2D/3D GIS-based Integration for Gold Exploration in the Abitibi and Ashanti Greenstone Belts

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MERC/PDAC
Short Course
March 03, 2018

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Why are GIS important for exploration geologists?

- **GIS tools are keys for modern mapping and exploration projects:**
  - It takes less and less time and/or people to make a map => less cost
    (e.g., a 1000 km² can be mapped in one year at 1/20,000 by one geologist)
  - Modern GIS tools include:
    - Field instruments to support mapping *(smartphones, GPS, handheld computers, laptops, etc.)*
    - 2D/3D display and modeling softwares *(Google Earth, QGIS, Geosciences Analyst, etc.)*
- **Exploration companies commonly have GIS specialists** (responsible for data compilation and display) **but rarely GIS-experienced geologists** (to produce advanced map/data interpretation and integrated analysis)

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Main GIS applications for gold exploration

- **Support traditional field mapping and planning**
  - Display geographic data, topographic data, existing geological maps, point location, drillhole location, etc.

> 80 %

- **Build and display series of layers**
  - e.g., geological, geophysical and geochemical maps

- **Interpret these layers to build integrated geological models**
- **Use all the available knowledge for prospectivity analysis**

< 20 %

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Two main approaches …

- **"Visual" integration** *(i.e., commonly geologist-approach)*
  - Uses every piece of information, including previous geological knowledge
  - Field observation are always used to validate/support the interpretation
  - Subjective *(i.e., two geologists will end-up with two different models)*

- **"Automated" integration** *(i.e., commonly geophysicist-approach)*
  - Uses continuous or discrete input values
  - Uses statistical *(e.g., PCA)* or image processing *(e.g., edge detection)* methods
  - Not user dependent *(i.e., two users will end-up with the same results)*
  - Metadata are rarely considered *(i.e., analytical method, uncertainties)*
  - Limited use of field observations and geological knowledge

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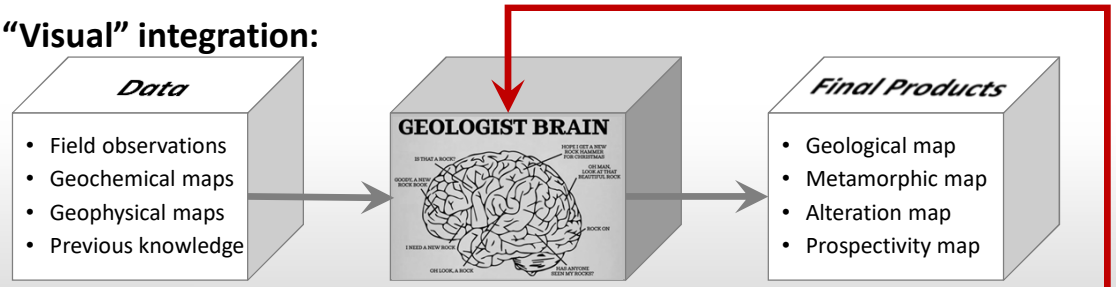
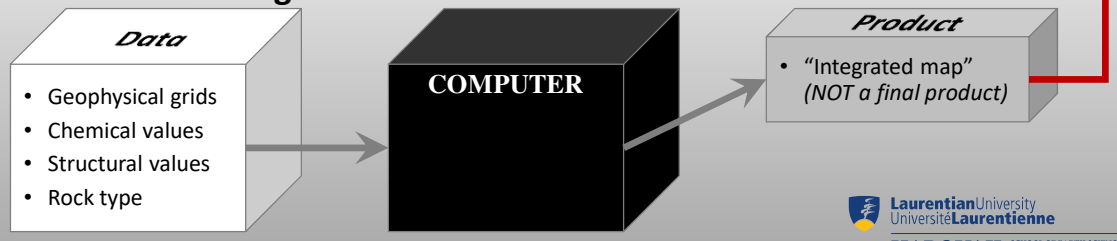
How do they work?

- **"Visual" integration:**



- **"Automated" integration:**



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Mapping using a "Visual" integration approach

Geological Mapping for Gold Exploration
in the Ashanti Greenstone Belt, West Africa

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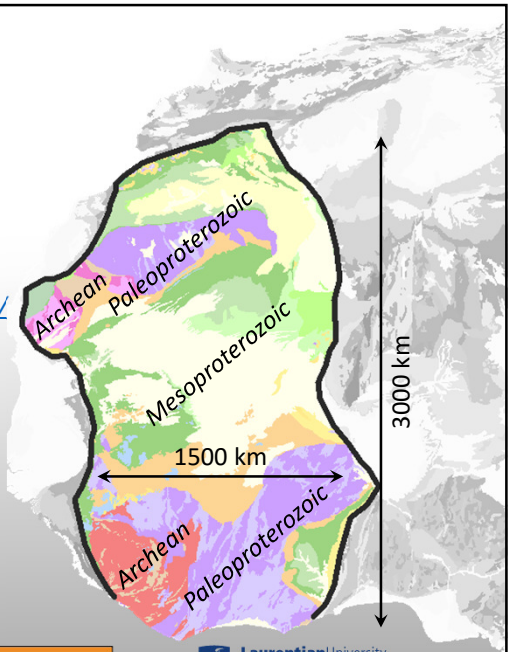
West African craton

- **Precambrian in West Africa:**
  ~ 5,000,000 km² ⇔ ½ Canada area
- **WAXI Project *(2006-2018)*** http://www.waxi2.org/
  - 12 West-African countries
  - 73 partner organizations over 12 years
  - 80 international publications so far
  - 90 HQP training (PDF, PhD, MSc, BSc)
  - 650 GB, 250 layers, exploration GIS
  - 650,000 km² of geophysically constrained geological mapping (1/200,000 to 1/10,000)



Jessell et al. (2017 – Exploration 17)

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WAXI - West African Exploration Initiative
IXOA - L'Initiative d'Exploration Ouest Africaine

