock; An example from the layered anorogenic granite dykes, Cadomian Brno Batholith, Czech Republic

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The examination by LA-ICP-MS and electron microprobe of magmatic garnet and other major, minor and accessory minerals found within A-type subaluminous granite (Cadomian Brno Batholith, Czech Republic) was undertaken with the aim to determine relative contribution of individual minerals to bulk budget of Y+REE in the rock. The study revealed minor to accessory garnet (2 vol. %) as the major container of Y+REE of the Hlína granite, in which around 84 % of the Y and 61 % of the REE reside in the garnet. Coincidentally with [1] and [2] zircon was detected as other important carrier of REE in the rock with ~13 % Y and ~11 % REE from whole rock Y, REE budget. The results demonstrate that at least ~63 % of the LREE were hosted probably by monazite, which is altered to the mixture of secondary REE-bearing phosphates and clay minerals. Low Y+REE fraction (~1 % Y; 10 % LREE; ~1 % HREE, except Eu which reside by its 90 % in feldspars) of major rock forming minerals such as quartz and feldspars was detected, despite their high modal number. Minor muscovite and magnetite hold each ~1 % Y and ~2 % REE. The contribution of accessory clinozoisite to the Y+REE whole rock budget is insignificant. Magmatic garnet distinguished within Hlína granite corresponds to almandine-spessartine $Sps_{41-46}Alm_{28-44}And_{0-13}Grs_{6-12}Prp_{0-1}$ characterized by its higher Y and HREE concentration (up 1.54 wt. % Y; up 1 wt. % Σ REE).

The A-type Hlína granites show quite unusual mineral assemblage. Despite its subaluminous character, the allanite is absent. Its dry composition as well as the low content of P and F prevented early precipitation of amphiboles, allanite, apatite, and Y+REE fluorides. Such dry conditions enabled to conserve Y+REE in the melt into the later stage when garnet crystallized. This dry character of melt probably also donated to Y+HREE incorporation into garnet because their Y+REE distribution coefficients decrease with increasing water content [3].

Once garnet identified as major residence of Y+HREE in magmatic rock its economic potential regards to Y+REE should be re-evaluated in next days.

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Platinum group element geochemistry of the Scourie Dykes: Parental melt sources and insights into the Lewisian subcontinental lithospheric mantle

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Increasing awareness of 'critical metals' such as the platinum group elements (PGE) has seen renewed exploration effort for these elements. This research forms part of a larger investigation into the potential for Ni-PGE mineralisation in western Scotland and Northern Ireland, incorporating Archaean, Caledonian, and Palaeogene lavas and magma conduits in an attempt to understand the underlying factors that could influence mineralisation.

The NW-SE trending Scourie Dyke swarm comprises a variety of deep-seated mafic and ultramafic dykes, intruded into the Lewisian tonalite trondhjemite granodiorite foreland at the end of the Invernian deformation, between 2.42 to 2.38 Ga [1]. Dyke samples have been collected from across the mainland Lewisian foreland, encompassing a variety of dyke types [2] including picrite, olivine gabbro, and dolerite suites. All 72 samples collected were analysed for major and trace elements, and a representative selection of 32 samples were assayed for bulk PGE. Prior to this investigation, few analyses existed of the Scourie Dykes, with only 5 published PGE analyses [3]. This research now forms the most comprehensive geochemical database of Scourie Dykes to date.

All dyke groups display normalised rare earth element (REE) patterns that are moderately enriched in the light REE, however the picrite dykes are most enriched in light REE. The dolerite group dykes have flatter REE patterns, but the highest total REE concentrations. All dykes are enriched in large ion lithophile elements (however this may in part be caused by variable dyke alteration) and depleted in high field strength elements. Mantle-normalised multi-element plots for all dyke suites display a negative Nb-Ta anomaly. Additionally, the picrites have a negative Ti anomaly. The cause of the Ti anomaly is currently unclear, however it suggests retention of a Ti-rich mineral phase (e.g. rutile) at source, as supported by lower Fe, Nb, and Ta in this suite. Picrite dykes also have the highest Ba/Th, La/Nb, and Ce/Sm ratios, which may suggest some degree of subcontinental lithospheric mantle (SCLM) contamination of their parental mantle melts, or a different mantle sources to the other dyke suites, in agreement with [2].

Total PGE+Au concentrations range from 38.3 ppb (olivine gabbro group) to 2.7 ppb (dolerite group). All dykes have fractionated PGE trends, enriched in Pd-group PGE (PPGE). Dolerite dykes show a marked depletion in Ir-group PGE (IPGE), indicating a lower degree of mantle melting, leaving a significant residue of Ir-Os alloys in the source. Chalcophile element ratios (e.g., Cu/Pd) are typically higher than estimated primitive mantle. This suggests that the Archaean mantle source underwent low degrees of partial melting, thereby contributing low concentrations of PGE to the S-undersaturated parental magmas of the Scourie Dykes, or that these magmas experienced sulphide depletion during ascent. PGE profiles suggest that the olivine gabbro suite is likely to be the most primitive of all the Scourie Dyke suites.

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Aillikite – an unconventional diamond host rock and its importance in the ‘Greenland-Labrador-(Scotland?) Diamond province’

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Aillikite is the carbonate-rich endmember of the ultramafic lamprophyre (UML) clan (essential primary groundmass carbonate), macroscopically resembling kimberlite. It is commonly observed associated with, and grading into carbonatite. These typically highly volatile-rich (dominantly CO₂) ultrapotassic, strongly silica undersaturated, inequigranular, ultrabasic rocks (M > 90% - where M is defined as mafic and related minerals, i.e. including primary carbonate and apatite) are characterised by widely varying modal proportions of olivine and phlogopite macrocrysts and/or phenocrysts, and groundmass primary carbonate (calcite and/or dolomite), phlogopite (Al-Ti phlogopite which evolves by Al-depletion to Ti-poor tetraferriphlogopite), spinel (forming the ‘tianomagnetite’ trend and have Cr# < 0.85), ilmenite, rutile, perovskite, Ti-rich garnets (melanite or schorlomite and kimzeyite) and apatite. Less commonly groundmass clinopyroxene (if present shows Al and Ti enrichment) and amphibole occur, at the expense of carbonate, more abundantly so within mela-aillikites. The pre-fix ‘mela-’ is applied to aillikites, which are more melanocratic (colour index > 90%) due to the presence of the silicates, clinopyroxene and amphibole. In rare instances, monticellite may occur. Melilite, or the products of its subsolidus alteration, leucite and nepheline, are absent, else the UML would classify as either an alnöite (essential groundmass melilite) and damtjernite (essential groundmass nepheline and/or alkali feldspar). Alteration, sometimes extreme, typifies the vast majority of aillikites, resulting from the deuteric reaction between early crystallising phases and residual carbonate-rich fluids (autometasomatic alteration). Many aillikites in West Greenland (WG) show several mineralogical characteristics corroborating with a kimberlite affinity, but with one or more of the critical criteria not complying with the strict definition of kimberlite s.s. In WG at least, the diamond prospectivity of the intrusions does not appear to be dependant upon them being kimberlite s.s. or aillikite, with some aillikites hosting sub-economic grades of diamond despite them not being considered conventional host rocks. Recently several exploration companies have taken up licences over areas of aillikitic magmatism for diamond exploration in the ‘Greenland-Labrador Diamond Province’ (GLDP), with the most advanced exploration at Garnet Lake, near Safartôq in WG. The recent discovery of the first reported occurrence of aillikite from the United Kingdom, in northwest Scotland opens up the potential for the ‘Greenland-Labrador-Scotland Diamond Province’ [1]. The growing number of aillikite occurrences shown to be diamond-bearing demonstrates that aillikite magmatism has the potential to sample diamondiferous parts of the sub-continental lithospheric mantle. Hence, the potential exists for lamprophyres (particularly var. aillikite) to be the next group to move into the conventional category as a primary source of diamond, thus represent a worthy exploration target. It is cautiously postulated that with respect to diamond exploration the exact petrographic classification may be extraneous, as long as the carrier melt can be proven to have originated from well within or below the diamond stability field and rapidly emplaced at the surface or near surface at a rate that minimises reabsorption and allows the survival of entrained diamond. Indeed it is evident that there is a substantial lack of research into determining how wide the field of diamondiferous rocks extends, and how this affects traditional diamond exploration methods, such as diamond indicator mineral chemistry. It is negligent to assume that a mantle derived igneous rock displaying evidence for an origin within the diamond stability field should be excluded from exploration just because it is not kimberlites.

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Diamond Exploration in West Greenland – The Qaamasoq Prospect

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The Qaamasoq diamond prospect is situated within the West Greenland North Atlantic Craton (WG-NAC), approximately 130 km northeast of the Greenlandic capital, Nuuk. While all known occurrences of kimberlitic rocks in Greenland are dykes or sills, with occasional blows up to approximately 4 metres in width [1], examples of economic dykes of similar widths are known, for example the Snap Lake deposit in Canada. However, due to Qaamasoq's position high within the weathering profile of the WG-NAC, the potential for kimberlite pipes being preserved is greater in comparison to the more deeply eroded lower crustal levels of the craton. Previous exploration within the Qaamasoq licence area by a joint venture including Cominco Ltd. recovered a 0.28 x 0.28 x 0.21 mm clear, white macled diamond from a 34.6 kg kimberlite float sample [2]. NunaMinerals A/S began diamond exploration within the licence in 2010, flying a 2131 line-km helicopter-borne magnetic geophysical survey. Ground-truthing of resulting magnetic targets demonstrated that kimberlite float occurs abundantly at four localities: The Promontory, The Island, TMR-Q1-14 and Ullu. The abundance and size of mantle-derived kelyphitised pyrope garnet and the presence of eclogitic garnet within the kimberlites justified further evaluation. In addition the presence of large (>10cm) peridotite xenoliths also demonstrated a carrying capacity for large diamonds. Hence bulk samples were collected for Diamond Indicator Mineral (DIM) separation and characterisation, and subsequently caustic fusion for microdiamond analysis (in partnership with Rio Tinto Exploration Ltd). DIM analysis revealed that the majority fall within well-established prospective fields, particularly the mineral chemistry of the peridotitic- and eclogitic-garnet suites, some falling in the G10(D) and G3(D) fields [3]. The 'D' suffix is applied to garnet-categories with strong compositional and P-T association with diamonds [3]. The DIM chemistry is similar to the Garnet Lake diamond deposit; 150 km to the north where the largest diamond from Greenland to date (2.4 ct) was recovered during reconnaissance sampling [4]. Of the three samples processed, totalling 150.4 kg, all were found to be diamondiferous, resulting in six diamonds with the largest stone recovered from the 212-micron sieve. The processing of small samples such as these encompasses significant statistical uncertainties with respect to grade estimation. Hence the positive result is deemed encouraging and worthy of continued exploration. Ullu (Greenlandic for 'the Nest') is a NE-SW striking topographic depression situated only 1 km away from a major terrane boundary between Archaean grey gneisses to the west, and the Archaean Tasersuaq granodioritic gneisses to the east, within the vicinity of a regional noritic dyke. This significant tectonic boundary may represent an important control on kimberlite emplacement. Significantly Ullu also represents the northeast continuation of a highly prospective kimberlite indicator mineral trail previously identified by the GEUS [1]. The trend of the Ullu float extends 1 km to the distinct magnetic target TMR-Q1-14. At Ullu over 200 boulders of kimberlite, up to 1.5 m in size occur within a 250 x 550 m area, partially covered by a glacial boulder field. Rare examples occur in which the kimberlite float at Ullu delicately preserves their contact with K-feldspar-phyric orthogneiss, which taken in combination with the volume of float observed supports a proximal, if not underlying source. Prior diamond exploration within the WG-NAC has shown that due to preferential weathering, it is unusual to be able to establish an in-situ source for kimberlite float without drill sampling. It is expected that geophysical techniques such as ground magnetics or resistivity however, may assist in establishing the depth and dimensions of any buried source rock.

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The Comsos greenstone succession; Insights into an Archean volcanic arc, associated with komatiite-hosted nickel sulphide mineralisation, from U-Pb dating, volcanic stratigraphy and geochemistryde Joux, A.¹ and Thordarson T.¹¹School of GeoSciences, University of Edinburgh, Grant Institute, The King's Buildings, West Mains Road, Edinburgh, EH9 1LU

The Archean Kalgoorlie Terrane, within the Eastern Goldfields Superterrane, part of the Yilgarn Craton in Western Australia, contains several world-class nickel-sulphide ore deposits. Massive and disseminated nickel sulphide deposits are commonly hosted by thick ultramafic bodies, those mechanisms of emplacement remain contentious, particularly in the Agnew-Wiluna Greenstone belt where recent reviews have reiterated a dominantly intrusive origin for thick, nickel-sulphide hosting, ultramafic adcumulate bodies associated with felsic volcanics [1]. The Cosmos mine site lies on the western edge of the Agnew-Wiluna Greenstone belt and this previously unstudied mineralised volcanic succession contrasts markedly in age, geochemistry, emplacement mechanisms and probable tectonic setting to that of the majority of the belt [1,2].

Despite experiencing mid-amphibolite metamorphism, many of the primary volcanic textures within the footwall succession have been preserved allowing protoliths to be established. This underlying footwall succession to the Cosmos mineralised ultramafic body consists of a complex sequence of both fragmental and coherent extrusive lithologies, ranging from basaltic-andesites through to rhyolites, plus later-formed cross-cutting felsic and mafic intrusions. The occurrence of thick sequences of amygdaloidal intermediate lavas intercalated with extensive sequences of dacite tuff, coupled with the absence of marine sediments or hydrovolcanic products, indicates that the majority of the volcanic succession, including the mineralised komatiite lavas, were formed in a sub-aerial environment. Chemical composition of the non-ultramafic lithologies is dominated by a calc-alkaline signature, indicative of a volcanic arc setting. Trace element and REE data indicates that the compositional variability was not achieved via fractional crystallisation alone, and that crustal assimilation and/or different sources must be invoked to explain the observed basaltic-andesite to rhyolite magma suite.

Recent U-Pb dating, undertaken on several samples from various levels within the established stratigraphy, has indicated that the emplacement of the Cosmos succession took place between ~2736Ma and ~2653Ma, making it significantly older and longer-lived than other dated greenstone successions within the Kalgoorlie Terrane. Extrusive periodic volcanism spanned ~50Ma with three cycles of bimodal intermediate/felsic and ultramafic volcanism occurring between 2736Ma and beyond 2685Ma. Periodic intrusive activity occurred for a further ~32Ma until ~2653Ma.

The age, composition and geochemistry, particularly a lack of TTD affinity, of the intermediate and felsic succession at Cosmos contrasts with much of the adjacent Agnew-Wiluna greenstone belt [1], indicating the Cosmos succession is a separate, older terrane with a distinct sub-aerial extrusive volcanic succession formed in a long-lived volcanic arc setting.

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Global Cu Resources: Changing trends and endowments

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Copper plays a crucial role in modern society across the world, contributing to infrastructure, technology and lifestyles. Although mineral resources are commonly considered to be finite, global Cu production has grown steadily throughout the twentieth century, and has been matched by substantial growth in estimated Cu reserves and resources. Here, we present a detailed compilation and assessment of globally reported Cu resources for 2010 (i.e. in situ Cu that has not to date been exploited or extracted) split by project and mineral deposit type [1]. The 730 mining and mineral exploration projects within our database reported mineral resources using the JORC Code or other national equivalents (e.g. NI 43-101, SAMREC), yielding a minimum total amount of global Cu resources of ~1,800 Mt, with a further 80.4 Mt Cu of potentially less robustly reported resources in China. These data indicate that global Cu resources continue to increase, despite a coincident increase in Cu production and a decrease in cut-off and ore grades, increasing impact of environmental issues (e.g. tailings and waste rock management, acid and metalliferous drainage, mine site rehabilitation, water resource issues, greenhouse gas emissions, etc.), and other aspects that affect mineral resource reporting, including the allocation of Cu resources by deposit type in mining camps containing multiple types of mineral deposit [2].

Our compilation provides a reasonable snapshot of the current global state of delineated Cu resources, and indicates that the vast majority of Cu resources are hosted by porphyry-type deposits, with the bulk of these located in Chile, and with the total contained Cu in porphyry-type resources more than ten times higher than the contained Cu in any other single mineral deposit type. Our compiled data, although extensive, is not exhaustive as numerous countries with substantial Cu deposits do not publicly report Cu resources; this indicates that the total contained Cu presented here should therefore be considered a minimum. These data also suggest that the abundant Cu resources already identified can meet growing global demands for a number of decades to come, as long as resources are effectively converted to reserves and extracted. Although there are many projects where resources increase over time as a project proceeds to development and exploration success and economic factors facilitate ongoing mining or expansion (e.g. Grasberg; [2]), there are also numerous projects which are not developed. One example is Windy Craggy in British Columbia, one of the largest Bessemer-type VMS deposits discovered to date, where development was blocked as the area around this mineral deposit has been incorporated into a world-heritage listed national park. Other projects face major community opposition and regulatory hurdles (e.g. Pebble in Alaska, USA) or are remote and currently uneconomic (e.g. Frieda River, Papua New Guinea). Overall, in considering the future of Cu mining, it is clearly important to build databases such as the one presented here to allow more comprehensive assessment of global Cu resources and to model aspects such as ore types and grades and production capacity, enabling the linking of these factors to the environmental, social and economic aspects of Cu extraction. In summary, currently known Cu resources and trends indicate that copper is far from a 'peak' in known resources or production, with a range of social, economic and environmental factors likely to govern whether given projects that could meet future increases in demand for Cu can be effectively and economically developed.

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A follow up study of platinum-group minerals from the Jinchuan intrusion, Gansu province, NW China

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The Jinchuan mafic-ultramafic intrusion in NW China along the northern margin of the fault-bounded Longshoushan Belt is host to the third largest Ni deposit in the world after Noril'sk and Sudbury. Debate remains over the affinity of the intrusion, however, it has recently been interpreted as a highly tilted sill [1] which is cut by a series of northeast trending strike slip faults dividing the intrusion into three sub-chambers; the west, west-central and east sub-chambers hosting orebodies #24, #1 and #2 respectively [2]. Core from three boreholes from orebody #1 traversing from west to east as well as one borehole from the relatively Cu-rich orebody #24 was sampled for this study of platinum-group minerals (PGM).

The samples studied show a variety of sulphide ores ranging from net-textured, 'patchy' net-textured, disseminated and massive. These classifications are complicated further by varying amounts of sulphide veining or remobilisation which is particularly evident in the non-massive samples. The dominant sulphide phases present are pentlandite, pyrrhotite and chalcopyrite with minor gersdorffite-cobaltite (NiAsS-CoAsS) and nickeline (NiAs) also identified. Initial PGM analyses of these samples under the scanning electron microscope (SEM) has resulted in the identification of predominantly sperrylite (PtAs₂), foodite (PdBi₂), and irarsite which may include minor constituent Pt and Rh as part of the hollingworthite-irarsite-platarsite solid solution series ([Ir-Pt-Rh]-As-S).

Froodite phases occur as small (typically 1-4 µm²) rounded anhedral phases associated with either base metal sulphides (BMS) or magnetite which itself is often closely associated with the BMS. Sperrylite phases, however, occur as rarer but much larger crystals (from 10-170 µm²) with subhedral to euhedral forms. Sperrylite is identified in sulphide, oxide and silicate phases showing no significant preference for any one host. The occurrence of this sperrylite may account for the considerable variation in Pt concentrations and Pt/Pd ratios observed in the whole rock PGE data published as a result of previous studies of the Jinchuan deposit (e.g. [2, 3] etc.). More interesting still is the overwhelming association of irarsite with gersdorffite. Despite the rarity of gersdorffite, particularly in comparison to the other BMS present, irarsite (typically 5-20 µm²) is consistently identified within small gersdorffite phases (usually <0.5 mm²). Furthermore, Rh is also identified in solid solution in some of these gersdorffite phases under the SEM. In several cases, Rh concentrations are high enough (up to several atomic percent) to produce faint yet visible gradational anhedral patches within gersdorffite. These observations support the increasing evidence that PGE will preferentially partition into sulpharsenide phases over the more common magmatic sulphides such as pentlandite, pyrrhotite and chalcopyrite (e.g. [4, 5] etc.).

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Petrological Controls on Intrusive Hosted Polymetallic Mineralisation, Tirua Hill, South New Georgia, Solomon Islands.

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The Solomon Islands arc, SW Pacific, is the result of the ongoing convergence of the Indo-Australian and Pacific plates. The arc has a complex tectonic history, with plateau collision, polarity reversal, and ridge subduction occurring impacting its structural and magmatic development. A complex series of tectonic and magmatic events. The western arc is above a series of slab windows due to the subduction of the Woodlark spreading ridge [1]. In this part of the arc, Tirua Hill on the island of South New Georgia is host to a diverse set of intrusive and extrusive rocks including picrites, picritic basalts and more evolved diorites, tonalites and andesites [3]. Several of these units have been later affected by hydrothermal alteration and polymetallic mineralisation, plus noticeable pyrite [3]. Tirua Hill is an ideal natural laboratory to study slab window magmatism and the suspected link to porphyry and epithermal style mineralisation [4].

The Tirua Hill area is yet to be fully understood due to poor exposure and lack of detailed research that combines petrographical and geochemical data; the timing and relations of the wide range of lithologies, magmatic evolution and potential mineral deposits are not yet understood.

To attempt to better understand this complex system, the area will be taken apart intrusion by intrusion to form a database which will hold the information necessary to decipher the overall petrogenesis of the entire suite. This project's foundation will be formed by a range of petrographical and geochemical studies to break down and understand fractionation orders, alteration and mineralisation phases which until now have not been attempted. The area has previously been lithologically grouped in to several broad categories [2, 3], however preliminary results show that these units will require modification as the variety of samples are the main focal point for understanding the relationships from one unit to the next.

