GEOPHYSICAL EXPLORATION CHALLENGES FOR LARGE AND SMALL MINING COMPANIES

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KEGS
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CHALLENGES/GEOPHYSICS

- Mining Companies rely on Geophysical Techniques and Interpretations to
  - Guide and Focus Exploration
  - Formulate Business Decisions
- Numerous challenges and opportunities for Exploration Geophysicists.
- Meeting these challenges will result in an increase in discoveries by both large and small companies.
- Current success rate (large ore-bodies) has dropped sharply in Canada and around the world.

CHALLENGES: GEOPHYSICS LARGE Au COMPANIES

- Existing Au reserves are being depleted even at a time when potential profitability is increasing.
- “Even more concerning matter” ….. Senior geologists/ geophysicists and development team leaders are being dismissed while new projects are being stalled (Nov – 2012)
- … The bean counters appear to have seized control, as budgets are slashed, exploration curtailed and highly respected geoscientists are shown the door….
- Without a firm commitment to press on with exploration and development activity, the big mining companies will be doomed to inevitable decline “Mike Kachanovsky”…. Mining World 2012

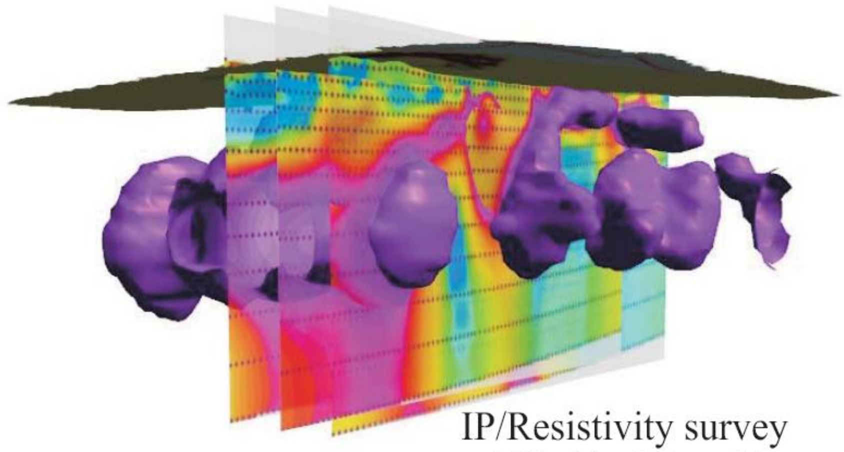
CHALLENGES: GEOPHYSICS
SMALL EXPLORATION COMPANIES

- 10% - 20% of Budget allocation spent on exploration of greenfields projects.
- Led to reduction in field time by all geoscientists
- More time spent on H.R, social responsibility, environmental issues, health, proliferation of reporting…
- “all pervasive obsession with computerized data manipulation and communication”… R. Sillitoe (Oct 2010)
- Mining companies spend excessive amounts of time indiscriminately collecting/ collating masses of geological/ geochemical and especially geophysical data … R. Sillitoe (2010)
- NOT ENOUGH TIME SPENT THINKING CRITICALLY ABOUT TARGET ENVIRONMENTS.

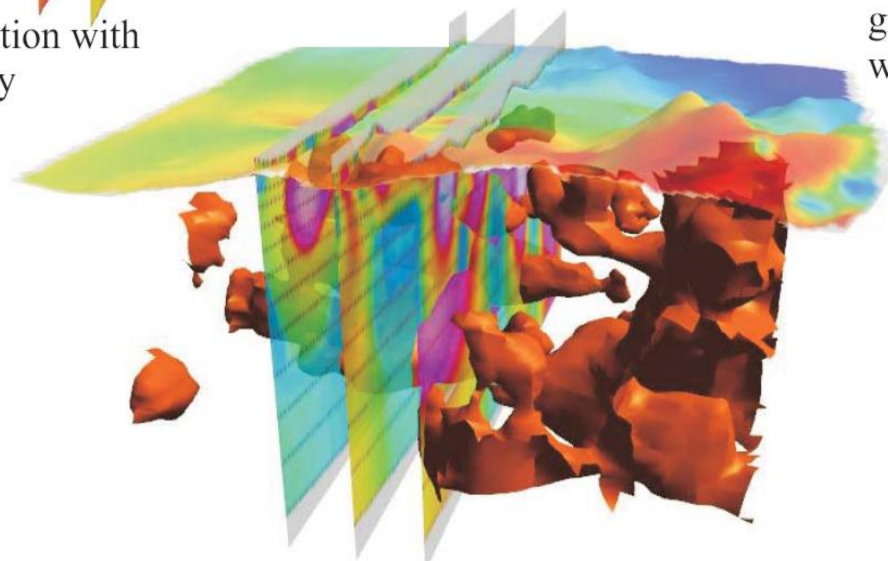
SYSTEMIC CHALLENGES IN GEOPHYSICAL SCIENCES

- Changing scene of the quality and availability of Geophysicists.
- Commitment to Basic and Regional Data gathering with clear access to GIS-type portals for historical and new data.
- Improved Detection Methods and Applications for both lithologies (continental scale) and ore-environments.
- Innovative 3D and 4D interpretations and applications of geophysical data.

3D Geology integration with IP/Resistivity survey



IP/Resistivity survey gridded in 3D and integrated with local geology.



3D inversion of ground magnetic data using IP/Res as constraints.

H. Ugalde 2011

CHALLENGES: IMPROVED DETECTION TECHNIQUES HIGH RESOLUTION AND DEEP DEPOSITS

- Surface mapping and Geochemical sampling are less successful for large/deep deposits.
- Conventional geophysics less effective at depth.

IMPROVED DEEP DETECTION METHODS

- **Focus on signatures that reflect major deposits.**
  - Structural Avenues
  - Block/Terrane edges
  - Fluid Delivery Systems
- **Individual World-class Deposit cost approx. $2 billion to $5 billion — either buying or exploring.**
  - Speed up timeframe will require approx. 10% of each W.C. Deposit into Research (Government, Industry, University).
  - Large companies spend approx. $50 million for discovery of a large deposit.
  - Small companies have a yearly budget of $2 million to $5 million.

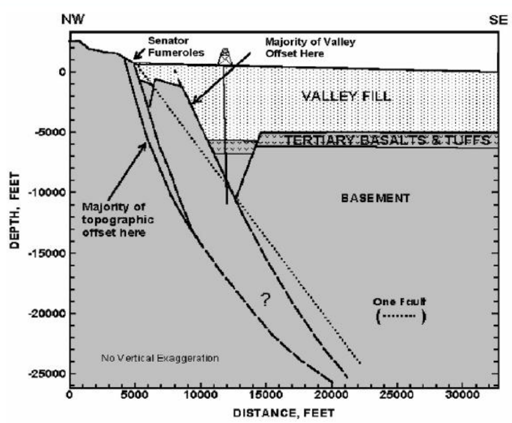
SPECIFIC SIGNATURES

- Map cover type/thickness, Regional/Continental scale
- Map fundamental lithospheric structure
- Four necessary advances on the Regional Scale
  - High Resolution Magnetics, over greenfields areas
  - Deep penetrating Electromagnetics, especially low-frequency M.T.
  - Airborne Gravity/Total Field and Gradient
  - Seismics, including R.T.M.

SPECIFIC METHODS

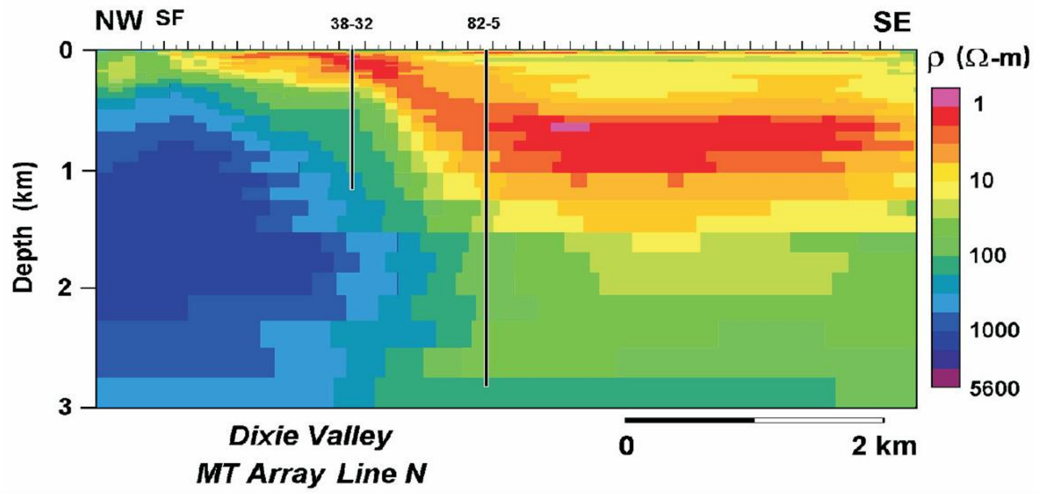
- Deep Penetrating EM (MT and Airborne)
  - Excellent for brownfields and regional reconnaissance.
  - Ground systems penetrate from a few 100 metres to over 10 km
  - Airborne Systems are now approaching these depths of penetration

