NSERC-CMIC Exploration Footprints Network

C.M. Lesher, Laurentian University
M.D. Hannington, University of Ottawa

Research Network

- **One of the largest and strongest research teams ever brought together in Canada for a project of this type**
  - 60+ researchers from 24 universities across Canada
  - 60+ industry collaborators from 30 mining, mineral exploration, and mining service companies
  - Collaborations with GSC-TGI-4, Ministère des Ressources naturelles du Québec, Geological Survey of Saskatchewan, and Geological Survey of British Columbia
- **Includes geologists, mineralogists, geochemists, petrophysicists, geophysicists, and computer modelers**
- **5-year funding** (Phase 1: April 2013 - April 2018)
  - $7.8M cash and cash-equivalent in-kind funding from industry
  - $5.1M matching funding from NSERC (largest Collaborative Research and Development grant ever awarded by NSERC)
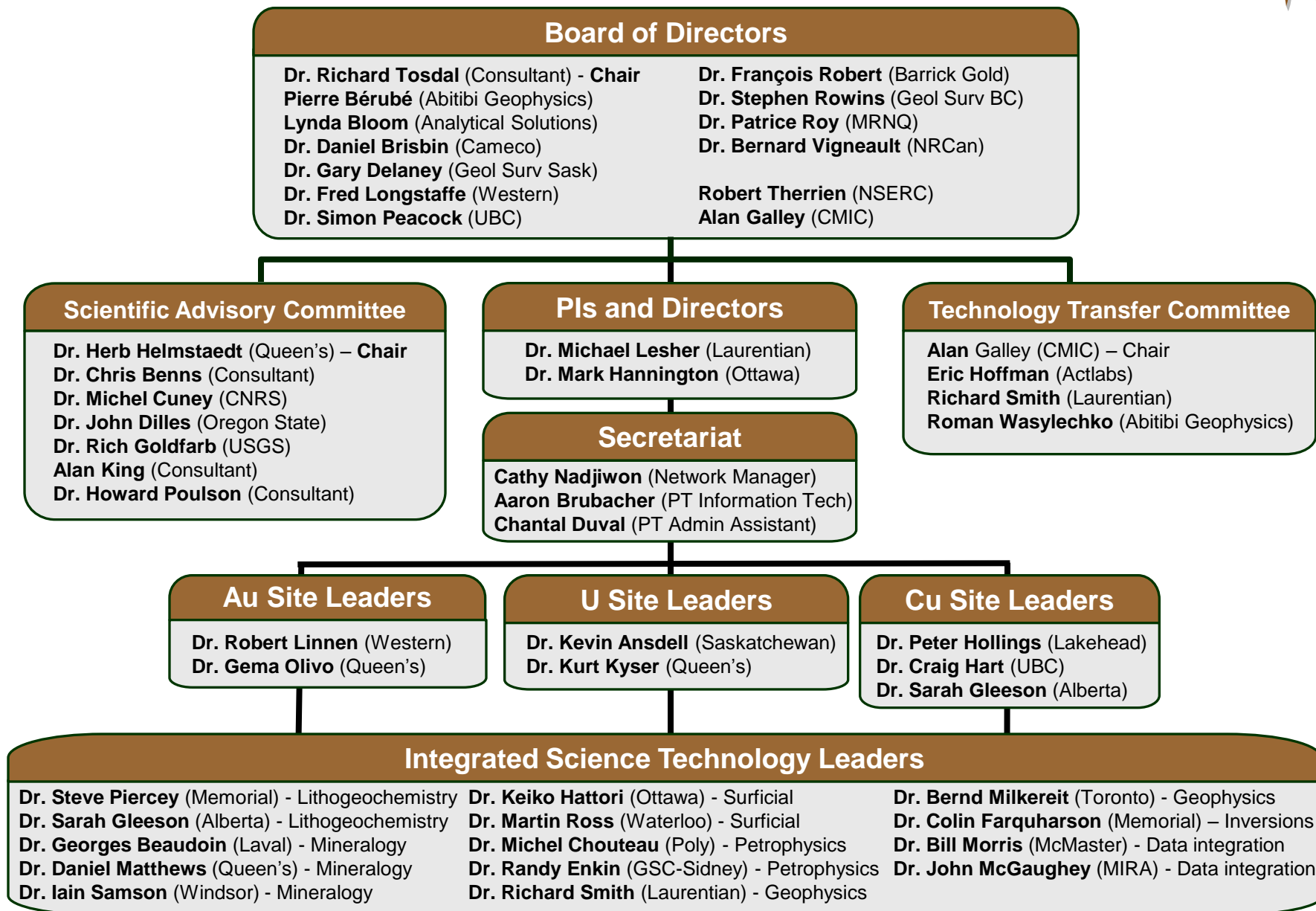 - Total = $12.9M