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Hydrothermal vein formation in the Southern Schwarzwald ore district

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The Schwarzwald in south-western Germany is part of the Central European Variscan orogen, mainly comprising gneisses and post-tectonic late-Variscan granites. The Schwarzwald ore district is host to more than 1000 known hydrothermal vein occurrences [1, 2], the vast majority of which are of subeconomic value. Based on their ore mineral associations several styles of mineralisation can be distinguished, the most common of which are Pb-Zn-Cu, U-Bi-Co-Ni-Ag, Sb-Ag-(Au) and Fe-Mn [1, 3, 4, 5]. Barite, fluorite and quartz are the main gangue with minor carbonates also present. This mineralisation formed during the last 300 My with a peak during the Jurassic [6] in distinct tectonic settings [7] due to cooling of ascending fluids (Permian) and mixing of ascending brine with formation or meteoric water (post-Variscan) [8, 9].

In this study hydrothermal veins in an area of 16 km² in the Belchen region, about 15 km south of Freiburg, were mapped and sampled. The samples were analysed using optical microscopy (transmitted and reflected light), cathodoluminescence (CL), electron probe micro analyses (EPMA), fluid inclusion microthermometry and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to shed light on the sequence of mineralising events and the processes responsible for mineral precipitation.

In the field four main types of mineralisation were identified: (1) quartz-hematite veins with typical NW strike; (2) two sets of fluorite-barite-quartz veins striking N and NE; (3) rare breccia veins with varying mineral contents and strike directions; (4) chalcopyrite-rich quartz-carbonate veins. Quartz-hematite veins were precipitated from low salinity (0-7 wt.% NaCl equivalent) H₂O-NaCl-(KCl) fluids at temperatures of 300°C-380°C. Fluid inclusion boiling assemblages allowed precise determination of pressure at the time of formation. Assuming hydrostatic conditions, this pressure translates into a depth of formation of 2300m below surface. These veins are interpreted to be of Permian age. Fluorite-barite-quartz veins are interpreted to be Jurassic in age and to have formed by mixing of H₂O-NaCl-CaCl₂ dominated fluids with similar salinities (20-25 wt.% NaCl+CaCl₂) but different NaCl/CaCl₂ ratios. Temperatures of formation range from 105°C-170°C. Mineral textures and compositional variations of zoned minerals indicate that fluid mixing and mineral precipitation during the formation of these veins was a multistage process. The timing of formation of the breccia veins remains uncertain but the presence of similar fluids to both, the Permian and Jurassic veins noted above suggests that they formed and were reactivated several times. Quartz-carbonate veins with abundant chalcopyrite are the youngest mineralisation type and follow or crosscut older veins.

The observation of multiple stages of hydrothermal activity is in agreement with other parts of the Schwarzwald and Central Europe. The mixing of fluids was the essential process in the formation of base metal veins.

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Orogenic gold in the Senegal-Mali Shear Zone: fluid sources and potential for IOCG systems in the Birimian of West Africa

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The Palaeoproterozoic Kédougou-Kéniéba Inlier in West Africa hosts outstanding mineral wealth. Two separate Birimian (2.1Ga) terranes sutured along the Senegal-Mali Shear Zone (SMSZ) host some 45Moz of gold and 630Mt [1] of iron ore. To the west of the SMSZ the Falémé Volcanic Belt, comprised of volcanoclastic sediments and andesitic lavas intruded by calc-alkaline plutons, hosts iron ore in a series of magnetite-apatite skarn deposits. Orogenic Au deposits are hosted in the thick metasedimentary sequences of the Kofi Series to the east of the SMSZ. These include the Gara, Yalea and Goukoto mines. The fluid chemistries and mineral paragenesis of the Au deposits in the Kofi Series challenge the dominance of metamorphic fluids in orogenic gold emplacement, suggesting the existence of a new magmatic influenced sub-class with possible Iron Oxide Copper-Gold (IOCG) affinities.

The Au deposits of the Kofi Series are characterised by unusual REE-enrichment. As-poor ore assemblages are pyrite dominated with accessory chalcopyrite, Ni-sulphides, scheelite and REE phosphates. Widespread albite alteration is associated with early stages of mineralisation; this is also present in the Falémé belt, associated with the magnetite-apatite skarns. A strong boron anomaly extends along the strike of the shear zone; this is linked to intense tourmalinisation associated with mineralisation at Gara. Two distinct hydrothermal fluids were involved in Au mineralisation in the SMSZ: 1) a high temperature, hypersaline, Na-Fe-Cl-B bearing magmatic sourced fluid; and 2) a lower temperature, low salinity, CO₂-N₂-H₂S rich metamorphic fluid [2]. The magmatic fluid is absent at the Yalea deposit, which represents a typical orogenic Au deposit formed from unmixing of the CO₂ rich fluid. The Gara and Goukoto deposits are thought to have formed due to mixing of the two fluids. This has profound implications for the application of the standard model for orogenic Au genesis [3, 4] in this region, as it suggests mixing of oxidized magmatic fluids and reduced, lower temperature metamorphic fluids. This model is further strengthened by mineralised veins and sulphides from Au deposits across the SMSZ, showing $\delta^{34}\text{S}$, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values indicating a mix of magmatic and metamorphic sourced fluids. The hypersaline, magmatic sourced fluid is heterogeneously distributed throughout the deposits, with increasing abundance toward the Falémé belt in the west.

The magnetite-apatite skarns in the Falémé belt provide evidence for a magmatic source for this hypersaline fluid. These deposits show enrichment in LREEs, P, Cu, Au, U, Ni, Co and As. They are also associated with the same widespread sodic alteration present in the Kofi series, in addition to more localised actinolite - epidote \pm magnetite \pm apatite alteration. This indicates potential affinities with IOCG systems. A highly altered quartz feldspar porphyry (QFP) hosting the Karakeane Ndi skarn in the Falémé belt provides a tangible link between the hypersaline fluid, igneous intrusions and the magnetite-apatite deposits that they host. These QFPs contain high temperature, H₂O-CO₂-NaCl-rich hypersaline fluid inclusions within quartz phenocrysts. These inclusions are comparable to those observed in auriferous veins throughout the Kofi series. It is therefore proposed that the magmatic fluid system, which has interacted with Au mineralisation in the Kofi Series, may be directly related to the magnetite skarn system. This is leading to the development of a conceptual model linking the genesis of IOCG-like magnetite-apatite skarns and orogenic Au in the SMSZ.

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Structural Controls on Gold Mineralisation along the Dugbe Shear Zone, Eastern Liberia

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The Palaeoproterozoic Birimian terrane of West Africa is one of the fastest growing areas for discovery, development, and production of gold in the world. Field and geochronological studies have indicated that the eastern half of Liberia is an extension of the Birimian age province [1,2]. However, until recently prolonged periods of civil war have hindered exploration.

Hummingbird Resources, founded in 2005, were first movers in eastern Liberia. Their initial land package focussed on NE trending crustal scale shear zones which have been prime locales for significant sized ore bodies across the Birimian of West Africa [3]. Intensive exploration along the Dugbe shear zone led to the discovery of three closely sited gold deposits (Dugbe 1 Project) near to the shear zone with a total resource of over 3.81 Moz [4]. On going fieldwork sponsored by Hummingbird Resources has focussed on delineating the deformation sequence in the Dugbe 1 Project area to compare with the Birimian terrane and to better understand structural controls on gold mineralisation.

Structural observations are consistent with a polyphase tectonic model, similar to that proposed for the Birimian of Ghana and Burkina Faso [3,5,6]. Initially thrust tectonism (D1) dominated during crustal accretion at the onset of the Eburnean Orogeny [7]. Progressive deformation of S1, a penetrative foliation sub-parallel to original lithological contacts and primary bedding, resulted in both small and large scale tight N-S trending folds (F2) across the Dugbe 1 area. Syn-tectonic partial melting and granitic sill emplacement occurred as a result of crustal thickening during this phase of deformation. A transition in tectonic style to a transcurrent regime defines the D3 event. Sinistral motion along the Dugbe shear zone is characterised by near vertical mylonitic fabrics (S3) and shear zone parallel large scale E-W orientated open folds (F3). Refolding of early F2 generation folds about late F3 folds formed a dome and basin like arrangement. A number of poorly exposed cross-cutting shear zones have been tentatively attributed to a D4 event. Late brittle structures related to uplift are of minimal extent across the Dugbe 1 area.

Dugbe 1 disseminated gold mineralisation is linked to F2-F3 dome shaped fold interference structures proximal to the Dugbe Shear Zone. High gold grades tend to coincide with the intersection of F2 and F3 antiform hinges. Sheet like ore bodies are variably developed in the hinge and limbs of both generations of folds at these locations. The fact that D3 structures are traps for gold mineralisation suggests that the transition from D2 to D3 deformation had a strong influence on fluid flow at a regional scale along the Dugbe Shear Zone. It is proposed that permeability contrasts in dome structures and related antiform hinges and limbs focussed fluid flow along permeable pathways and facilitated gold deposition.

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Curraghinalt Gold Deposit, Co.Tyrone, N.IrelandLawther S.E.M.¹ and Moloney M.¹¹Dalradian Gold, 3 Killybrack Road, Omagh, Co.Tyrone. slawther@dalradian.com

Dalradian Gold Limited (a wholly owned subsidiary of Dalradian Resources) has 4 exploration areas (DG1-DG4) with licences for base and precious metals exploration within Co. Tyrone and Co. Londonderry, N.Ireland. The project area totals approximately 844km² of prime geological terrain in the upper Pre-Cambrian Dalradian sequence and the younger Ordovician volcanic terrain. Our main focus, the Curraghinalt mesothermal gold deposit, lies within the Dalradian sequence in licence DG1. Curraghinalt has an NI 43-101 compliant measured mineral resource of 10,000 ounces of gold (0.02 million tonnes grading 21.51 g/t gold), indicated mineral resource of 460,000 ounces of gold (1.11 million tonnes grading 12.84 g/t gold) and an inferred mineral resource of 2.23 million ounces of gold (5.45 million tonnes grading 12.74 g/t gold).

The Curraghinalt deposit is located 3 km to the north of the northeast-southwest striking Omagh Thrust Fault. This major fault has thrust Dalradian Supergroup rocks from the northwest over the Ordovician-aged Tyrone Volcanic Group (TVG) rocks located to the south.

The Curraghinalt deposit consists of WNW trending veins which dip ~60-70° N. To date the deposit consists of at least ten primary gold-bearing veins ranging in width from 0.3 m to more than 2.0 m, and the deposit is open both along strike and down dip. Parnell et al [1] studied the textures of the veins and results indicate that they are composite veins that have been developed over time by four distinct periods of quartz injection and sulphide-rich hydrothermal fluids. Structurally, the veins are controlled by a series of high-angled, east-west trending shears that are interpreted to represent hanging-wall accommodation structures caused by a ramp in the footwall of the Omagh Thrust [2]. These structures are expressed geophysically as strong Fraser filtered VLF-EM linears. The shears are vertical to northerly steep dipping structures, which dextrally offset the veins. The veins are also offset sinistraly by ENE to NNE trending normal faults that dip to the NW and with general displacements of approximately 10 metres. Low angle, north-dipping thrust faults are also evident in the main access adit.

Our most recent exploration efforts have included an airborne geophysics survey, soil sampling program and re-interpretation of the historic drill core. Each study was focussed on a different scale and element of the deposit, and all have provided Dalradian with new potential prospects for follow-up.

1) The airborne survey has revealed a large magnetic anomaly that is sub-parallel to and adjacent to the main ore veins. Similar anomalies but on a smaller scale also occur along strike and coincide with one of our regional prospects. This indicates that whatever this feature is, it may exert some control on the location of veining. 2) The soil survey identified gold anomalies along strike of the Curraghinalt trend with one particularly interesting anomaly located 1700m east of the main deposit. 3) Re-interpretation of the historic core has identified a second orientation of mineralised veins. These veins are ~ 0.1 – 40cm wide, predominantly composed of carbonate and may or may not be mineralised with pyrite percentages up to 70%.

All of these results provide us with several excellent prospects to focus on for the incoming exploration season and indicate that Curraghinalt could become one of Europe's largest gold deposits.

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The evolution of porphyry Cu deposit magmas

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The genesis and evolution of the source magmas is critical in understanding the formation of porphyry Cu deposits. Here, the petrogenesis of magmatic rocks from two large, high-grade porphyry Cu deposits; Resolution (Arizona) and Oyu Tolgoi (Mongolia) is discussed. Field and drill core observations are compared with corresponding bulk rock data, to better understand the fundamental controls on porphyry magmatic evolution.

Resolution (late-Cretaceous porphyry Cu-Mo) and Oyu Tolgoi (late-Devonian porphyry Cu-Au) share similar features in spite of their differences in age, location and regional tectonic setting. Both have some mineralisation hosted in felsic porphyry stocks, but the majority is hosted in mafic igneous country rocks, the presence of which may have contributed to the high Cu grades. Both deposits also have a similar style of mineralisation, containing late-stage chalcopyrite + bornite ± chalcocite, contributing to high grades. At Resolution, several distinct porphyritic units are currently recognised from drill core: rhyodacite, quartz latite and latite, and aplite porphyries. Although all intrusive units are considered broadly contemporaneous, some cross cutting relationships have been noted. Rhyodacite and quartz latite porphyries are distinguished on the presence of 'quartz eyes', which are largely absent in latite. Aplites are narrow dykes of fine-grained qz + fsp (+ biotite). Porphyry intrusions at Oyu Tolgoi can be subdivided into the Quartz Monzodiorite (QMD) and Biotite Granodiorite (BiGd) units. Several generations of QMD are defined by the strength of alteration and style of mineralisation, but any textural variation that occurs is not systematic. QMD displays strong sericitic to advanced argillic, potassic and weak propylitic alteration. BiGd is present as both fine-grained, crowded types; and coarser, less crowded porphyries. Both types of BiGd are unaltered to weakly altered and are considered to immediately post-date mineralisation.

Bulk rock data from porphyritic units at both Resolution and Oyu Tolgoi attest to the hydrous, calc-alkaline nature of porphyry deposit source magmas. Chondrite-normalised rare-earth element (REE) patterns for these rocks show enrichment in LREE and a relative depletion in HREE. Some porphyry magmas typically demonstrate REE patterns with minima at Dy-Ho (MREE), indicating strong amphibole fractionation. At Oyu Tolgoi, the early-forming QMD displays such patterns. However, the later-stage BiGd, along with all intrusions from Resolution show systematic variation in the shape of these REE patterns, suggesting that a different mineral assemblage was important in igneous fractionation. Specifically, high Dy/Yb and depletion of HREE is the result of garnet fractionation in the early magmatic system, implying high pressure fractional crystallisation in the deep crust. The thickening of arc crust at Oyu Tolgoi, as suggested by previous authors, could be responsible for this change in the fractionating assemblage, while the consistent garnet signature for Resolution rocks can be attributed to its continental arc setting.

While high-pressure igneous fractionation has occurred at both deposits, garnet fractionation occurred throughout the magmatic history of Resolution, but only in the latter stages at Oyu Tolgoi.

Characterising a geochemical and isotopic halo of the Navan Zn-Pb Irish-type deposit

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The world class Navan carbonate-hosted Zn-Pb Irish-type deposit is the biggest in the Irish Ore Field and the largest zinc producer in Europe. It is widely accepted that it was deposited by the mixing of hot metal-rich, sulphur-poor hydrothermal fluids (+ve $\delta^{34}\text{S}$) and cool seawater brines enriched in bacteriogenic sulphur (-ve $\delta^{34}\text{S}$). Economic mineralisation is hosted by Lower Carboniferous carbonates that have been extensively fractured, thereby providing pathways for the fluids to mix.

The nature of the mineralized halo around the main orebody is much less well known. This poster illustrates some of the mineral textures, geochemical data and sulphur isotope results from a NW transect across the halo of the Navan orebody. Understanding the nature of the halo will aid future exploration at Navan and within the Irish Ore Field.

Eight textures have been defined in the halo. These represent at least three different stages of sulphide deposition. Common textures are diffuse and fracture-fill veins, muddy sulphides and later sulphides associated with hydrothermal carbonate veins. Analysis of $\delta^{34}\text{S}_{\text{CDT}}$ in sphalerite and galena provides an insight into the origin of these textures; for example bacteriogenic sulphur (-ve $\delta^{34}\text{S}$) is present in some samples up to 2 km from the main orebody.

Zn:Pb ratios in the halo are on average 1:1, compared to an average of 5:1 for the main orebody. The relatively lower values of Zn are possibly due to low availability of sulphide i.e. less bacteriogenic sulphide; areas with high Zn and Pb values and high Zn:Pb ratios correlate with a -ve $\delta^{34}\text{S}$ signature.

Previous work on trace elements on a micro scale in the main orebody shows that sphalerite enriched in Cd, Sb, Cu and Ag carries a +ve hydrothermal sulphur signature, whilst sphalerite enriched in Fe and As bears a -ve bacteriogenic sulphur signature [1]. This has been applied to whole rock geochemistry in the halo. It is seen that Cd, Cu (correlating with +ve $\delta^{34}\text{S}$) and As (correlating with -ve $\delta^{34}\text{S}$) show the same trend as seen on a micro scale. Identifying this relationship may allow an understanding of sulphur source without analysing sulphur isotopes.

Distribution of sulphide mineralisation at Navan is in part linked to the distribution of dolomite. Cathodoluminescence (CL) imaging of dolomite allows different stages of dolomitisation to be identified and a comparison between halo and main orebody dolomite CL stages will be presented. This will form a basis for C and O isotope analysis of dolomite from the halo and its comparison with the main orebody [2].

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Mineralogy of the Peschanka porphyry copper deposit, Chukchi Peninsula, Russia

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The giant Peschanka porphyry Cu-Au-Mo deposit with ~6 Mt of Cu and 320 t Au located 250 km southeast of Bilibino (Chukchi region, Russia) is hosted by the Early Cretaceous Egdigkich monzodiorite intrusion. The deposit is controlled by a large meridional dextral strike-slip fault and is quartz-sulfide stockwork of 6 by 0.6 km in area on the surface. There are four types of wall-rock alteration (from early to later): potassic, propylitic, phyllic and advance argillic. The most abundant potassic alteration hosts phyllic zones (up to few meters thick). Both types of metasomatic contain copper mineralization. Propylite forms outer zone of alteration halo. Potassic altered rock is composed of Ba-bearing K-feldspar, relict and hydrothermal biotite, albite, and relict diopside; accessory minerals are rutile and apatite.

Pre-ore propylitic alteration occurs as a wide halo around the deposit, and also as relict patches within later alteration types. Propylite is composed of epidote, albite, K-feldspar, quartz, amphibole, chlorite and tourmaline. Accessory minerals are rutile, titanite, calcite, prehnite; ore minerals are pyrite and magnetite. Tourmaline is classified as an intermediate member of the "oxy-dravite"-povondraite series with the $Fe^{3+} \rightarrow Al$ isomorphic substitution typical of porphyry deposits. Amphiboles evolved from maghiesiohornblende to tremolite-actinolite. Content of Al in chlorite decreases toward the outer part of propylitic halo testifying to decreasing temperature of crystallization.

Muscovite and quartz are the major minerals of the phyllic altered rocks; minor minerals are chlorite, albite, tourmaline and carbonates. Tourmaline is classified as dravite-"oxy-dravite" with $Al+O \rightarrow Fe^{2+}+OH$ isomorphic substitution indicating predominance of Fe^{2+} and lower Fe_{tot} content. It is probably caused by increasing H_2S and starting deposition of sulfide minerals related to phyllic alteration. Phyllic chlorite is characterized by negative correlation between Al and Si ($r=-0.94$), Fe and Si ($r=0.6$) and positive correlation between Fe and Al ($r=0.92$), which indicates $Si+Mg \rightarrow Al+Fe^{3+}$ isomorphic substitution (Tschermack type).

Ore mineralization has been formed during two stages: 1) mesothermal with bornite, chalcopyrite, and molybdenite, 2) epithermal with galena, sphalerite, chalcopyrite, minerals of the tennantite-tetrahedrite group, Se-bearing galena, native tellurium, altaite, hesite, high fineness gold. The tennantite-tetrahedrite group minerals evolved from Fe-rich tennantite associated with bornite and chalcopyrite to Zn-rich tennantite-tetrahedrite replacing cleophane. This evolution is probably caused by increasing H_2S fugacity during hydrothermal process. Small amount of epithermal ore minerals, abundant bornite, and relatively narrow zones of phyllic alteration testify to the deep erosion level of the Peschanka deposit.

The fluid inclusion study indicates two types of inclusions in quartz: (1) chloride brines with gas bubble and daughter crystal homogenized at 374-405°C, fluid salinity 44.7-405 wt % eq NaCl and (2) aqueous solution with gas bubble homogenized at 120-290°C, fluid salinity 0.4-7.5 wt % eq NaCl. The first inclusion type is related to the formation of potassic alteration; the inclusions of the second type are related to the formation of the phyllic alteration and epithermal mineralization.

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How do we get uranium out of crystallised granites? A synchrotron scanning X-ray fluorescence micromapping study of a U-REE deposit source rock

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Whether Cu, Au or U-REE, many magmatic-hydrothermal ore systems source metals from intrusive magmatism. Once crystalline, relatively little is known about microscale metamorphic and remelting processes that can remove and re-distribute these elements. We re-examine uranium-sourcing processes from the U-rich Sybella Batholith, associated with U-REE deposits at Mount Isa, Australia.

The 1670Ma Sybella Batholith is anomalously enriched in radiogenic heat-producing U, Th and K, rare-earths and fluorine [1]. The Batholith margins have been metamorphosed, with the development of migmatites to the south in ductile amphibolite grade zones, and shearing to the north, associated with brittle greenschist grade zones. Regionally, this metamorphic event coincided with development of world-class Cu, IOCG and U-REE deposits.

Intrusive rocks tend to concentrate lanthanide and actinide elements in fine-grained accessory minerals (e.g. apatite, zircon, monazite) rather than major phases (e.g. feldspars, quartz [2]). This makes accurate element distribution mapping difficult with conventional microscope techniques. Mass balance calculations suggest that grain boundaries may be a significant reservoir for U and Th, as they cannot be accounted for through whole-rock abundances of observed mineralogy [3].