SPARTAN MT DEEP RESISTIVITY SOUNDING



Dixie Valley geologic model
vs. resistivity image

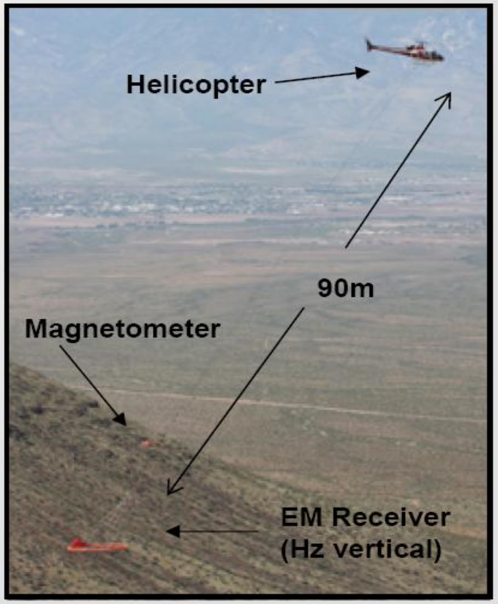
Senator Fumeroles



GEOTECH LTD. AIRBORNE GEOPHYSICAL SURVEYS

ZTEM system

ZTEM SYSTEM IN FLIGHT - Portugal

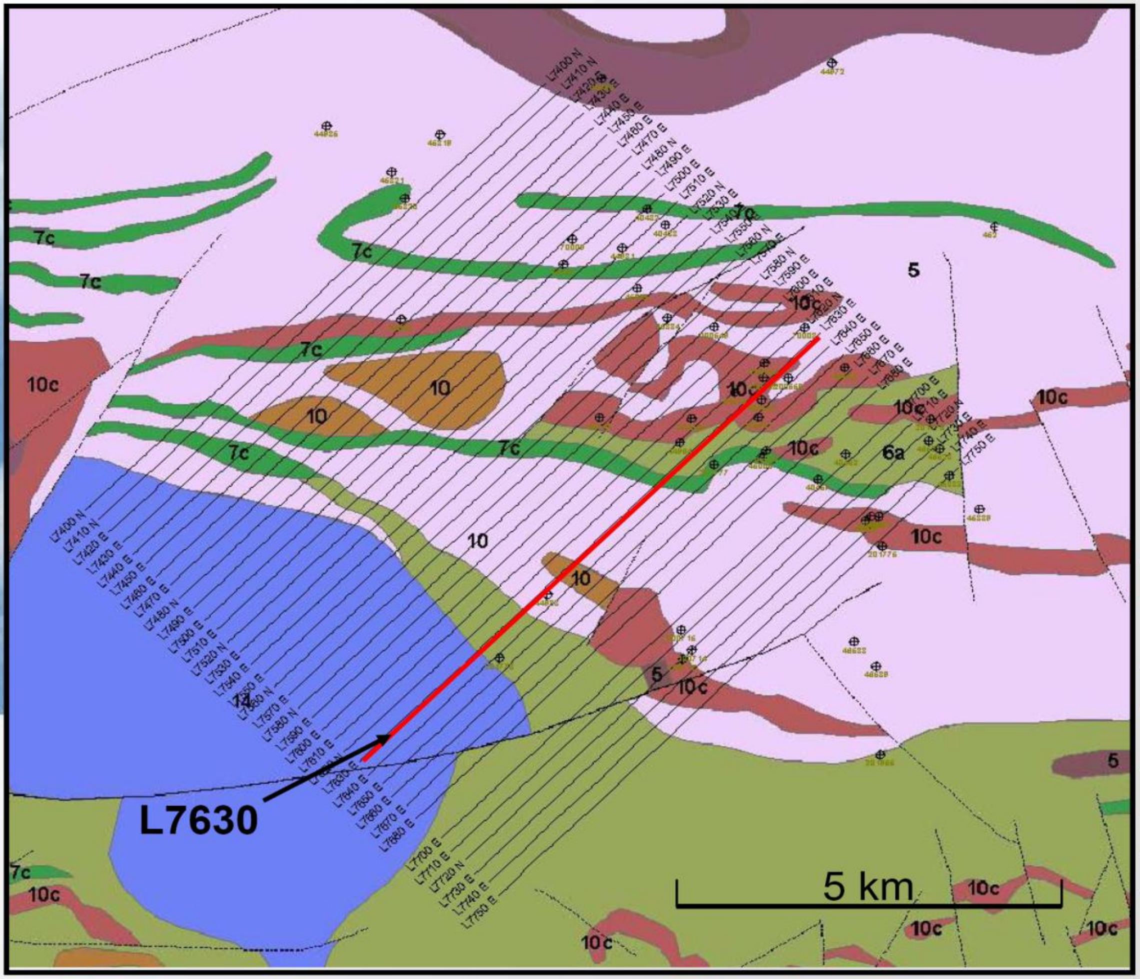


ZTEM Z-AXIS RECEIVER AND MAGNETOMETER
Hyden, WA

ZTEM AIRMT BASE-STATION
Hyden, WA

GEOPHYSICAL SURVEYS

Local geology and flight planning



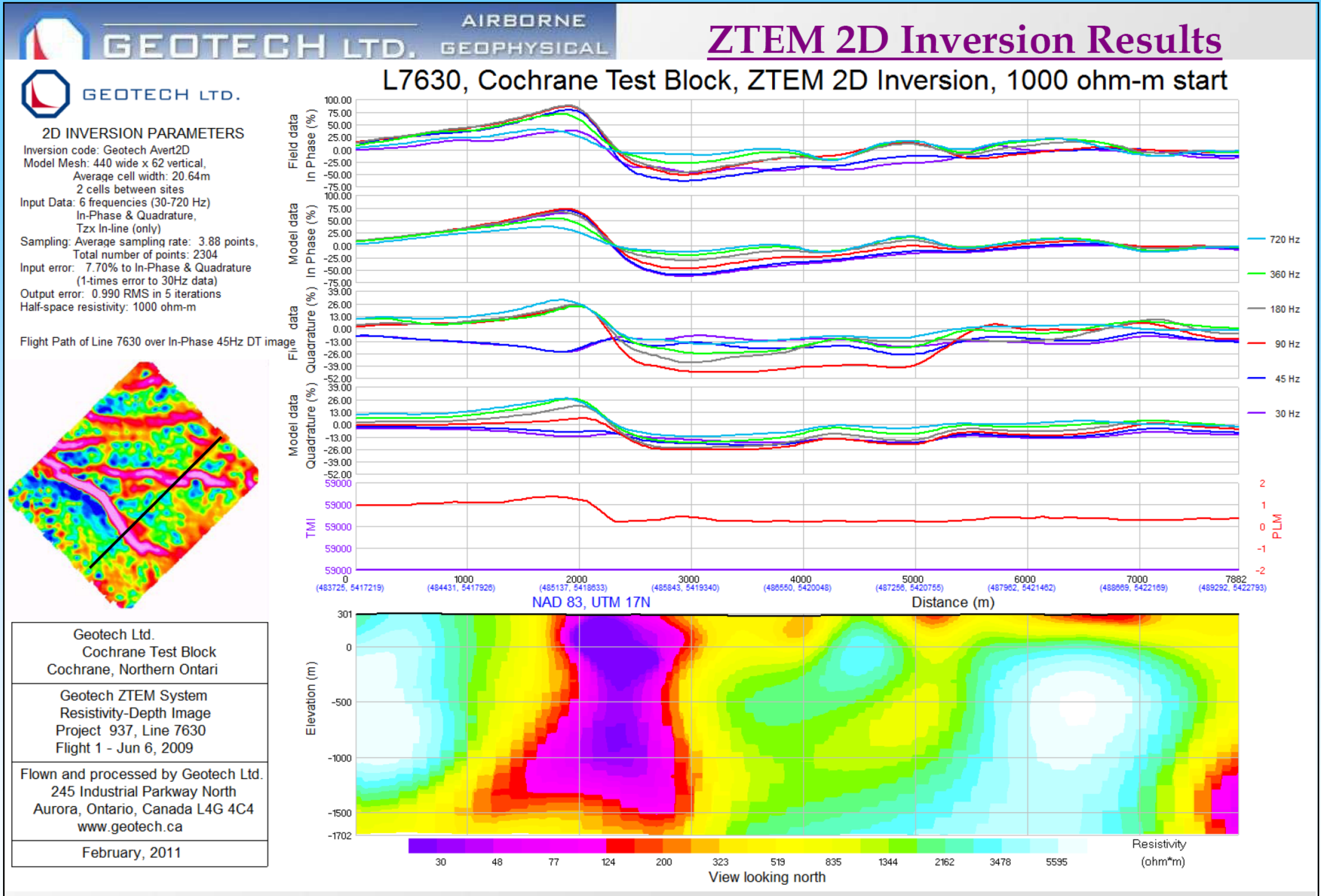
⊕ 44979 Historical drilling (adapted from Ontario Geological Survey, 2010)

Legend

- **5** Mafic to intermediate metavolcanic rocks (basaltic and andesitic flows, tuffs and breccias, related migmatites).
- **6a** Felsic to intermediate metavolcanic rocks (diacitic and andesitic flows, tuffs and breccias).
- **7** Metasedimentary rocks (wacke, siltstone, arkose, argellite, slate, marble, chert, iron fm, minor metavilcanics).
- **7c** Metasedimentary rocks (marble, chert, iron fm).
- **10** Mafic and ultramafic rocks (gabbro, anorthosite, ultramafic rocks).
- **10c** Mafic and ultramafic rocks
- **14** Diorite – monzonite – granodiorite suite (diorite, tonalite, monzonite, granodiorite, syenite and hypabyssal equivalents,).

From Kaminski et al., CMOS-CGU, Ottawa, Jun-2010

ZTEM 2D Inversion Results



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CHALLENGES: AIRBORNE GRAVITY

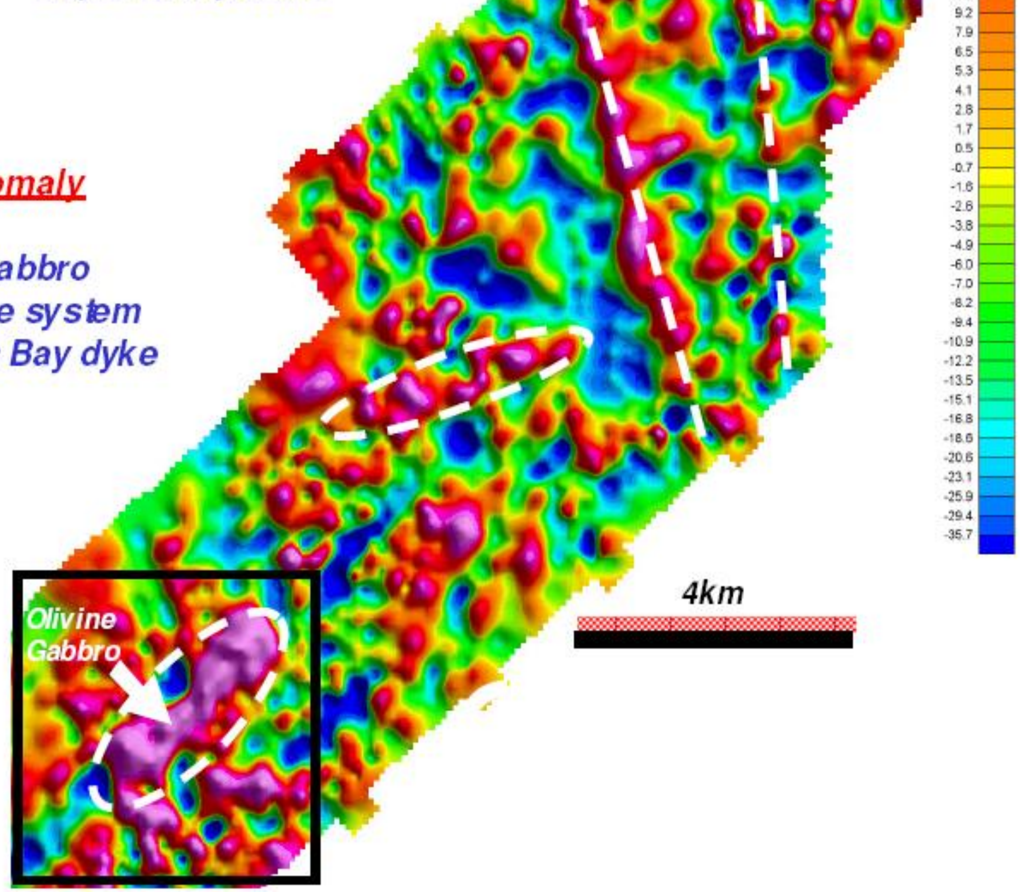
- Since the introduction of the Falcon system, Airborne gravity has become a standard technique for regional reconnaissance.
- 10 companies and over 1 million line kms flown annually (most for oil/gas).
- $50 million investment over last 6 years, and will increase over next 10 years to $100 million.
- Four Systems currently flying: ARKex, Bell Geospace, Fugro System and GT 1A Micro-Gravity.
- Five systems in development.
- Examples presented for Bell, Micro Gravity and Falcon with emphasis on GT 1A system used in Africa.