Sponsors/Collaborators

ABITIBI GEOPHYSICS

Actlabs
Quality Analysis...
Innovative Technologies

AGNICO EAGLE

ALS

AngloGold Ashanti

AREVA

BARRICK

Cameco

CGG
Passion for Geoscience

DENISON MINES

DGI
DGI Geoscience Inc.

Franklin Geosciences Ltd.

DS GEOVIA

GEOSOFT.

GOLD FIELDS

HudBay MINERALS

IAMGOLD CORPORATION

JCU

KINROSS

Mira Geoscience
...modelling the earth

Paradigm
Deeper Insight into the Subsurface

Paterson, Grant & Watson Limited
Consulting Geophysicists

PitneyBowes Software

REFLEX
intelligence on demand

SGS

Src SASKATCHEWAN RESEARCH COUNCIL

srk consulting

Teck

YAMANAGOLD

Collaborators: GSC TGI4 Program
MRNQ
Saskatchewan Geol Survey
BC Geological Survey

Supporters: Fullagar Geophysics
UBC Geophysical Inversion Facility

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Chantal Duval (PT Admin Assistant)

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Richard Smith (Laurentian)
Roman Wasylechko (Abitibi Geophysics)

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Dr. Gema Olivo (Queen's)

U Site Leaders

Dr. Kevin Ansdell (Saskatchewan)
Dr. Kurt Kyser (Queen's)

Cu Site Leaders

Dr. Peter Hollings (Lakehead)
Dr. Craig Hart (UBC)
Dr. Sarah Gleeson (Alberta)

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Dr. Sarah Gleeson (Alberta) - Lithogeochemistry
Dr. Georges Beaudoin (Laval) - Mineralogy
Dr. Daniel Matthews (Queen's) - Mineralogy
Dr. Iain Samson (Windsor) - Mineralogy

Dr. Keiko Hattori (Ottawa) - Surficial
Dr. Martin Ross (Waterloo) - Surficial
Dr. Michel Chouteau (Poly) - Petrophysics
Dr. Randy Enkin (GSC-Sidney) - Petrophysics
Dr. Richard Smith (Laurentian) - Geophysics

Dr. Bernd Milkereit (Toronto) - Geophysics
Dr. Colin Farquharson (Memorial) – Inversions
Dr. Bill Morris (McMaster) - Data integration
Dr. John McGaughey (MIRA) - Data integration

Current Numbers

24 Universities

43 Faculty Researchers

8 Research Scientists (1 more to be added)

7 PhD Students (more to be recruited as project progresses)

11 MSc Students (1 completed, more to be recruited)

9 BSc Hons Students: (more to be recruited as project progresses)

4 BSc Summer Students: (more to be recruited as project progresses)

30 Sponsors:

- **15 Mining and Mineral Exploration Companies**: Agnico-Eagle, AngloGold Ashanti, Areva, Barrick, Cameco, Denison Mines, Franklin Geosciences, Goldfields, HudBay Minerals, Iamgold, Japan-Canada Uranium, Kinross, Teck, Yamana Gold
- **4 Geochemical Service Companies**: Actlabs, ALS, SGS, SRC
- **5 Geological and Geophysical Service Companies**: Abitibi Geophysics, CGG, DGI, PGW, SRK Consulting
- **6 Software Service Companies**: Geosoft, Geovia, MIRA Geoscience, Paradigm, Pitney-Bowes, Reflex

Collaborators: GSC TGI-4, MRNQ, SGS, GSBC

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Footprints Project Objectives

