predictive mineral discovery

COOPERATIVE RESEARCH CENTRE

# Application of geochemical modeling to ore systems
# Lead and Zinc Solubility in skarn deposits


Martina Bertelli - School of Earth Sciences

James Cook University

email: Martina.Bertelli @jcu.edu.au


## INTRODUCTION

This project represents an attempt to clarify issues related to ore deposition using an approach that combines geochemical modeling and fluid inclusion data. The project is proposed as part of the pmd*CRC projects F1 (Fluid chemical paths in ore forming processes) and F3 ( Micrometallogeny of hydrothermal fluids).

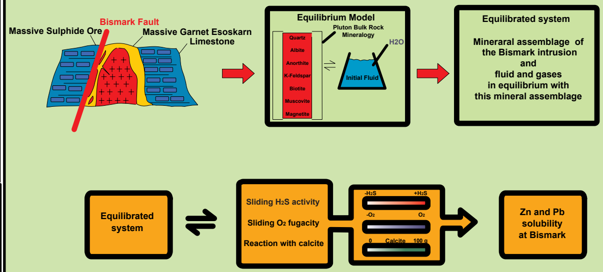
The first part of the project has focused on the study of the Bismark deposit (northern Chihuahua, Mexico).This deposit has been chosen considering its well understood geological setting and the availability of fluid inclusion data. The same approach will be applied to Iron oxide Cu-Au deposits in the Cloncurry district.

### Background

The Bismark deposit (northern Chihuahua, Mexico) is an example of stock-contact Zinc-rich skarn. The deposit contains Zn (8%) with minor Pb (0.5%), Cu (0.2%) and Ag (50 g/t) in massive sulfides. The main aim of this study is to understand the mechanisms that control Pb and Zn solubilties at Bismark.

## METHOD

### Geochemical modeling-GWB




Zn and Pb solubilities were tested setting galena and sphalerite in equilibrium with the initial system in equilibrium with the Bismark stock. This approach was used to evaluate variation in Zn and Pb solubilities induced by oxygen fugacity and $H_2S$ activity changes.

For the reaction with the carbonate host rock the initial system contained Pb and Zn as aqueous species.

## Sliding $H_2S$ activity

### Constant T (550°C)

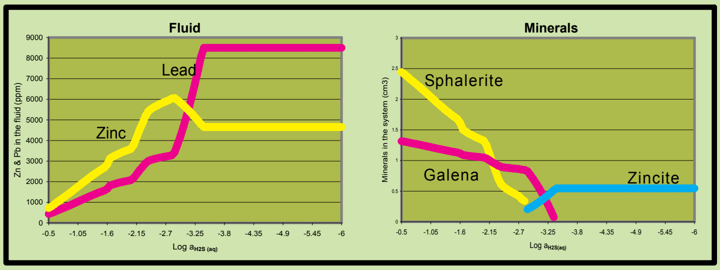



FIG.1 Zn and Pb solubilities generally increase as $H_2S$ activity decreases.The higher Pb content in the fluid relative to Zn for low $H_2S$ activities is caused by precipitation of zincite, and sphalerite is not present in the system.

### Cooling (550-100°C)

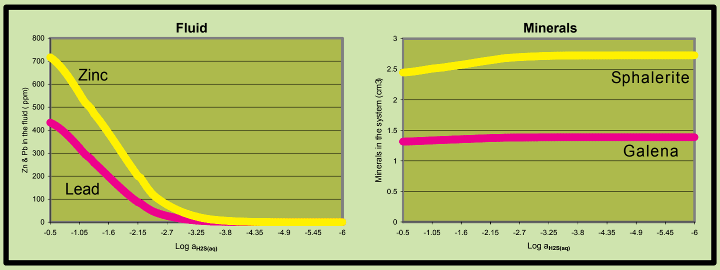



FIG.2 Lead and zinc solubilities generally decrease with decreasing $H_2S$ activity . Lead predominates over zinc in the fluid, while sphalerite is more abundant than galena.

## Reaction with calcite

### Constant T (550°C)

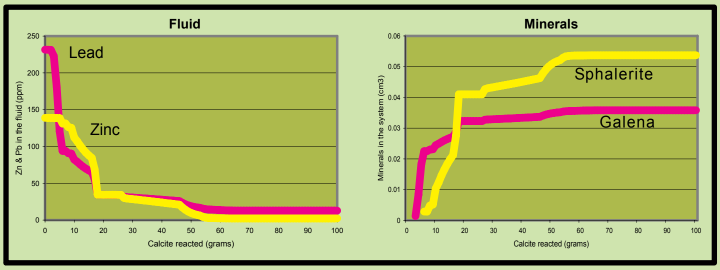



FIG.3 Initially the Pb fluid content drop rapidly, causing a relative Zn enrichment . As the reaction proceeds the fluid is depleted in Zn, and Pb becomes more abundant. Sphalerite predominates over galena.