Terrain Corrected Tzz

- Delineate Troctolite Olivine Gabbro ("Feeder-Dyke") associated with Ni mineralization
- Maps fault systems

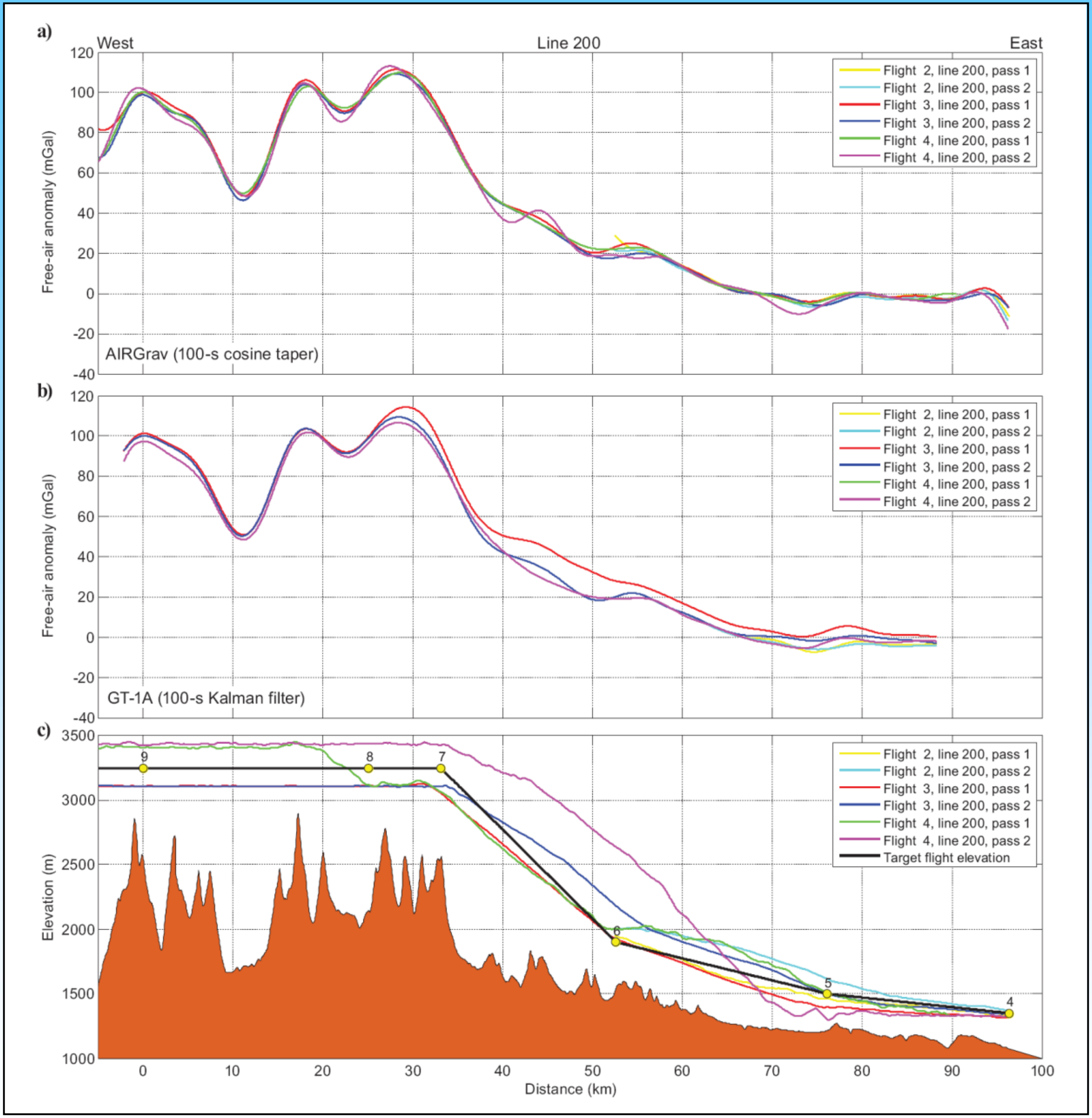
Air-FTG Nickel (Ni-Cu-Co) Anomaly

- Hosted in troctolite olivine gabbro
- Associated with "feeder-dyke system
- Continuation of the Voisey's Bay dyke system



COMPARISON OF AIRBORNE GRAVITY SYSTEMS

- Sander Air-Grav and Canadian MicroGravity Pty. GT-1A tested in 2007 in Western Canada.
- Current systems are cost effective and may be used for regional mapping as shown in Western Canada and in Africa.



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DIRECT DETECTION OF MASSIVE (I.O.C.G.) DEPOSITS

- Detailed surveys and Regional for detection of prospects.
- 2009 Prominent Hill Deposits: S. Australia.
- Approximately 2,500 line km @ \$85/km^2 for small companies.
- Now cost effective for small companies

KEGS

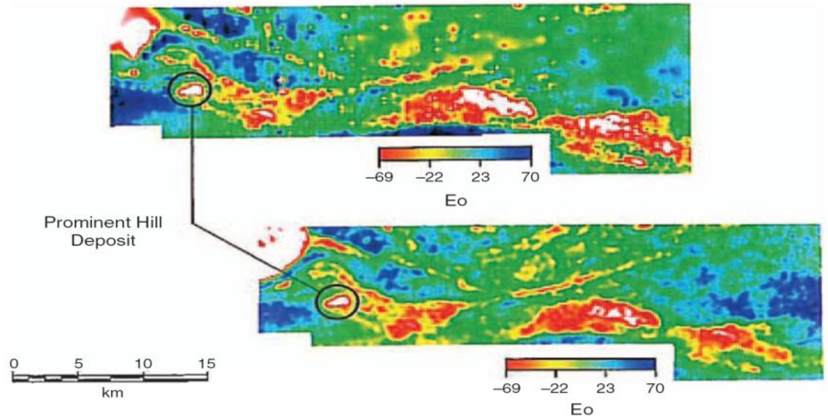
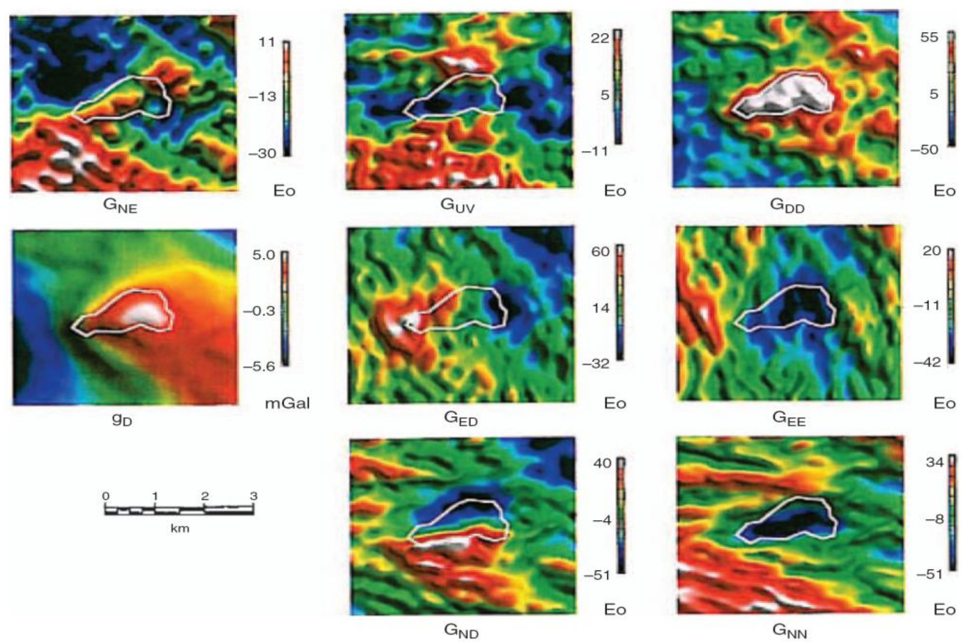


Fig. 9. *Prominent Hill IOGC deposit – upper image is ground gravity data and lower image is Falcon GDD survey data.*



These images show all the components of the gravity gradient tensor over Prominent Hill. The top row shows the two components measured by the Falcon airborne gravity gradiometer system (G_{NE} and G_{UV}), where $G_{UV} = (G_{NN} - G_{EE})/2$ and the vertical gradient (G_{DD}). The second and third rows show the vertical gravity (g_D) and the remaining independent gravity gradient tensor components.

CHALLENGES: REGIONAL SEISMIC FOR MINING EXPLORATION

- Ultra Deep High Resolution Basin Imaging, unexplored or mature basins are being reviewed by attempting to map “macro level” features within a regional petroleum system — putting discoveries, leads and prospects in broader chronological context of source rocks, sediment deposition, regional tectonics, and thermal maturation. — statement for oil/gas but applies equally well to mining.
- Need to resolve:
  - Cover types
  - Fundamental lithospheric structures
  - Map large fluid systems at 1 to 5 km
- Oil/Gas Geophysicists using these methods — applicable to mining?