- **Develop comprehensive and robust models of the footprints of large-scale ore-forming systems at three integrated study sites**, combining geological, mineralogical, geochemical, and physical rock properties from the local to the camp scale

- **Develop novel methods for integrating and interrogating multiple data sets** that will enhance the exploration process and, at the same time, answer fundamental questions about the origins of large-scale ore-forming systems

- **Identify the best combinations of geological, geophysical, petrophysical, mineralogical, and geochemical tools** to detect the footprints of major ore-forming systems

Limit of Cryptic Alteration
Limit of Geochemical Footprint
Limit of Mineralogical Footprint
Limit of Geophysical Footprint
Ore Body

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Multiple Data Layers

Cullaton Lake B Zone

F Zone

Discovery - Meliadine East

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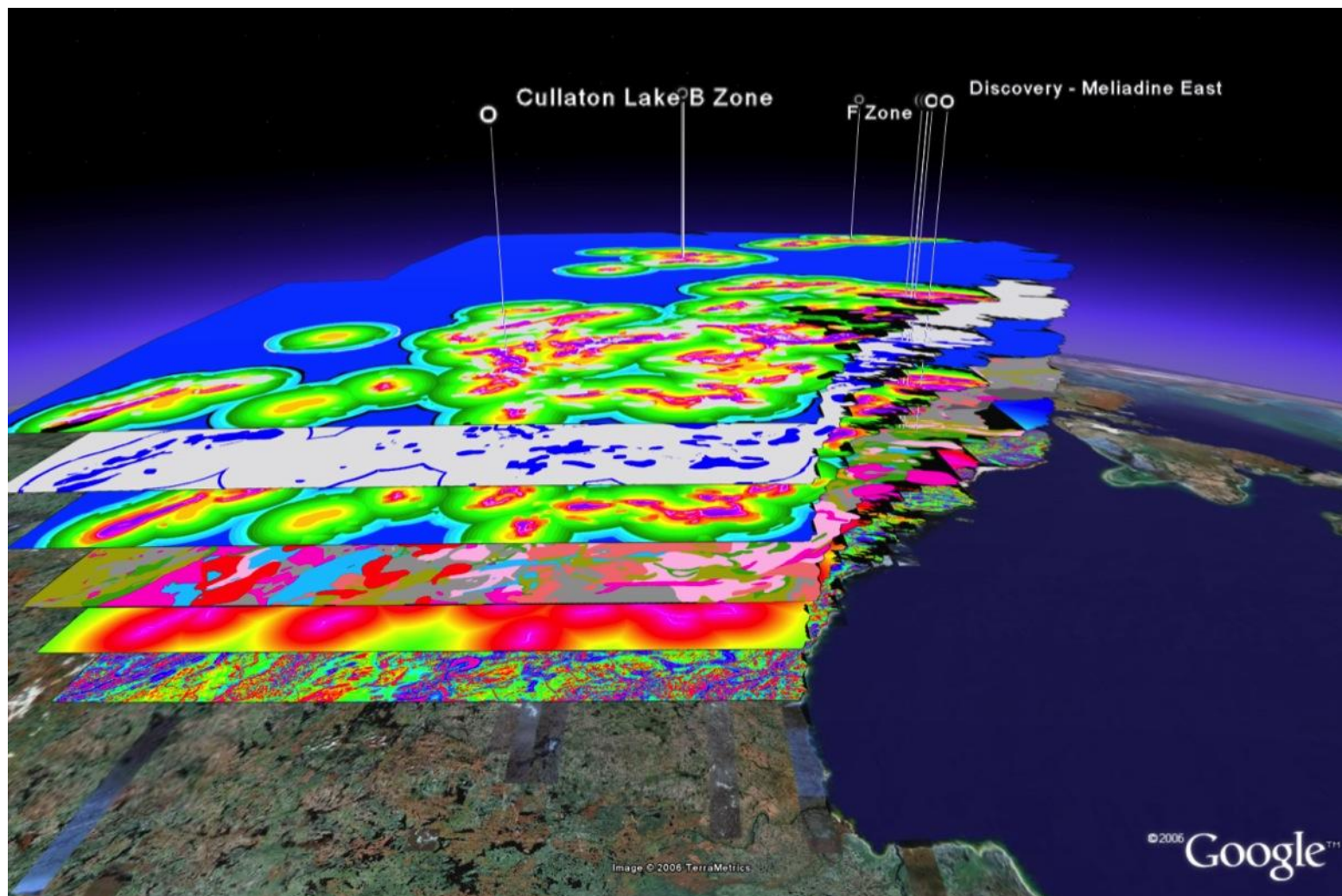
Jeff Harris and
Chang-Jo Chung,
NRCan