Our experiment used the penetrative, high resolution, and rapid scanning capabilities of the XFM beamline at the Australian Synchrotron. We quantitatively mapped the distribution of U, Th and REE in diffuse and fine-grained accessory minerals. In both migmatites and brittle shear zones, we compared relatively primary granite samples against those progressively melted or sheared. This represents the first time these elements have been mapped at such high resolution and spatial dimensions to apply quantitative micro-scale data on intrusive rocks to macro-scale regional processes (heat-production, magmatic differentiation and ore-formation).

In the northern granite margin, greenschist grade metamorphism caused hydrothermal albitisation and chloritisation of shear zones. We find that accessory metamict zircon, associated with primary biotite-fluorite clusters and REE-fluorocarbonates, broke down into a range of currently unnamed uranium-thorium-zirconium silicate minerals. These accessory silicates concentrated in fine veinlets on major silicate mineral grain boundaries. They indicate U, Zr and Th were locally mobilised and along with K and F, uranium was preferentially removed compared to thorium in sheared samples.

There are several U-REE deposit and granite associations. Rare uranium-zirconium silicates in local ore zones are remarkably similar to those identified in the batholith. The deposits share unusual F, Zr, Ti, P and REE enrichment, magmatic-derived carbonate C and O isotope signatures, and have reversed Th/U ratios compared to the granite. We suggest F⁻, OH⁻ and CO₂ ligands sourced from granite fluorite and REE-fluorocarbonate minerals during the infiltration of regional sodic fluids were crucial to the mobilisation of U, Zr and incompatible elements. Sourced from metamict zircons, U and Zr were transported in these fluids to local U-REE deposits.

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Definition of structural controls on formation of lode deposits of associated to mayor OTU shear zone fault system at El Limon Au vein, Zaragoza - Antioquia, Colombia.Mendoza, F.¹, Giraldo K.²¹Universidad Nacional de Colombia – Medellín Campus, School of Mines. famendozav@gmail.com²Universidad Nacional de Colombia – Medellín Campus, School of Mines

The Zaragoza area is characterized by the occurrence of a sequence of metamorphosed Paleozoic rocks of the Cajamarca complex, which were intruded by Jurassic quartz-diorites and granodiorites associated to the Segovia batholith. All these units are covered by latest Tertiary and Quaternary alluvial deposits. In this geological context emplace a series of Au – Ag veins composed of pyrite, Pb-sulfides (galena) and sphalerite with quartz. These Veins mainly define NS trends and dip with varying inclinations to W.

For El Limon deposit has been predicted stressing a direct relationship with the dynamics of the OTU fault and its associated secondary structures [1] y [2]. This approach has been corroborated by detailed survey geological mapping during field work, showing that the structures in which the veins are located with varied width and mineralization (N05-10W/15-20W and N05-15W/30-45SW) but very well defined trends (fluid flow in cracks system associated with shear Zone - Riedel) correspond to two overprinted Riedel shear systems and apparent shear zones with two temporal occurrences consistent with a very expressed change in the system of regional stress. That can be very important for wing cracks and schelones development, represented by veins and veinlets. On the planes of the El Limon vein and other secondary veins, as well as faults that cut the vein, could be found gouge development, which has abundant sulfides and calcite.

To the East of the area can be found phyllonites and mylonites marking the trace of the OTU fault, with an obvious shear zone trend N10-30W and about 50m wide. There can be observed kinematic indicators showing a dextral movement, in the top of this shear zone may be found a folded and faulted fine sandstone alluvial formation (not known the age of this formation, thus to be able to know the age of the last movement) with about 60m of difference with the current Juan Vara creek level, gauge development on the veins and local faults, shows a clear recent tectonic activity in the area, the structures show that this last movement of the its fault was a OTU fault reversed displacement. All the collected evidence of structural, lithological and mineralogical nature associated with El Limon Deposit gives insights that this corresponds to a Shear Zone Hosted Orogenic Gold Deposit [3] y [4].

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LA MC-ICPMS In-situ Analyses of Galena, Altaite and K-Feldspar from the Pampalo Mine, Hattu Schist Belt, Eastern Finland: Lead-isotopic Signatures of Overprinting Proterozoic Events on an Archaean Orogenic Gold Deposit

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Orogenic gold deposits along the 'Karelian Gold Line' occur in N-S trending shear zones hosted by folded epiclastic and volcanogenic sequences (2.67-2.94 Ga). These units are aligned between TTG, sanukitoid and leucogranite intrusions (2.71-2.79 Ga; U-Pb zircon data from [1] and [2]). Amphibolite facies metamorphism (at 4-6 kbars pressures and at 500-600°C temperatures [3]) affected these units at ca. 2.7 Ga. The area was also affected by emplacement of NW-trending, 2.3-2.0 Ga old mafic dikes and tectonothermal events between 1.85 and 1.7 Ga due to overthrusting of an up to 5-6 km thick nappe complex during the Svecofennian orogeny. This latter process re-set K-Ar ages of mica in Archaean rocks [4].

Primary deposition of ore exploited in the Pampalo Mine had taken place prior to or during the Archaean metamorphism. Disseminations of ore minerals are hosted by carbonate-K-feldspar-quartz seams and thin veins and also occur in the groundmass of the sheared biotite schist and deformed felsic porphyry dikes. The ore mineral assemblage is dominated by pyrite. Chalcopyrite and other base metal sulphides including traces of galena occur in subordinate amounts only. Gold grains, typically 20-30 microns in size, are associated with pyrite and also form complex intergrowths with fine grained Pb-, Bi-, Au-Ag-tellurides. The presence and texture of low temperature tellurides in association with gold are in contrast with the high temperature-pressure conditions of Archaean metamorphism and require evaluation of the importance of superimposed processes on ore formation. Pb-isotope ratios in galena, altaite, adularia and rock forming K-feldspar were analysed by LA MC-ICPMS. Employing short rasters of a 3 micron wide laser beam allowed us to determine Pb isotope ratios in more than 100 mineral grains with sizes as small as 30-40 microns on thin sections where their textural relationships in the ore are preserved.

Galena is characterised by homogeneous within grain and heterogeneous inter-grain Pb-isotope compositions. Galena inclusions in pyrite and some individual galena grains in the carbonate-K-feldspar-quartz veins show low $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ ratios. Their calculated two stage model ages are around 2.7 Ga ($\mu=9.6-9.4$, $\kappa=3.8-4.1$), close to the U-Pb zircon ages of host rocks and the age of amphibolite facies metamorphism. However, many K-feldspar and galena grains have anomalous Pb-isotope compositions. Data from the least radiogenic galena and K-feldspar grains from each analysed sample define a trend on the $^{206}\text{Pb}/^{204}\text{Pb}$ vs. $^{207}\text{Pb}/^{204}\text{Pb}$ diagram: this trend is likely the result of mixing of lead from the Archaean ore with more radiogenic lead accumulated in supracrustal rocks between 2.7 Ga and 1.7 Ga at the time of the development of Svecofennian nappes. The least radiogenic Pb-isotope ratios for altaite are along the galena-K-feldspar secondary isochron, but many altaite grains and especially galena from an evidently late, cross-cutting carbonate-fluorite vein have more radiogenic Pb-isotope ratios. These latter altaite and galena grains precipitated during mixing of Pb from the ore and Archaean basement, which had recrystallised at 1.7-1.8 Ga, with more radiogenic Pb from the cover units during the Neoproterozoic exhumation (1.0-0.6 Ga) of the Fennoscandian Shield. Overprinting events have already been recognised in Archaean and Palaeoproterozoic ore deposits of the Fennoscandian Shield [5]: evaluation of their metallogenetic importance requires regional-scale application of further micro-scale studies.

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XRD and QEMSCAN® quantitative mineralogical evaluation of the karst bauxite deposits in Campania (Southern Italy)

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Bauxite resources in the world are estimated to be 55 to 75 billion tons, occurring in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%) and elsewhere (6%) [1]. These resources are mostly used to produce alumina for metallurgical purposes. Approximately 70 to 80% of the world's bauxite production is processed first into alumina (Bayer process) [2], and then into aluminium by smelting and electrolysis (Hall-Héroult process). The mineralogical variation in the composition of bauxite can affect the Bayer process, e.g. the effect of reactive silica, which contaminates the aluminium extraction process, and titanium minerals, which reduce the efficiency of the Bayer Process [3, 4]. In this study, mineralogical characterization of some bauxite occurrences in Southern Italy has been carried out, including a comparison of results obtained from the quantitative analysis of the ore using the classic XRD-QPA (X-ray diffraction-Quantitative Phase Analysis) method, and QEMSCAN® (Quantitative Evaluation of Minerals by Scanning electron microscopy) automated technology, which represents a mineralogical investigation tool commonly used in the bauxite industry [5].

The bauxites of Southern Italy that are presently uneconomic can be considered as a model analogue for economic karst bauxite ores. Several bauxite occurrences from two former mining districts in Southern Apennines (Matese Mts. and Caserta province) have been analyzed. XRD-QPA allowed an exact evaluation of the amounts of minerals occurring in the bauxite. The main Al-rich mineral is boehmite, while the most common silica-bearing phase is kaolinite. Hematite is the main Fe-bearing mineral. Goethite also occurs, as well as sporadic lepidocrocite. Anatase and rutile are quite ubiquitous. QEMSCAN® was used in the fieldscan mode, and allowed: 1) the identification and classification of the mineralogical phases on the basis of their chemical composition, and 2) the abundance (wt.%) of these phases. Moreover, this technique has provided evidence of the textural characteristics of the ore that can be important in the Bayer process. In particular, it has been possible to determine that boehmite, which tends to be more concentrated in the ooids than in the matrix, contains variable amounts of Fe. Hematite occurs solely as detrital elements, kaolinite occurs mainly in the bauxite matrix and, Ti-oxides are generally associated with goethite and hematite.

Comparison between the XRD quantitative mineralogical analyses and the correspondent amounts determined by QEMSCAN® shows convergent results [6]. The XRD quantitative evaluation of bauxite phases gives useful constraints for the interpretation of QEMSCAN® raw data, which may be very detailed but cannot separate polymorphous minerals that occur in bauxite. Furthermore, QEMSCAN® quickly highlights the main textural characteristics of the bauxite, which can affect the Bayer process, but there are also some problems in identifying the composition of phases that have a grain size lower than the provided scanning resolution. However, by using both methods, and with the support of manual SEM (Scanning Electron Microprobe), all the issues were isolated and resolved. For this reason the XRD-QPA and QEMSCAN® techniques should be considered complementary for bauxite ore evaluation, and can provide a very powerful tool for their exploitation and mineral processing.

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The origin of MREE- and HREE-enrichments in carbonatites: evidence from field, petrographic and experimental investigations

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Enrichment in the light rare earth elements, with chondrite-normalized values for La at least two orders of magnitude higher than Lu is typical of nearly all carbonatites [1, and references therein]. However, the middle and heavy rare earth elements are the most critical of the rare earth elements and it is now recognised that they are enriched in some ferro-carbonatite occurrences, sometimes to economic concentration [2]. Examples such as the Allihies ferrocarbonatite, Ireland, have clear paragenetic sequences that place rare earth element concentration at the end of magmatic activity and into the hydrothermal stage. The primary mineralogy of the Allihies carbonatite is dominated by Fe-rich carbonatites including Fe-dolomite, pistomesite and sideroplesite, which have spongy dissolution textures where they are replaced by a muscovite- and chlorite-dominated assemblage that includes the Gd and/or Dy-enriched churchite-(Y). The RE-bearing mineral assemblage at Allihies contrasts markedly with regional copper-rich hydrothermal mineralization and has stable isotopes with the same mantle signature as nearby carbonatite and lamprophyre rocks that are likewise unaffected by regional hydrothermal activity.

The results of simple analogue experiments that simulate melting of a carbonated mantle at pressures of 3 GPa show that the Ca-Tschermaks content of clinopyroxene is very low where melts are P₂O₅- and CO₂-rich (< 6 mol % CaTs, Fig. 7a) and apatite is not a stable phase. This suggests that the coupled substitution REE³⁺ + Al³⁺ = Ca²⁺ + Si⁴⁺ [3] may be a very minor control on REE partitioning between clinopyroxene and carbonatite magmas, which is in contrast to melts that are mantle-sourced alkali basalt compositions in equilibrium with clinopyroxene that has ~ 22 mol % CaTs [4]. The polyvalent phosphorous cation PO₄³⁻ complexes with Ca²⁺ in the melt and promotes Na partitioning as the sodium carbonate molecule, such that the jd component of clinopyroxene is also low. The low aluminium concentration of clinopyroxene promotes the stability of garnet, which preferentially sequesters HREE in the mantle source region of carbonatites while LREE are released, explaining the LREE-enriched profile of nearly all carbonatites.

The implication of the experimental results is that carbonatites should not contain MREE and HREE enrichments where garnet remains in the residual assemblage. There are two likely mechanisms by which garnet may not remain in the residual assemblage: (1) In the case that garnet is transported in the magma, becomes comminuted and reacts with the magma, MREE and HREE will be released and become enriched in carbonatite melt. (2) Where the partial melt fraction increases such that silicocarbonatite magma is produced, garnet may melt and release MREE and HREE to the magma, which may subsequently evolve to become carbonatite. There is evidence for the transport, comminution and reaction of mantle-derived chromite in silicocarbonatite magmas near to the Allihies locality, such that the potential for a combination of the two processes is also possible. Regardless of the mechanism for incorporating the heavier REE into the primary, mantle-derived magma, a second petrogenetic stage is required that involves the evolution of a fluid phase, into which the REE preferentially partition to produce a late-stage magmatic hydrothermal event.

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Constraining a genetic model for mineralisation at the Hana Mining Ltd. Ghanzi copper-silver Project, Botswana: Source and evolution of fluids.

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The Hana Mining Ltd. Ghanzi project is part of the Kalahari Copper-belt which lies within the Pan-African Damara belt extending from the Atlantic coast in Namibia up through Botswana for over 1000 km^[1]. Mineralisation is generally hosted in the first 20 m above the contact between the oxidised, immature siliciclastic red-bed Ngwako Pan Formation and the fine grained relatively reduced siliciclastic and carbonate D'kar Formation. The mineralisation is believed to be a sediment hosted stratiform copper deposit which has an estimated strike length of 600 km of which only around 11% has currently been explored by Hana Mining. This project will use stable isotopes, transmitted and reflected light microscopy and fluid inclusion microthermometry to constrain a mineralisation model and to identify new exploration targets for Hana Mining. This project will work in tandem with Gorman [2] which will investigate the geochemistry, structure and mineralogy of the Ghanzi Project. Mineralisation is hosted in veins and veinlets with associated disseminated and cleavage-hosted mineralisation.

Early petrographic studies carried out by the author have revealed bornite-chalcocite-chalcopyrite mineralisation with minor pyrite-sphalerite-galena higher in the system. There is a general decrease in the Cu:Fe of sulphides as the system evolves, with the latest stage of veins showing chalcopyrite as the main primary sulphide. The presence of bladed hematite in early stage veins both in the Ngwako Pan and the D'Kar implies that the mineralising fluid was oxidising and that mineralisation was likely to be precipitated as a result of the reaction with the reduced host rock.

Three stages of veining have currently been identified: 1) Early bedding parallel to sub-parallel deformed veins, 2) Middle stage veins usually at a high angle to bedding and 3) Late stage massive veins. Early veins are often mineralised with bornite and chalcocite exhibiting exsolution textures. They show evidence of being introduced before the main stage of deformation and are usually deformed to a similar degree as the bedding. Middle stage veins show evidence of being introduced during deformation; cutting through already formed axial planar cleavage in finely laminated siltstones and mudstones. The latest stage veins are large structures with apparent thicknesses of up to 4 m and are only found in the hinge zones of the large scale folds; although no obvious cross cutting relationships have been found they share distinct characteristics with veins identified by Muchez et al. [3] and are therefore inferred to be the latest vein stage.

Early studies in this project imply that mineralisation is contemporaneous with, and spanned the length of regional deformation. Sulphide assemblages seen in veins are identical in some cases with sulphides seen as fine grained disseminations in the host rock, this suggesting contemporaneous formation of both vein and disseminated sulphides. This is in agreement with the overview of Sillitoe et al. [4].

The next stage of the project will be to work with stable isotopes and fluid inclusions to try to further enhance the genetic model.

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Chemical fractionation of the Nb-Ta-Sn mineralised pegmatites of the Gatumba Area (Rwanda)

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The Gatumba area is situated in western Rwanda in the Mesoproterozoic Karagwe-Ankole Belt. This area is characterised by numerous rare metal mineralised pegmatites that are related to the barren G4-granites of early Neoproterozoic age. The pegmatites are affected by intense hydrothermal alteration resulting in albitisation and greisenisation. A regional mineralogical zonation within the pegmatite field has been historically documented by Varlamoff [1]. It comprises 7 distinct phases: (1) biotite, (2) biotite-tourmaline, (3) biotite-tourmaline-muscovite, (4) muscovite-tourmaline, (5) muscovite and (6) and (7) characterised by niobium–tantalum–tin mineralisation.

This study aims to determine the origin and evolution of the pegmatites and the mineralising fluids, and to model the mineralogical zonation in terms of geochemical fractionation. Mineral separates of feldspar, biotite, muscovite and tourmaline representing the whole gamut of regional pegmatite zonation and alteration have been analysed for major, minor and trace elements, in particular the rare earth elements (REE).

Tourmaline from different pegmatite phases shows significant compositional variation. The black schorl variant occurs in the first 5 pegmatite phases. The crystallisation of schorl consumes magnesium, titanium, manganese and iron to the extent that the mafic components of the pegmatitic melt drop to trace levels. This hampers the biotite stability and promotes the growth of muscovite. The green elbaite variant of tourmaline is restricted to the highly evolved pegmatitic quartz cores of phase 6 and 7. The evolution from schorl to elbaite is paragenetically separated by a transient cessation of tourmaline crystallisation which allowed for an increase of the boron-content of the melt due to fractionation. Fractionation also raised the lithium-content to the level needed to stabilise the formation of elbaite. The observed compositional variation of tourmaline implies that the 7-phases zonation of Varlamoff [1] can be simplified to one involving only 4 phases: a biotite, a two-mica, a muscovite and a mineralised phase.

Alkali element variations (potassium-rubidium-caesium) in muscovite and alkali feldspar and the subsequent fractional crystallisation modelling indicate that the origin of the different pegmatite phases can be explained by a single path of fractional crystallisation of a granitic melt with a G4-composition. Trace element variations and modelling show an evolutionary path from the granite to the pegmatite and alteration assemblages. It reflects the increasingly more fractionated melt composition and the systematic enrichment of the incompatible elements such as lithium, rubidium, caesium, beryllium, tantalum, niobium and tin according to the newly redefined zonation sequence. The REE patterns of the separates are in agreement with the presented bulk fractionation model. Moreover, the light rare earth element (LREE)-depleted REE patterns of separates from the more evolved pegmatite phases point to the important impact of monazite crystallisation on REE fractionation.

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Alteration, mineralization, and geochemistry of the Viper (Sappes) epithermal Au–Ag–Cu–(Sb–Te–Se) orebody, Thrace, NE Greece

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The Sappes gold project in Thrace, NE Greece is being developed by Glory Resources and its 100% owned Greek subsidiary Thrace Minerals SA. It comprises three orebodies (Viper, St Demetrios and Scarp), which have a combined JORC resource of 2.64 Mt @ 9.8 g/t for 830 koz Au [1]. Also, with relatively abundant selenide and telluride minerals and Sb contents up to 1.1 %, there is potential for by-product critical metals [2]. The high-grade hypogene mineralization (280 kt @ 19.5 g/t Au; 9 g/t Ag; 0.4 % Cu [1]) in the Viper orebody is “blind”, flat-lying and elongate (60 x 131 x 550 m) and located at a depth of approximately 200–240 m below the current surface. Ore occurs as multi-stage silicified hydrothermal breccias, and disseminations in stockwork quartz-veinlets and vug-fillings within altered calc-alkaline to high-K Miocene andesitic–dacitic volcanic rocks [2]. Optical microscopy, PIMA and XRD analyses of drill core identify two events of gold-associated advanced argillic–vuggy quartz alteration (AAA) and one stage of argillic alteration and silicification (AAS), which are spatially correlated with hydrothermal breccias and veinlets. Stage I AAA is pervasive and characterized by quartz, fine-grained kaolinite–dickite+alunite and pyrite. Stage II AAA overprints previously altered rocks, it is restricted to pores and fractures and mostly comprises open fill crustiform-banded, and cockade, quartz–pyrite–alunite–Al-phosphate sulphate-minerals; kaolinite–dickite occurs locally. AAS alteration is pervasive and characterized by illite (sericite), quartz and pyrite without alunite; its relationship to both stages of AAA is not clear. However, cross-cutting relationships suggest that stage II AAA postdates the AAS alteration. The bulk of Au–Ag–Cu mineralization is related to AAA assemblages and LA-ICP-MS analyses of associated pyrite and enargite suggest that Au is genetically linked to their precipitation and maybe structurally bound. At the microscopic scale a variety of complex Pb–Bi–Cu sulphosalts, tellurides and selenides are intimately associated with native gold. However within these mineralised zones, high-grade (> 30 g/t) sections can have an AAS signature. 3D modelling of alteration patterns and geochemical variations in Pb, Bi, Cu and Sb show that this association can be extended to the deposit scale and potentially be used as a vector to high-grade gold mineralisation. Quartz-hosted fluid inclusions from intermediate to high-grade (11–63.4 g/t) intersections have salinities of 1.5–5.3 wt% NaCl eq. Homogenization temperatures (L+V->L) range 156–266°C, with most values between 178–244°C. The presence of low-density vapor-phase inclusions suggests low-pressure conditions and that boiling may have triggered Au deposition. However, rapid cooling of the system may have been the main control on pyrite- and enargite-hosted gold. Sr⁸⁶/S⁸⁷ (0.7067 to 0.7071) in barite plus δ³⁴S (–9.7‰ to +0.6‰) in pyrite and enargite indicate a strong magmatic control to the mineralisation.