DATA PROCESSING FOR MINING GEOPHYSICS

- Image Structures (folds and faults)
- Locate and enhance/ trace diffractions

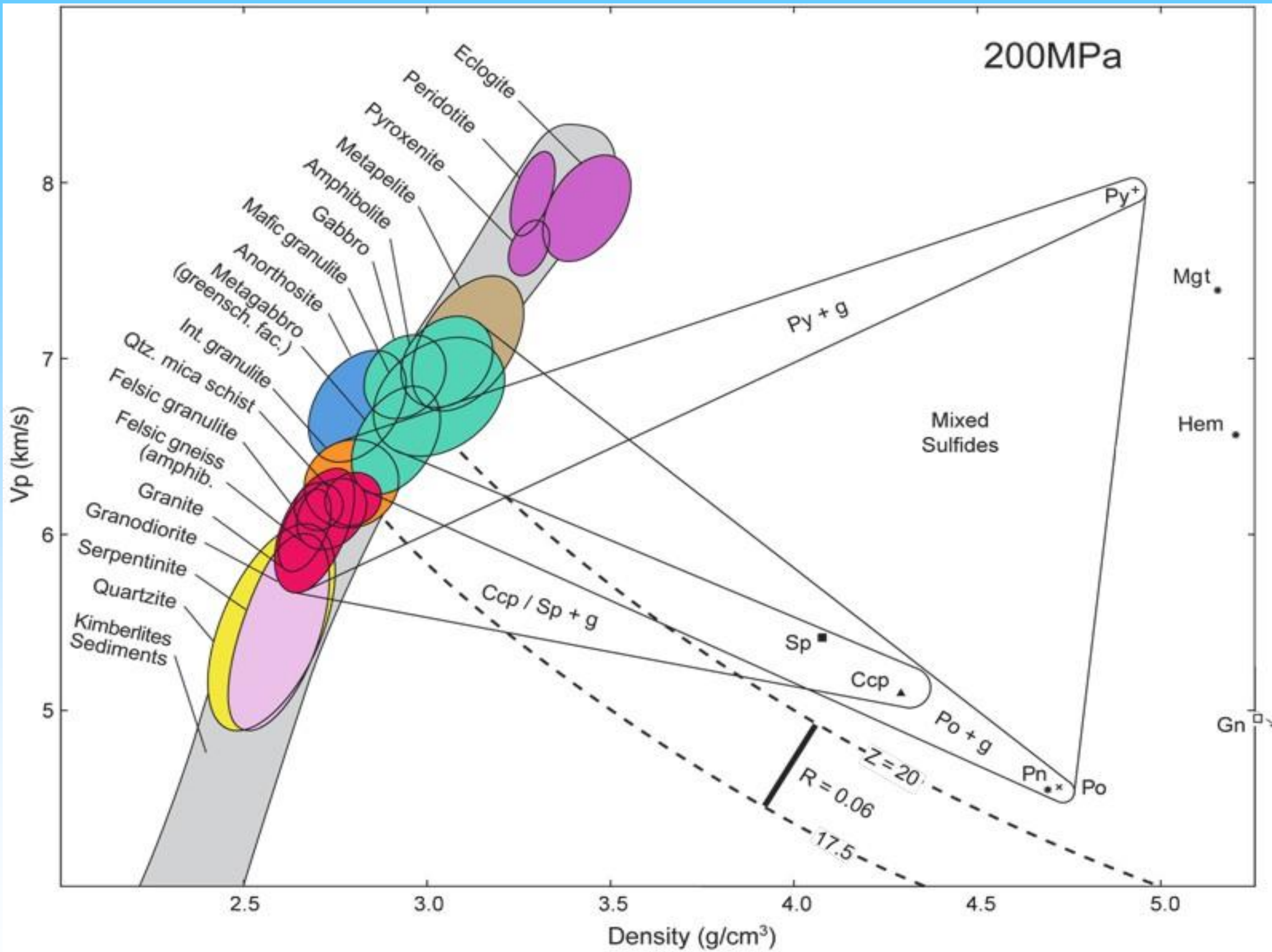
  Carry out prestack migrations so that small targets are not treated as noise.

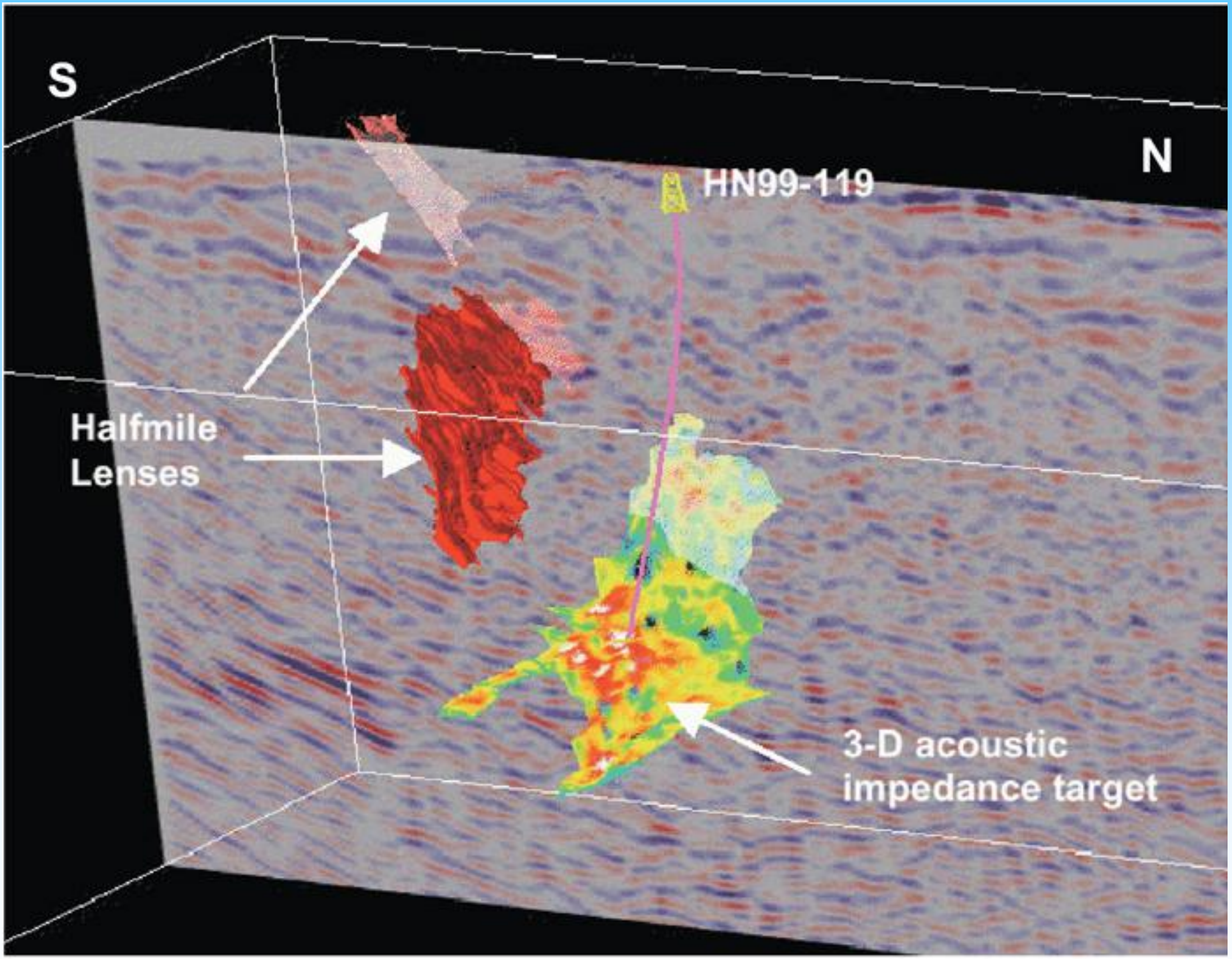
- Cost: 2D $6,000/km

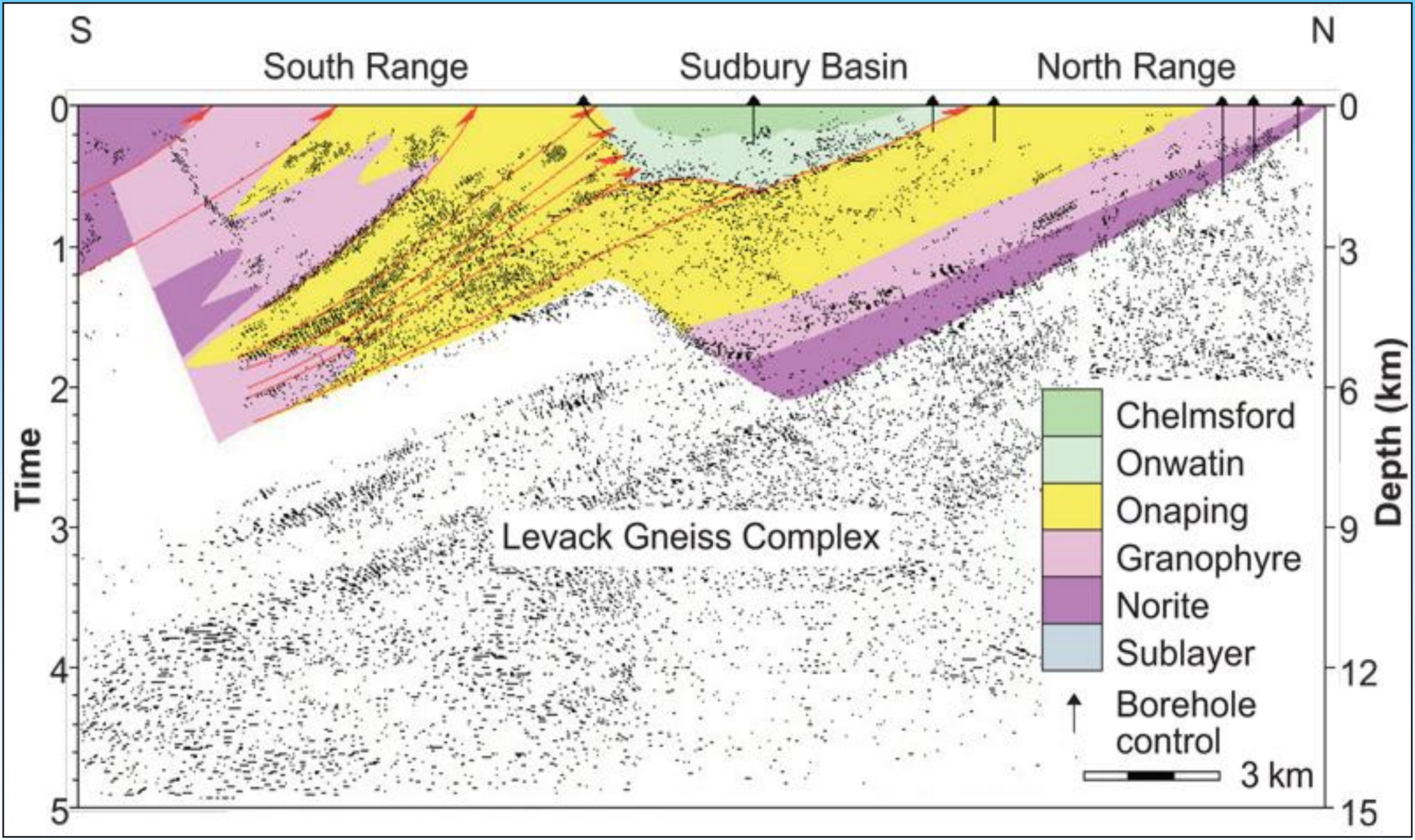
  3D $50K/km^2

In order to use seismic effectively in mining geophysics

- Difference in acoustic impedance between deposits and horizons must be sufficient and
- Geometry must allow detection (Rayleigh limit)