### Cooling (550 -100°C)

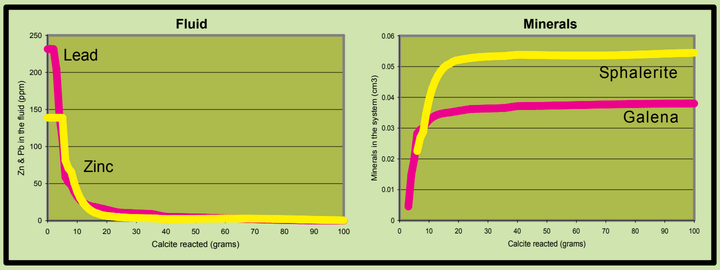



Fig.4 Initially the solubility trend for Zn and Pb is similar to that obtained for the reaction conducted at constant temperature. As the reaction proceeds the Zn and Pb content becomes similar. Sphalerite predominates over galena.

## Sliding $O_2$ fugacity

### Cooling (550 - 100°C)

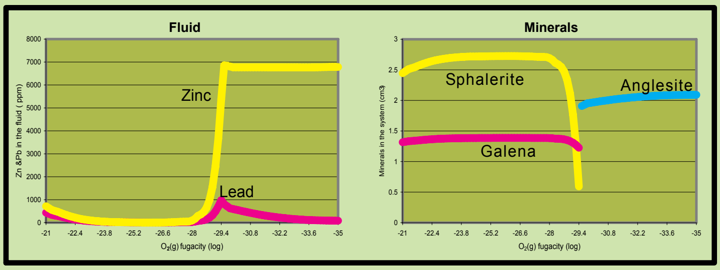



FIG.5 This different behaviour displayed by Zn and Pb at low oxygen fugacity is a consequence of the precipitation of anglesite, whithout formation of any Zn - bearing mineral. This caused the fluid to be enriched in Zn relative to Pb.

## PRELIMINARY CONCLUSIONS

Preliminary results suggest that Zn and Pb solubilities at Bismark were mainly controlled by the reaction between the magmatic fluid and the carbonate host rock. The role of other factors (oxygen fugacity, H2S activity) seems negligible.

# pmd*CRC F3: Micrometallogeny of Hydrothermal Fluids

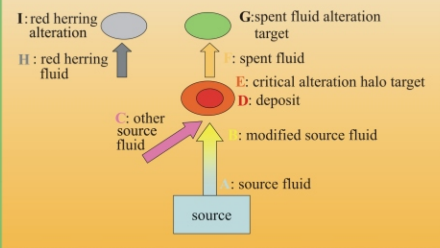
Compiled by: Roger Mustard, Geordie Mark and BinFu

## Participants:

Tim Baker, Pat Williams, Roger Mustard, Bin Fu, Nick Oliver (JCU), Terry Mernagh (GA), Chris Ryan, Esme van Achterberg (CSIRO), Thomas Ulrich, John Mavrogenes (ANU), Joel Brugger (SAM); *pmd**CRC Links: Geordie Mark, Andy Wilde (Monash), Steffen Hagemann, Peter Neumayr (UWA), Dave Phillips, John Miller (University of Melbourne) .

## Project Aims:

- To produce a fully integrated approach to characterising hydrothermal fluids (fluid inclusions)
- Driven by geology - terrane and ore system based studies (I2/I4/Y3)
- Through the development of advanced analytical methods (integration of enabling technologies such as PIXE, LAICPMS, Laser Raman)
- For use in exploration & fluid modelling (F1)




Application of *fundamental shift* concept to a hydrothermal system

We aim to:

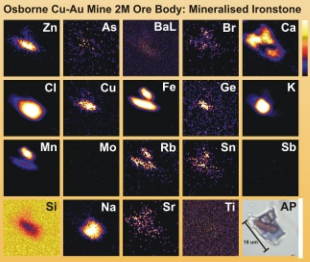
- Distinguish barren versus mineralized hydrothermal systems
- Enable explorationist to test whether they've drilled a potential metal-carrying system
- Integrate with F1 for predictive medelling

## Regional, Magmatic and Deposit Fluid Types

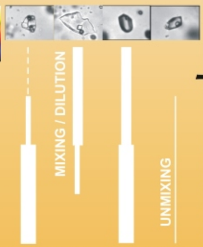
### Osborne Mine

Mustard Unpublished

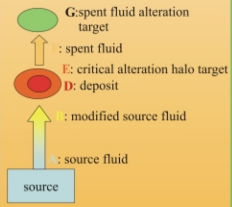
Osborne Cu-Au Mine 2M Ore Body: Mineralised Ironstone