Although similar in many respects to classic high-sulfidation epithermal deposits, the Viper orebody has some atypical features: (i) the mineralisation is flat-lying rather than the more typical upwardly flaring vertical pipe-like structure, (ii) high grade (>30 g/t) sections of drill core have an additional illitic pattern of alteration and exhibit colloform-banded and chalcedonic quartz more characteristic of low- and intermediate-sulfidation mineralisation and (iv) Au is genetically linked to the precipitation of pyrite and enargite, whereas in typical high-sulfidation mineralisation it generally post-dates these sulphides [4].

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What we know, what we (I!) think we know, and what we don't know about the concentration of PGE and chromite in the Bushveld Complex.

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While the PGE content per square metre in the whole of the Critical Zone, when projected to the base, is relatively uniform (100-150 g/m² Pt) in the interval from the top of UG-2 to top of Merensky Reef the PGE content increases from the NW Bushveld (Pt = 50 g/m²) to the Southwest Bushveld (Pt = 20-24 g/m²) to the Eastern Bushveld (Pt = 12-16 g/m²).

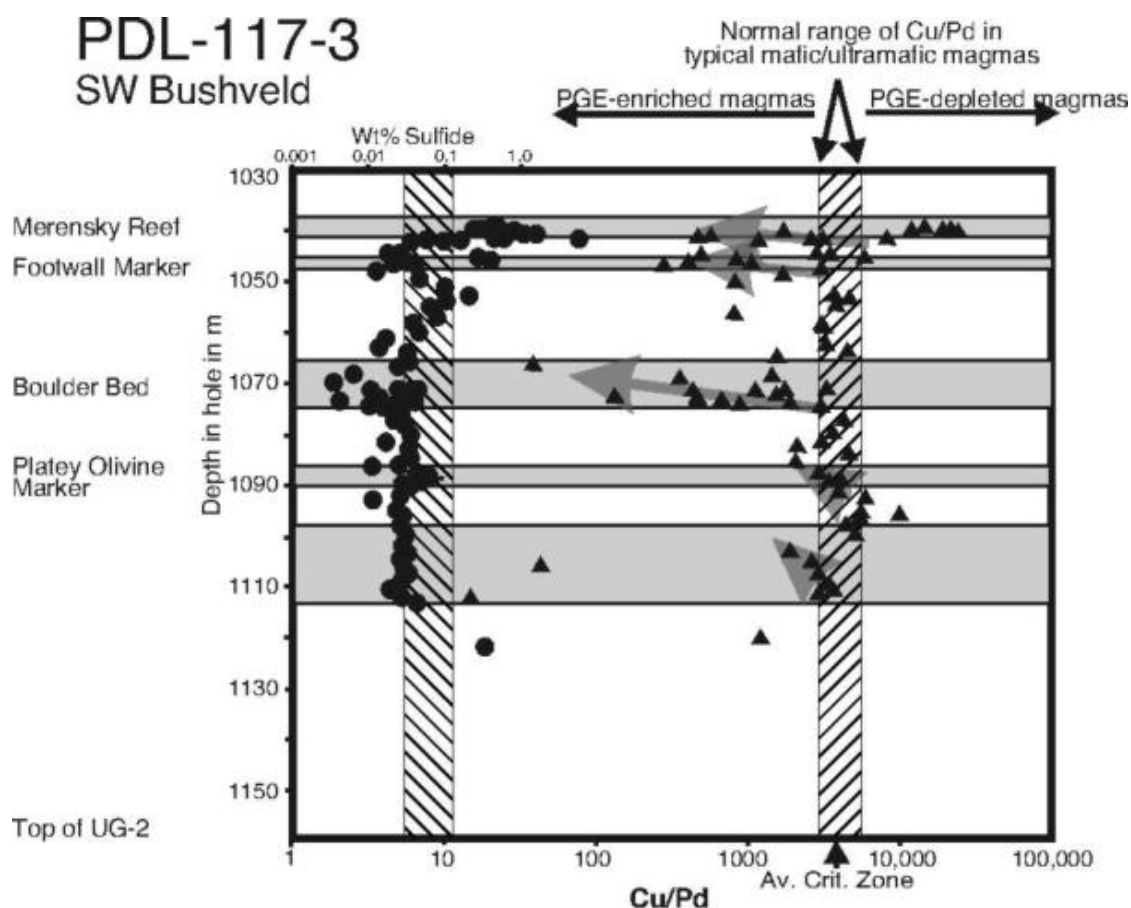


Fig. 1 Variation in Cu/Pd ratio in Cu/Pd ratio between the UG-2 and Merensky Reef

In this same interval in the Rustenburg area a steady crystallisation of opx and plag was interrupted by at least 5 waves of more mafic PGE-enriched magma with low Cu/Pd (see Fig. 1). The Merensky Reef was the culmination of these waves. Furthermore, the integrated Pt tenor of sulfides in the Merensky Reef decreases from 2000-5000 ppm in the NW to 300-2700 ppm in the Southwest to 200-600 ppm in the East. These variations in PGE content and tenor are consistent with magma spreading from the Northwest (as suggested by [1] and [2]) during the interval above the UG-2.

In contrast, little systematic variation of PGE content with location is observed in the UG-2. The composition of chromite and variations in PGE content in the chromitites suggests that the chromitites crystallised *in situ*, not from the introduction of chromite-rich slurries as has been suggested in the past. The question arises as to how 2 m of massive chromitite can form from the proposed Critical Zone magma without being diluted by orthopyroxene. Modeling using the

thermodynamic-based programme MELTS, indicates that, contrary to earlier suggestions, an increase in pressure, mixing with felsic magma, mixing of primitive and evolved magma, or the addition of H₂O will not cause the Critical Zone magma to precipitate chromite in preference to orthopyroxene. Increase in fO_2 would give rise to chromites highly enriched in Fe³⁺, which is not observed in Bushveld chromitites. Critical Zone magma containing > 0.2 wt% Cr₂O₃ will only crystallise chromite alone over a brief temperature interval, before orthopyroxene appears on the liquidus, during which interval less than 20% of the contained Cr₂O₃ will be precipitated. This implies that the the 9.4 m of massive chromitite in the Critical Zone must have crystallised from > 13 km of magma, in comparison with the 1.3-1.7 km of Critical Zone cumulates, a further illustration of the Eales (2000) quandary of the missing Bushveld magma.

PGE in the Bushveld chromitites generally increase upward, except for a decrease in the interval MG-4 to UG-1. The PGE content of the chromitites is tied to the former presence/absence of sulfide, which is thought to be related to the degree of contamination that the Critical Zone magma was undergoing.

It is proposed that the missing Bushveld magma has escaped up the walls of the different Bushveld chambers (the “pudding basin” model) and that the Platreef and Sheba’s Ridge deposits are remnants of its passage (Fig.2). The present location of this magma is uncertain, although [3], amongst others, has proposed that the Malope Farms complex represents some of this magma.

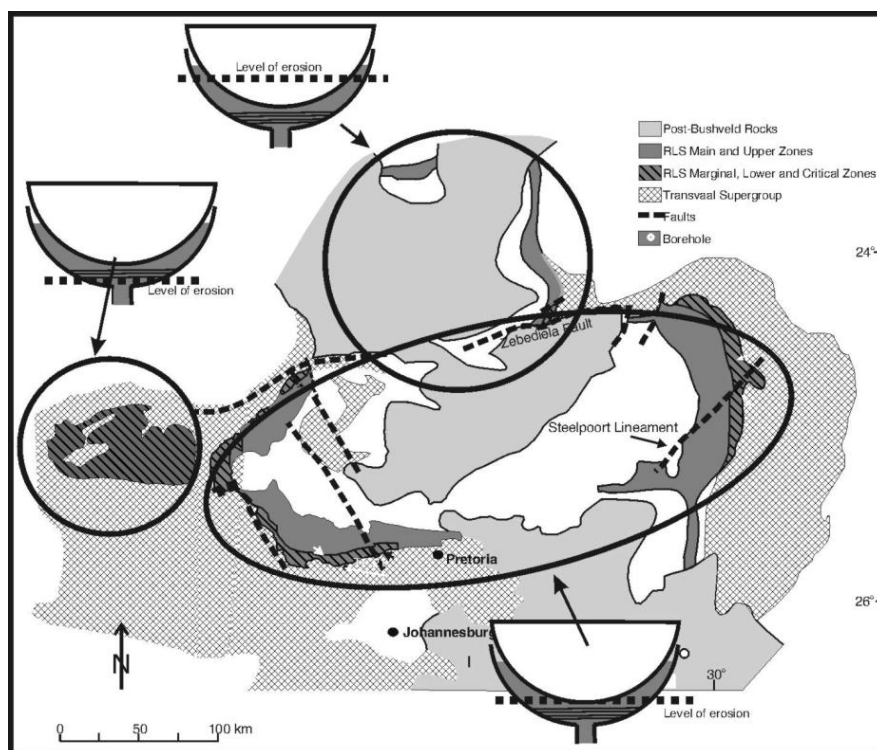


Fig. 2 The pudding basin mode

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Using the NefTex Earth Model for mineral exploration

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This presentation illustrates the strengths of combining the NefTex global plate tectonic model with integrated geoscience data as an effective tool in global screening for greenfield mineral exploration opportunities and providing a better geodynamic understanding of known mineral deposits.

The NefTex Geodynamic Earth Model is a sophisticated global plate model which currently allows reconstructions for any age between 595 Ma and present day. This internally consistent model is supported by our unique understanding of global stratigraphy and tectonics. Within this framework we can identify (and differentiate) geodynamic features of interest including active margins, magmatic arcs, the positions of major continental and oceanic plate boundaries in addition to large igneous provinces, major collisional belts, rifting and the Phanerozoic redistribution of mineral rich Archean terranes.

We will demonstrate how simple exploration concepts can be tested at the global scale in reproducible workflows where the boundary conditions can be evaluated and refined. As an example, we will highlight a workflow for the global identification of Phanerozoic volcanic arc systems and predictions of where they are likely to have intersected subducting ridge segments, which may have led to the development of shallow level copper/gold-enriched porphyritic intrusions and epithermal systems. We can therefore also highlight regions of prolonged subduction, enhanced fluid flow and potential mineral enrichment. The results show remarkable agreement with >85% of the known Phanerozoic porphyry copper, epithermal gold as well as volcanogenic massive sulphide deposits worldwide, providing a predictive framework and global road map for future exploration.

Nickel substitution in iron oxyhydroxides: Combining studies of natural and synthetic materials with implications for nickel extraction from goethite-rich laterites

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The iron oxyhydroxide mineral goethite (α -FeOOH) is the major host of nickel in limonitic zones of nickel laterites and forms from the deep tropical weathering of Mg-rich ultramafic protoliths where significant Ni was present in Mg-silicates. Previous work suggests up to 4wt% Ni can be incorporated into goethite under normal conditions^{1,2}. The purpose of this PhD project is threefold: 1) to understand the importance of the precursor phases in the reaction pathway that enables nickel to become incorporated into goethite; 2) to characterise how nickel is incorporated into the structure of goethite and model the crystal-structure distortions that result from the nickel (Ni^{2+}) for iron (Fe^{3+}) substitution and 3) to use the knowledge of the mineralogical mechanisms, structures and reactions pathways to determine how low-impact nickel leach extraction technologies may be applied to oxide-rich laterite deposits.

Goethite has been synthesized at different temperatures, pH conditions, nickel concentrations and through different reaction pathways. These synthetic products are being characterised chemically and structurally and once the nature of the nickel residence is fully understood, investigations into their leaching behaviour can begin. X-ray diffraction data shows goethite to be the only crystalline phase present in synthetic samples containing up to 10wt% Ni but this is not realistic based on previous work. Excess Ni may therefore be adsorbed onto crystal surfaces or bonded within additional poorly crystalline phases such as ferrihydrite, a well-known precursor to goethite.

Additionally, Ni may have increased the stability of potential precursor phases such as Ni-ferrihydrite or $\text{Ni}(\text{OH})_2$ and thermal analysis (TGA) appears to quantify the relationship between the proportion of precursor phase and the experimental conditions. Samples were then washed using a range of reagents to remove any poorly crystalline precursors and then reanalysed. Raman spectroscopy of leached and un-leached products suggests that ferrihydrite is indeed present in the synthesised material, and it follows that up to 7wt% Ni may be bonded within the crystal structure of ferrihydrite. High-resolution transmission electron microscopy (TEM) reveals the variation in crystallite size for goethites produced via different reaction mechanisms and also shows the effectiveness of different chemical leachates in removing the precursor phases, whilst leaving the goethite intact.

Preliminary conclusions are:

- The maximum nickel substitution level into goethite is actually 2–3 wt%, more consistent with observations in natural goethite.
- Nickel appears to stabilise the goethite precursor phase ferrihydrite which may accommodate the excess nickel.
- EDTA washing removes impurity phases without leaching goethite.
- The amount of ferrihydrite in the sample appears to be influenced by both the presence of nickel and the synthesis conditions.

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Stable isotopic evidence of an evolving fluid system within the Zambian Copperbelt.

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Oxygen, carbon, hydrogen and chlorine isotope analyses were conducted on vein quartz and carbonate samples from Cu+/-Co deposits across the Copperbelt and the Domes Region of Zambia, Central Africa. These samples include deposits within the classic Copperbelt stratigraphy, e.g. Konkola, Konkola North and Nchanga, the basement in this region, e.g. Samba and deposits and prospects from across the Domes region: Lumwana, Kansanshi, Kalumbila-Sentinel and Enterprise.

Oxygen isotope data from vein quartz and carbonate were corrected for temperature using fluid inclusion microthermometric data to give values of $\delta^{18}\text{O}_{\text{fluid}}$. Data from Kansanshi, Lumwana, Nchanga, Kalumbila-Sentinel, Samba, and Musoshi give mean $\delta^{18}\text{O}_{\text{fluid}}$ values ~ -3 to $+5$ ‰. In contrast, Enterprise, Konkola, Konkola North give heavier $\delta^{18}\text{O}_{\text{fluid}}$ values of $\sim +8$ to $+11$ ‰, which may represent basin brines beginning to equilibrate with metasediments and metamorphic rocks [1,2,3]. The $\delta^{13}\text{C}$ of vein carbonates varies from ~ -1.5 ‰ at Kalumbila-Sentinel to -19 ‰ at Konkola. Kansanshi data show a consistent $\delta^{13}\text{C} \sim -3$ ‰ and the data from Konkola and Konkola North are similar. Samples enriched in ^{12}C represent the oxidation of organic matter and subsequent carbonate generation due to ore formation. Samples with isotopic ratios similar to those of Neoproterozoic carbonate reflect the presence of carbonates within the host sediment packages or succession, allowing isotopic buffering. Hydrogen isotope ratios from fluid inclusions within quartz and carbonate vein material from all deposits vary greatly between -116.6 and -16.9 ‰. When combined with the $\delta^{18}\text{O}_{\text{fluid}}$ data, analyses from the Copperbelt plot away from the meteoric water line and seawater. The data for Nchanga show more variation in $\delta^{18}\text{O}_{\text{fluid}}$ than δD , whereas Kansanshi and Lumwana show tight grouping in $\delta^{18}\text{O}_{\text{fluid}}$ and wide variation in δD . Much of the hydrogen data from the Copperbelt shows lighter isotope ratios than expected with regards to the generally accepted palaeolatitude, suggesting a strong fractionation effect is required to produce these results. There is no correlation between yield and light δD and there is no significant difference between data from carbonate and quartz samples, indicating that any influence on the results by structural hydrogen was negligible. Analyses of post kinematic veins from Lumwana and Kansanshi show a wide range of δD values. We suggest that the isotopically light hydrogen may represent the influx of meteoric waters generated at high altitude into the system during orogenesis.

$\delta^{37}\text{Cl}$ measurements from fluid inclusion leachates show little variation and fall around 0 ‰, indicating seawater was the most likely source of chlorinity. Post kinematic veins generally show $\text{Cl}/\text{Br} > 658$ with a negative trend between $\delta^{18}\text{O}_{\text{fluid}}$ and Cl/Br , indicating less oxygen isotopic equilibration in late fluids. Combined with δD evidence suggesting the influx of meteoric fluids, it is proposed that this trend reflects fluid residence time, with early (low Cl/Br) fluids exhibiting heavier $\delta^{18}\text{O}_{\text{fluid}}$ due to longer residence times and lower water-rock ratios for isotopic equilibration.

Fluids in the Copperbelt originated from evaporating seawater formed near the equator, with these fluids sharing many isotopic characteristics of basin brines, subsequently modified by the evolution and inversion of the basin, and orogenesis.

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Mineralogy, geochemistry and small-scale atmospheric acid leach experiments of the Araguaia Nickel laterite deposit

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The mineralogy and geochemistry of the Araguaia nickel laterite was determined using X-ray diffraction, scanning electron microscopy / X-ray energy dispersive spectroscopy and atomic emission spectroscopy. Small-scale atmospheric temperature and pressure sulphuric acid leach experiments were also carried out on sub-samples to investigate the dissolution behaviour of minerals and assess the application atmospheric acid leaching.

The Araguaia nickel laterite is a clay type deposit that developed from a serpentinised peridotite. The weathering profile was characterized as: a thick saprolite zone, dominated by chlorites and smectite; a layered transition containing a mixture of clays and iron oxides; and a discordant limonitic zone containing primarily goethite and hematite. Nickel was found to concentrate in the transition and upper saprolite zone with up to 2 wt% as a result of element-mobilisation from the limonitic zone. SEM analysis of leach residues showed the main nickel bearing minerals are nontronites, clinocllore, talc-chlorite, hematite, goethite and asbolane.

Acid leach results show that the solubility of the laterite minerals in sulphuric acid decreases in the following order: lizardite, nontronite > hematite, clinocllore, Mn oxides > goethite > talc > chromite, maghemite. Nontronites displayed fast incongruent dissolution, releasing up to 1/3 of their nickel content in the first 7 days. Goethite displayed much slower dissolution rates with purer phases preferentially dissolved. Chromite, maghemite and talc were not dissolved and kaolinite was found to absorb nickel from acid solution. Both element substitution and style of dissolution are important factors determining the release of nickel.

After 28 days of leaching, acid solutions of the limonite (0.77 wt% Ni), transition zone (1.4 wt% Ni), saprolite (1.1 wt% Ni) and serpentinite (0.18 wt% Ni) contained 22 ppm, 263 ppm, 229 ppm and 26.9 ppm Ni respectively. Saprolite ore from the Araguaia deposit ore responds more effectively to atmospheric acid leaching than the limonitic ore. Results for the limonitic ore are inconsistent with results from the limonitic ores of the Çaldağ laterite deposit in Turkey where much better results have been demonstrated. The experimental methods used in this project are readily suitable for the characterisation and testing of lateritic ore behaviour prior to larger scale atmospheric acid leach testing.

Ni-Co weathering crust of the Charsk zone in East Kazakhstan

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East Kazakhstan is one of the most important mining areas in Kazakhstan. There are numerous ore concentration plants and metallurgical combines for extraction and processing of base, precious and rare metals. Strengthening of mineral resource base for mining enterprises is important for the region that includes geological structures of the Greater Altai and adjacent regions of Gorny Altai and Chingiz-Tarbagatai. Significant part of the territory is composed of Mesozoic and Cenozoic hypergene weathering crusts that are best developed on the surface or under a thin cover of unconsolidated depositions within the depressions of Semipalatinsk, Irtysh and Zaisan [1].

In 2003, the Altai Division of the Institute of Geological Sciences published a compilation of maps of weathering for East Kazakhstan in scale 1:200 000 [2]. These maps include 17 sheets and cover West Kalba and Zharmasaur zones. As a result of this mapping project, there were defined perspective areas for gold and cobalt-nickel mineralisation, as well as for rare earth elements, titanium and non-metallic mineral resources (bentonitic clays, refractory and fire clays, zeolites and other). Therefore, scientific research focused on studying weathering crusts of Mesozoic-Cenozoic cover and determination of their non-traditional mineral potential for East Kazakhstan appears to be highly relevant [3].

In the Precambrian, as a result of oceanic rifting within the system of deep mantle fault zones, the Charsk-Gornostaevo and Baiguzin-Bulak belts of hyperbasites were formed in the Charsk zone. The Charsk-Gornostaevo ophiolite belt is a suture of the Zaisan collision zone that separated the Kazakh and the Gorny Altai microcontinents. Precambrian ores (Cr, Ni, Co etc.) are controlled by deep mantle faults and occur in xenoliths of metamorphites and protrusions of hyperbasites, in thrust-melange structures, squeezed out during Hercynian collision. In the Mesozoic, Ni-Co ores were accumulated in weathering crusts. There are signs of platinum occurrence in these ores too. Research of previous years showed that the Charsk-Gornostaevo belt is a large ore-bearing structure but it is not sufficiently studied at depth and flanks [4].

A number of Co-Ni deposits have been explored within the Charsk branch of the ophiolitic belt; these deposits are spatially and genetically related to the weathering crust developed over serpentinised hyperbasites. Approved reserves of Ni and Co of the Gornostaevo and Belogorskoe deposits are 130 and 140 thousand tonnes, respectively. Analysis of geological and geophysical data of the Charsk zone shows good perspectives for discoveries of new Ni-Co deposits [5].

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Dating vein-hosted gold deposits in the Caledonides of N. Britain

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The Caledonides of N. Britain host some important vein-hosted gold deposits. However, the relationship between gold mineralization and regional tectonics, magmatism and metamorphism is uncertain. This is primarily due to the absence of precise temporal constraints for the mineralization. Here we report high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ and Re-Os ages for the two largest known deposits at Curraghinalt (470koz, measured.+ indicated) in N. Ireland and Cononish (55koz) in Scotland and discuss these in relation to the regional geological history of the Caledonides.