200MPa
Eclogite
Peridotite
Pyroxenite
Metapelite
Amphibolite
Gabbro
Mafic granulite
Anorthosite
Metagabbro
(greensch. fac.)
Int. granulite
Qtz. mica schist
Felsic granulite
Felsic gneiss
(amphib.
Granite
Granodiorite
Serpentinite
Quartzite
Kimberlites
Sediments
Py+
Py + g
Mgt
Hem
Mixed
Sulfides
Ccp / Sp + g
Sp
Ccp
Po + g
Pn
Po
Gn
Z = 20
R = 0.06
17.5
Vp (km/s)
Density (g/cm3)
8
7
6
5
2.5
3.0
3.5
4.0
4.5
5.0


S
N
HN99-119
Halfmile
Lenses
3-D acoustic
impedance target



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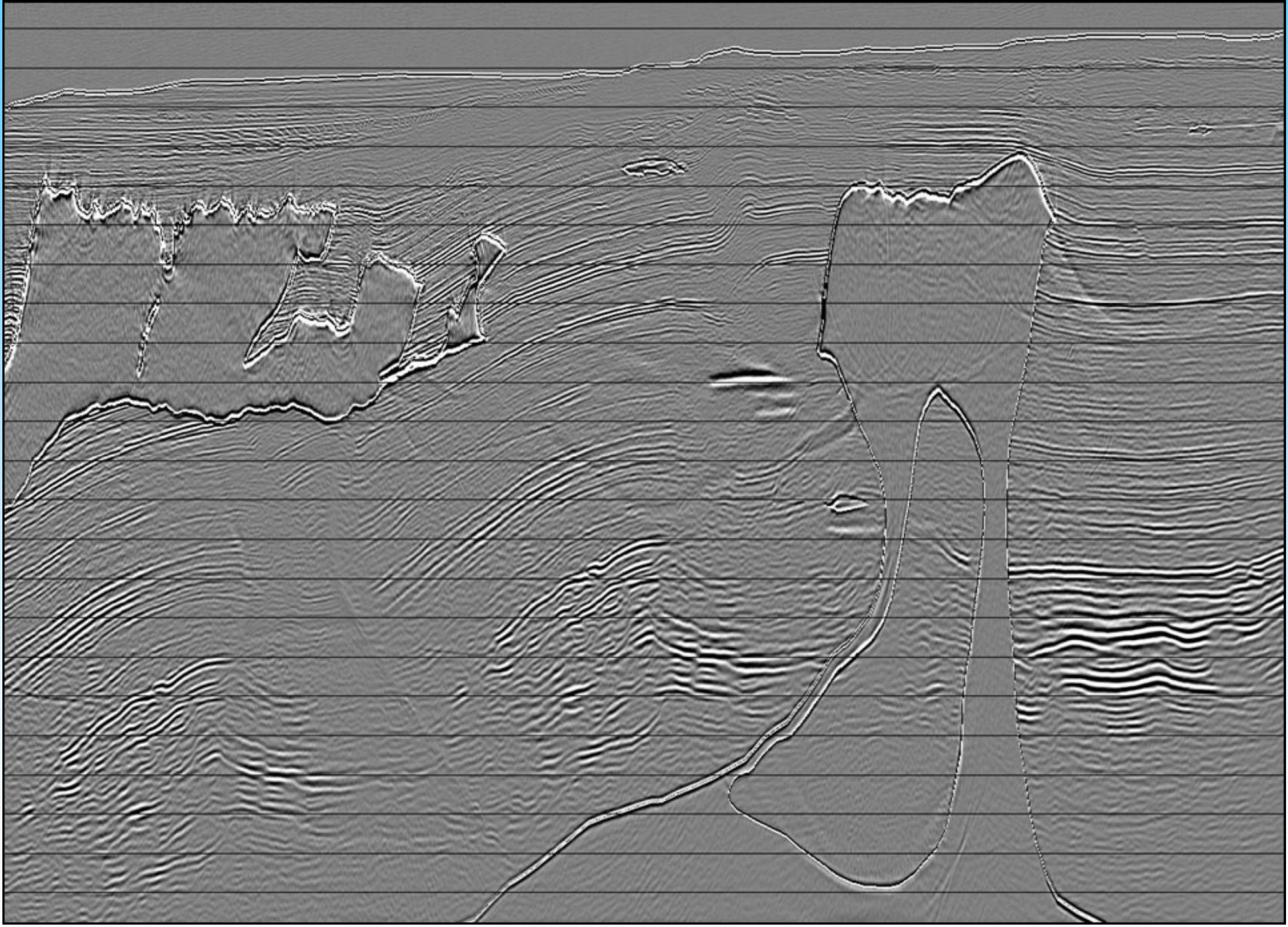
DATA PROCESSING OF SEISMIC DATA

- Reverse Time Migration — accurate two-way wave equation migration for imaging in and below areas of structural and velocity complexity.
- RTM computes numerical solutions to the complete wave equation — no dip limitations.
- Requires massive parallel computing clusters.

WesternGeco's Reverse Time Migration (RTM) accurately images steep dips in complex sub-salt areas as demonstrated on the BP 2004 velocity benchmark dataset.



CHALLENGES: MINING GEOPHYSICAL EXPLORATION EDUCATION/TRAINING

What exactly do we mean!

1) Geological Interpretation of Geophysical Datasets. Utilizing Potential Field Datasets to produce Lithological/Structural Maps.
2) Numerical and Math/Physics-based geophysics that incorporates skills to assign geophysical surveys, perform physics/geology-based interpretations and provide to others original ideas in the use of instruments and processing algorithms.
3) Solid Earth Geophysics — Geodesy, heat flow, geodynamics — fundamental study of the Earth and planets and their physical processes.

SURVEY: CURRENT MINING GEOPHYSICS EDUCATION TRAINING

England – B.G.A. / R.A.S. / I.O.P.

- Essential for Oil/Gas and Mining Exploration!
- Shortage of employees in both industries/academia
- Ignorance of Geophysics at all school levels
- 2008 — 5 funded/defined M.Sc. graduate courses reduced to 1 (7 students)
- 80% reduction in Geophysics courses in last 15 years

Europe (I.T.C.)

- B.Sc. and M.Sc. geophysics graduates for last 4 decades.
- 250 graduates — 50 post graduates
- Students from Africa/S.E. Asia, S. America
- At height of activity, 3 mining geophysics professors and 5–7 grad students — now zero!

GEOPHYSICAL EDUCATION: AUSTRALIA / CANADA

- Two Primary Nations for Mining Geophysicists, 1967–2007.

Australia

- 1998 11 universities for undergraduate geophysics.
- 2008 Number reduced to 4. These remaining include all types of graduates for oil/gas/academic/government/mining.
- 2010 Number reduced to 1?
- 3 major concerns
  - Competition for graduates
  - Majority of professors specialize in solid earth and/or oil/gas
  - Few mining professors and they are “older”
  - Students proficient in math/physics not attracted to mining geophysics

GEOPHYSICAL EDUCATION: AUSTRALIA / CANADA

Canada

- 2002 Canadian government noted that geophysicists are aging faster than the general population.
- 2008 — Mining industry called on all levels of government to address the skilled geophysicist deficiency.
- 2010 CSEG listed all Geoscience Departments — massive drop in enrolment.
- 2012 — 45% of all geophysicists will be over 65.

GEOPHYSICAL TRAINING: CANADA

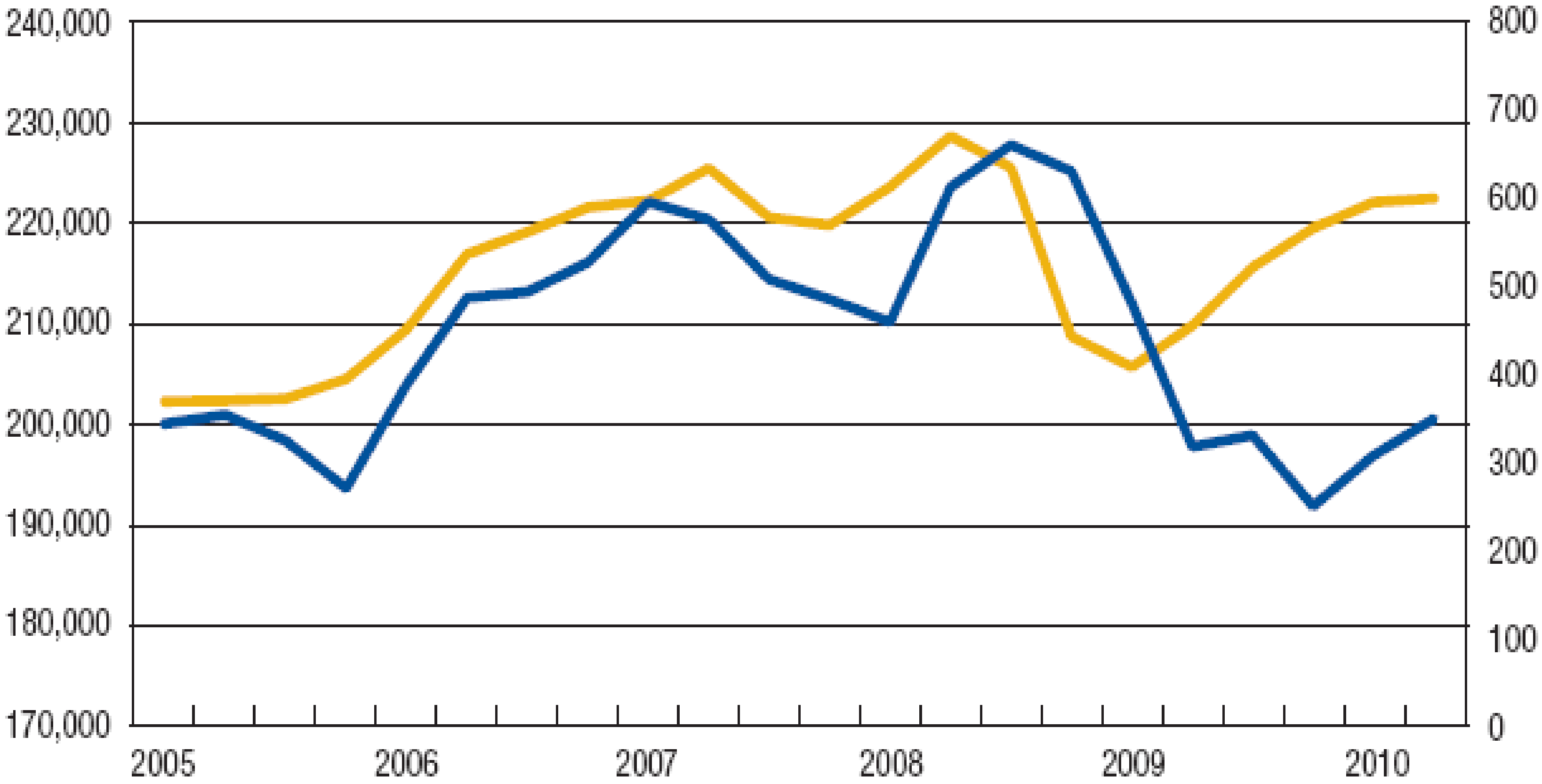
- CSEG lists 14 universities that offer Geophysics Programs.
- Majority of universities focus on oil/gas/environmental or solid earth studies.
- Currently two professors list areas of interest to be “mining exploration.”
- This year two Canadian universities will continue to “de emphasize” mining geophysics — McMaster and U of T.
- Since 2002 the need for increased enrolment has been noted by mining companies.
- In the United States — 50% of B.Sc. graduates in geophysics work outside disciplines.