Often acquired ... but in this project they will be *integrated*

What is needed are models where geology, structure, mineralogy, and geochemistry are completely integrated with rock properties and their geophysical responses:

Most models include only a few charac-teristics and are layered, but not truly integrated

Geology/Structure

Geochemistry

Mineralogy

Rock Properties

Geophysics
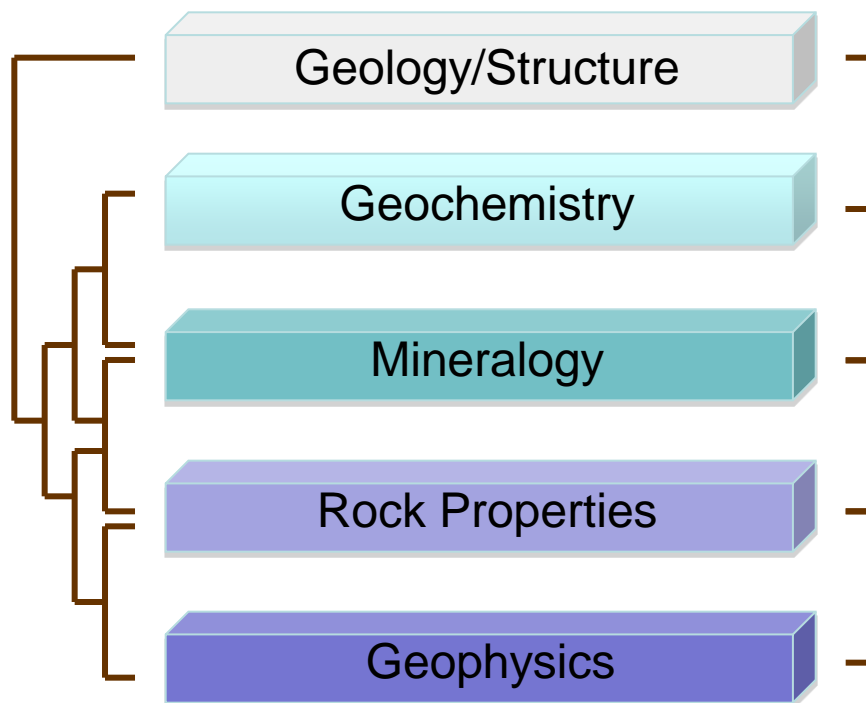
This project will produce genuinely integrated multi-parameter models

Integrated Study Sites: Phase I

Legend:
- Porphyry Copper (red)
- Uranium (yellow)
- Lode Gold (green)