PIXE Image of a multisolid brine inclusion from mineralised ironstone in the Osborne Cu-Au Mine. PIXE indicates solids present include halite (NaCl), sylvite (KCl), 2x ferropyrosmallite (Fe, Mn) and Ca in the fluid. Cu and Zn is associated with a Mn-poor ferropyrosmallite



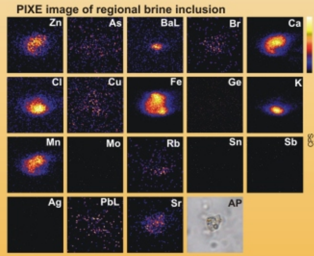

Distribution of fluid inclusion types present at Osborne in relation to four selected samples. Pre-syn mineralisation unmixing and syn-post mineralisation mixing observed.



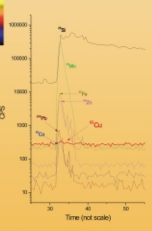

Application of the conceptual model for selection of samples for fluid inclusion study. Samples from top to bottom include: (1) unmineralised vein, (2)quartz-chalcopyrite veined ironstone, (3) mineralised ironstone and (4) pegmatite.

### Regional Albite Alteration

PIXE image of regional brine inclusion



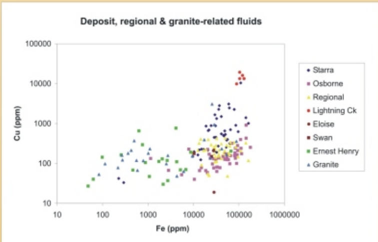

Critical difference between regional brine inclusions and Osborne brine inclusions is the low Cu content as shown in PIXE and LA images. Bin Fu Unpublished.

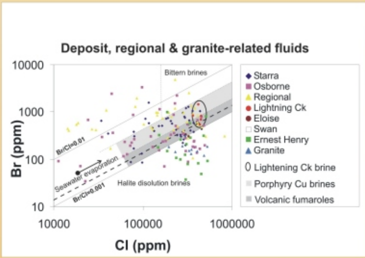


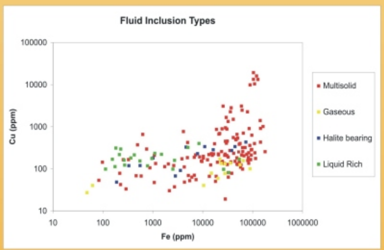

LA spectra for regional brine inclusion

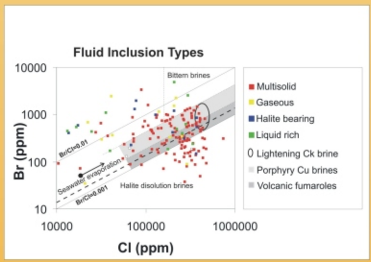

Regional processes recognised:

## Comparison of Fluid Types:



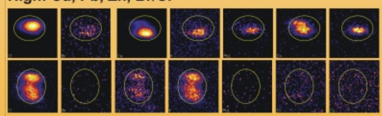




### Magmatic Fluid

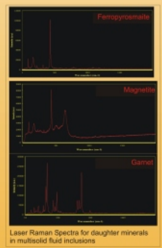
Fluid Inclusion Types:

Two phase (L-V) aqueous inclusions
Halite-salited inclusions
Multisolid inclusions: ferropyrosmalite, magnetite, hematite, calcite, garnet, diospide
$CO_2$-rich inclusions: narcolite

Hypersaline inclusions:
High: Cu, Pb, Zn, Br/Cl



Low: Cu, Pb, Zn, Br/Cl




Laser Raman Spectra for daughter minerals in multisolid fluid inclusions

## Discussion:

- Major and trace element compositions of fluid inclusions have been collected (using PIXE and LA-ICPMS) for a range of separate Fe-Oxide Cu-Au systems, regional alteration and intrusions including Lightning Creek & Mt Angelay (n= 245).
- Comparing fluids from a range of different systems will assist us in: (1) Discriminating between potential carrier and spent fluids, (2) Understanding the role of key fluid processes such as mixing and unmixing in the mineralisation process, and (3) Determining potential fluid sources.

