iCRAG: Increasing the Chances for Exploration Success in the World-Class Irish Zn Orefield.

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Talk Outline

• The Irish Orefield

• What is iCRAG

• Irish Orefield geology

• iCRAG’s minerals research
Irish Zn-Pb Orefield:

- Hosted within Carboniferous Carbonates
- Zn-Pb + minor Ag
- Active exploration > 50 years
- 15 deposits with >1Mt Zn-Pb
- 5 zinc mines operated
- 2 very significant prospects

“Most Zn discoveries per km²”
Current Exploration & Orefield status:

- Active green and brown-field exploration (majors & juniors)
- Ongoing exploration and resource evaluations at:
  - Pallas Green, Kilbricken, Ballinalack, Galmoy, Harberton Bridge and Abbeytown.
- Good State support:
  - good licensing and fiscal framework in place.
  - mineral rights mostly with State (low royalties)
  - all geological data and reports available online
- Recent mine closures: Lisheen 2015 & Galmoy 2011
  - Navan only remaining operating mine
- Exploration Challenges:
  - Poor definition of bedrock geology (peat, till)
  - Depth to target lithologies

New Thinking and New Tools are Required
What is iCRAG?

• Established in 2015
• One of 17 State-funded National Research Centers
• Hosted by 5 universities and 2 institutions

• Goals of Centre:
  - Help unlock Ireland’s natural resources (minerals expenditures €1bn in 2012)
  - Contribute to securing supply of energy and safe water
  - Educate and improve understanding of geosciences
  - To achieve international excellence in applied geoscience research.
iCRAG Structure:

- Currently 150 researchers
- 5 research Spokes
- 4 research Platforms to support Spokes

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<th>Role</th>
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<td>Principal Investigators</td>
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iCRAG Sponsors and Partners:

- Jointly funded by Science Foundation Ireland (€18M) and industry (€8M)
International Collaboration

- Prof. Mike Lesher, Geochemistry
- Prof. Harold Gibson, Volcanology, VMS
- Prof. Darrel Long, Sedimentology, placer gold
- Prof. Elizabeth Turner, Sedimentology, SEDEX
- Prof. Doug Tinkham, Thermodynamics
- Prof. Phil Thurston, Geochemistry
- Dr Jaime Wilkinson, Hydrothermal Geochemistry
- Prof. Chris Jackson, Basin Analysis
- Prof. Matt Jackson, Geological Fluid Mechanics
- Dr Adrian Butler, Subsurface Hydrology
- Dr Tina van der Flerdt, Isotope Geochemistry
- Prof. Sanjeev Gupta, Sedimentation and Tectonics
iCRAG’s Zn-Pb Research:

• 10 Post Doc and PhD. Zn-Pb related research projects

1. Designed to better understand the controls on Irish-type deposits:
   - Strong association with normal faults
   - Formed by mixing of metal-bearing hydrothermal fluid with Carboniferous seawater
   - 4D Structural \ Stratigraphic
   - Geochemical

2. And develop tools to find them:
   - Seismics
   - Vectors

(Everett et al. 1999; Gleeson and Yardley 2002; Banks et al. 2002; Kinnaird et al. 2002; Wilkinson et al. 2005a; Walshaw et al. 2006; Wilkinson 2010)

Diagram after Wilkinson et al 2011

Brines; ~ 50 - 130°C, high salinity, sulphur-rich (bacteriogenic sulphur)

Hydrothermal Fluids; ~ > 240°C, low salinity, metal-bearing
Overview of Irish Zn-Pb Orefield Geology

1. Basement:
   - Caledonian closure of Iapetus Ocean along NE-SW trending suture
     - Laurentian terrane to the NW, Avalonian terrane to SE
     - Ordovician and Silurian Iapetus ocean arcs and sediments in between

Research Questions:
   - Can we identify all the distinct terranes (micro-terranes)?
   - Is there heterogeneity of the basement as a source?
   - Location of terrane bounding faults (gravity & magnetics) – first order control on location of Zn-Pb deposits?
Overview of Irish Zn-Pb Orefield Geology

2. Carboniferous marine transgression (south to north):

- Conformable on ORS in south
- Unconformable on Lower Palaeozoic basement elsewhere
- Facies variability related to emergent areas and regressions

Research Questions:

- How much topography was on the Late Palaeozoic surface?
- What caused of recognised regressions during this time? - eustatic or local tectonic?
- Were emergent areas the source of early dolomitising solutions?
Overview of Irish Zn-Pb Orefield Geology

3. Onset of extensional faulting:

- Begins in mid-Tournaisian (ABL) as many extensional segmented fault arrays centred and developing out from the Iapetus Suture Zone
- Subtle formation thickness changes at first but clear syn-rift differences develop (Waulsortian) resulting from fault death and transfer of displacement to fewer arrays
- Continued transgression – complex spatial interplay of facies, faulting and time.