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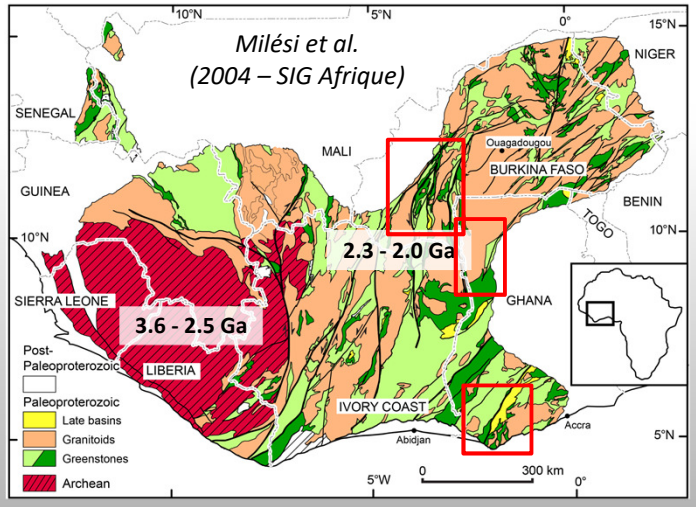
Leo-Man shield

- **Archean nucleus** composed of granitoid-greenstones terranes in the SW
- Series of **Paleoproterozoic greenstones belts**, accreted from the E, and separated by granitoids or meta-sedimentary basins
- Regional-scale **Eburnean orogeny ~ 2.1 Ga** and gold mineralization



Jessell et al. (2017 – Exploration 17)