Cameco — McArthur-Millennium

Teck — Highland Valley

YAMANAGOLD
AGNICO EAGLE — Canadian Malartic

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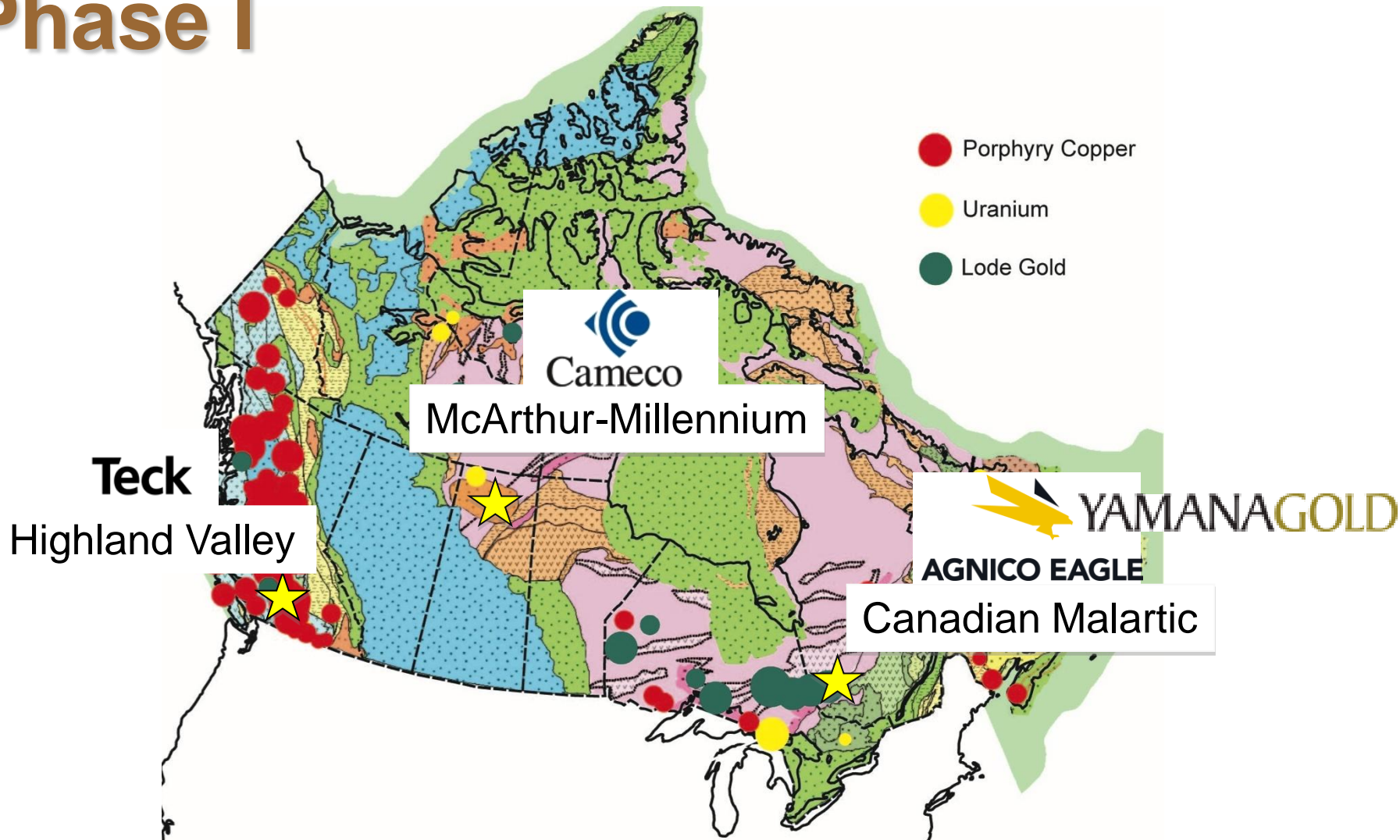
Integration Matrix

- **Work at each site focussed through** Site Working Groups

- **Research methods focussed through** Integrative Science (Technology) Groups **that include** Service Providers **and** Industry Subject Matter Experts

- **Ensures multi-disciplinary collaboration and best practices across all sites**