GA 02/000

predictive mineral discovery

GEOSCIENCE AUSTRALIA
THE UNIVERSITY OF MELBOURNE
MONASH UNIVERSITY
THE UNIVERSITY OF WESTERN AUSTRALIA
JCU JAMES COOK UNIVERSITY
CSIRO
AMIRA INTERNATIONAL

# predictive mineral discovery

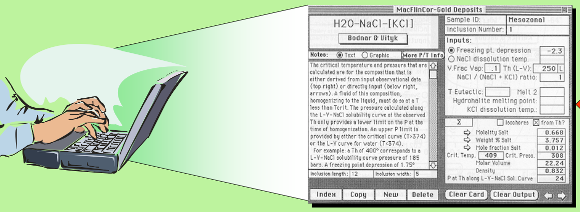
## COOPERATIVE RESEARCH CENTRE

# AN INTEROPERABLE FLUID INCLUSION DATABASE TO RECORD OBSERVATIONS AND CONSTRAIN CHEMICAL MODELLING

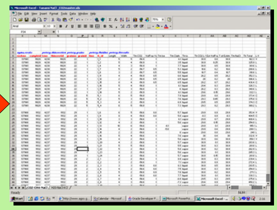
**Terry Mernagh, Stuart Girvan, and Lesley Wyborn**
**Geoscience Australia, GPO Box 378, Canberra, ACT 2601 Australia**

## The Way We Used To Do Things

Fluid inclusion studies were carried out in isolation by individual researchers. The data was kept on their own computer. Often this data was not backed up and was lost when they left university or got another job.



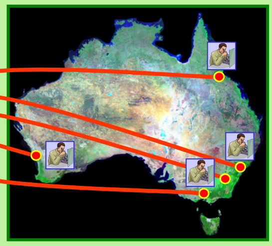
Observations could be recorded in MacFlinCor but you had to have a Macintosh computer to use this program.

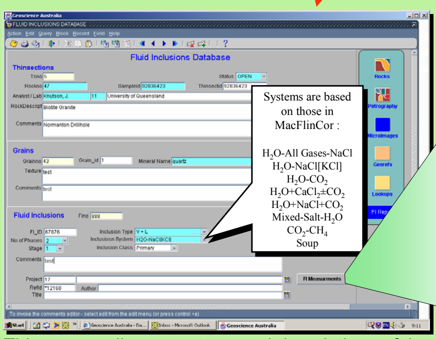


The data had to be exported into Excel for further massaging and for plotting isochores.

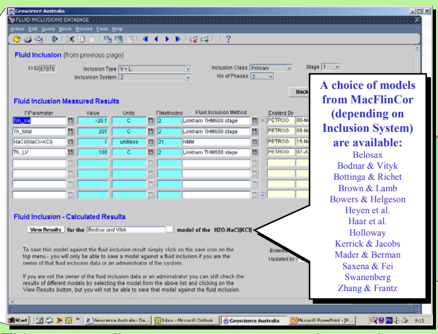
## The Way We Now Do Things

pmd*CRC researchers across Australia can now enter their data into the Fluid Inclusion Database at Geoscience Australia to build a library of ore fluids that can be used to Constrain geochemical modelling.

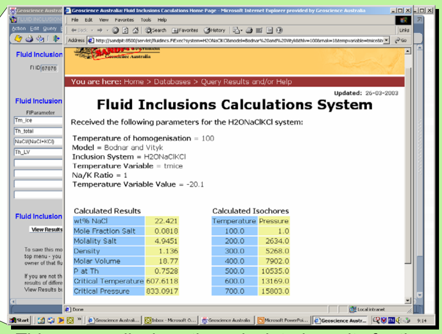






This screen allows you to record descriptions of the thin section and the individual fluid inclusions.




This screen allows you to enter your observations and choose a model for calculating the fluid properties.

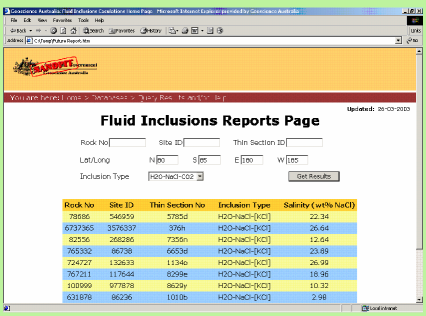



This screen displays the calculated results for the chosen model in a web browser. You can simply change models and recalculate the results without changing the observed fluid inclusion parameters.