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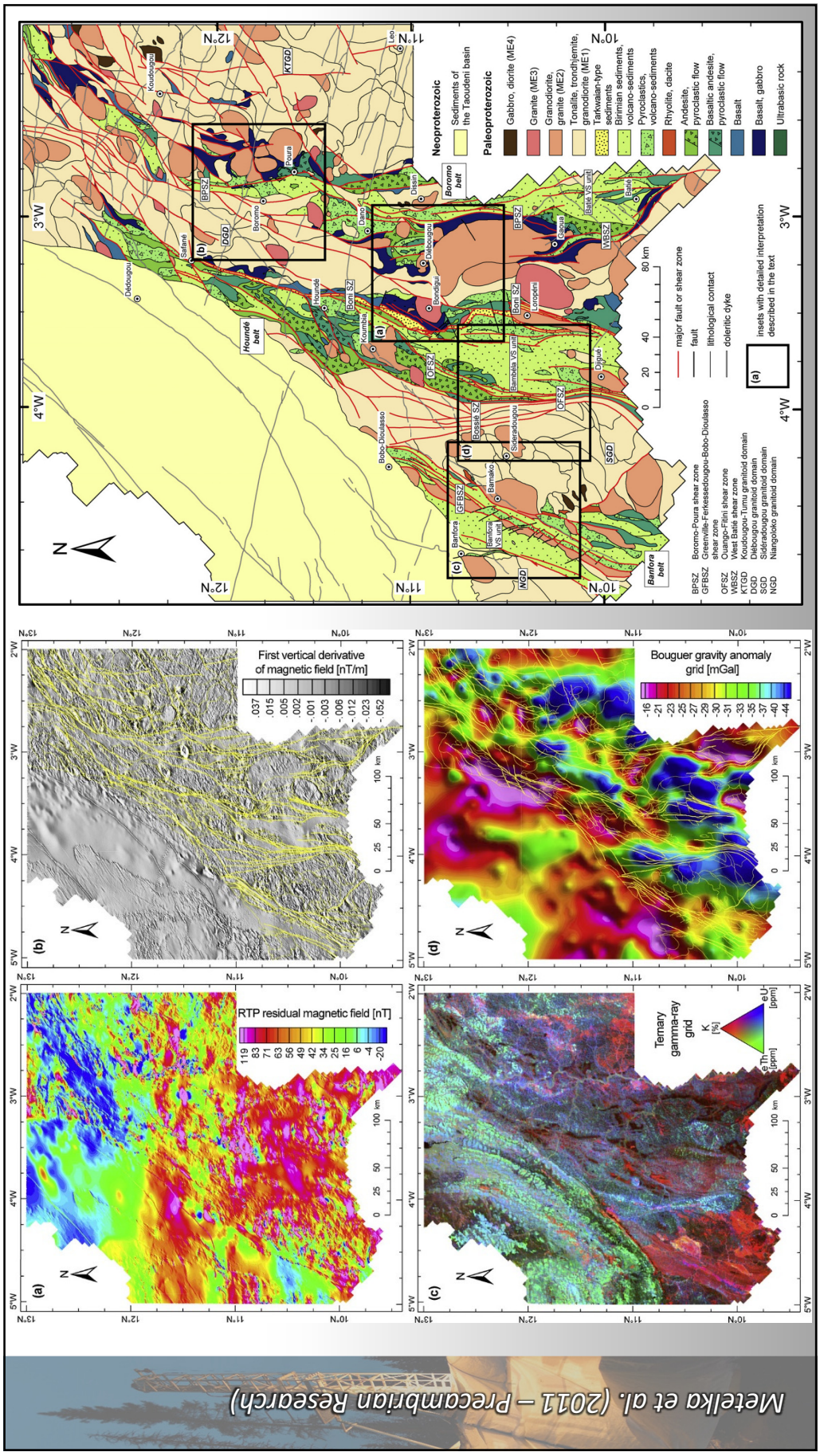
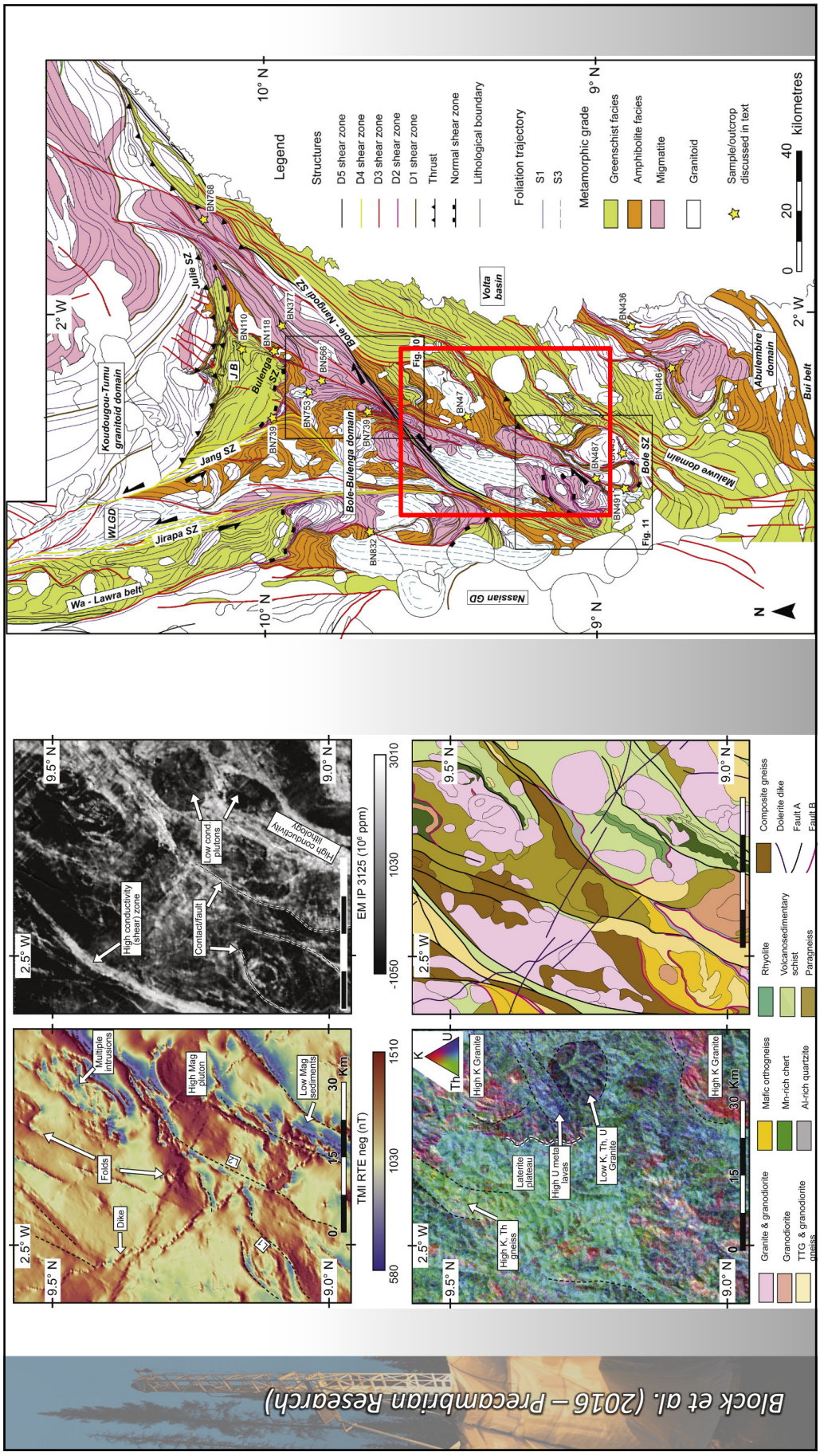
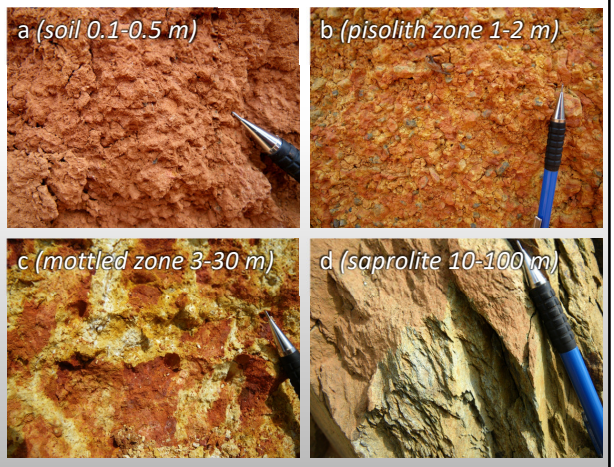

Neoproterozoic
Sediments of the Taoudeni basin
Paleoproterozoic
Gabbro, diorite (ME4)
Granite (ME3)
Granodiorite, granite (ME2)
Tonalite, trondhjemite, granodiorite (ME1)
Tarkwaian-type sediments
Birrimian sediments, volcano-sediments
Pyroclastics, volcano-sediments
Rhyolite, dacite
Andesite, pyroclastic flow
Basaltic andesite, pyroclastic flow
Basalt
Basalt, gabbro
Ultrabasic rock
major fault or shear zone
fault
lithological contact
doleritic dyke
insets with detailed interpretation described in the text
BPSZ Boromo-Poura shear zone
GFBSZ Greenville-Ferkessedougou-Bobo-Dioulasso shear zone
OFSZ Ouango-Fitini shear zone
WBSZ West Batié shear zone
KTGD Koudougou-Tumu granitoid domain
DGD Diebougou granitoid domain
SGD Sidéradougou granitoid domain
NGD Niangoloko granitoid domain
Boromo belt
Houndé belt
Banfora belt
First vertical derivative of magnetic field [nT/m]
Bouguer gravity anomaly grid [mGal]
RTP residual magnetic field [nT]
Ternary gamma-ray grid
K [%]
eU [ppm]
eTh [ppm]