At Curraghinalt muscovite ($^{40}\text{Ar}/^{39}\text{Ar}$) in vein-hosted clasts of Dalradian wallrock provide a maximum age for mineralization; and molybdenite (Re-Os) and sericite ($^{40}\text{Ar}/^{39}\text{Ar}$) from micro-shears that cross-cut the veins yield a minimum age. K-micas were dated by either $^{40}\text{Ar}/^{39}\text{Ar}$ CO₂ laser step-heating or *in-situ* UV laser ablation. Wall rock muscovite yielded an age of 459 ± 2 Ma, which records the cooling of the host terrane through a ca. 500 °C isograd (post-peak metamorphism). Molybdenite and sericite from different shears yield indistinguishable Re-Os and $^{40}\text{Ar}/^{39}\text{Ar}$ ages at 95% confidence of 458 ± 6 Ma and 453 ± 4 Ma, respectively. These dates temporally bracket and thus constrain gold mineralization at Curraghinalt to within a maximum period of ca 12 Ma (i.e. 461 to 449 Ma). Molybdenite and sericite from the same shear plane yield ages of 459 ± 6 Ma and 424 ± 2 Ma, respectively. We suggest that a later reactivation of the shear caused a resetting of the Ar-Ar system but left the Re-Os system unaffected. Gold mineralization at Curraghinalt, therefore, is part of the Grampian Orogeny and may be classified as an Orogenic gold deposit [1]. The interval ca 460-450Ma is post peak metamorphism (460Ma) and, in N. Ireland, coincided with a period of uplift and pegmatite formation [2]. The occurrence of metamorphic, magmatic, basinal and meteoric fluids at Curraghinalt [3] may be explained by the short time interval between mineralization and peak metamorphism, and also rapid uplift promoting partial melting and contact with surface-derived fluid.

At Cononish K-feldspar crystals growing on pelitic clasts in auriferous quartz vein were dated using Ar/Ar analysis by *in-situ* UV laser ablation and CO₂ laser step heating. The K-feldspar yielded ages of 408 ± 2 Ma and 407 ± 1 Ma, respectively. The age links the mineralization to the Inner Starav granite (408 ± 0.5 Ma) [4] and is close to the late Silurian to early Devonian age bracket for sinistral movements on the Tyndrum Fault [5]. The age for gold mineralization at Cononish is indistinguishable from that in the Rhynie hot spring system, Aberdeenshire (407 ± 1 Ma) [6]. There are also similarities in structural setting and geochemistry (Mo and W anomalies) which suggests that Rhynie represents the leaking top of a Cononish-type system. Gold mineralization at Cononish and Rhynie was emplaced at the very end of the Caledonian Orogeny and followed oblique collision between Laurentia and Baltica/Avalonia. This setting generated a combination of regional-scale strike-slip faulting and magmatism, both favourable for mineralization. In contrast to Curraghinalt, Cononish is best classified as an Intrusion-related deposit [1].

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Porphyry and epithermal systems in subduction and post-subduction settingsRichards, J.P.¹

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Magmatic-hydrothermal porphyry Cu±Mo±Au and related epithermal Au±Cu deposits are formed from fluids that mainly originated as seawater subducted into the upper mantle in hydrated oceanic lithosphere. In fact, the nature of the ore-forming fluids closely resembles seawater in being aqueous, saline, and relatively oxidized. Such fluids, when raised to high temperatures, can readily dissolve Cu, Mo, Fe, Au, and a suite of other elements commonly found in porphyry and epithermal ore-forming environments (Pb, Zn, Ag, Sb, As, etc.).

Seafloor metamorphism of the oceanic lithosphere results in hydration and oxidation. Slab dehydration during prograde high pressure metamorphism (to yield infusible eclogite) releases aqueous fluid plus water-soluble elements (such as alkalis, some metals, and sulfur as sulfate) to the wedge of asthenospheric mantle overlying the subduction zone (and sometimes directly to the base of the overlying lithosphere). Hydration lowers the melting point of hot peridotite in the mantle wedge, such that hydrous basaltic magmas are formed, enriched in sulfate and fluid-mobile elements. The relatively high oxidation state of these primary arc magmas ($\Delta\text{FMQ} = 0$ to $+2$) causes sulfur to be dominantly dissolved as sulfate [1], and chalcophile and siderophile elements (such as Cu, Mo, Au, PGE, etc.) to partition preferentially into the melt (i.e., to behave as incompatible elements [2,3])

Ascent of these magmas into the upper plate lithosphere transports all the ingredients needed for subsequent porphyry and epithermal ore formation towards the upper crustal ore-forming environment. However, this magma flux may meet three possible fates en route: (1) in compressional tectonic settings, or where the flux of magma is low or of short duration, basaltic melts may stall at the base of the crust; (2) in extensional tectonic settings, or where the flux is large, magma may dominantly vent at the surface; or (3) under near-neutral stress states, magma may pool at various crustal depths to form large, long-lived batholiths sourced from lower crustal MASH zones [4,5]. Emplacement of evolved, volatile-rich magmas in cupola zones above such batholiths can generate magmatic-hydrothermal systems and porphyry ± epithermal ore deposits.

The controls on porphyry and epithermal ore formation exerted by primary magma supply rate (likely a function of subduction rate and angle) and regional tectonic stresses, result in the common observation that large deposits and deposits with similar metal ratios (e.g., high or low Cu/Au or Cu/Mo) characterize particular spatial and temporal belts of arc magmatism [6,7]. Large deposits only form where a key sequence of conditions and processes operate optimally; however, the more normal situation is that sub-optimal conditions or inefficient processes result in sub-economic or barren deposits, which are common in arcs worldwide.

A significant proportion of the primary arc magma flux crystallizes at the base of the crust (it is estimated that only ~20% of the arc magmas flux is erupted at the surface; [8]), and ~20% of the total water flux may be trapped as hydrous amphibolitic cumulates in the lower crustal roots of arc systems [9]. In addition, metasomatism may affect the sub-continental lithospheric mantle through which arc magmas and fluids migrate [10]. The potential exists to remobilize this subduction-modified material by a wide range of later tectonic process that can lead to partial melting. The hydrated nature of these amphibolitic residues renders them relatively fusible compared to other more typically anhydrous lower crustal or mantle lithosphere assemblages [11].

Possible post-subduction lithospheric melting scenarios, and consequent ore deposit styles, include [11]:

1. Syn- to late-collisional melting of thickened lower arc crust and/or metasomatized mantle lithosphere. Melting may be triggered by prograde metamorphism of hydrous amphibolites, or increased heat flow to the base of the crust following delamination of all or part of the mantle lithosphere. Because residues from arc magmatism are being melted, the derivative magmas may resemble calc-alkaline arc magmas, albeit commonly with somewhat elevated alkali contents (due to small degrees of partial melting). Ore deposits associated with such collisional magmatism may similarly resemble arc porphyry Cu±Mo±Au deposits, but associated high-sulfidation-type epithermal deposits are less common due to the lower sulfur content of these second-stage melts.
2. Post-collisional or back-arc rifting resulting in elevated geotherms and/or invasion of hot asthenospheric melts, causing partial melting of hydrous arc roots and/or metasomatized mantle lithosphere. The involvement of asthenospheric melts may lead to mafic alkalic magmatism, hybrid (asthenosphere–crustal) melts, or bimodal magmatism. Resultant ore deposits include alkalic-type epithermal deposits (where the asthenospheric component predominates) to felsic porphyry Mo deposits (where crustal melts predominate). As proposed by Pettke et al. [12] for the case of the giant Bingham Canyon porphyry Cu-Mo-Au deposit, such rift-related melting may post-date the original arc magmatism and metasomatism by millions to billions of years. Mumin and Richards [13] have also recently suggested that some magmatic IOCG deposits may similarly form from remobilized arc-metasomatized lithosphere during later rifting events, especially in the Proterozoic.

Depending on the oxidation state during lower crustal MASH processing of the original arc magma flux, cumulate residues may contain greater (relatively reduced) or lesser (relatively oxidized) amounts of magmatic sulfides. Under relatively oxidized conditions, sparse residual sulfides will be rich in chalcophile and highly siderophile elements, and can lead to the formation of Au-rich porphyry and epithermal systems during later partial melting events [11]. Under relatively reduced conditions (e.g., where the precursor lower crust contains reduced assemblages such as graphitic schists) derivative magmas, both during and after subduction, will tend to generate Au-poor porphyry Cu-Mo or S-type porphyry Sn-W deposits, or no significant mineralization at all if lower crustal sulfides are abundant (e.g., Japan [14]).

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New perspectives on the metallogeny of Malaysian tin granites

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The Southeast Asian tin granite province has previously been recognized as comprising three distinct granite belts (1,2); Middle Permian – Late Triassic Eastern Province with mainly subduction-related I-type granites associated with Cu-Au deposits, (2) Late Permian – Early Jurassic Main Range Province with mainly S-type granites associated with Sn-W deposits, and (3) Late Triassic – Cretaceous Western Province with mixed I- and S-type granites associated with Sn-W deposits. These ages were obtained mainly using whole rock Rb-Sr and K-Ar geochronology in the 70s and 80s – our recent work has focused on providing a revised chronological framework using SIMS U-Pb dating of zircon combined with geochemical studies of the various granite bodies sampled, and in so doing contribute to a better understanding of the tectonic, magmatic and metallogenic evolution of the region.

U-Pb dating reveals a westward younging trend across the Malay Peninsula. The Eastern Province hornblende- and biotite-granites in Eastern Malaysia have ages between 220-285 Ma. The Main Range Province, dominantly S-type granites, in west and central Malaysia, have ages between 206-226 Ma. In addition, certain granites of the region are characterized by Cretaceous ages (c. 81-80 Ma) that may indicate a younger magmatic-hydrothermal origin for some tin mineralization from both the Eastern Province (Tioman Island) and the Western province (Phuket, Thailand) (3).

The Main Range granites are typically fairly homogeneous in terms of their mineralogy and major element compositions, but are characterized by extreme variations in certain trace element concentrations, such as Rb, Sr and Ba (4). It is suggested that slow cooling and progressive nucleation, perhaps by sidewall boundary differentiation, at the scale of a magma chamber of batholithic dimensions, caused the extreme variations in Rb-Sr (and Ba) contents. Incompatible trace elements would have been systematically fractionated into the residual liquid, and then subsequently partitioned into the evolving aqueous fluid phase. Such processes could explain the extensive nature of Sn-W-B mineralization on a batholithic scale into pegmatitic fractions, miarolitic cavities and greisen-bordered vein systems.

It is becoming increasingly evident that granites in Malaysia cannot be simply categorized as I-, S- or A-type as they do not exhibit distinctive classification criteria and there is considerable overlap in geochemical characteristics. Likewise tin mineralization is not restricted to S-type granites and the metallogeny of the region is considerably more diverse than generally thought. Additional work is needed in order to place tighter constraints on the magmatic and tectonic evolution of the region, as well as to understand the nature, distribution and controls on mineralization in one of the great strategic metallogenes of the World.

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Digital Technology for Geological Mapping?

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Field mapping is used to gather geological data for analysis and the construction of models. The data gathering has traditionally been undertaken on paper maps with the geologist noting personal observations directly onto a map and additional notes being recorded in a field notebook. This information, typically recorded in pencil, would be required to be 'inked in' in the evening to ensure there was a fair copy of the data for analysis at a later date.

In the mining industry, model-building often begins with data collected during field mapping. When field mapping is carried out digitally, with the right software tools, the user receives the benefits and all the advantages of working with geospatial data yet loses none of the benefits of traditional paper mapping.

The collection of field data in a geo-referenced digital environment allows the user to integrate multiple data types, which can then be quickly referred to in the field (Gibbs 2012). Midland Valley's FieldMove application aims to replicate and enhance the traditional paper mapping experience and is designed to run on rugged tablet PCs. It provides the flexibility to work at multiple scales in one project. Digital mapping removes the potential for errors when generating a 'fair copy' map as there is no need to prepare it separately, allowing the user to directly start data analysis during the field campaign (Clelland et al 2011).

Data captured in FieldMove can also be imported directly into Move where the user has access to a wide range of tools for cross-section construction and 3D model

A redefined structural architecture for the McLeod Road – Birch Lake thrust panel and implications for gold mineralisation at the New Britannia Mine, Snow Lake, Manitoba, CanadaRubingh, K.E.¹, Lafrance, B.² and Gibson, H.³¹⁻³Department of Earth Sciences, Laurentian University, 935 Ramsey Lake Road, Sudbury, ON, P3E 2C6 Canadakate.rubingh@gmail.com

Improved understanding of the volcanic stratigraphy and structural history of the McLeod Road-Birch Lake Thrust (MB) panel suggests that stratigraphic units within the MB panel were imbricated during early bedding-parallel thrusting, followed by the formation of the Nor-Acme anticline and its axial planar cleavage. This axial planar fabric is defined by the flattening of volcanic clasts. It parallels the McLeod Road thrust and is the main foliation observed in the MB panel. A stretching lineation, which is defined by the elongation of the same clasts, lies along the foliation plane. It is parallel to the axis of the Nor Acme anticline and to the slip direction along the McLeod Road thrust. Although the McLeod Road thrust cuts across the Nor-Acme anticline, they share the same foliation and lineation, suggesting that they formed during the same progressive deformation event. The MRT was reactivated as a sinistral shear zone during the formation of a late, north-trending cleavage that overprints the thrust and the Nor-Acme anticline. These structures were later folded around a late open synform, called the Threehouse synform.

The two main deposits in the MB panel are the New Britannia deposit and the No.3 zone. Both deposits are located along lithological contacts and in secondary faults within the hinge of the Nor-Acme anticline. Mineralisation at the New Britannia mine occurs along the Howe Sound fault. The Howe Sound fault offsets the McLeod Road thrust and is oriented roughly perpendicular to the latter fault. Because both faults contains the same flattening foliation and stretching lineation, the Howe Sound fault is interpreted as a transfer fault that formed during thrusting. This suggests that the New Britannia deposit was emplaced during thrusting. The No. 3 zone consists of mineralized sinistral shear veins and oblique extensional veins of quartz and minor iron carbonate. This vein system cuts across the hinge of the Nor-Acme anticline, suggesting that the No.3 zone was emplaced during the formation of the late cleavage associated with sinistral reactivation of the McLeod Road thrust. The formation of gold deposits in the MB panel therefore occurred during two separate structural and mineralization events.

The Nonsulphide zinc mineralization of Reef Ridge, Alaska.

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The Reef Ridge (RR) prospect is located in the McGrath District, Yukon-Koyukuk region of west central Alaska, USA. It represents a "Nonsulphide" zinc deposit, currently under exploration by Doyon, Ltd. Reef Ridge belongs to the Farewell Terrane (FT), long regarded as a piece of the Paleozoic passive margin of Western Canada [1]. More recent studies suggest RR was a micro-continent between the Siberian and Laurentian (North American) cratons during the early Paleozoic [2]. The RR area occurs in one of the FT subterrane, known as the Nixon Fork subterrane (NFST) [3]. The NFST represents a sequence consisting of 3 different stratigraphic units separated by unconformities: 1) Precambrian metamorphic rocks; 2) Lower Paleozoic (Early Ordovician-Late Devonian) platform carbonate rocks; and 3) Upper Paleozoic and Mesozoic clastic rocks. The Reef Ridge nonsulphide zinc deposit is hosted in the Lower Paleozoic (unit 2), which mainly consists of Lower-Middle Devonian highly brecciated shallow water dolomites.

The most significant style of Reef Ridge mineralization consists of nonsulphide zinc ores with minor remnant sulphides. Breccia cement contains zones of patchy sphalerite, with minor amounts of pyrite and/or marcasite, as well as traces of galena. The area has been intensively oxidized, with both goethite and hematite present in surface gossans and in core specimens. Highly brecciated dolomites containing goethite and hematite are characteristic of core and surface samples containing 10% to a high of 48% zinc as primarily smithsonite. A second minor sulphide style of zinc mineralization was noted in two minor drill intercepts. Sulphide zinc mineralization consists of a moderately to strongly silicified lithotype comprised of a sphalerite rich breccia matrix and clasts of strongly silicified dolomite with variable sphalerite mineralization. Drill intercepts containing sphalerite mineralization yielded zinc assays of 8% to 24% zinc. The Reef Ridge area is still an active exploration project. New chemical data (soil sampling) have been collected during the summer 2012 and a new field activity will be planned in summer 2013.

A complete petrographic and mineralogical characterization of both core and surface samples from the Reef Ridge prospect has been carried out in collaboration with the Naples University. Samples were examined using a range of techniques: XRD, chemical analysis, SEM-EDS. Preliminary results indicate that most of the assayed zinc in the nonsulphide ore occurs as smithsonite (with up to 75% weight in a few samples). Smithsonite replaced sphalerite, and precipitated as cement in the micro-macroporosity of the carbonates, as well as in veinlets of various sizes. The highest enrichment, however, is associated with replacement fronts in the dolomite host rock. The unmineralized dolomite contains only traces of iron and rare zinc. However, dolomite fragments in the breccias appear non-mineralized in hand samples yet contain diffuse smithsonite mineralization (as micro crystals <1 µm) in thin section. Small amounts of zinc also occur in Fe-(hydr)oxides, which are present both in core and surface samples (especially in the gossanous specimens). Additionally, zinc traces have been identified in clay minerals (illite/muscovite and kaolinite).

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Jackpot at the P-T boundary: hot LIPs and giant deposits across EurasiaSeltmann, R.¹, Armstrong, R.¹, Schulmann, K.² and Pirajno, F.³¹CERCAMS, NHM London, London, SW7 5BD, UK rs@nhm.ac.uk²Université de Strasbourg, France and Centre for Lithospheric Research, Czech Geological Survey, Prague, Czech Republic³Geological Survey of Western Australia, East Perth and The University of Western Australia; Australia

The Central Asian Orogenic Belt (CAOB, synonymously used to describe the Altaids orogenic collage) was a very busy place in the late Carboniferous to early Permian. An extraordinary number of significant mineral deposits formed at ~290 Ma, including the Muruntau and Bakyrchik gold deposits, the Dhezkazgan copper deposit, and the Kalatongke-Maksut copper-nickel deposits, among many others.

The widespread, bimodal Early Permian magmatism of the CAOB, characterised by numerous A-type granites and mafic-ultramafic intrusions located in fault zones and suture shear zones, often of trans-lithospheric nature and commonly found also in the Permian rift basins, is considered to be essentially “post-collisional”, but it occurs during a time when magmatism should be shutting down at the termination of a Wilson cycle. The collisional phase was northward underthrusting of the continental Tarim Block beneath the Tien Shan region of the CAOB, as evident from structural studies and deep seismic data. However, the tectonic regime is demonstrably extensional or transtensional. Tectonic models have varied from ridge subduction to mantle “superplume” activity, but it is suggested that the magmatism was related to rapid retreat of the same long-term, W-dipping slab associated with accretionary development of the CAOB throughout the Paleozoic. As the Tarim and North China craton continental blocks approached the Siberian craton from the south in the Late Paleozoic, the CAOB was trapped between these two blocks, and it folded to produce the characteristic E-W trending oroclines of the orogen. Synchronously, the underlying oceanic slab retreated eastward as the intervening cratons juxtaposed, producing a transtensional stress regime that induced melting of asthenospheric depleted mantle and refractory lower crust in a distal backarc setting, to produce the Permian A-type granites and coeval mafic rocks. This combined tectono-magmatic scenario set the stage for the mineralization peak taking place at around 290 Ma.

As one example, nickel-copper mineralization associated with small often funnel-shaped mafic-ultramafic intrusions is localized along major fault structures in Central Asia. Many have an age that demonstrates a link with the 290 Ma Tarim Large Igneous Province (LIP). Two of the more significant ca. 290 Ma Ni-Cu bearing intrusive groups are the Maksut complex of Eastern Kazakhstan and the Kalatongke complex of northern Xinjiang region, north-western China, both of which are located along the Irtysh shear fault system. Key features of these Ni-Cu mineralized small intrusions are the association with crustal scale shear zones and the age match with the 290 Ma Tarim LIP. It is inferred that at 290 Ma a mantle plume arrived and spread out beneath the Tarim craton and Junggar block (supposedly spreading out as far as beneath Kurama and Kyzylkum), and that its melts opportunistically ascended along trans-lithospheric shear zones. Further verification of this concept will improve an exploration model of continued focus along these shear zones.

Petrography, Geochemistry, and Isotopic Dating of Eruptive Breccias of the Ryabinovoe Au-Cu Porphyry Deposit (South Yakutiya)

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Eruptive breccias with lamprophyre matrix were recognized and studied within the Ryabinovoe Au-Cu porphyry deposit located in the northwest part of the Elkon Horst in the Central Aldan Shield (South Yakutiya). The deposit is associated with high potassium intrusive rocks of the Ryabinovy stock composed of aegirine-augite alkali-feldspathic syenite, syenite-porphyry, and nordmarkite of the Aldan Suite and lamprophyre and eruptive breccias with lamprophyre matrix belonging to the Tobuk hypabyssal Suite.

The Ryabinovoe copper-gold deposit is related to the northeast endocontact part of the Rybinovy stock. The deposit is one of the largest porphyry-style copper-gold deposits in the Aldan Shield. Total gold resources of the deposit are estimated at 18 t, with grades 2 g/t. Copper grades vary from 0.5 to 1.0%. The ores also contain Mo and Ag with grades of economic interest. The Cu-Au porphyry-style mineralization of the Ryabinovoe deposit is associated with a coarse-grained syenite and syenite porphyry intrusive body, approximately 3 by 2 km in diameter. Ore mineralization of stockwork type is hosted in coarse-grained syenite and syenite-porphyry on the contact with eruptive breccias with lamprophyre matrix. The mineralization is traced to a depth of more than 200 m from exploration drilling. The ore mineralization of vein-disseminated style is accompanied by potassic and adularia-sericite-carbonate wallrock alteration containing impregnation of pyrite and chalcopyrite. Native gold is present in mineralized syenite-porphyry in the form of microinclusions usually less than 0.01 mm in size, confined to grains of pyrite, chalcopyrite and bornite and other minerals. As results of microprobe investigations showed gold is fine, with metal content from 63 to 95%. Silver and, rarely, copper are present as primary admixture.