GEOPHYSICAL TRAINING CANADA

MINING INDUSTRY HUMAN RESOURCES COUNCIL

- Human Resources at professional level are one of the largest threats to future competitiveness of Canadian Mining
- Baby boomers retiring, can't attract and keep younger workers, women and new Canadians.
- In the past the population of geoscientist tracked the M.P.I. – not so between 2009 and the present.

Mining Employment and the Minerals Price Index (MPI)



Source: Mining Industry Human Resources Council; Bank of Canada; Statistics Canada.

Cumulative Hiring Requirements – By Broad Occupational Categories and Relevant Occupations
Baseline Scenario – 2013, 2016, 2021

PROFESSIONAL AND PHYSICAL SCIENCE OCCUPATIONS			
Civil engineers	50	70	120
Geologists, geochemists and geophysicists	500	790	1,370
Mining engineers	235	370	665
Mechanical engineers	135	220	385
Electrical and electronics engineers	85	130	225
Geological engineers	20	35	60
Other professional occupations in physical sciences	65	100	190
Chemical engineers	80	110	185
Industrial and manufacturing engineers	155	230	415
Biologists and related scientists	10	10	20
Chemists	45	70	125
Metallurgical and materials engineers	85	120	220
Total	1,470	2,260	3,990

- By 2013 we will need 500 and by 2021 (9 years) we will need 1370 new geoscientific personnel.

GEOPHYSICAL EDUCATION: MINING GEOPHYSICS

- Three alternatives have been tried and are active to some extent in other disciplines.
- Will require co-operation of universities, government and industry.

1) M.Sc. in Mining Geophysics (2 Universities)
   - Designed for students to acquire skills in Field Exploration/ Computing/Interpretation

GEOPHYSICAL EDUCATION: MINING GEOPHYSICS

2) Eng.D. in Geophysical Exploration

- 4-year course, objective to train students to a Ph.D. standard in key areas of Geophysical Exploration/Instrumentation/Interpretation
- 2 years of courses (1 + 2) – Industrial sponsor/Contractor
- 3 years of research (2–4) – Research/ Industrial sponsor

3) Embedded Researcher Program (Msc. or Bsc.) – sponsored by Industry/Government focused on one or a group of companies (junior explorers or contractors)

GEOPHYSICAL EDUCATION:

Mining Geophysics and the CMIC Exploration Innovation Consortium. (September 2012)

Integrated Multi-Parameter Footprints of Ore Systems

- Canadian initiative to recognize large scale ore forming systems.
- “Vector-in” from the distal margins to the high-grade cores.
- Develop models of key features of large scale ore-forming systems.
- Better detect/ map at depth and improve resolution of sub-surface geology.

SPECIFIC SIGNATURES (SEPT 2012) Study sites and Technical Teams

- Three sites selected that represent important deposit types
  1) McArthur – Millenium: Unconformity U – trend Saskatchewan
  2) Canadian Malartic: Disseminated Gold, Abitibi, P.Q.
  3) Cu – Mo Porphyry (Highland Valley Copper), British Colombia
- Team – Industry led to oversee research
  - Sponsors – mining companies, service providers and Universities
  - Academics and graduate students
- Five year project at $1.5 M/ year
- Initiative that will have positive effects on Geophysical Education

CHALLENGES FOR MINING COMPANIES: NEW DATA / DEEP DEPOSITS

"Problem now is not getting data, as there are many data banks around the world and a lot of data is freely available!"

- Unfortunately, this is NOT TRUE! In addition to difficulty in accessing data, we have the dual problems of amalgamation and analysis of data.
- Much high resolution data held by many Companies/countries and if released could furnish new information on deep deposits.
- Existing data contains a lot of unrevealed information — need to combine and analyze in a unified framework.

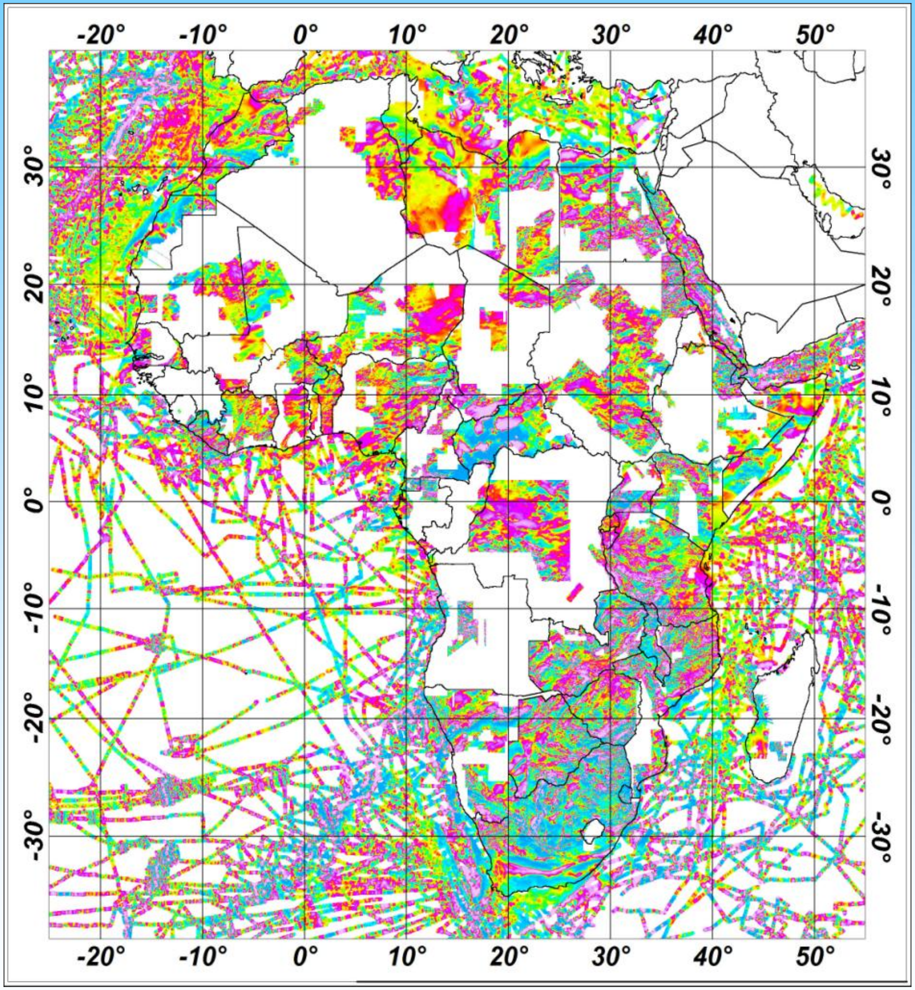
BASIC DATA / DEEP DEPOSITS

- High Resolution databases are essential for deep exploration and much of the greenfields areas are undergoing a “review.”
- The new high resolution database must incorporate not only the historical tools of aeromagnetics and radiometrics, but also the “new” components of gravity (airborne), passive seismic and Deep M.T. / E.M.
- Many countries have reinvested in their national databases and many of these products will prove to be extremely useful in the renewed search for greenfields Deep Deposits.
- Within the last decade the following African countries have reflown or initiated ambitious projects.

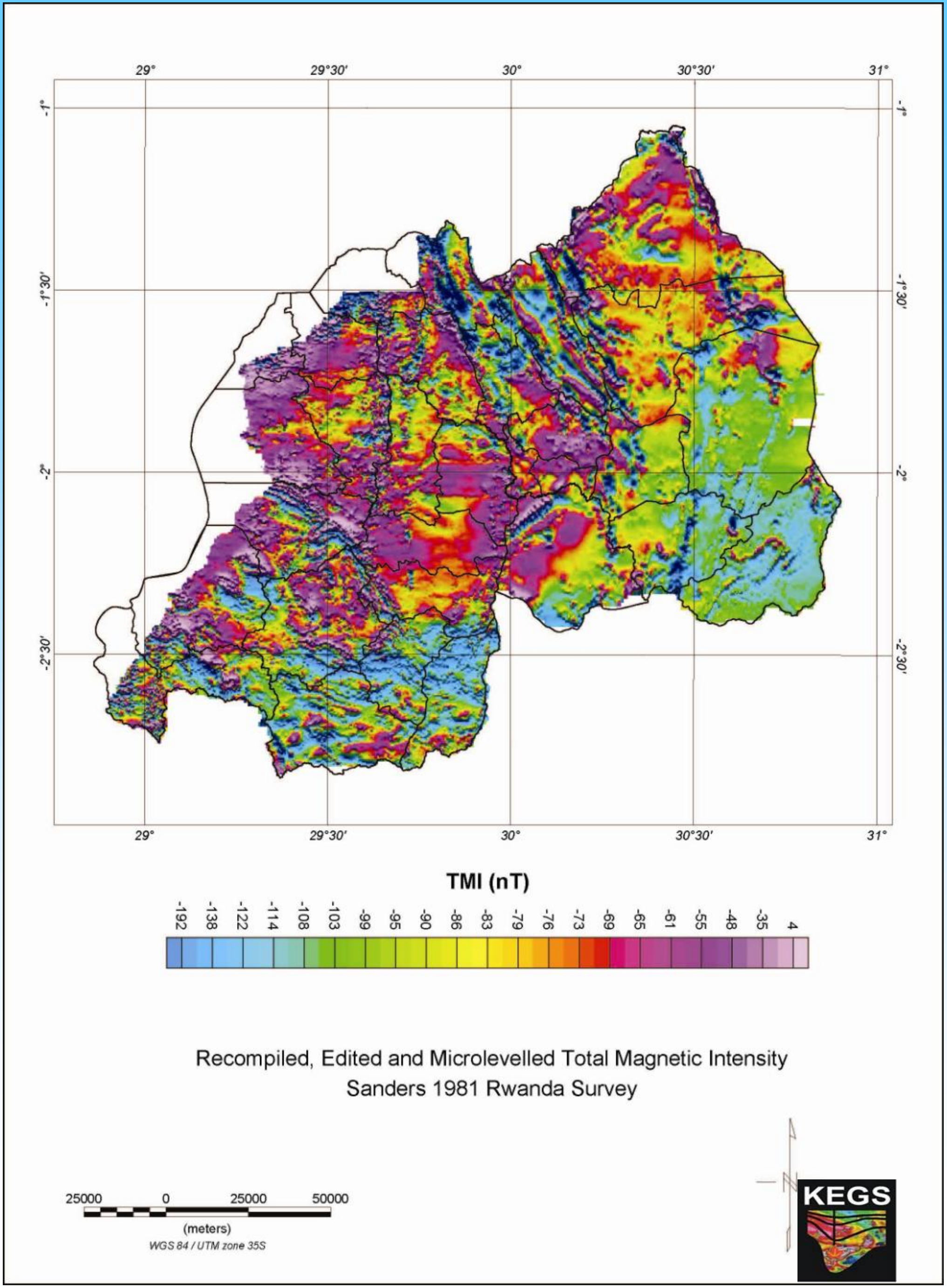
BASIC DATA / ACQUISITION

- Madagascar, Mozambique, Mauritania, Morocco, Namibia, Nigeria, Uganda, Rwanda, Guinea
- Major funding from E.U., W.B. and A.D.B. realizing the economic importance of mining exploration.
- Three countries of note have funded their surveys from local sources: Namibia, Rwanda and Nigeria.
- Rwanda will be presented as a new and Deep Deposit greenfield target country.