Project Synthesis

Data Management/Integration/Analysis

Integrative Science Groups

Canadian Malartic Au	McArthur-Millennium U	Highland Valley Cu

Inversion Modeling

Geophysics

Rock Properties

Surficial Materials

Mineralogy

Lithogeochemistry

Geology/Structure

Research Sites
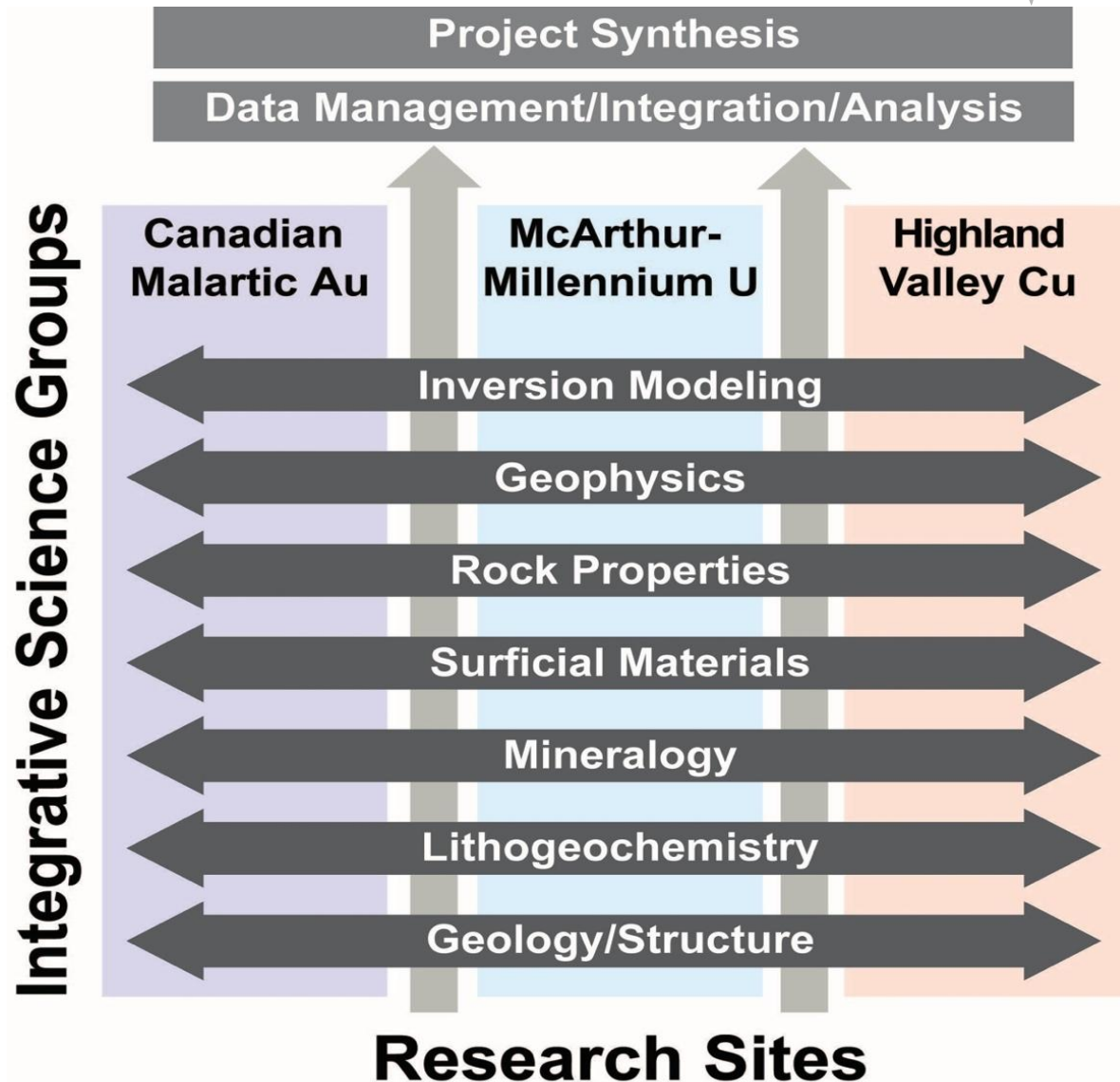
Research Methodologies

- **Full ore systems from distal edges to ore zones**, both at surface and at depth, and including the highest density of data and sampling opportunities

- **New and legacy data**, with emphasis on high-quality multi-parameter measurements on the same samples at each site

- **3D data are constrained using multi-parameter data from representative cross sections and surface/level plans** through each ore 10s km by 10s km) ore system

- **Same teams of researchers will work on all three sites** to ensure a uniform approach to defining the ore-system footprints