The studied eruptive breccias with lamprophyre matrix form a series of dykes, dyke-like bodies, and pipes (diatremes) up to 1,500 m long and up to 350 m thick. For example, the Ryabinovoe breccia pipe represents a complicated dyke-like body of 1.5 km long and up to 400 m thick in pipe body swells. Its strike is 25° with dipping towards the SE at angles 70°. The breccia pipe intrudes both least altered and mineralized intense altered syenites of the Aldan complex. The studied eruptive breccias mostly developed within the Ryabinovoe deposit stock correspond to alkaline lamprophyres (SiO₂ – 46-53%, MgO – 6-11%, K₂O+Na₂O – 8-12%, K₂O/Na₂O - 4-11). Mineralogically, breccias matrix is represented by dark-green microcrystalline aggregate of olivine-phlogopite-K-feldspar-clinopyroxene composition with variable admixture of secondary carbonate, chlorite, and serpentine. The breccia matrix includes numerous different-sized sharply angular fragments of syenites and syenite-porphyry (no rarely altered and mineralized) with size from mm to 5-10 cm, sometimes up to 60-90 cm.

Isotopic dating of rocks of the Aldan and Tobuk suites making up the Ryabinovy stock was carried out using local U-Pb (SHRIMP), Rb-Sr, and Re-Os isotopic study of accessory zircons and apatites as well as some of rock-forming minerals of syenites, lamprophyres, eruptive breccias (orthoclase, biotite, aegirine-augite) and their altered varieties (adularia, sericite, pyrite, chalcopyrite). Isotopic data shows that most rocks of the Ryabinovy stock including wallrock alteration and eruptive breccias were formed in the interval of 120-147 Ma that corresponds to Late Jurassic - Early Cretaceous. Formation of the Ryabinovy stock took place as result of intense mantle-crust interaction that proven by obtained high initial ratios of ⁸⁷Sr/⁸⁶Sr and ¹⁸⁷Os/¹⁸⁸Os equal 0.705 and 0.444, respectively.

Epithermal Au-Ag mineralization of the Baimka Cu-Au trend

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The Baimka Cu-Au trend, Northeastern Russia, located in the Oloi structural zone includes deposits Peschanka and Nakhodka, the largest porphyry copper-molybdenum deposits in Russia, and some prospects with total copper resources >20 Mt. Porphyry copper systems were formed in continental arc. The region comprises Upper Jurassic tuffaceous-terrigeneous sequence intruded by bodies of various composition and age. Late Jurassic gabbro is the most ancient. Then, the large bodies of porphyry diorite were intruded at the boundary between Jurassic and Cretaceous. The magmatic activity terminated in Early Cretaceous (U/Pb age of zircon 138-141 Ma) by the intrusion of large subalkaline pluton that is accompanied with numerous stocks and dykes of porphyry quartz monzonite and porphyry syenite. Porphyry Cu-Mo mineralization with the Re/Os age of 138±11 Ma determined from molybdenite is related to the late phase of this pluton.

Epithermal Au-Ag mineralization is not typical of the trend because of deeply eroded volcanic edifices intruded by subalkaline plutons and porphyry stocks, with which Cu-Mo mineralization is associated. The Au-Ag mineralization is economically important only at the Nakhodka deposit, where it occurs in the shallowest eroded southern part of the porphyry system. Epithermal Au-Ag mineralization occurs in quartz-carbonate veins and veinlets of 0.5-3 m thick hosted in both quartz-sericite and argillic rocks. These veinlets and veins are grouped in zones of 10-50 m in thickness and 500-1200 m in length. The ore texture is impregnation and breccia. The average grade is: 2.9 g/t Au, 56 g/t Ag, 0.9% Pb+Zn, and 0.15% Cu. The Ag:Au ratio ranges from 7:1 to 20:1. At the depth of 150-200 m below surface, veins and veinlets cut Cu-Mo stockwork that indicates the later deposition of epithermal Au-Ag mineralization.

The major epithermal ore minerals are As-rich pyrite, chalcopyrite, galena, sphalerite, and Zn-rich tennantite-tetrahedrite; electrum, native gold, hessite, and altaite are minor; petzite, pearceite, stützite, and acanthite are rare. Gangue minerals are quartz, calcite, dickite, illite, clinocllore, dravite, rhodochrosite, and Mn-rich dolomite. Low fineness gold (756-857) and electrum (657-743) enclosed and filling fractures in pyrite, galena, and tennantite-tetrahedrite are intimately intergrown with hessite and petzite.

In the central part of Nakhodka and at the Peschanka deposit, we have found very rare enargite, digenite, Fe-rich tennantite, native tellurium, clausthalite, gold of high fineness (>900), and not previously identified Te and Se phases.

Only one type of primary inclusions – aqueous solution with gas bubble – was established in vein quartz and sphalerite. These inclusions homogenized at 120-275°C contain fluid with salinity of 0.7-5.1 wt % eq NaCl.

According to geological setting, mineralogical and fluid inclusion study, the epithermal Au-Ag mineralization studied here is attributed to the intermediate and high sulfidation types. The former retained only at the flanks of deposit, whereas the latter is nearly complete eroded.

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Exploration and discovery of base- and precious-metal deposits in the circum-Pacific region

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Exploration in the magmatic arc terranes of the circum-Pacific region over the last decade for which full documentation is available (1998-2008) led to 31 major base- and precious-metal discoveries. All are dominated by gold, copper or, to a much lesser degree, silver, with more than two-thirds being porphyry copper ± gold and low- and intermediate-sulphidation epithermal gold-silver deposits. However, breccia- and sediment-hosted gold-silver + zinc-lead/copper, iron oxide-copper-gold (IOCG), pluton-related gold, skarn gold, sediment-hosted gold and gold-rich volcanogenic massive sulphide (VMS) are also represented. The majority of the deposits are located in Latin America, in particular Chile, Peru and Mexico, but also in Argentina, Colombia and Ecuador. The U. S. A. is also prominently represented as, to lesser degrees, are Indonesia, the Philippines, Russia and Australia.

The contributions to discovery of major, mid-tier and junior companies are determined. The discoveries are analysed from the standpoint of their location with respect to operating mines (greenfields versus brownfields) and old mineral districts or occurrences, and whether the mineralization is concealed beneath barren pre- and/or post-mineralization cover or at least partially exposed. The roles of different geological, geochemical and geophysical methods as well as other factors in the discovery process are assessed.

The conclusions are then used as a basis for comparison of circum-Pacific discovery over the decade under consideration with that for the preceding 30-year period. Many basic similarities between the two time slices are evident, although several outstanding differences regarding the discoverers and discovery methods become clearly apparent since the late 1990s. Less dramatic are changes in deposit types and the countries in which discovery took place.

Synthesis of the general conclusions for the entire 40-year period under review reveals a straightforward strategy for discovery of base- and precious-metal deposits in the circum-Pacific region. The strategy differs little from that utilised over the past several decades, without any significant contribution from high-tech approaches advocated by some recent observers. The role of scientific excellence and innovation remain pre-eminent. The currently successful discovery methodology is thought likely to remain valid for the foreseeable future, although several specific additions and modifications could be of potential benefit.

Distribution of critical metals in biotite and Li mica granite from Cornwall, UK.Simons, B.S.^{1*}, Andersen, J.C.Ø.¹ and Shail, R.K.¹

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The growing demand for low carbon energy technologies feeds a rising demand for a number of metals that have not been the traditional targets for large scale mining. Lithium (Li), beryllium (Be), gallium (Ga), germanium (Ge), tungsten (W), bismuth (Bi), indium (In), antimony (Sb) and the rare earth elements (REE) are vital components in wind turbines, photovoltaic cells and nuclear power. Many of these metals are now considered to be critical for the development of technologies in the EU, and this has led to the realization that their supply cannot be taken for granted. The increased demand for these metals has not been met by proportionate increases in their supply, and this has led to the production of a number of “risk lists” ([1], [2], [3]) for metals that are considered to be of particular strategic significance. The supply issues have led to a greater emphasis on the identification of domestic resources, yet such exploration is limited by the poor knowledge of the behaviour of these elements during geological processes.

The polymetallic mining district in Cornwall and SW Devon has mineral deposits with significant concentrations of a number of these “critical metals”. Sb, Bi and W have historically been mined within the county and currently the contents of metals such as W, Sn and In are significant for the economic potential of active mineral prospects in SW England (Wolf Minerals at Hemerdon in S Devon, New Age Exploration at Redmoor, and Western United Mines at South Crofty).

This study investigates the distribution of the critical metals within a sample of the Carnmenellis granite (from Holman’s test mine near Camborne) and from samples within the St. Austell and Tregonning Li mica granites. The samples were selected because of their unaltered and un-mineralised characteristics.

Preliminary whole rock data for indicate that all of the metals listed above are present in higher concentrations in the granites than expected for crustal rocks. Be, Ge, As, Cd, In, Sn and Sb are more enriched in the older biotite granite whereas Li, Ga, Nb, Ta, W and Bi are more enriched in the evolved younger Li mica granite. This split of the critical metals between the granite types conforms to the chalcophile (Ge, As, Cd, In, Sn, Sb) and lithophile (Li, Ga, Nb, Ta, and W) classification of Goldschmidt [4] indicating possible exploration targets for the metal groups. In both granite types the micas are important as hosts for the critical metals.

Ultimately over the course of the study, several granite and mafic samples from across the region extending from Dartmoor to the Isles of Scilly will be analysed by ICP-MS to establish the baseline values of critical metals within the region. The study aims to better constrain the concentrations and partitioning of the critical metals between the granitic source magma and common silicate minerals. It will be used to assess the significance of the host granites as sources for critical metals in the magmatic-hydrothermal mineralisation styles and to help inform exploration for further resources.

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Magmatic or hydrothermal? High purity quartz from south Norwegian pegmatites

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High Purity Quartz (HPQ; quartz containing less than 50 ppm trace elements [1]), is of increasing economic significance due to its necessity in new types of high tech components (computer chip and semiconductor manufacture) and green technology (silicon wafer production) [2]. Current HPQ deposits (such as hydrothermal veins and leuco-granites/alaskites) are extremely rare and volumetrically small. Unless significant new deposits are found, increasing demand for HPQ will raise its price, elevating the strategic nature of this limited commodity. The large volumes and simple mineralogy of pegmatites and the high chemical purity of their constituents make them an attractive target for HPQ. Trace element, cathodoluminescence (CL) and O-isotope data will be presented from PhD studies being carried out on quartz from the Evje-Iveland pegmatite field of the Bamble-Evje pegmatite cluster, southern Norway. The area was targeted due to its well constrained geological setting and previously identified potential for HPQ (e.g. [3]); there are HPQ pegmatites elsewhere in Norway e.g. Drag. The overall aims of the investigation are to develop exploration tools for HPQ by determining the genetic history of the pegmatites and mode of HPQ formation.

The study initially focussed on the profiling of 7 pegmatites and their host rocks, obtaining whole-rock geochemical compositions from relatively fine grained 'chilled margin' facies and country rocks (including the proximal Høvringsvatnet granite which has been suggested to be genetically linked to the pegmatites [4]) and assessing pegmatite mineral compositions. Quartz studies consisted of CL imaging in scanning electron microscope (SEM) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Field studies (corroborated by geochemical modelling) indicate the Iveland pegmatite formed by 'in situ' partial melting of host meta-gabbros, whilst others originated from more distal sources. Each pegmatite shows distinctive zonation, with quartz/feldspar intergrowths at the margins, a massive quartz core and a variety of accessory (including REE-bearing) phases. For pegmatite quartz, no relationship could be found between its trace element content and the degree of fractionation in each pegmatite body. From the trace element compositions of the pegmatites and the U/Pb age of the granites, it is deemed highly unlikely that the pegmatites formed by fractional crystallisation of melts represented by the Høvringsvatnet granite.

Certain pegmatites (the Landsverk region) contain brecciated feldspar and replacement quartz, interpreted to be of 'hydrothermal' origin. From LA-ICP-MS data, hydrothermal quartz, compared with magmatic quartz, shows relatively elevated levels of Al and Li, low Ge and a complete absence of Ti, indicating relatively low temperature formation. Different quartz domains (revealed by SEM-CL) show distinct $\delta^{18}\text{O}$ values; late stage low trace element zones show values consistent with derivation from meteoric fluids. In situ LA-ICP-MS chemistry and future fluid inclusion studies will provide further information about the composition of the fluids which have replaced/refined magmatic quartz with high purity meteoric/hydrothermal quartz. This beneficiation process is a potential mechanism for the generation of economically significant HPQ deposits.

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Lower crustal cumulates and porphyry fertility

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A number of recent studies have concluded that primitive arc magmas will tend to fractionate a sulphide phase in the lower crust, due to MORB-comparable redox states of the primitive melts [1], or the onset of crystallisation causing a shift to lower fO_2 [2]. Chalcophile/ siderophile elements, including Cu and Au, will therefore be sequestered into lower crustal cumulates. Recycling of these lower crustal cumulates can generate fertile magmas capable of generating Cu and Au mineralisation in the mid to upper crust, either syn- [3] or post-subduction [4].

Lower crustal cumulates may include ultramafic to mafic rock types, such as gabbros, dunites, pyroxenites and hornblendites [5]. Amphibole-bearing facies in particular are capable of partially melting and generating fertile melts [3,4,6] and the water content of amphibole-rich assemblages is necessary for the formation of magmas sufficiently hydrous to exsolve an aqueous phase in the mid to upper crust and form hydrothermal mineralisation.

The presence of abundant amphibole in the lower crust of volcanic arcs is confirmed by the chemistry of the erupted magmas [6], and xenoliths/ autoliths [5,7], but the formation of these cumulates is considered “cryptic”: amphibole is not a common or abundant phase in erupted suites, even where evidence of its fractionation remains.

A suite of xenolith samples from Savo volcano, Solomon Islands, show textures that indicate the formation of amphibole in cumulates is by metasomatic reaction of evolving melt with already-formed clinopyroxenes. Experimental studies of primitive arc magma crystallisation support the conclusion that amphibole forms at the expense of previously crystallised pyroxene [8]. Cryptic fractionation thus occurs by the overprinting of pyroxenites in the cumulate pile (“mush”) by through-going evolved silicate liquids. Daughter melts migrating from the mush to the upper crust and surface may be amphibole-poor for a number of reasons: the melts move to pressures below the lower stability limit for amphibole [9]; the metasomatism of the cumulate pile may lead to a net loss of water in the daughter melt and clinopyroxene will be favoured in the drier melts; and/or the melts dispatched from the mush are superheated relative to their liquidus and will resorb any entrained crystals, and not begin a second phase of crystallisation until lower pressures and temperatures [10].

Nominally anhydrous cumulate assemblages can be progressively hydrated by repeated or prolonged magmatism in a “hot zone” [10] and thus can be later recycled to boost water, Cu and Au contents of melts leaving the hot zone. Periods of Cu-Au mineralisation in arcs are favoured when the cumulate sequence is disrupted and recycled.

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The nature and setting of PGE mineralisation in the Rooipoort area, south of Mokopane, northern Bushveld Complex

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The northern limb of the Bushveld Complex is currently a highly active area for platinum-group element (PGE) exploration and research. This limb is host to a number of PGE deposits with the most significant being the Platreef, which represents the third largest PGE deposit in the world. The Platreef forms the base of the mafic succession north of Mokopane and is developed as a 10-400m thick package comprising texturally heterogeneous and variably altered pyroxenitic lithologies [1 and 2]. To the south of Mokopane, where the Platreef is considered absent a 400-800m thick layered package termed the Grasvally Norite-Pyroxenite-Anorthosite (GNPA) member is developed. The GNPA member is lithologically distinct from the Platreef, comprised predominantly of gabbro-norites, norites, anorthosites and pyroxenites, with two laterally continuous PGE-rich chomitites developed towards the base. PGE mineralization is associated with discontinuous sulphide enriched zones with typical grades ranging between 1 and 4 ppm (3PGE+Au). Pt/Pd ratios are consistently lower than the Platreef at <1 [3].

The observed distribution and mineralogy of PGE and BMS mineralisation within the GNPA member is considered to result from the interplay of both magmatic processes and low temperature alteration. The initial style of BMS and PGE mineralisation is magmatic in origin and characterised by the primary sulphide assemblage pyrrhotite-chalcopyrite-pentlandite with Pt-As and Pd-Bi-Te platinum group minerals (PGM). Low temperature alteration has altered much of the primary mineralogy developing pyrite and millerite dominated assemblages with associated Sb-bearing PGM. The PGE, Ni and Cu were initially concentrated and collected by an immiscible sulphide liquid within the GNPA magma. During crystallisation, PGE formed discrete PGM and also partitioned into pyrrhotite and pentlandite forming a typically magmatic distribution [4]. The presence of PGE in solid solution within the secondary pyrite and millerite implies these phases altered from the primary sulphides. Although PGE have remained in solid solution during alteration there is also evidence to suggest that low temperature alteration resulted in the partial remobilisation of Pd and Au thus disturbing the primary distribution of PGE.

A comprehensive S isotopic study has revealed that the GNPA member primary and secondary sulphides exhibit S values indicative of both mantle ($\delta^{34}\text{S}$ -1.8 to 2.4‰) and crustal derived S with an overall range of $\delta^{34}\text{S}$ +1‰ to +7‰. Whether the addition of crustal S was critical in the genesis of PGE mineralisation currently remains unclear.

There is currently a strong effort to constrain the relationship of the northern limb with the rest of the Bushveld Complex which has been made difficult due to the complexity of the northern limb ore-bodies. Before this can be achieved however it is critical that the relationship between the Platreef and GNPA member is fully constrained and understood.

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Metallurgical investigation of the ore from Cononish gold deposit, Scotland

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The Cononish Gold deposit is located approximately 4 km SW of the village of Tyndrum, Perthshire, Scotland containing a measured, indicated and inferred resource of 169,200 Oz's Au^[1]. The owners of the deposit Scotgold Resources have been granted planning permission to develop an underground mine at the site and are currently working to begin mining operations. The deposit consist of a narrow (<6 m) wide vein system that is structurally controlled within the Eas Anie fault, which forms a minor splay of the Tyndrum fault.

This study is being undertaken as part of a larger interdepartmental project at the University of Leicester between the Geology and Chemistry departments. The aim is to develop new hydrometallurgical methods of extraction of the gold from the deposit using ionic solutions as solvents. To optimise this process detailed and accurate data needs to be obtained on the properties of the ore. Investigation of exposure in the 700 m exploration adit, developed in 1989/90 by the previous owner, combined with hand specimens and thin sections collected from the underground exploration adit has been conducted.

Observations show there has been protracted veining and brittle fracturing within the hosting Eas Anie fault structure, with previous workers^{[2][3]} and preliminary results indicating at least four generations of veining: 1) Early coarse quartz veins with coarse pyrite. 2) White quartz with pyrite, galena, chalcopyrite and gold deposited in fractures within earlier veins. 3) Dark veins of quartz with disseminated very fine sulphides associated with shearing and observed to crosscut previous generations. 4) Later vuggy friable quartz with galena. Preliminary investigations of the location of the gold within the deposit show that the majority of it is associated with stage 2 veining and is located on grain boundaries and in fractures of stage 1 sulphides.

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The roles of intermediate density fluids, vapours and brines in the formation of Mo-rich porphyries: Evidence from the El Teniente Cu-Mo deposit, Chile

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The El Teniente porphyry Cu-Mo deposit, Chile, is one of the World's largest and most complex hydrothermal ore systems, with a current and mined resource total > 1.4 Mt Mo [1]. Vein distribution analysis along several drillcores reveals that typical Mo ore grades (e.g. 0.02 wt.%) are controlled by the abundance of main-mineralisation stage quartz veins. However, highest Mo grades (e.g. 0.09 wt.%) coincide with the presence of late-stage (tourmaline-anhydrite-carbonate-gypsum) veins and breccias that are particularly abundant at shallow mine levels. Analysis of fluid inclusions in quartz, anhydrite and gypsum was undertaken in order to identify the hydrothermal fluid characteristics that promoted Mo transportation and deposition in the two distinct phases of Mo mineralisation. Results reveal that Mo was transported by fluids with highly contrasting densities and salinities that deposited Mo under different pressures-temperature [P-T] and pH conditions as the system evolved.

At shallow mine levels (1800-2200 m asl) main-mineralisation stage veins are dominated by the presence of liquid-rich fluid inclusions ($V_f = 20-50\%$) that have salinities of 1-19 wt.% NaCl_{eq} . Intermediate-low density fluid inclusions ($V_f = 40-70\%$) with a consistent salinity range persist to deep mine levels (1200 m asl). This indicates that Mo was partitioned at depth into low density fluids/vapours that contracted during ascent. Previous LA-ICP-MS analyses of main-stage veins show that the highest Mo concentrations occur in high salinity fluid inclusions [1,2,3]. However, the low abundance of brine and coexisting vapour inclusions in these veins suggests that Mo was predominantly deposited from the contracting, single-phase fluids prior to significant vapour-brine unmixing. This occurred at consistent homogenisation temperatures [T_h] (360-390°C) and prior to the onset of sericitic alteration, which occurs at temperatures of <450°C [4].

Late-mineralisation stage tourmaline-anhydrite breccias are abundant at shallow mine levels and are dominated by the presence of low density vapour and brine inclusions. Brine inclusions display a range of salinities (30-65 wt.% NaCl_{eq}) and homogenise, together with vapour inclusions, over a range of temperatures (220-470°C). This is attributed to large fluctuations in pressure during late-stage brecciation events with associated boiling. Although intermediate density fluid inclusions are rare, the presence of boiling trails in two samples suggests that Mo may have partitioned from highly evolved magma into single-phase fluids that subsequently unmixed. This vapour-brine partitioning is likely to have further concentrated Mo into dense brines as highly soluble ion pairs, including KHMnO_4 , Na_2MoO_4 and K_2MoO_4 (aq) [5]. This enhanced solubility may explain the deposition of Mo under lower P-T-pH conditions than in the main-mineralisation stage, as indicated by the presence of intense quartz-sericite alteration. Additional late-stage Mo deposition occurred in veins that exploit radial and NW-trending faults, which opened during the final stages of deposit formation. Veins of quartz-anhydrite-carbonate contain inclusions with a mix of V_f s (20-90) and low salinities (3-9 wt.% NaCl_{eq}) that homogenise between 350-450°C. These veins are often replaced by gypsum, containing aqueous fluid inclusions ($V_f = 10-30\%$) with low salinities (2-10 wt.% NaCl_{eq}) and T_h values (160-280°C). Further fluid inclusion analysis and Re-Os molybdenite dating is underway to determine the exact nature and timing of these final Mo-bearing fluids.