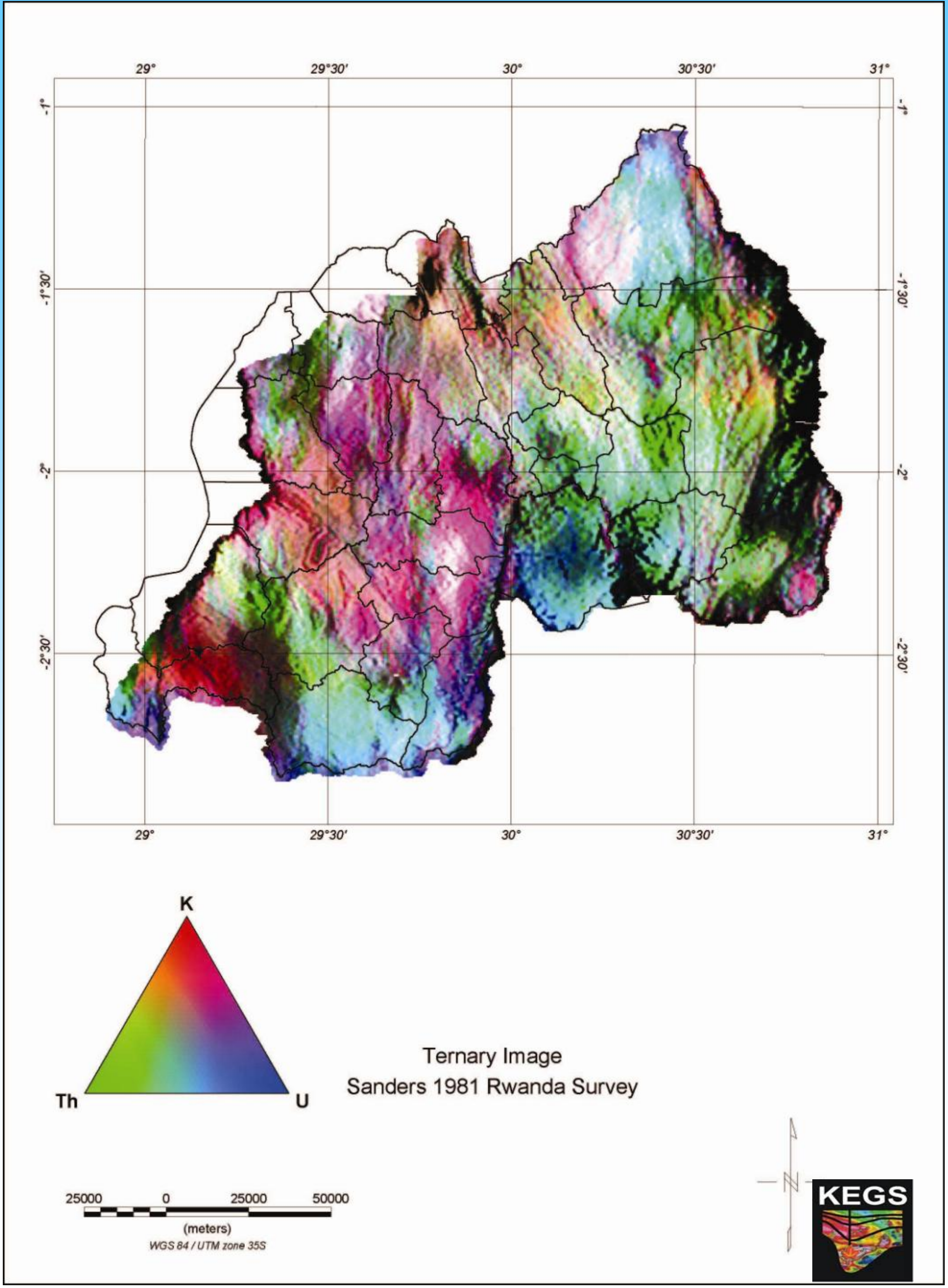
Rwanda



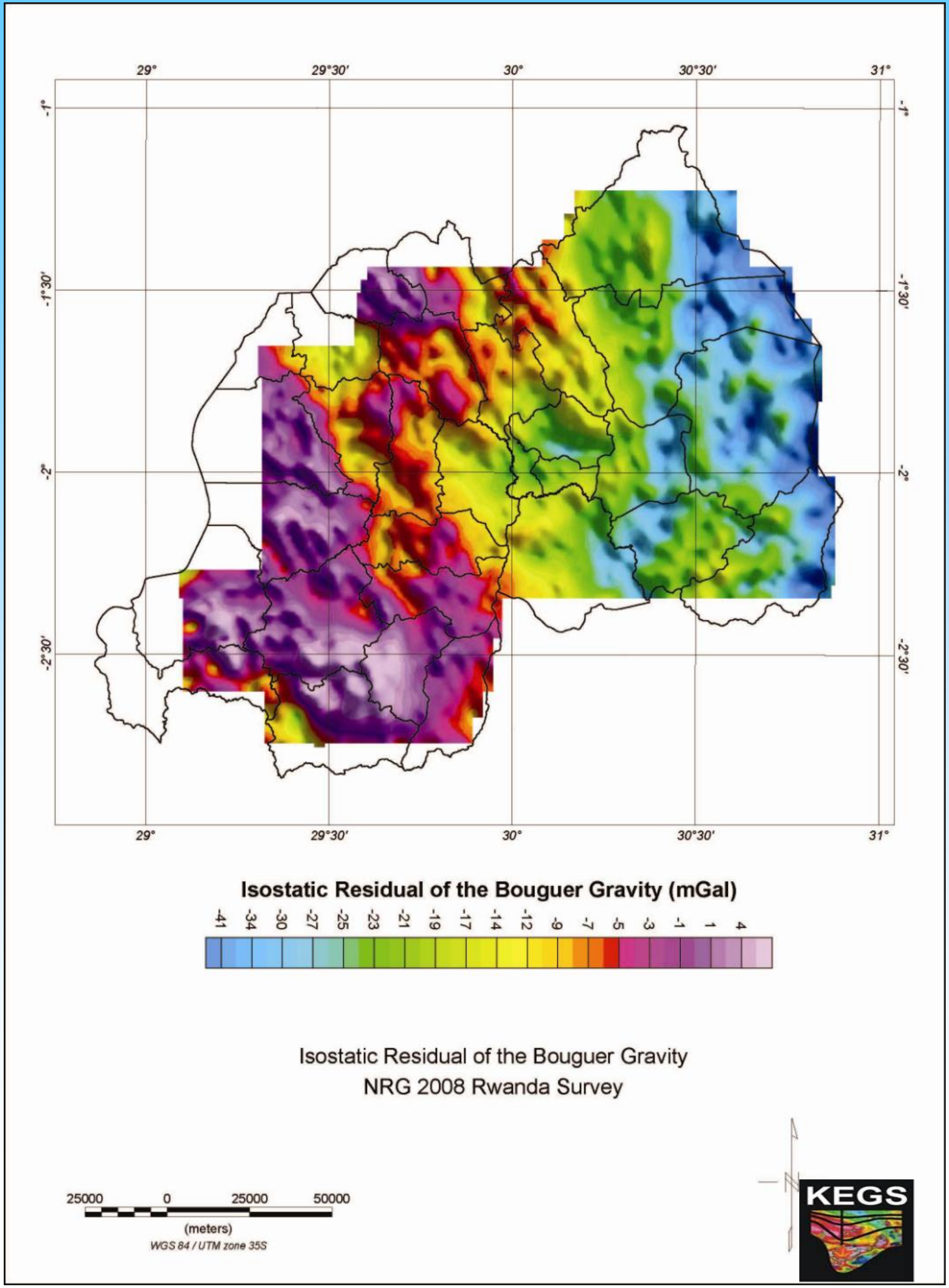
Geophysical Data: Magnetics 2009



Geophysical Processing: Ternary Plot



Geophysical Processing: Isostatic Gravity Residual



Mineral Potential of Rwanda Prospective Target Areas as Interpreted from Geophysical Data