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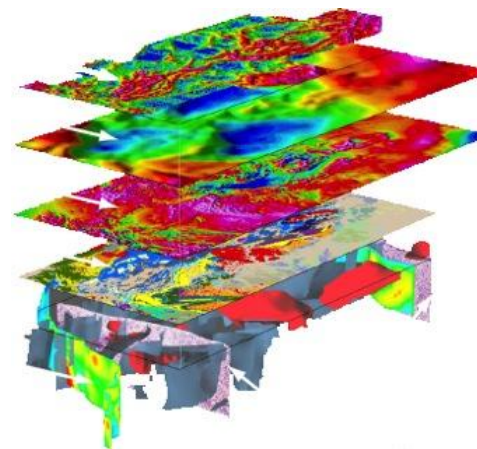
Common Focus of Subprojects

- **Collate and integrate existing data sets**

- **Identify key sections to characterize the deposit footprint**

- **Select new analyses to fill critical gaps in multi-parameter data sets**

- **Identify unique combinations of parameters at the appropriate scales**

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Common Data Integration Model
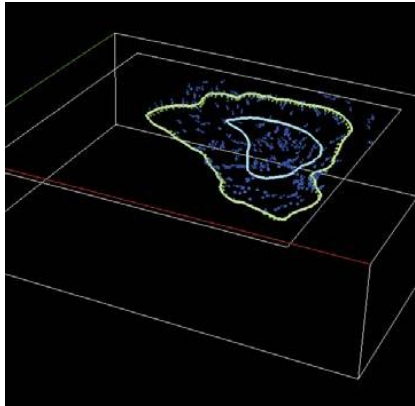
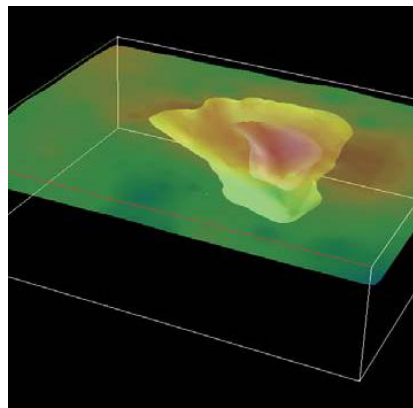Map contacts and point structural data
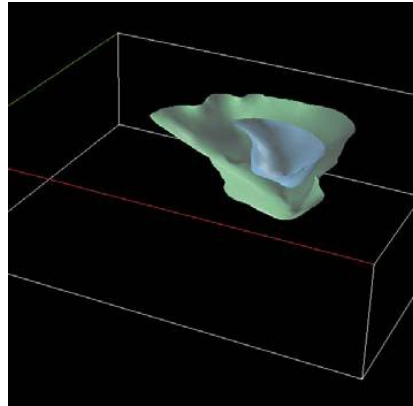
Modelled formational contact surfaces
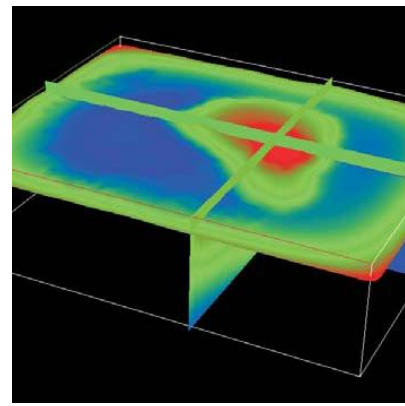
Gravity forward mode
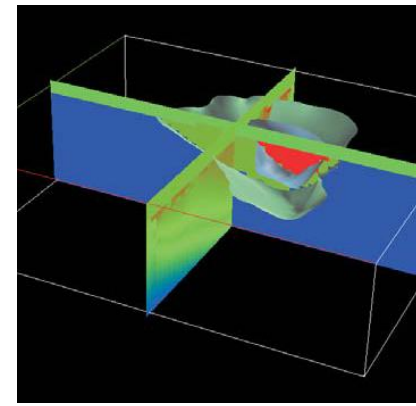
Unconstrained gravity inversion
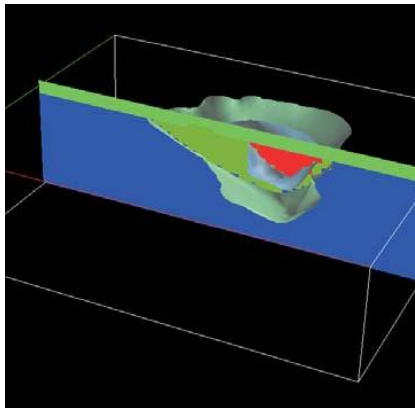
Section through 3D density grid