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Investigating the Controls on Critical Metal Distribution in Porphyry Deposits

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Porphyry copper deposits are often associated with copper, molybdenum and gold mineralisation; however some are also enriched in so called critical metals, which include the Platinum Group Elements (PGEs), tellurium, selenium, rhenium and silver. This study is investigating critical metal enrichment in high level calc-alkaline systems in Greece and Turkey, testing the hypothesis that enhanced levels of critical metals in porphyry systems results from the interaction between the porphyry magmas and pre-existing mafic and ultramafic rocks, rather than from mantle derived melts. The first case study is the Muratdere deposit in western Turkey, a joint venture between Stratex International Plc. and Pragma. This Cu-Au porphyry system is hosted in a suite of Palaeocene-Eocene granodiorite and quartz-feldspar porphyry intrusions, with a strike length of 4000m, a width of 200m and shows significant Mo, Ag, Te and Re credits. The porphyry system intrudes a Cretaceous ophiolite melange and is covered by Pliocene conglomerates and Quaternary alluvium. Core logging revealed several generations of veins and mineralisation, along with extensive potassic alteration. An initial quartz-pyrite vein set is associated with the majority of the Cu-Au mineralisation, along with a later disseminated pyrite-chalcopyrite phase. Molybdenite is disseminated within the host rock, and in quartz veins which cross-cut the earlier quartz-pyrite veins. High Re concentrations, up to 2.37 ppm, are associated with an increase in molybdenite content which suggests it was introduced during the same mineralisation phase. A later faulting event generated a series of breccias which are also associated with increased Re. This may indicate the fault planes acted as a conduit for a second Re formation event, however not all the breccias show this enrichment, so they may be intersecting previously enriched Re-rich areas of the system. The Muratdere deposit also contains Te, up to 5.9 ppm, which is associated with a late polymetallic quartz vein generation, characterised by abundant sphalerite, pyrite and molybdenite and containing significant contents of lead and zinc.

These initial studies recognise a series of vein events, each with discrete chemistry and mineralization. This suggests that the Re formation is part of a multiphase evolution of the porphyry system, with the Re-Mo event postdating the main Cu-Au mineralization and associated with K-spar alteration and the presence of magnetite. The Te-Pb-Zn event postdates the main Re-Mo event but predates the breccia formation which may constitute a second phase of Re formation. There is a notable destruction of grade by a later propylitic event.

The nature and genesis of PGE-rich sulphide horizons on the farm War Springs, northern Bushveld Complex, South Africa

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The northern limb of the Bushveld Complex is part of the world's largest repository of platinum group elements (PGEs). Whilst its Eastern and Western counterparts are largely predictable in terms of mineralisation – occurring in the laterally continuous Upper-Group 2 (UG2) chromitite and Merensky Reef – the northern limb is somewhat more enigmatic [1]. Mineralisation north of Mokopane occurs within the Platreef; south of Mokopane, and of the Ysterberg-Planknek Fault, mineralised packages are much more discontinuous and do not appear to correlate with the Platreef [2].

Two boreholes from Platinum Group Metals' project on the farm War Springs (or 'Oorlogfontein') are being studied to determine the nature and genesis of mineralised horizons, for comparison with both the Platreef to the north, and the GNPA member to the south [1],[2].

Sulphide mineralogy appears to correlate somewhat with that of the GNPA member, with primary magmatic pyrrhotite-pentlandite-chalcopyrite assemblages being replaced by pyrite and millerite. Sulphides tend to occur as interstitial disseminated patches or polyphase blebs within all of the rock types studied. Sulphide inclusions within chromite grains have not been found at War Springs.

A comprehensive platinum-group mineral (PGM) study is being undertaken. Initial results from over 100 individual PGM identified show the majority being Palladium (Pd) rather than Platinum (Pt) dominated. This is consistent with the generally low Pt/Pd ratios across both boreholes [3]. The compositional types of PGM vary with lithology. Within mottled anorthosite and pyroxenite, tellurides and bismuthotellurides dominate, with rarer arsenides and antimonides. The chromitite is dominated by Pt, Pd-Hg and Ru sulphides as well as irarsite (IrAsS). Interpretations remain tentative at this stage, however it is clear that the PGMs have been precipitated by primary magmatic processes (tellurides and bismuthotellurides), and also from the interaction with hydrothermal fluids (arsenides, antimonides). The dominance of primary magmatic minerals may suggest that hydrothermal activity (possibly related to localised contamination from floor rock sediments) has been a remobilising, rather than orebody forming event [4].

These interpretations will be tested further during analysis of sulphur isotopes on the sulphides; more detailed mineralogy and bulk geochemistry will allow greater comparison between the rocks at War Springs and those at Rooipoort and Grasvally in order to try and correlate the local stratigraphy of this poorly understood sector of the Bushveld Complex.

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Plateau driven porphyry formation? The geodynamic context of Cu + Au mineralisation in the Solomon Island Arc

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The Solomon Island-Bougainville arc, SW Pacific, is host to one of the largest Au-rich porphyry deposits at Panguna, the low sulphidation Gold Ridge Mine and numerous other Plio-Pleistocene aged porphyry and epithermal prospects formed in association with high Sr/Y magmatic signatures indicative of hydrous arc magmatism [1,2]. Abundant, young mineralisation occurring after collision and accretion of the Ontong Java Plateau (OJP) and a forced reversal of subduction zone polarity has drawn attention to empirical links between this complexity in its tectonic evolution and potential for deposit formation [3], yet no evidence for the causal relationship has been identified.

To examine the interplay between geodynamic setting and mineralisation in the arc we adopt a combined approach of field observations, U-Pb geochronology and igneous geochemistry. We identify that wide-spread porphyry and epithermal mineralisation occurred notably, prior, to reversal of subduction zone polarity. Late Oligocene-Early Miocene mineralised intrusions reveal that rather than a simple intra-oceanic setting, the arc has evolved through cyclical extension and shortening following rifting from the Australian continent.

Interaction between the OJP and the arc at 26 Ma caused a contraction of the arc, during which voluminous intrusive stocks formed in shallow, dry conditions. Subsequent melts with anomalous HFSE fractionation and trace element chemistry indicate that melting of an amphibole-rich reservoir occurred and was the important step to produce hydrous melts emplaced into the thickened arc crust. Early Miocene intrusions prior to extensive uplift and erosion were associated with mineralisation and elevated Sr/Y. The transition to fertile, hydrous melts was rapid (<2 Ma) and correlates with changes in Australian Plate motions. Melting of the lower crustal amphibole-rich reservoir was likely driven by thermal disturbance during Pacific Slab break off.

Collision of the OJP and thickening of the arc was key for the development of a metal bearing, hydrous amphibole-rich reservoir [4]. Early Miocene mineralisation was an expression of this change in crustal nature and magmatic processes. The post-collision setting has not allowed the arc to re-enter an extension phase and various styles of Plio-Pleistocene magma genesis have caused the continued recharge and liberation of volatiles from the reservoir, giving rise to a fertile environment for Cu and Au mineralisation.

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By-product potential of critical metals (Nb/Ta/REE/W) and Sn within IMERYS kaolin operational areas, St Austell Granite, Cornwall

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With current global economics and supply-demand changing towards high-tech and more environmentally friendly technologies, the price of tin (Sn), tungsten (W), tantalum (Ta), niobium (Nb) and rare earth elements (REEs) have risen sharply within the last seven years (although declined during 2012) which has resulted in interest to re-evaluate potential resources within the UK. Historic extraction of cassiterite and wolframite from former kaolin pits and previously published works suggesting Nb/Ta enrichment [1], suggests the St Austell Granite (SAG) as a suitable target for investigation. The distribution of minerals hosting critical metals within the SAG is likely to be influenced by variable mineralogical and textural types of granite within the study area. IMERYS Minerals Ltd (IML) currently operates as the major kaolin producer from the SAG and is keen to evaluate the potential for commercial extraction of critical metals as a by-product to kaolin. This will be achieved by utilising the knowledge base, skills and capabilities from the University of Exeter in a joint venture with IML.

A pilot study aiming to understand the nature of the disseminated mineralisation and characterisation of heavy mineral content in the principal unaltered granite types of the SAG has been undertaken. Five unaltered granite samples were processed representing the different granite types of the St Austell Granite currently defined [2]: Biotite Granite, Tourmaline Granite, Fine Grained Tourmaline Granite, Li Mica Granite and Topaz Granite. Samples were geochemically analysed by X-Ray Fluorescence (XRF) to assess the current granite classification scheme. Heavy mineral concentrates and off-cuts of samples were analysed by Quantitative Evaluation of Mineral by scanning electron microscopy (QEMSCAN) and optical microscopy.

A broad correlation between the results of the pilot study and the former granite classification scheme was identified, however, depleted in Rb. Nb/Zr and Nb/Y plots proved a more effective method at defining differences between granite types. Major geochemical variances of K₂O and Na₂O give a suitable preliminary classification, which may be more robust than using previously published maps and mineralogy to classify the granites. QEMSCAN analyses shows cassiterite as being the most abundant target mineral comprising 3.9% average in all concentrates, ilmenorutile, monazite and columbite with average concentrations of 1.3%, 0.7% and 0.3% respectively. Cassiterite was most concentrated in the Tourmaline Granite, ilmenorutile, monazite and columbite most concentrated in the Li Mica Granite, Biotite Granite and Topaz Granite respectively. This project has reported preliminary evidence to suggest that cassiterite is disseminated within granites at larger grain sizes than previously suggested [3], and provides an idea of the locations and concentrations of disseminated mineralisation in the unaltered granite types of the SAG.

Current work aims to improve the confidence of the pilot study results by expanding the sample density to sixty samples and include samples from the former Goonvean Kaolin operations. With a better understanding of the unaltered mineralisation, this project will then assess the effect of kaolinisation alteration and vein assemblages on mineral mobility, taking particular note of current operational waste streams. The result will be a resource model allowing the identification of areas with the potential for heavy mineral recovery.

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Discrete element modelling experiments on the formation of layer-parallel veins in multilayer sequences

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Mechanical anisotropy caused by layering in rocks and the occurrence of pre-existing layer-parallel veins can have an influence on formation of subsequent layer-parallel veins. We use Discrete Element Modelling (DEM) with the ESyS-Particle code [1] to gain insight into the parameters that control the formation, spatial and thickness distribution of layer-parallel veins in multilayer sequences.

Virtual rock samples are represented numerically in 2D by packings of spherical discrete elements. An insertion-based algorithm generates isotropic, randomised particle packings with a power-law particle-size distribution. These spheres interact with each other through frictional and bonded interactions. Brittle failure is represented by the breaking of these bonds. The coalescence of multiple broken bonds represents a fracture. These fractures can subsequently be filled with new discrete elements, effectively modelling the formation of veins.

Four parameter sets of mechanical micro properties of inter-particle bonds are defined in the models, essentially yielding (1) a competent and (2) incompetent matrix, (3) a vein material and (4) a vein-matrix interface. Each combination of parameters and particle packings is calibrated to fit a predetermined Mohr-Coulomb type failure envelope, via an automated calibration procedure.

Several multilayer models are generated and these numerical specimens are brought to extensional failure under constant strain rates by gradually changing effective stress states at the model boundaries. Different types of veins and vein generations can be modelled, ranging from single veins, over crack-seal veins to anastomosing veins, by varying the mechanical strength of competent and incompetent matrix, vein and interface material. Our approach allows a systematic study of the mechanical parameters controlling the progressive formation of layer-parallel veins, vein spacing and fracture and vein thickness distributions. In particular, the influence of mechanical anisotropy caused by lithological layering and/or pre-existing veins can be assessed.

Here we present preliminary results on these DEM experiments and some first insights gained from the parameter sensitivity study. We tentatively compare the modelling results with some natural vein systems, which will be the focus of further study.

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The Massawa gold deposit, Eastern Senegal, West Africa: an orogenic gold deposit sourced from magmatically derived fluids?

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The Massawa gold project is situated on the Senegalese side of the highly prospective/productive Kédougou-Kéniéba inlier, which hosts several world-class orogenic gold deposits/districts in western Mali (e.g. Loulo and Sadiola). The Massawa orebody has a strike length of at least 4 km and a current resource of 3.61Moz of gold at an average grade of 2.76g ton⁻¹. The ore body is structurally controlled and located within a package of low grade regionally metamorphosed volcanoclastic sediments (tuffs and ash-tuffs), quartz-feldspar and lithic wackes, carbonaceous shales, hydrothermal breccias, and gabbro and porphyry sills. These rocks have undergone pervasive silica alteration followed by a sericite-ankerite alteration event related to mineralisation.

Two major styles of mineralisation are recognized at Massawa from field and laboratory studies. The first stage of sulphide-Au mineralisation is associated with disseminated arsenopyrite-pyrite, which follows shear bands in the sedimentary-igneous host rocks. The second stage consists of quartz-stibnite ± tetrahedrite veining distinguished by coarse visible gold mineralisation. The two mineralisation stages are separated by a phase of quartz-molybdenite veining. A distinctive base metal trace assemblage is linked to stibnite formation including multiple Sb phases such as chalcostibite, zinkenite, roshchinite, aurostibite, jamesonite and robinsonite. This Sb-Au mineralisation is likely to represent a late-stage shallow (< 6 km) overprint on the primary mineralisation.

Sulphur isotope data yield magmatic $\delta^{34}\text{S}$ values for all stages of mineralisation suggesting a strong magmatic fluid influence on mineralisation. This is consistent with field data that suggest mineralisation is synchronous with emplacement of a sequence of felsic dykes. Shallow-level mineralisation is also suggested by fluid inclusion studies on quartz-stibnite veins which show the predominance of low temperature (homogenisation temperatures between 115-252.8°C) H₂O-NaCl fluids (<6 wt% NaCl equiv.). A combination of phase petrology, stable isotope and fluid inclusion data suggest deposition of mineralisation from low salinity, magmatic fluids, probably released from felsic rocks similar to those emplaced into the Massawa sequence during mineralisation

Distribution and mineralogy of REE-Zr-Nb-Ta mineralisation within pegmatite sheets at Citadellet, Kangerdlugssuaq Alkaline Intrusion, East Greenland.

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In recent years advances in technology, and mass production of them, has meant the availability of rare earths and ability to find and produce them economically has become substantially more important. The most significant REE deposits outside China are carbonatites and peralkaline silicate rocks, which will become critical in meeting the expected growth of demands on REEs [1].

The Kangerdlugssuaq Alkaline Intrusion (KAI), east Greenland, is a zoned alkaline intrusion of Palaeogene age; it covers an area of ~1000km² and is one of the largest syenitic intrusions in the world. It is located in a region with abundant mafic to alkaline intrusions and flood basalts belonging to the Palaeogene North Atlantic Igneous Province. The outer edge of the KAI is made up of quartz normandites, it then becomes gradually less contaminated and more primitive through pulaskites and ending in foyaites, according to research by Riishuus [2]. Late-stage pegmatite veins and sheets have previously been identified in all rocks of the intrusion; two types of sheets have previously been identified. The first type are simple sheets consisting of coarse grained versions of the host rock, whilst the other main type are complex, agpaitic, zoned parallel to the walls with variable grain size and lithologies [3]. These second sheets are the focus of this study.

Field work carried out in 2011 with Platina Resources Ltd identified the REE-Nb-Zr-Ta-bearing sheets within the pulaskites in the central portion of the KAI at Citadellet. The Citadellet locality was identified in the 1970s, but no detailed scientific work has previously been undertaken on these sheets until now. The sheets, which appear layered, have been split into 11 zones determined by petrography, allowing them to be assessed separately and relative to each other.

Currently, geochemical assays show progressive fractionation across the sheet, with similarities between groups of elements, which correlate with the prominent REE bearing minerals in each zone. For example, a correlation of light REE along with Nb and Ta can be observed, but does not continue with Zr and heavier REE. SEM work has been carried out to identify these primary REE bearing minerals, predominantly pyrochlore (Nb,Ta), kentbrooksitite (Zr, Nb, REE), bastnesite (Ce), loparite (Ce,Nb) and perrierite (Ce, La). The majority of these tend to be associated with each other, however in varying quantities within each zone, mirrored by bulk rock geochemistry. Promising grades have also been observed at other sites, such as Trebjornebjerget where 3 different types of sheets were identified in 2011, so how these sheets relate to each other could give further understanding of their genesis.

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A study on the structural evolution of karst-associated bauxites of the Parnassos-Ghiona Zone, Central Greece

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The karst-associated bauxite ore deposits (part of the Mediterranean belt bauxites) present within the Elmin SA concessions of the Parnassos-Ghiona zone (Central Greece) formed the material of the present study. Three Triassic to Late Cretaceous bauxite horizons (B1, B2 and B3 from bottom to top) are intercalated with carbonate lithologies of various facies, of which two (B2 and B3) occur in the study area around Mts Iti and Ghiona. As the majority of the Greek bauxite ore deposits at, or near to, the surface have been mined, exploration and extraction is now mostly an underground activity. The thick overburden comprised of limestone sequences and flysch deposits along with the complex structural evolution of the host rock-ore system poses a significant exploration challenge.

The main aim of the present study is the refinement of existing bauxite exploration approaches by (1) obtaining a better appreciation of the regional and local scale structural and evolutionary variables critical to exploration activities and ultimately (2) to offer a model of the structural evolution of the Parnassos-Ghiona rock-ore system.

On the basis of data from existing structural studies and from this on-going study we envisage the following structural evolution of the overall Parnassos-Ghiona rock-ore system:

- During the formation of the Parnassos-Ghiona carbonate platform, compressional deformation associated with subduction of the surrounding Pindos Ocean crust took place. NE-SW orientated structures formed during this compression appear to have been exploited during karstification and controlled the orientation of the subsequent bauxite ores.
- During the Palaeocene the region was subject to an extensional phase.
- During the Eocene, a second compression phase shaped the Parnassos-Ghiona zone into a large, open anticline, also causing several N-S orientated thrust faults. Mount Iti was also overthrust by the Pelagonian zone from the north-east as indicated by underground and surface investigations. These have shown that local asymmetrical NW-SE orientated folds have been created with a SW vergence, and a near vertical E-W orientated limb., E-W extension formed several major normal faults across both mountains, creating sub-parallel faults that offset ore bodies.
- At present, the Parnassos-Ghiona zone is incorporated into the NNW-SSE extensional regime associated with the Aegean back-arc basin, which has created several large ESE-WSW striking normal faults, including the Sperchios Valley Fault, the Corinth Valley Fault and the North Ghiona Fault. Ore bodies close to these faults can be offset by associated smaller normal faults by up to 5 metres, and where the ore horizons are vertical, normal faulting can cause horizontal 'stacking' of potentially bauxite-bearing limestone contacts.
- Geochemical analysis of the ore bodies has also shown that fractures and faults have promoted fluid flow, liberating iron and silica from the bauxite close to the faults and passively increasing the Al₂O₃ content (e.g. from 35-45 wt% up to 65-70%).

The results of this investigation have shown to date that studies of regional and local geological structure and evolution can aid exploration within the Parnassos-Ghiona zone, locate higher-grade (Al-rich) bauxite associated with structurally controlled geochemical alteration and that higher recoveries may be achieved in bauxite bodies associated with certain structural elements (i.e. inclined limbs).

Ore genetic –evolutionary features of karst-associated bauxites in the Parnassos-Ghiona Zone, Central Greece

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The karst-associated bauxite ore deposits (part of the Mediterranean belt bauxites) present within the Elmin SA concessions of the Parnassos-Ghiona zone (Central Greece) formed the material of the present study. Three Triassic to Late Cretaceous bauxite horizons (B1, B2 and B3 from bottom to top) are intercalated with carbonate lithologies of various facies, of which two (B2 and B3) occur in the study area around Mts Iti and Ghiona. As the majority of the Greek bauxite ore deposits at, or near to, the surface have been mined, exploration and extraction is now mostly an underground activity. The thick overburden comprised of limestone sequences and flysch deposits along with the complex structural evolution of the host rock-ore system poses a significant exploration challenge.

The main aim of the present study is the refinement of existing bauxite exploration approaches by obtaining (1) a better understanding of the ore-forming processes within the overall Iti and Ghiona rock-ore system, and (2) to offer an exploration-oriented ore genetic model. A combination of field mapping, mineralogical and geochemical studies have been employed for deciphering critical ore genetic and ore-evolutionary processes. Field data indicate that the bauxites occur as irregular shaped ore bodies, infilling karstic structures in the underlying limestone and with either a conformable or thrust contact with the overlying limestone. They are considered to have formed through weathering and residual enrichment of predominantly mafic and ultramafic lithologies, and transportation and re-deposition onto the karstified Parnassos Carbonate platform during periodic aerial exposure. Textural analysis of samples from the B2 and B3 horizon bauxites has indicated several cycles of deposition, consolidation and dissolution with further “reworking” of the bauxite material indicating a complex, dynamically evolving, oscillatory, self-organized ore-forming system. Bauxites formed under primarily oxidising conditions typically have hematite or goethite as the dominant Fe phase, and diaspore as the main Al phase. Bauxites formed in predominantly reducing conditions are composed of goethite, siderite and/or pyrite, with or without chamosite and diaspore. The latter can often be found with significant coal concentrations (up to 1 metre thick) around the margins of the orebody, at the contact with the overlying limestone.

A process of epigenetic alteration of the bauxites has been observed. This process is mainly associated with the mobilization and re-working of iron and silica. The degree of this alteration varies from minor lateral remobilisation of Fe and Si in zones less than a metre in thickness, to more extensive alteration associated with fluid flow in fault zones and karst tubes that intersect the bauxites and which can produce zones 5-10 cubic metres in size of low-Fe-Si, Al-rich bauxite.