Research Questions:

- What was the influence of basement structure on faulting?
- Did hydrothermal activity commence at this time?
- Were there sub-basins (Lough Allen, Limerick)?
Overview of Irish Zn-Pb Orefield Geology

4. Continued faulting into Lower Visean\Arundian:
   • Major extension - ‘bottom fall out of the basin’ approximately along the trend of the Iapetus Suture Zone
   • Mineralisation probably at its zenith
   • Faulting appears to slow or cease (thermal sag phase?)
   • Development of distinct shelf and basinal facies that bury all ore-hosting lithology and controlling structure

Research Questions:
   • Is this model correct?
   • What are the geochemical constraints on mineralisation?
   • Where within this framework do all the planets align?
Where to look next?

It is almost certain that many other deposits exist

BUT –

1. At depth >300m

2. Buried by thick (up to 800m) poorly constrained shelf sequences and even more poorly constrained and thicker basinal limestones

3. Controlling faults don’t extend through these rocks – unless inverted (which many are)

4. Poor exposure to construct good maps (peat and till cover)

5. Biostratigraphy required to constrain Visean shelf and basinal limestones (Tuffs?)
What can iCRAG research deliver to industry?

- Improve Genetic Models for Irish Orefield
  - 4D tectonostratigraphic research to improve definition of bedrock geology and its development
  - Geochemistry research using new analytical techniques, technologies and capabilities to better understand mineralisation processes and identify likely settings for mineralisation

- Develop and improve exploration tools (seismic) and search for new thermal \ geochemical vectoring methodologies

- People – the professionals for the industry of the future - 70% of researches will move to industry.
4D tectonostratigraphic research

- Geometric and structural analysis
- Tectono-stratigraphic basin evolution analysis
- Restorations
- Geochemical data and vectors
- Groundwater flow analysis and modelling
- Geothermal modelling

‘Active structural setting in which mineralisation is occurring’

- Required to study the intricate links through time between:
  - Transgression and distribution of lithologies (host rocks)
  - Development of structures during rifting (fluid pathways)
  - Evolving fluid flow pathways of mineralising fluids to trap sites (metals)
4D tectonostratigraphic research (data)

- In collaboration with industry and State bodies including GSI - providing excellent geological data sets (Tellus, drilling, geochemical and geophysical including seismic).
- Mine and regional data (~4.000.000 km drillhole data)

Regional seismics (~500km 2D onshore lines)

Lisheen
71,000 assays
8000 u\(\text{g}\) and surface boreholes
45,000 face-maps

Silvermines
2000 u\(\text{g}\) and surface boreholes & 21,000 assays
Geological sections & level mapping plans

Potential Field data – e.g. Tellus

Mine-scale seismics
Geochemistry Research

• A range of modern analytical instrumentation including:
  - New LA-ICPMS system dedicated to metal analysis
  - Rb-Sr, Sm-Nd, Lu-Hf and Pb isotopic analysis, Re-Os-HSE in development
  - 2 new Q-ICP-MS systems
  - MC-ICPMS (Neptune)
  - LASS for MS-ICPMS
  - Access to clumped isotope analysis (East Anglia)

• Capable of quickly conducting analysis previously not possible
• Automated mineralogy by SEM-EDX - higher spatial resolution
• In situ analysis of trace elements in ore and related minerals (LA-ICP-MS)
• Visualisation of trace element distribution (mapping) in ore and related minerals
• Improved in-situ Pb isotope analysis: help to decipher the origin of Irish Pb & Zn
Exploration Tools: Seismic

- Depth beyond limits for many geophysical techniques (excl. gravity & magnetics)
- Seismics previously too expensive for minerals industry (initially hydrocarbons industry)
- Currently employed by five companies in Ireland but this likely to increase.
- First seismic discovery in Ireland by Boliden in 2012
Seismic discovery of Tara Deeps

- 10 Mt @ 10.2% Zn+Pb at 1500 to 2000 m depth
- Regional exploration drilling >500 m now routine
- Reflection seismic is key part of the mineral exploration toolkit

Best Hole: 91.5m 11.3%Zn 1.2% Pb
Drilled through steep dipping, structurally controlled mineralisation
Exploration Tools: Geochemical Vectors

- Projects underway to identify possible new geochemical and thermal vectors to mineralisation:
  - Trace-element mapping of syn-sed laminated pyrite using SEM, LA-ICPMS at Navan
  - Trace element geochemistry of various pyrite generations (diagenetic vs hydrothermal)
  - Clumped C-O isotope analysis of carbonate phases at Navan and Lisheen
Public Perception and Understanding

- Many mining legacy issues (pits, shafts, spoil-heaps, tailings)
- Projects can be delayed or even stopped
- Need to understand people and communities
- World-class mine closures at Lisheen and Galmoy
- Media coverage can be ‘unbalanced’
Public Perception and Understanding

• PPU research of geological activities uses an interdisciplinary approach bringing together geology, psychology and sociology.

• The aim to help guide how we, as geoscientists, engage with and communicate with non-geoscientists.

• Targeted projects in local communities in Ireland are conducting public consultation and survey work.

Example: survey comparing attitudes and emotions of geoscientists and non-geoscientists relative to mining and quarrying.
Concluding Comments:

- Ireland is still a world-class Zn\Pb province
- iCRAG’s research is focused on assisting industry make successful discoveries
- New research has provided better understanding of the structural, stratigraphic, geochemical and temporal controls on mineralisation.
- Newly applied exploration tools (seismic & analytical) have been successfully applied and have opened up large areas previously overlooked.
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