Block et al. (2016 – Precambrian Research)
Legend
Structures
D5 shear zone
D4 shear zone
D3 shear zone
D2 shear zone
D1 shear zone
Thrust
Normal shear zone
Lithological boundary
Foliation trajectory
S1
S3
Metamorphic grade
Greenschist facies
Amphibolite facies
Migmatite
Granitoid
Sample/outcrop discussed in text
kilometres
Koudougou-Tumu granitoid domain
Julie SZ
Jang SZ
Jirapa SZ
WLGD
Wa - Lawra belt
Bole - Nangodi SZ
Bolé-Bulenga domain
Bulenga SZ
J B
Volta basin
Nassian Gb
Bole SZ
Malwwe domain
Abulembire domain
Bui belt
Fig. 10
Fig. 11
BN832
BN753
BN739
BN566
BN110
BN118
BN377
BN766
BN47
BN487
BN491
BN446
BN436
TMI RTE neg (nT)
EM IP 3125 (10^6 ppm)
Multiple intrusions
Folds
Dike
High Mag pluton
Low Mag sediments
High conductivity lithology
Low cond. plutons
Contact/fault
High conductivity (shear) zone
Granite & granodiorite
Granodiorite
TTG & granodiorite gneiss
Mafic orthogneiss
Mn-rich chert
Al-rich quartzite
High K, Th gneiss
Laterite plateau
High U metal. lavas
Low K, Th, U Granite
High K Granite
Rhyolite
Volcanosedimentary schist
Paragneiss
Composite gneiss
Dolerite dike
Fault A
Fault B

Why mapping using GIS-based data integration?

- A typical outcrop (greywackes):



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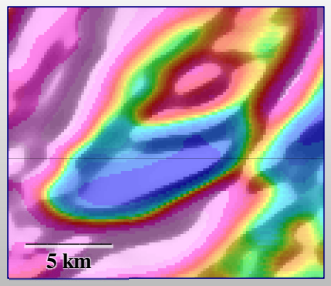
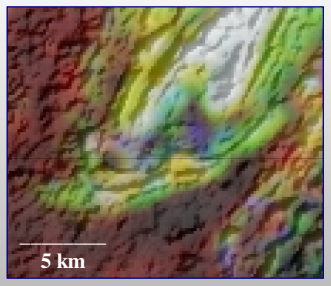
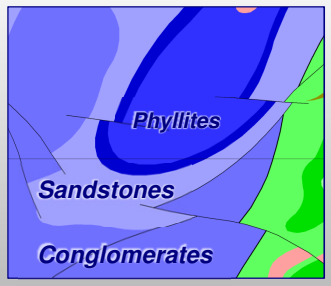
Integration for lithological mapping

Lithology	Phyllites	Sandstones	Conglomerates
Magnetic Susceptibility	Moderate (0.001 SI)	Low (0.0001 SI)	High (0.005 SI)
Geochemistry *(U, Th, K)*	High U, Th, K	High Th, low U, K	Low U, Th, K







Perrouty et al. (2012 – Precambrian Research)

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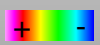
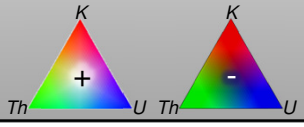