The present study has indicated that the limestone directly beneath and adjacent to the bauxite has been subject to enrichment in Fe, Si, REE and several other elements, giving it a distinctive colour and appearance that has potential- although restricted in scale- as an exploration tool. In addition our current data point out that iron removal can occur in bauxites that are lacking sulphide minerals as source of sulphuric-acid rich fluids and that this process is recursive as well. Further work on trace element distribution and sulphur isotope ratios will be employed as an additional tool in resolving the nature of the alteration fluid, the mode by which iron can be mobilized in these bauxites and in contributing to the ore genetic-evolutionary model.

Mineralogical and Fluid Characteristics of 'Monakoff-Style' Iron-Oxide-Copper-Gold (IOCG) Mineralisation in the Cloncurry Area, Queensland

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The Eastern Succession of the Proterozoic Mount Isa Inlier is one of the worlds' most productive mineral provinces and is recognised worldwide for its diversity of IOCG styles, within a relatively small area. The Eastern Succession is host to several significant IOCG deposits, including Xstrata Copper's Ernest Henry, Monakoff and E1 deposits. The latter two of these represent a potentially new (Monakoff) style, of relatively high grade IOCG deposits, characterised by high abundances of barite and fluorite.

The Monakoff deposit is narrow (<15m wide), deformed and structurally controlled, forming within a dilational jog, in an E-W trending shear zone, which is thought to have allowed the mixing of fluids and deposition of mineralisation [1]. Mineralisation is hosted within meta-sediment units between two more competent units, consisting of dolerites and basalts of the Toole Creek Volcanics in the hanging wall (~1658Ma) and volcanics of the Mt Norna Quartzite Formation in the footwall (~1654Ma). The E1 deposit, ~25km NNE from Monakoff, is composed of three distinct copper-gold deposits; E1 North, South and East. The deposits all exhibit slightly different structural controls, however, the style of mineralisation, within magnetite altered volcanics and late-stage fluorite and sulphide-bearing veins, is comparable between all three satellite deposits.

Petrological and mineralogical data indicates that the ore mineralogy of Monakoff and the E1 group of deposits is similar. They both contain comparable base metal assemblages, including pyrite, chalcopyrite, sphalerite, galena, anglesite and magnetite in a multi-stage paragenesis. Gangue minerals include apatite, albite, manganoan calcite and quartz, with high abundances of fluorite and barite. Accessory REE, U and precious metal minerals are also similar, with richetite

(Pb (UO₂)₄O₅·4H₂O), several U-silicates, treasurite (Ag₇Pb₆Bi₁₅S₃₂) and Bastnäsite-La ((La, Ce)(CO₃) F) being detected within both deposits. In addition to the stark similarities in mineralogy between the two deposits, preliminary results of fluid inclusions within fluorite indicate a connection in fluid types, which have not been observed previously [1]. Both deposits display multi-phase inclusions, with daughter minerals (e.g. halite) present. This supports the presence of a high salinity, >26wt % NaCl, mineralising fluid at both Monakoff and E1, consistent with the common credence that high salinity brines are involved in the ore genesis of these IOCG deposits [2]. These initial observations indicate that a common fluid(s) may be present in both deposits and that these fluids give rise to the characteristic 'Monakoff-style' mineralogy. As such, this newly defined style of mineralisation represents an exciting target for exploration within the region.

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Characterisation of metabasite occurrences in the Dalradian stratigraphy of NE Northern Ireland: an assessment of PGE potential

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The geology of the Dalradian inlier of northeast County Antrim comprises a series of basic sills (basalt/gabbro composition) which were intruded into a sedimentary sequence of basinal marine sandstones and mudstones. The intrusions and sedimentary pile were subsequently metamorphosed during the Grampian Orogeny to produce Dalradian metabasites and metasediments respectively [1] [2]; lying unconformably above this Dalradian sequence are the Cretaceous Ulster White Limestone Formation and Palaeogene flood basalts of the Antrim Lava Group (ALG) [2].

The Dalradian metabasites and Palaeogene igneous activity may possess potential to host platinum group element (PGE) mineralisation. The metabasites and surrounding metasedimentary country rocks are known to host sulphide mineralisation. PGE potential may be aided in the metabasites and the ALG through crustal contamination, resulting in sulphide saturation, which ultimately provides a possibility for PGE enrichment. This could have potentially occurred during the emplacement of the metabasites; with the assimilation of country rock sulphur being enough to saturate the sulphur levels within the metabasites and facilitate a scavenging of PGE. Similarly, this could also have happened during the later emplacement of the ALG, with the magma possibly assimilating sulphur from the country rocks during its ascent.

This project aims to chiefly investigate the possibility of PGE potential in the metabasites; samples of metabasites and surrounding country rock were collected during fieldwork and additional borehole samples have been made available. Various techniques including transmitted and reflected light microscopy, scanning electron microscopy (SEM) will be used to characterise and describe the petrology of the rocks and identify any possible PGE mineralisation. Sulphur isotope samples have been sent for analysis to determine the provenance of the sulphur within the metabasites; a crustal source would indicate that assimilation of country rock sulphur has taken place and possibly led to sulphur saturation, encouraging for potential PGE prospectivity.

A previous MGeol project has already acquired sulphur isotope values in several samples within the Dalradian inlier; by synthesising the pre-existing and newly acquired data, the sulphide fingerprint of the ALG can also be assessed. In addition, sulphur isotope values acquired from this analysis will be added to a developing database for this area of Northern Ireland.

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Pegmatite Fluids as a Source for Gold Mineralisation

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The association of gold mineralisation with low salinity, CO₂-rich fluids has been known for many years, and is often linked to the higher solubility of H₂S in dilute aqueous fluids, enhancing Au-solubility as bisulphide complexes. In recent years many authors have assumed that such fluids are of metamorphic origin, but in fact it has been known for over 60 years [1] that low salinity CO₂ – H₂O fluids are also characteristic of evolved granitic pegmatites. Li-rich pegmatites from both the Damara belt and the Mozambique belt in southern Africa are associated with metamorphosed shelf sequences including mature quartzites and dolomitic marbles. These pegmatites commonly contain spodumene, petalite, lepidolite, eucryptite, beryl, amblygonite and associated tin-tantalum mineralisation. They commonly occur with post-orogenic tourmaline-bearing granites whose metamorphic aureoles overprint regional folding. In both regions gold mineralization post-dates metamorphic sequences and can be linked in time to emplacement of the pegmatite bodies.

Quartz from the core of the Muiane pegmatite, Mozambique, collected by the late O. Von Knorring, contains large, pure CO₂-rich dilute aqueous fluid inclusions characterised by high Li-B-As-Cs-Sb-contents. Inclusions appear to have trapped the aqueo-carbonic fluids and some of the associated evolved melt during crystallisation and de-gassing. Within the fluid inclusions, crystals of arsenolite and claudetite (As) and hambergite (Be, B) are frequently present. Laser ablation analysis of the inclusions reveals clear Au peaks which appear to be associated with the gas phase, or its outer surface. Quantification is difficult because of the unusual fluid composition, but clathrate melting indicates that the aqueous phase now contains about 5% dissolved salts, and this indicates likely values of c. 5-10 ppm Au in the bulk inclusion. We believe these figures, which are higher than the values commonly assumed in models for the formation of orogenic gold deposits, are likely comparable to the levels in low salinity metamorphic ore fluids.

In the Damara belt of Namibia, including the world-class Navachab gold mine, Au-mineralization is often associated with very late stage fractures in metasediments, including marbles. Artisanal pegmatite mines that often yield Li-tourmalines are common features of areas that are prospective for gold. Field relationships between Au-mineralisation and pegmatites indicate that both are later than the regional metamorphism [2,3]. Gold mineralisation is also observed in pegmatite and aplite intrusions in the vicinity of the Navachab open pit.

These pegmatite districts are unlikely targets for metamorphic Au-mineralisation, as pegmatites and related granites are clearly later than regional metamorphism; furthermore similar metamorphosed sequences of continental shelf sediments are commonly associated with high salinity fluids with immiscible, as opposed to dissolved, gases [4]. We suggest that late-stage Au in such settings is derived from evolved pegmatite fluids, rich in dissolved gases and common pathfinders such as As and Bi, and with low salt contents. Fluid inclusions in the Muiane pegmatite give an indication of the composition and Au content of the evolved pegmatite fluids. Field relations confirm a close spatial and temporal relationship between gold mineralisation and pegmatite intrusion indicating that the pegmatite association should be specifically considered when prospecting in orogenic belts.

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Field occurrence and lithology of 2.8 Ga Mistuhe hydrothermal section, Utik Lake greenstone belt, Canada

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The Utik Lake greenstone belt is located in the northwestern part of the Superior Province. The greenstone belt can be subdivided into mafic metavolcanic and mafic intrusive rocks. These mafic rocks are separated by conformable metasedimentary rock sequences [1]. The voluminous mafic metavolcanic at southwestern Utik Lake were locally pervasively altered by hydrothermal systems [1]. Gold-bearing chert were deposited directly on the highly altered metabasaltic rock in Mistuhe Island of southwestern Utik Lake [2].

The purpose of this study is to describe paleohydrothermal environments on an oceanic surface of middle Archean age, and particularly to identify distribution of hydrothermal vent system. We have made 1:100 geologic maps at the Mistuhe hydrothermal section. The Mistuhe hydrothermal section (30 m long and 15m wide) is composed of bedded chert and metavolcanic rock. 30-100cm-wide hydrothermal quartz vein intrude metabasalt with more than 25 m in thickness. Bedded chert was 2-3 m thick and conformably overlies metabasalt. Upper 20-30 cm part of the metabasalt is highly altered by hydrothermal activity. Vein preserved thin blanch and form amoeboidal boundary shape. Hydrothermal quartz vein consist of recrystallized quartz and actinolite.

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Gold in massive sulfide (base metal) and carbonaceous gold sulfide deposits in Eastern Kazakhstan

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Samples of pyrite-base-metal ores from the Ridder- Sokolnoe deposit (Rudnyi Altai) and from the gold deposit Bakyrchik (West Qalba belt) were studied. The Ridder-Sokolnoe deposit is located within the Leninogorsk ore field which is a graben-syncline in the axial part of the main regional structure of the Sinyushinsk anticlinorium. Ores of the Ridder-Sokolnoe deposit are localised in the Devonian rocks of the Kryukovskaya and Leninogorskaya suites and in metamorphic rocks of the Upper Ordovician [1]. These are complex base-metal ores with ore types distinguishable from their lead-zinc and copper contents. The upper levels of the Ridder-Sokolnoe deposit are richer and mainly of lead-zinc composition. Some lenses have high grades of gold and silver. The grades of lead and to a lesser degree zinc usually decrease down dip, whilst copper grades increase.

The Bakyrchik deposit is located in the Western Qalba gold-bearing province which stretches as a strip from the north to the west for more than 300 km, its width is 50-70 km. It borders the West Qalba deep fault in the south-west and the Qalba-Narym rare metal granite massifs (with tungsten-tantalum-beryllium-iron mineralisation) in the north-east. The Qalba area is in the Hercynian Greater Altai which forms a part of the Central Asian Mobile Belt. The mineralisation belongs to the metasediment-hosted, shear-zone controlled ore deposits type. This type is intermediate between the (quartz vein) lode type and the sulfide lenses type. The ore bodies are mainly composed of clastic, abraded and silicified carbonaceous-argillaceous, argillaceous slate and silty rocks, and mylonites with lenses of quartz [2]. All these rocks contain nests, veinlets and disseminations of fine-grained sulfide minerals - pyrite, sphalerite, stibnite, chalcopyrite, arsenopyrite, galena, and others, with native gold. Mineralization is represented by vein-disseminated ores in black-shale (terrigenous) formation of Early-Mid Carboniferous age containing a significant admixture of carbonaceous matter. Free gold is rare. It is essentially associated with pyrite and arsenopyrite. Age of granitoid magmatism and co-genetic mineralisation is approximately 299 Ma (CERCAMS, unpublished).

Analyses were carried out in the "IRGETAS" laboratory of the East Kazakhstan State Technical University (EKSTU). Samples were analyzed using scanning electron microscope JSM-6390LV, transmission electron microscope JEM-2100 and inductively coupled plasma-mass spectroscopy ICP-MS 7500cx with the aim to define the mineral composition of the ores, to study the morphology and dimensions of the mineral phases, and to study their chemical composition. Analyses indicate that the gold-bearing mineral phases show a number of similar textural features, including the occurrence of invisible gold within initial growth phases. Invisible gold can occur in solid solution within the host crystal lattice or exist as <1 μm submicroscopic particles.

In the studied lead-zinc ores of the Ridder-Sokolnoe deposit gold is mainly associated with pyrite and is of rather large size. The minimum size of gold particles is nearly $1\mu\text{m}$ and was observed in silver telluride. Gold in the Bakyrchik deposit is ultrafine and compared with complex ores it is associated with arsenopyrite. The study of ore deposits under the scanning electron microscope determined the size of gold grains: minimum 5 nm to maximum 10 μm , at an average of less than 1 μm . The size of gold grains in the pyrite-polymetallic ores is larger than in gold deposits of the black-shale series.

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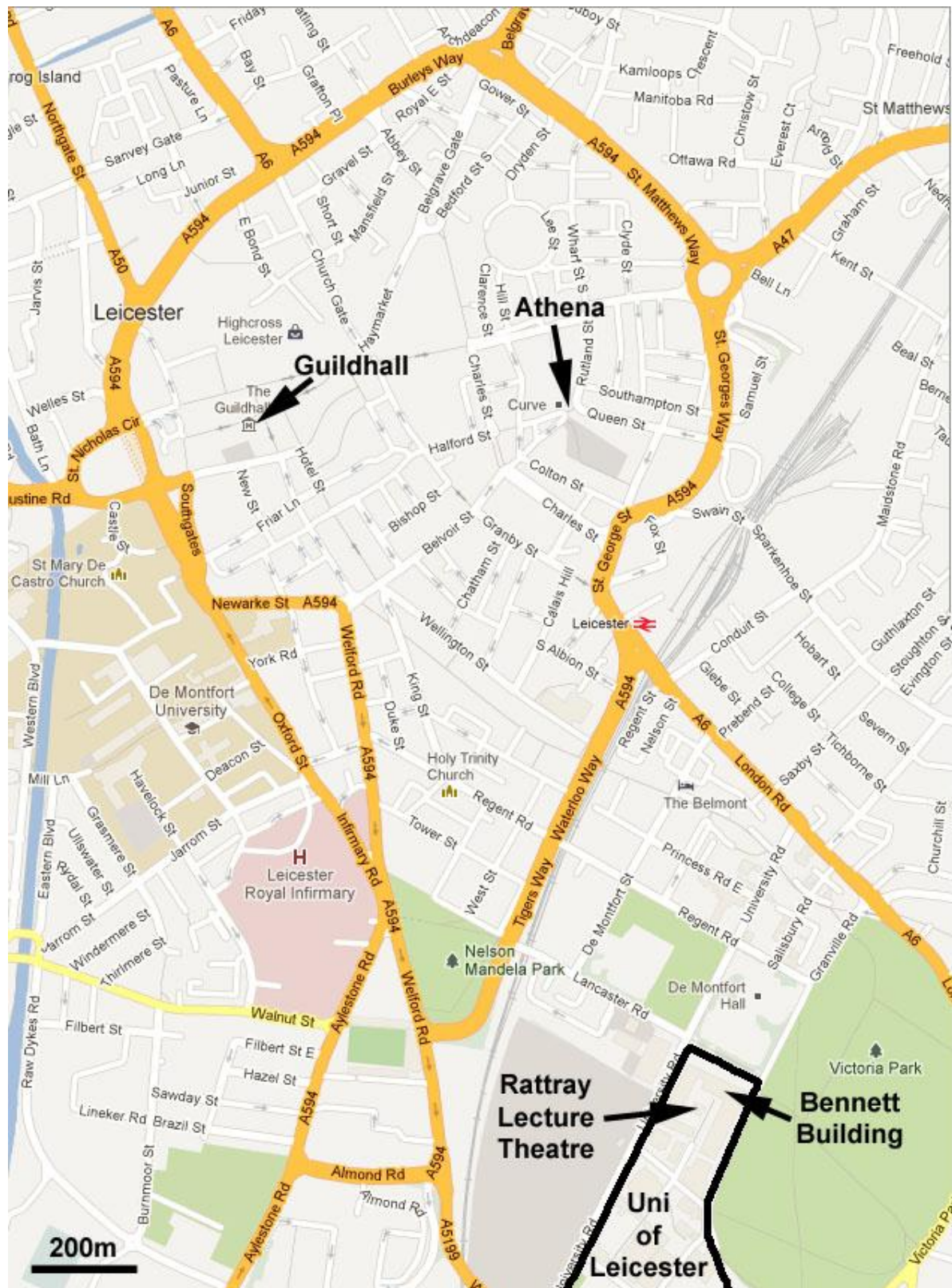
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Grace	Shephard	University of Leicester
Richard	Siddle	Micromine Consulting Services
Julia	Sidorina	Lomonosov Moscow State University
Richard	Sillitoe	SEG International Exchange Lecturer
Bethany	Simons	Camborne School of Mines
Peter	Simpson	Imperial College
Chris	Smeathers	Sirocco Mining

Jennifer	Smith	University of Leicester
Christopher	Smith	University of Brighton
Dan	Smith	University of Leicester
Dermot	Smyth	Lonmin Plc
Ben	Snook	Camborne School of Mines
Carl	Spence-Jones	University of Leicester
Edward	Spencer	Imperial College
Roy	Starkey	The Russell Society
Geoffrey	Steed	Cardiff University
Benedikt	Steiner	Rio Tinto Exploration
Hugh	Stuart	HS Exploration Consultants Ltd
Katie	Sullivan	University of Southampton
Abbie-Jade	Sutherland	University of Leicester
Simon	Tapster	University of Leicester
Christopher	Tatham	University of Edinburgh
Luke Sidney	Taylor	Cardiff University
Steve	Tennant	Bluestone Geological
Ben	Thompson	University of Exeter
Ben	Thompson	University of Leicester
Alexandra	Thornber	University of Leicester
Vanessa	Tranter	Barrick Gold Corporation
Peter	Treloar	Kingston University
Oakley	Turner	Camborne School of Mines
Karen	Volp	CSA Global UK Ltd
Matthew	Walker	Bariq Mining Ltd
Sandy	Walker	Rio Tinto
Frances	Wall	Camborne School of Mines
Alex	Walsh	University of Leicester
Hollie	Warman	University of Leicester
Alex	Weaver	Glamorgan University
Jamie	Wilkinson	Imperial College
Megan	Williams	University of Leicester
Michael	Williams	Stratex International Plc
Richard	Williams	University of Brighton
Ben	Williamson	University of Exeter
Robert	Willian	Consultant
Anthony	Wong	University of Leicester
Ruth	Woodcock	University of Leicester
Louise	Wright	Anglo American
Bruce	Yardley	University of Leeds
Yongfeng	Zhu	Peking University
Natalya	Zimanovskaya	EKSTU

MAPS

Map of Leicester City Centre showing conference venues

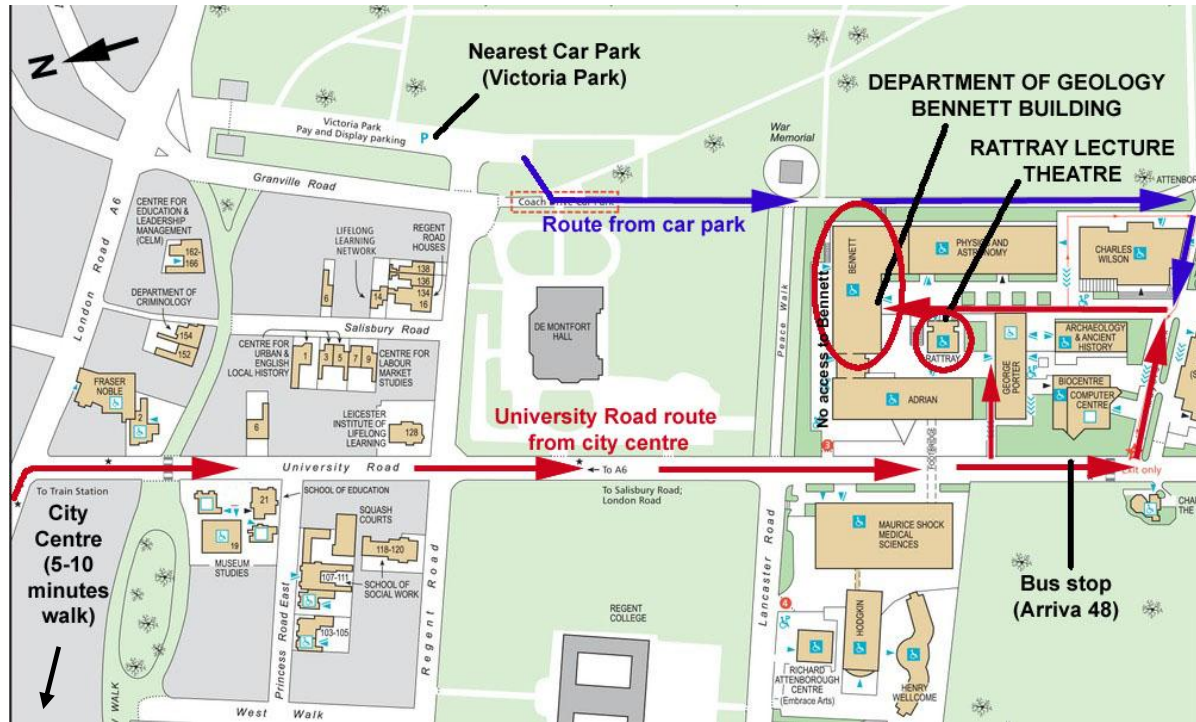


University of Leicester Campus: LE1 7RH

Guildhall: LE1 5FQ

Athena: LE1 1QD

Map of University of Leicester Campus



Bennett Building map

Location of Emergency Facilities
in the
DEPARTMENT of GEOLOGY
Bennett Building
University of Leicester