## The Way We Plan To Do Things In The Future

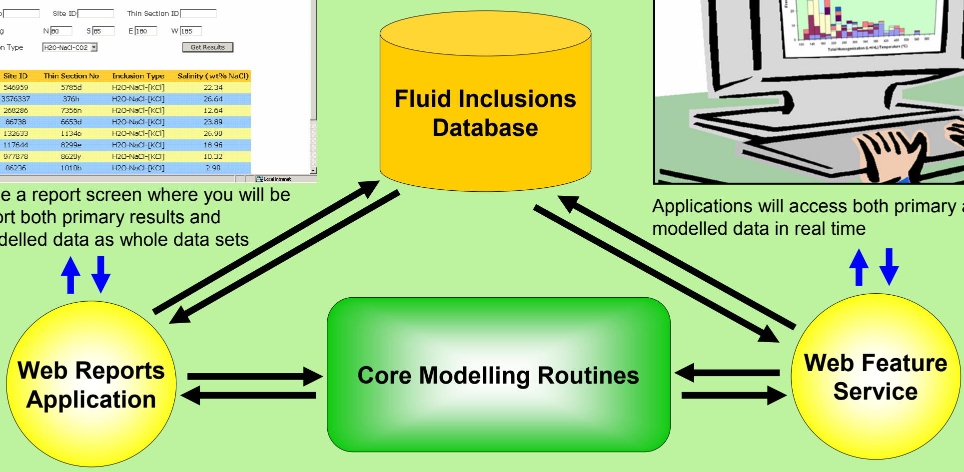
pmd*CRC researchers will be able to create reports of fluid inclusion data over the internet. The data set reported will be defined by a number of criteria (for example spatial boundaries) set by the user and will include both primary and derived data.

Applications which are written to handle web feature service data will be able to read data in real time.




There will be a report screen where you will be able to report both primary results and derived/modelled data as whole data sets

Applications will access both primary and modelled data in real time



# predictive mineral discovery
## COOPERATIVE RESEARCH CENTRE

# Exploring Fluids in Fe oxide-Cu-Au deposits

David Gillen
School of Earth Sciences, James Cook University, QLD, 4811
david.gillen@jcu.edu.au

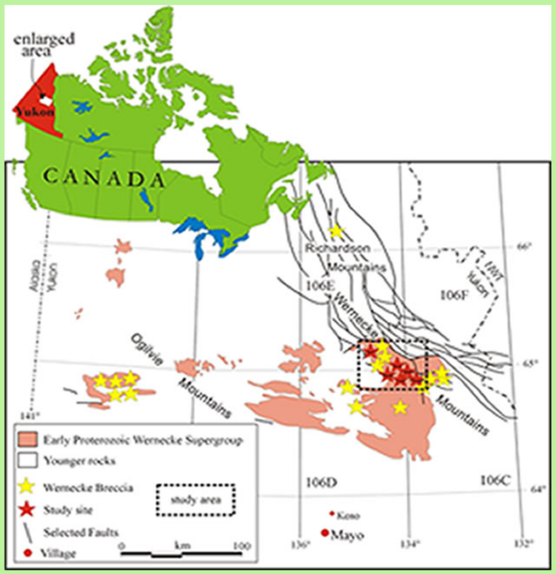



Figure 1: Map showing the location of the Wernecke Mountains, Canada and the distribution of breccia sites and associated mineral prospects.

## Introduction

### Fe oxide-Cu-Au deposits

- Very large masses of iron oxide (hematite/magnetite)
-Economic components: copper, gold (uranium, REEs, cobalt, nickel)
- Very large scale metasomatism

### Fluid source debate

- Major theories
  -Magmatic
  -Evaporitic
  -Mixture (incl meteoric)

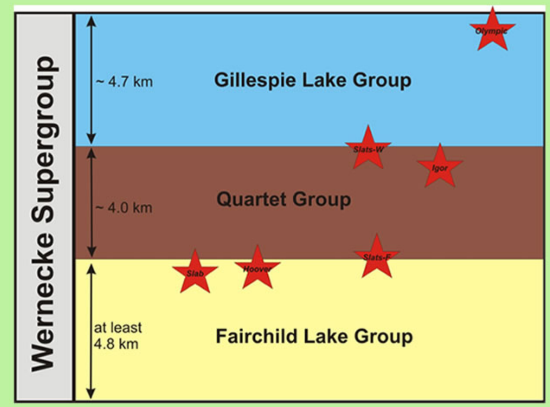



Figure 2: Relative stratigraphic positions of the study sites/prospects. The relative depths of the prospects and differences in the rock types in which each prospect lies, may have an influence on fluid properties.

## Wernecke Geology

### Dominant rocks

-Early Proterozoic Wernecke Supergroup(1840-1725 Ma) Siltstone, shale, dolostone, sandstone
-numerous breccia zones (1595 Ma)
-widespread hydrothermal Cu-Co-Au-U mineralisation related to the breccias
-no known economic deposits

## Fluid source?

### Intrusions

-dikes @ 1720 and 1270 Ma
-no intrusions @ ~1600
(assoc with breccia and mineralisation)

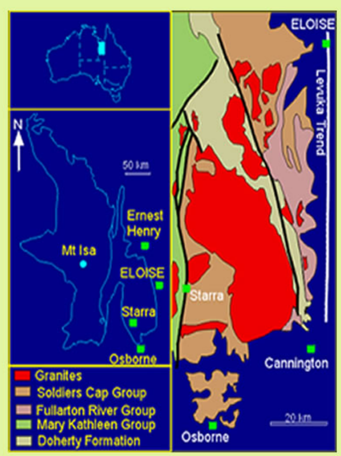



Figure 3: Map of the Cloncurry district, showing deposit locations. Note the dominance of granite intrusions (red) in the area. Such intrusions are notably absent in the Wernecke region.