Anomalies



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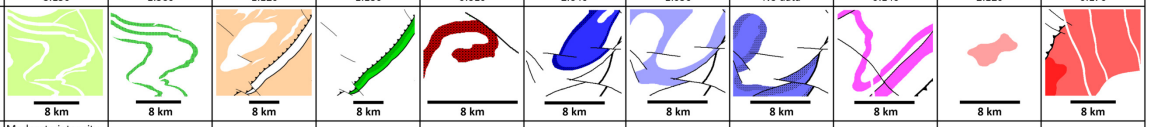
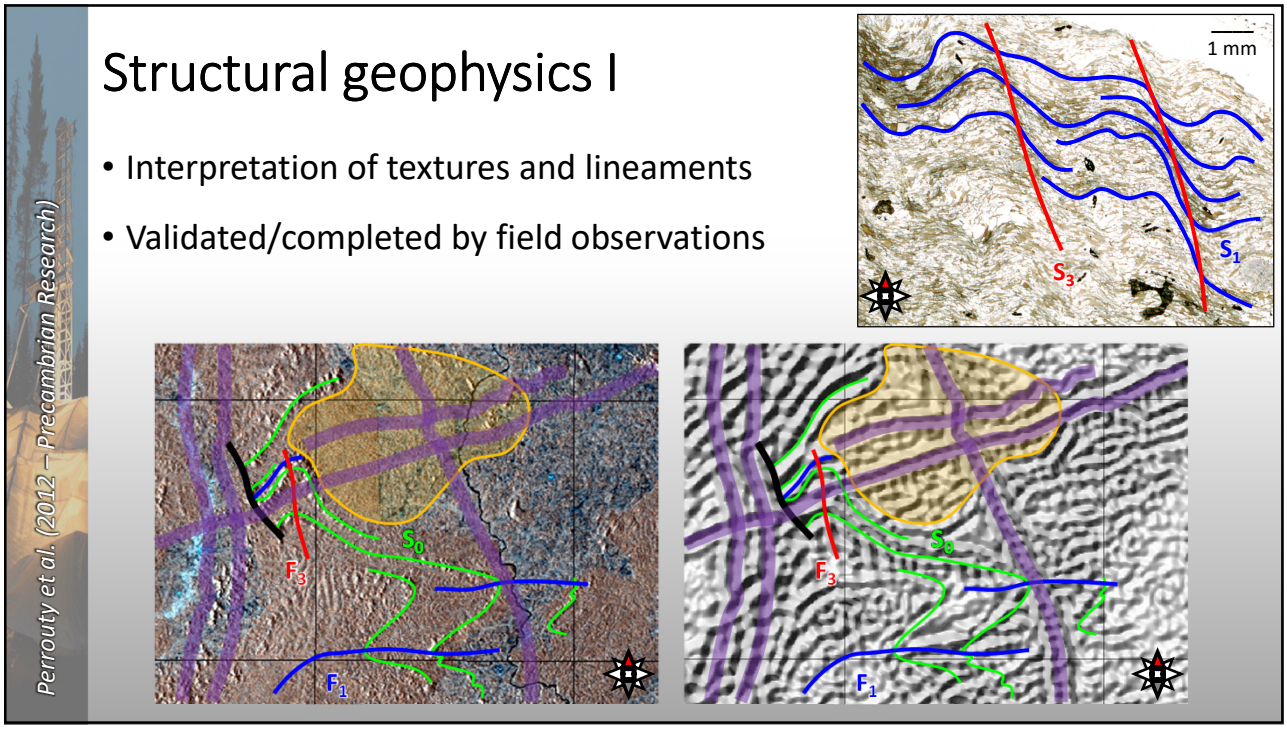
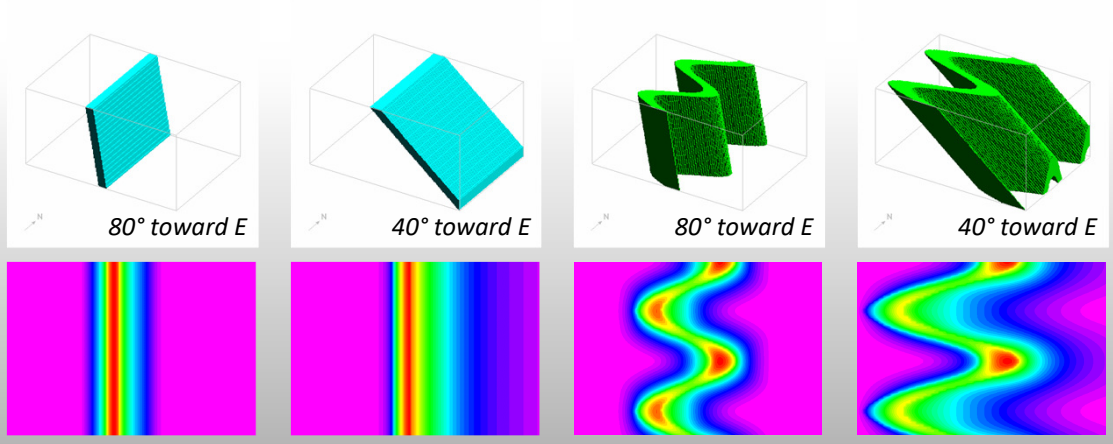
	Birimian					*Tarkwaian*			*Eburnean Intrusions*		*Eoeburnean Intrusions*
Lithology	Micaschists	Volcanoclastic metasediments	Phyllites	Metabasalts Metaandesites	Metagabbros	Phyllites	Sandstones	Conglomerates	Dolerite (sills)	Granite Granodiorite	Granodiorite Tonalite
Mineralogy	qz, pl, chl, ms, bt, gph, gt	qz, pl, chl, bt	chl, ms, bt, gph, qz, ep	chl, bt, pl, qz, ser, ank, dol, cal	cpx, hbl, pl, chl, bt, qz	chl, ms, bt, gph, st, gt	qz, mgt, bt	qz, Birimian and Granitoid pebbles	cpx, hbl, pl, chl, bt, gt, cal	bt, ms, qz, pl, kfs	pl, qz, bt, chl, ep
Susceptibility range (10^{-3} SI)	0.24 - 0.32	0.24 - 0.56	0.06 - 0.60	0.09 - 4.22	0.35 - 24.70	0.08 - 0.16	0.08 - 0.32	0.13 - 13.10	No data	0.06 - 38.00	0.05 - 8.06
Sample	GH101B	GH504	GH515	GH503	GH129G	GH397	GH512	No Sample	GH395	GH237	GH507
U (ppm)	1.440	0.460	0.460	0.350	0.310	4.500	0.880	No data	0.740	0.650	0.110
Th (ppm)	5.100	1.650	1.030	1.220	0.750	9.290	3.580	No data	2.220	1.510	0.270
K_2O (%)	3.150	1.360	1.120	1.130	0.610	2.640	1.050	No data	0.140	2.120	0.170
Map											
Airborne Magnetic Response	Moderate intensity domains Strong magnetic fabric (parallel to bt. alignment)	Moderate intensity layers	Low intensity domains, uniform	Moderate to high intensity layers	High intensity bodies	Moderate intensity layers	Low intensity layers	Moderate to high intensity layers	Moderate to low intensity layers	Moderate to high intensity bodies	Low intensity bodies Strong magnetic fabric (parallel to bt. alignment)
Airborne Radiometric Response	Medium U High Th Medium K *(dark green)*	Low U Medium Th Low K *(green)*	Low U Low Th Medium to high K *(red-violet)*	Low U, Th, K Often covered by high U, Th regolith (blue-green)	Low U, Th, K Often covered by high U, Th regolith *(blue-green)*	High U High Th Medium K *(white-yellow)*	Medium U High Th Medium K *(green - yellow)*	Low U Low Th Medium K *(dark red)*	Medium U High Th Low K *(light green)*	Low U Low to medium Th Medium K *(dark red)*	Low U Low to medium Th Low K *(dark red-green)*



Structural geophysics II

Noddy

- "Structural measurements" from airborne geophysical data (e.g., gravity)



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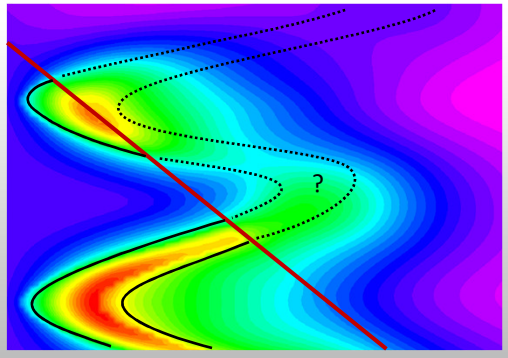
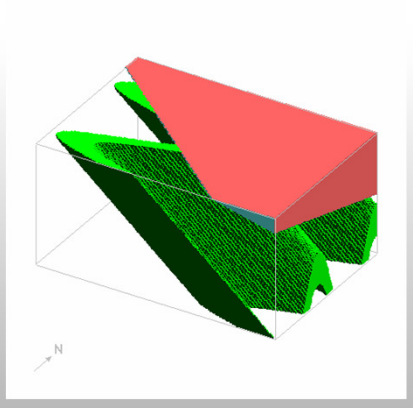
Structural geophysics III