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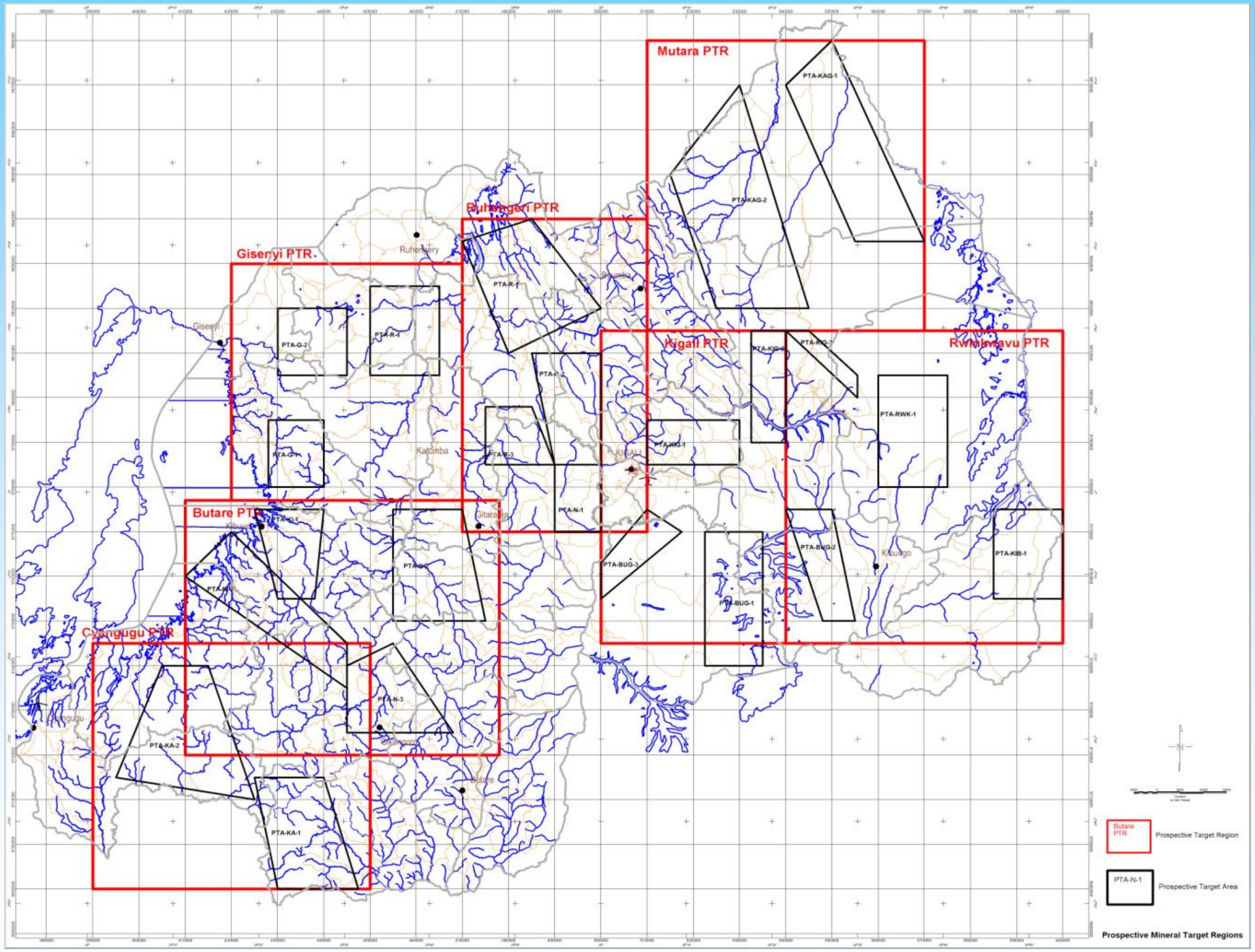
New Mineral Deposits: Characteristics

- Sn and W-Ta/Nb
  - Presence of voluminous granites that extend to depth and rise to within 2-3 km or less depth.
  - Competent surface metasediments with organic rich members.
  - Prospective intrusive zone lies within or borders regional shear zone, with individual and cross-faults in the area.

Prospective Mineral Target Regions



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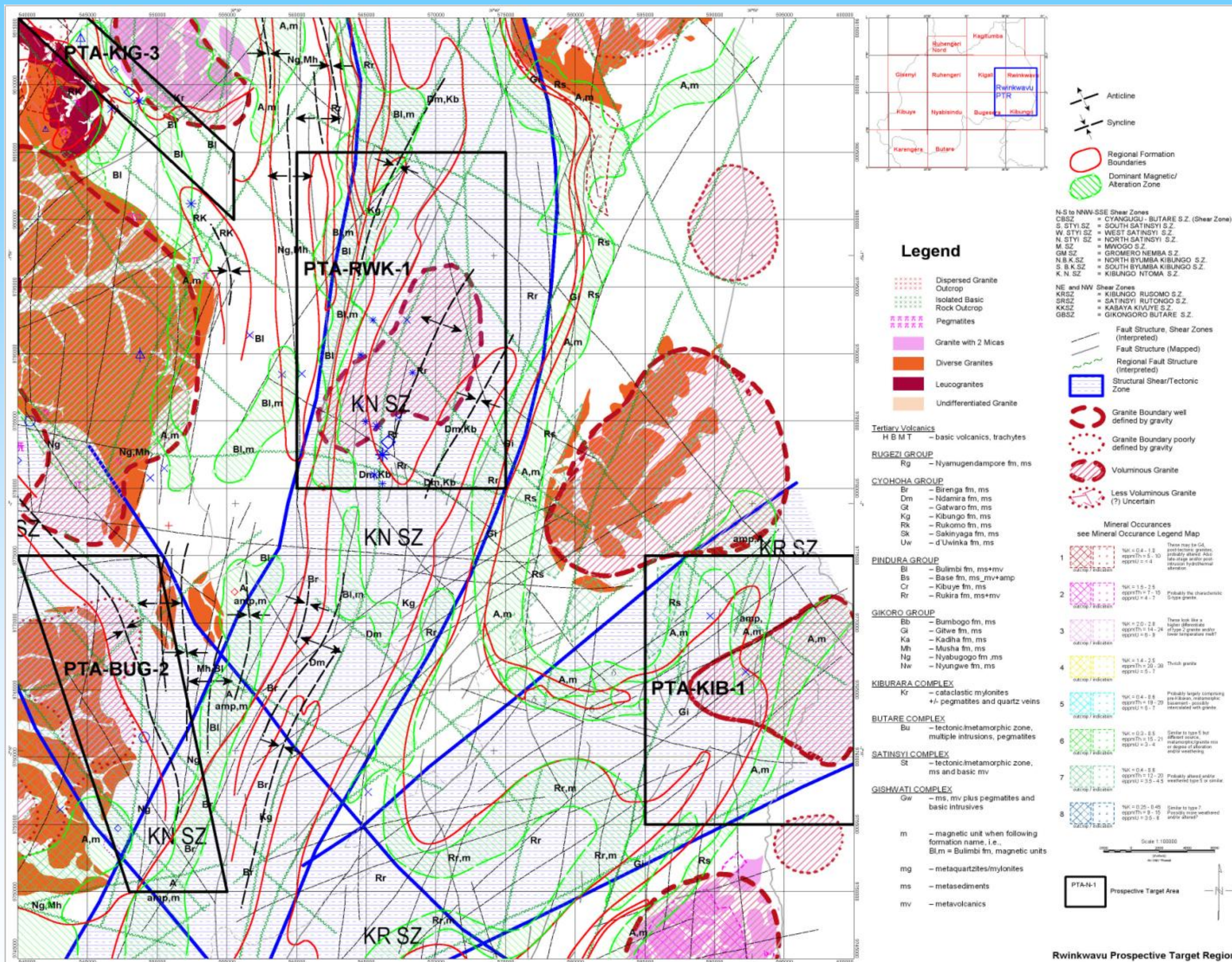
Rwinkwavu PTR



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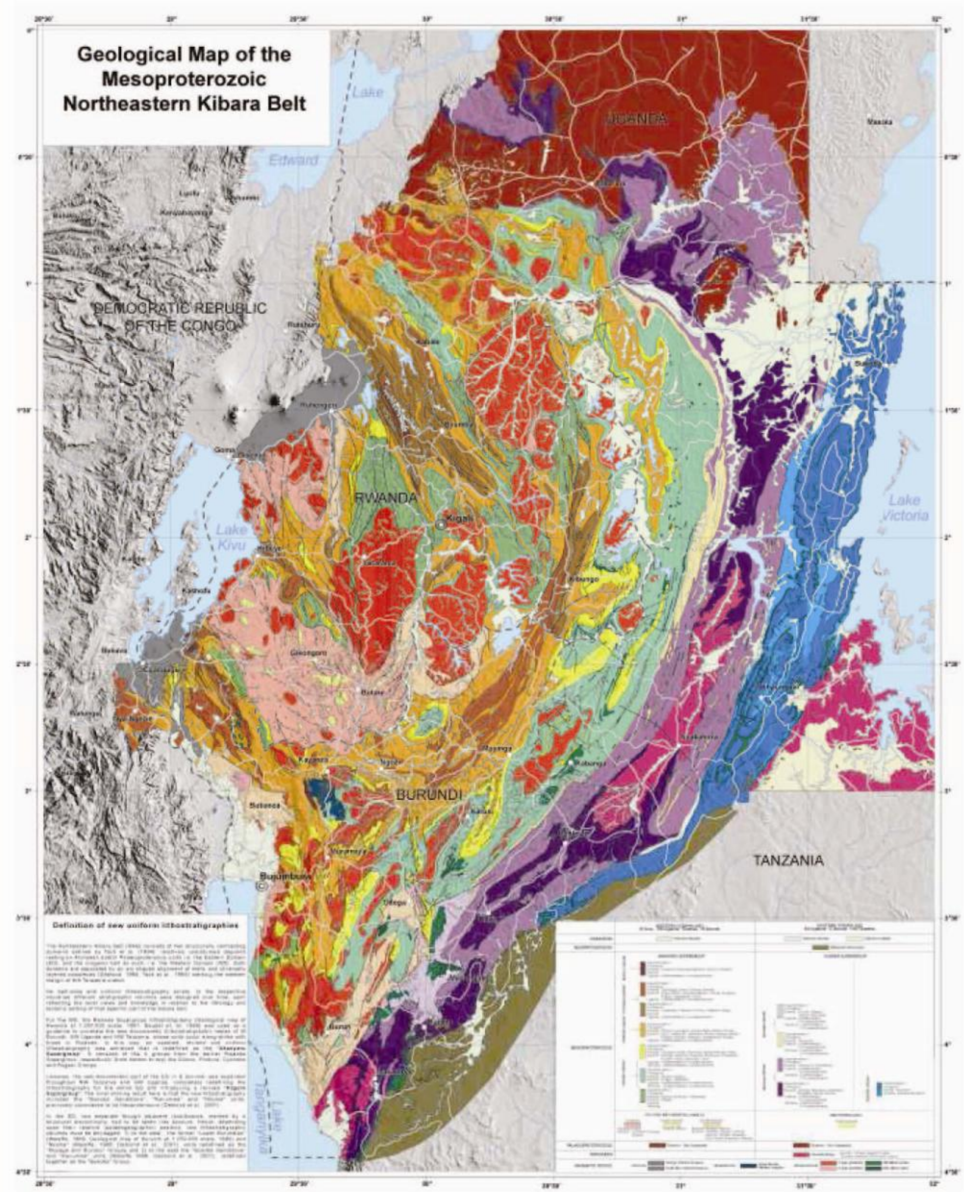
CHALLENGES:
BASIC DATA: GREENFIELDS EXPLORATION

- Geological Map of Rwanda / Uganda / Burundi / Tanzania.
- Type of Compilation needed to link with Geophysical Databases and Earth Evolution Model.

Geology of Rwanda, 2007



Geology: 2007

CONTINENTAL SCALE CHALLENGES

- We need more Regional Data
- Wider application of “Deep” methods (MT and Seismic)
- Critical need for more Mining Geophysicists