## Wernecke vs Cloncurry

### Similar types of deposits

-Large hydrothermal systems
-Brecciation
-Age

### Key differences

-Granitic intrusions
-Fluids?
-Grade of metamorphism/ P-T conditions
-Economic deposits

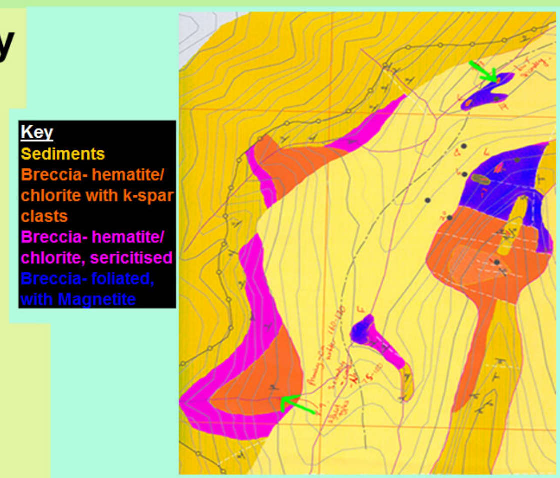



Figure 4: Basic map of the Igor prospect showing the occurrence of breccia zones within the Wernecke Supergroup sediments.

-possible intrusion at depth?

**Evaporites**

-not obvious

-scapolite may be indicative of evaporitic influence

Previously no fluid inclusion data to indicate fluid source

**Important Questions with implications for exploration**

-Which of these "key differences" are responsible for the lack of economic deposits in Wernecke Mountains

-eg. What is the importance of magmatic intrusions in terranes?

-What are the crucial factors for ore deposit formation?

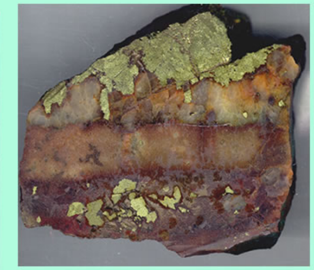


Figure 5a (left) and 5b (above): Breccia samples collected from the Igor prospect. Photos show quartz veins and associated mineralisation. The quartz contains fluids (in inclusions) which may have been associated with this mineralisation

| Sample | Type | Tfm | System | Salinity | Th vap | Th hal |
|---|---|---|---|---|---|---|
| | | | | (wt% NaCl equiv) | (degrees C) | |
| | | | (H20-NaCl +) | *(NaCl +CaCl2) | | |
| Slab SW | L+V+S | -61 to-54 | +CaCl2 | ~40* | 167-230 | 202-261 |
| Hoover | L+V+S | -55 to-49 | +CaCl2 | ~50?* | 152-200 | ??? |
| Igor | L+V+S | -50 to-47 | +CaCl2 | ~30* | 150-174 | 175-184 |
| Igor | L+V | -56 to-38 | +CaCl2 | | 70-136 | |
| Igor | L+V | -32 to-21 | +K/Fe? | 3-23 | 85-138 | |

Table 1: Summary of thermometric data on fluid inclusions in Wernecke samples

## Summary of Data

-2 main fluid types

-$H_20$-NaCl-K/Fe?

-$H_20$-NaCl-$CaCl_2$

Salinities

-relatively high for L+V+S inclusions

-lower for L+V inclusions

Homogenisation temperatures

-relatively low compared to usual temp of magmatic fluids

-2 phase inclusions homogenise by vapour disappearance

-3 phase homogenise by halite dissolution

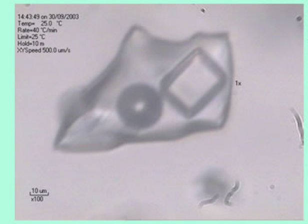


Figure 6a (above) and 6b (right): The two types of fluid inclusions observed in quartz from the Wernecke region. a) 3 phase, L+V+S with halite crystal as the solid phase and b) simple 2 phase L+V.