Noddy

- "Structural measurements" from airborne geophysical data (e.g., gravity)





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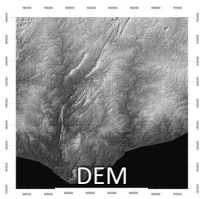
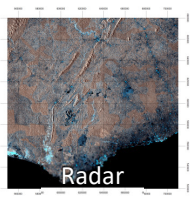
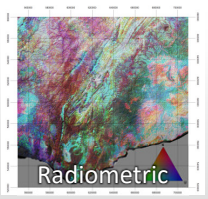
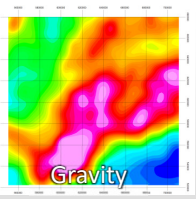
GIS - Ashanti Greenstone Belt

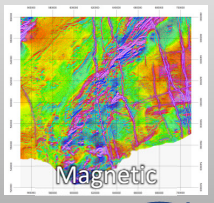
- **> 150 Moz Au**, including the giant Obuasi deposit (62 Moz) and the Tarkwa paleoplacer (40 Moz)
- Over 2000 years of exploration for gold
- 5 regional deformation events
- 4 main episodes of mineralization (early, syn- and late orogenic + paleoplacer)
- 38 GB of geological data to be integrated

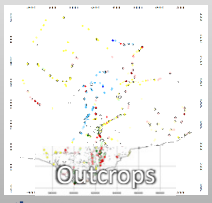












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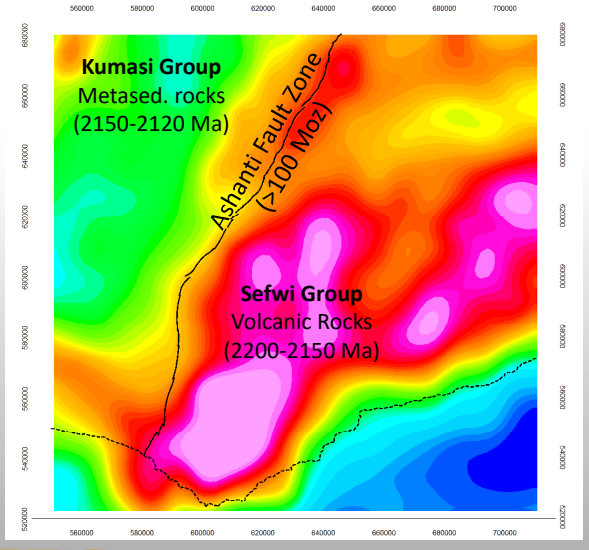
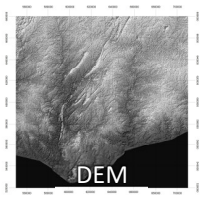
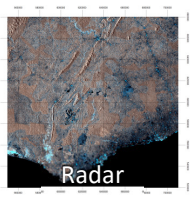
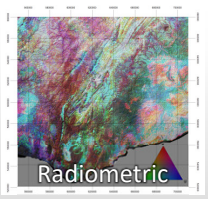
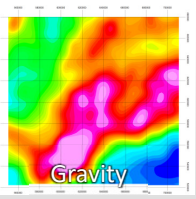


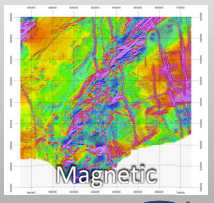
Free Air Gravity

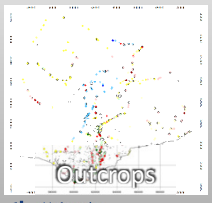












Perrouty et al. (2012 – Precambrian Research)