Geology seen through gravity data
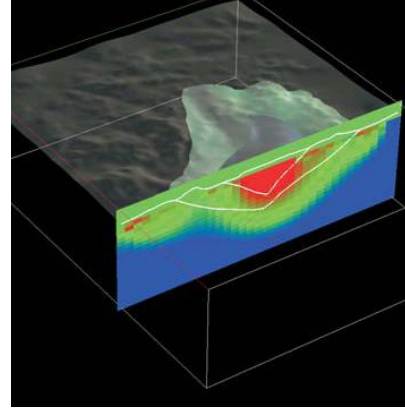
Unconstrained gravity inversion
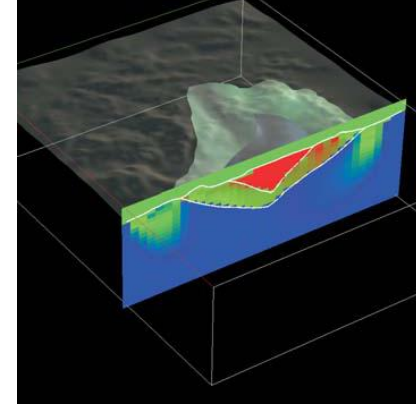
Geologically constrained inversion

McGaughey 2006 *GAC SP44*

Essential common framework for 2D (cross-sections)**, 3D GIS, physical properties, borehole logs, structural modeling, advanced geophysical modeling and inversions**

Major Deliverables

- ⊙ **Fully integrated, multiparameter footprint models** of three major types of ore systems in Canada and the methods for creating models of other ore deposit types

- ⊙ **Maps and sections of the detectable features of the ore-system**, including full geological, mineralogical, geochemical, geophysical and derived attributes

- ⊙ **Database of physical rock properties** linked to the mineralogical and geochemical attributes of ore-hosting lithologies and alteration

- ⊙ **Geophysical survey data reprocessed** with new software and constrained by new geological information and **physical property measurements specific to the ore system**

- ⊙ **Modifications of existing tools or methods** to enhance the measurement and detection of footprints at a range of scales

Current Status

- **Officially started in April 2013, presently near end of Y2**

- **Au Site**: two seasons of field/structural/geophysical work and sampling completed; one round of lithogeochemical/mineralogical/petrophysical work completed

- **U Site**: one partial and one full season of field/surficial/structural/geophysical work and sampling completed; first round of lithogeochemical/mineralogical/petrophysical work completed

- **Cu Site**: one season of field/structural work, geophysical work, and sampling completed; first round of lithogeochemical/mineralogical/petrophysical work in progress

- **Data Integration**: workflows planned, legacy data being compiled, preliminary gOcad models completed

White Papers

1 **Lithogeochemical Processing** (Piercey)

2 **Lithogeochemical QCQA** (Piercey)

3 **Lithogeochemical Sampling and Analytical Protocols** (Piercey et al.)

4 **Mineralogical Analytical Methods** (Beaudoin & Layton-Matthews)

5 **Hyperspectral Comparison** (Layton-Matthews)

6 **Geophysical Methods** (Morris et al.) – in preparation

7 **Data Analysis Methods** (Feltrin et al.) – in preparation

8 **Surficial Geochemical Methods** (Hattori-Leybourne-Ross-Winterburn) – in preparation

Interim Results

- **Au Site**: *five* new footprint components identified so far, *two* of which will clearly be useful for vectoring within the footprint

- **U Site**: one new footprint component identified so far, which appears to be useful for vectoring within the footprint

- **Cu Site**: one previously-recognized footprint component extended a significant distance away from the deposit

- **Y3 will focus on the Common Earth Models**

- **Y4 will focus on Multivariate Data Integration**

- **Y5 will focus on Multidiscipinary Footprint Generation**

Sponsors/Collaborators

NSERC-CMIC FOOTPRINTS

Collaborators: GSC TGI4 Program
MRNQ
Saskatchewan Geol Survey
BC Geological Survey

Supporters: Fullagar Geophysics
UBC Geophysical Inversion Facility