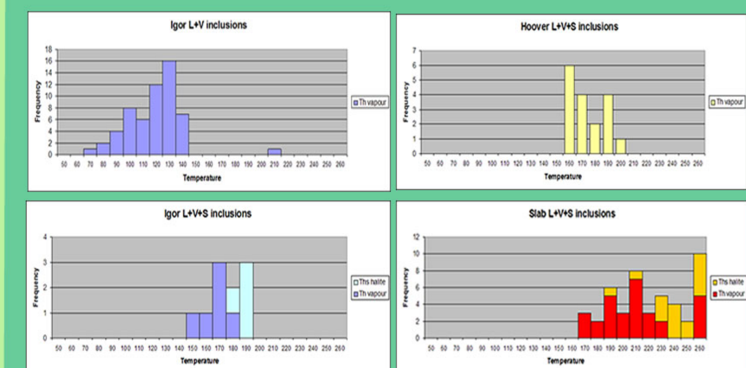



Figure 7: Histograms displaying the homogenisation temperatures observed in fluid inclusions from the Igor, Slab and Hoover prospects. The L+V inclusions homogenised by vapour disappearance, while the L+V+S inclusions homogenised via halite dissolution.

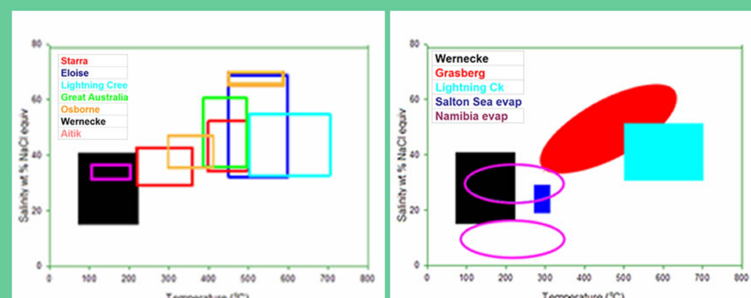



Figure 8a (left): Plots fluid salinity vs temperature for Australian Fe-oxide-Cu-Au deposits. Wernecke and Aitik (Sweden) fluid data has been added for comparison. Fluids from the Australian deposits are thought to be predominantly magmatic, while the Aitik fluids are magmatic with a strong evaporitic influence.

Figure 8b (right): Similar plot comparing Wernecke fluids with endmember magmatic and evaporitic fluids. They seem to lie at the evaporitic end of the spectrum.

## Results/conclusions to date

-Wernecke fluids initially seem more consistent with evaporitic type fluids

-But using temperature and salinity alone is very broad and limited

-So further techniques are required to enable better characterisation of the fluids

-In particular- detailed compositional data

-PIXE, LAICPMS, Laser raman, Bulk/leach techniques

Predictive Mineral Discovery www.pmdcrc.com.au

Australian Government Geoscience Australia · The University of Melbourne · Monash University · The University of Western Australia · JCU James Cook University · CSIRO · AMIRA International

# Fluid Flow in Extensional Environments: Numerical Modelling with an Application to Giant Microplaty Hematite Ores

[1] John G McLellan, [1] Nicholas H.S. Oliver, [2] Peter M. Schaubs

1 James Cook University
2 CSIRO Exploration & Mining

## AIM

To test the effects of extensional deformation and topography on fluid flow and apply numerical modelling outcomes as a predictive tool for Giant Microplaty Hematite Ores.

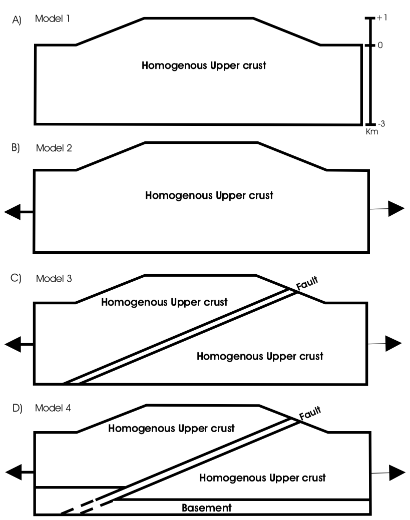



**Figure.1.** Starting conditions for four basic conceptual models 1) mountain range without deformation, 2) mountain range undergoing extension, 3) normal sense reactivation of former thrust faults, and 4) basement impermeable block and collapse of basement thrust. Note: vertical scale = horizontal scale.

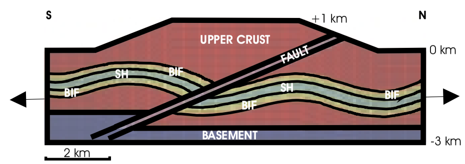



**Figure 2**. Conceptual Model 5 consists of a 12 km x 3 km two dimensional block of upper crustal material with additional 1 km of topographic relief, which represents simplified topographical and geological elements of an inferred Opthalmian mountain range. Additional structures include a fault, a granite basement block , and folded stratigraphy (BIF- banded iron formation, SH- shale).