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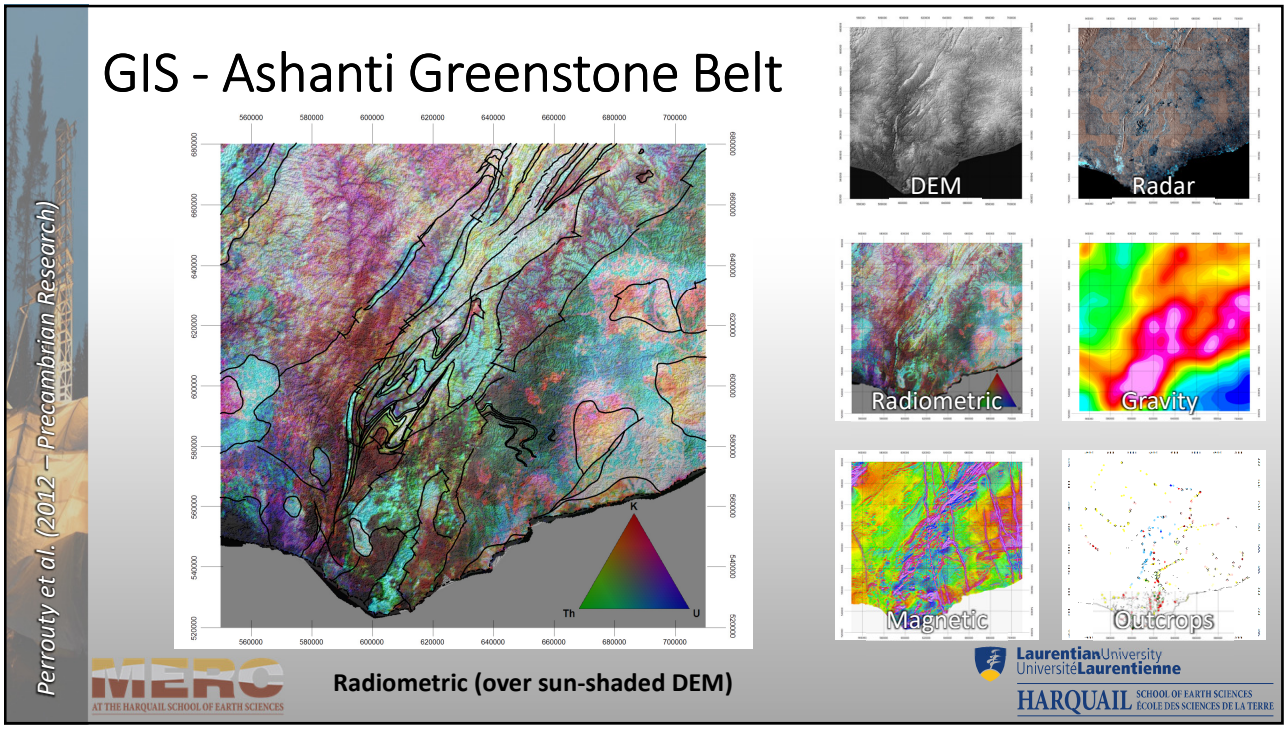
GIS - Ashanti Greenstone Belt
Perrouty et al. (2012 – Precambrian Research)
DEM
Radar
Radiometric
Gravity
Magnetic
Outcrops
K
Th
U
Radiometric (over sun-shaded DEM)
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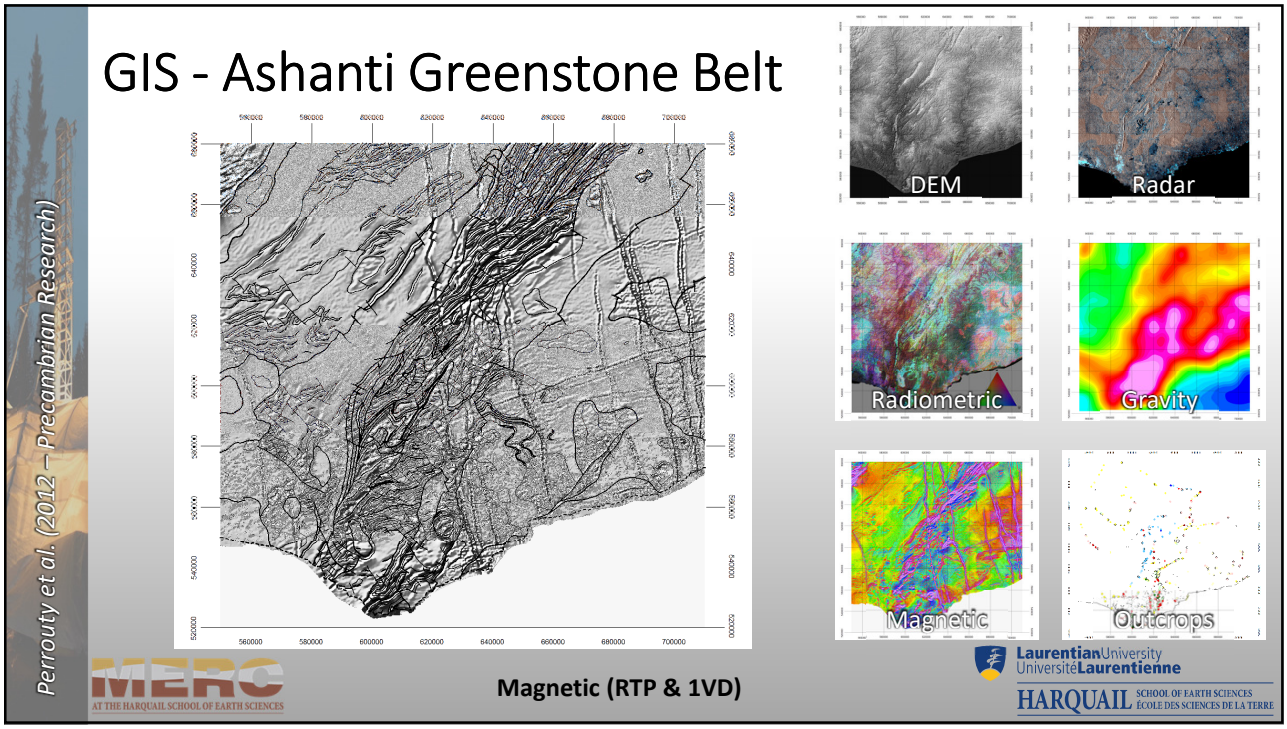
GIS - Ashanti Greenstone Belt
Perrouty et al. (2012 – Precambrian Research)
DEM
Radar
Radiometric
Gravity
Magnetic
Outcrops
Magnetic (RTP & 1VD)
MERC
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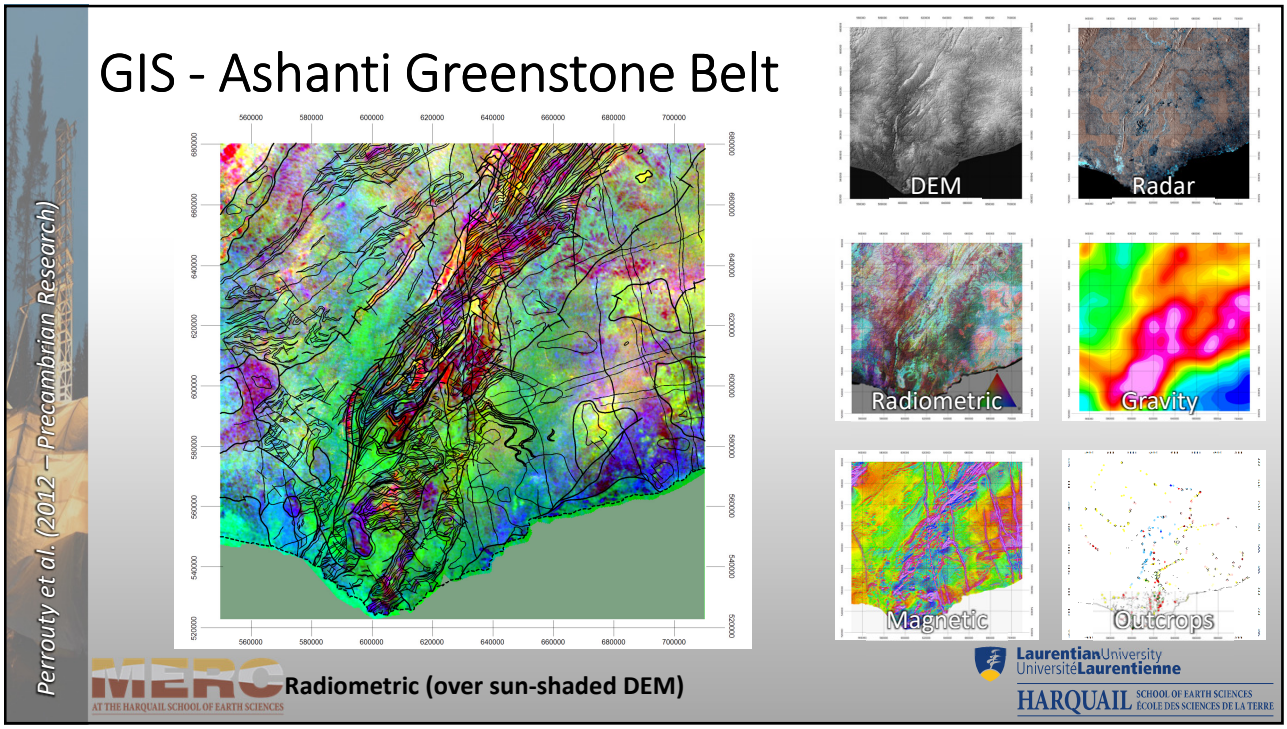