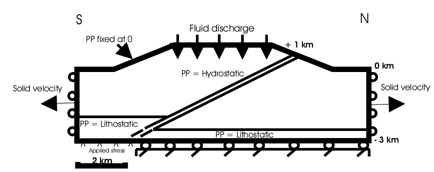
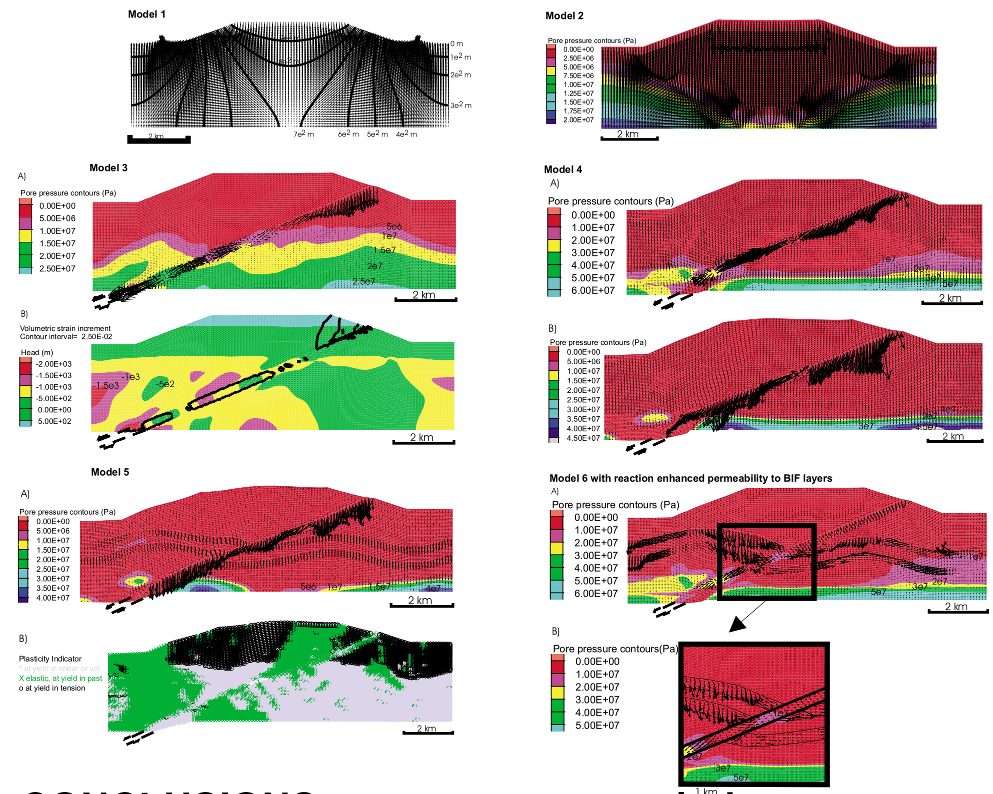



**Figure 3**. Mechanical boundary conditions for all models. The geometry is progressively altered throughout the models but basic conditions remain constant. Rolling boundaries allow extension or contraction but edges remain planar. Initial pore pressure conditions are hydrostatic but allowed to change on all boundaries during deformation. A stress equal to the overburden is applied at the base of the hangingwall, which allows normal sense movement on the fault during extension but prevents the base of the model from collapsing. Pore pressure is fixed at zero at the top of the model, hydrostatic initially in most of the models throughout the mountain range, and lithostatic initially at the base of some models. Fluid is applied to the top of the model at a rate of 1e-10 ms$^{-1}$ simulating rainfall.

## CONCEPTUAL MODELS

Model 1 - Mountain range without deformation
Model 2 - Mountain range undergoing extension
Model 3 - Mountain range extension with a permeable shear zone
Model 4 - As Model 3 with a low permeability basement material
Model 5 - (Fig.2) As Model 4 with folded BIF and Shale layers
Model 6 - As Model 5 with a reaction enhanced permeability function

## Results




## CONCLUSIONS

**-The presence of topography demonstrates the strong influence of hydraulic head in a homogenous material.**
**-Extension drives fluid flow down into the centre of the model.**
**-Addition of a permeable structure allows focussing of fluids within a shear zone and the competition between upward and downward fluid migration is evident.**
**-Lateral fluid migration can be noted within BIF layering and this is magnified by permeability enhancement during silica dissolution.**

Predictive Mineral Discovery Co-operative Research Centre www.pmdcrc.com.au

Corresponding Author email: John.McLellan@jcu.edu.au