GIS - Ashanti Greenstone Belt
Perrouty et al. (2012 – Precambrian Research)
DEM
Radar
Radiometric
Gravity
Magnetic
Outcrops
MERC
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Radiometric (over sun-shaded DEM)
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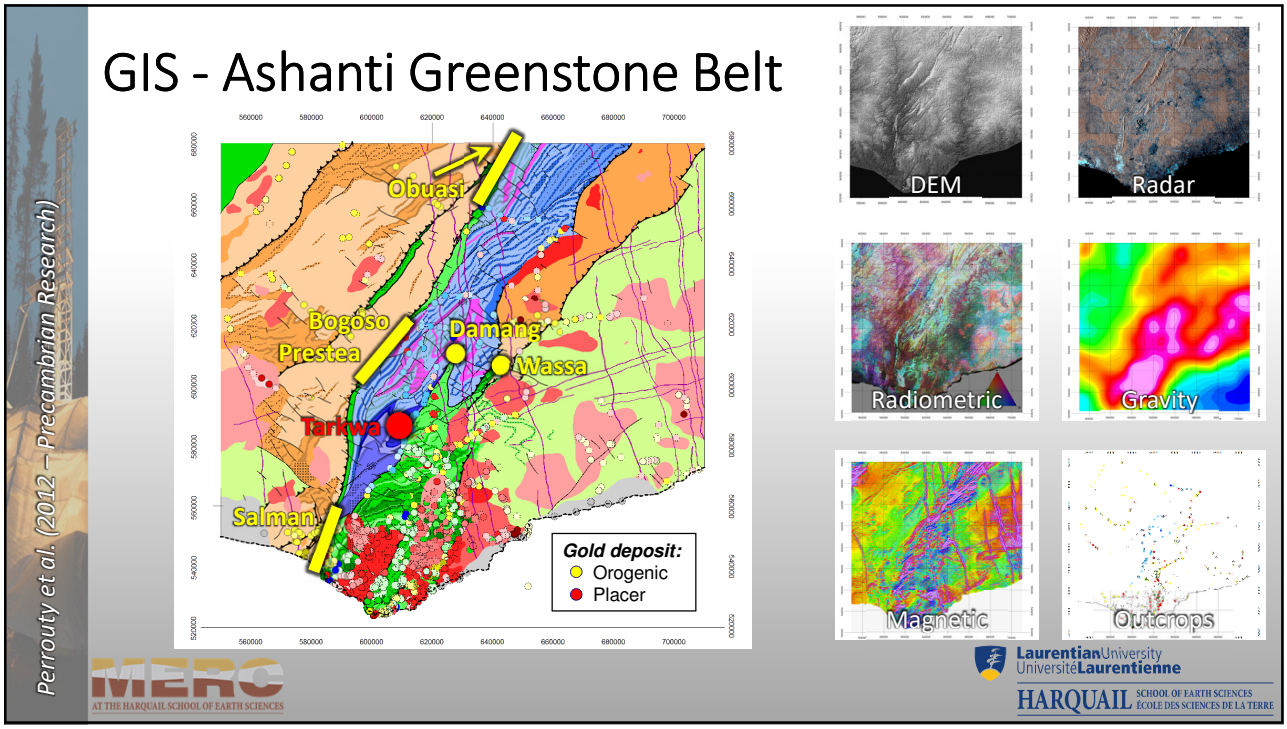
GIS - Ashanti Greenstone Belt
Perrouty et al. (2012 – Precambrian Research)
Obuasi
Bogoso
Prestea
Damang
Wassa
Tarkwa
Salman
Gold deposit:
Orogenic
Placer
DEM
Radar
Radiometric
Gravity
Magnetic
Outcrops
MERC
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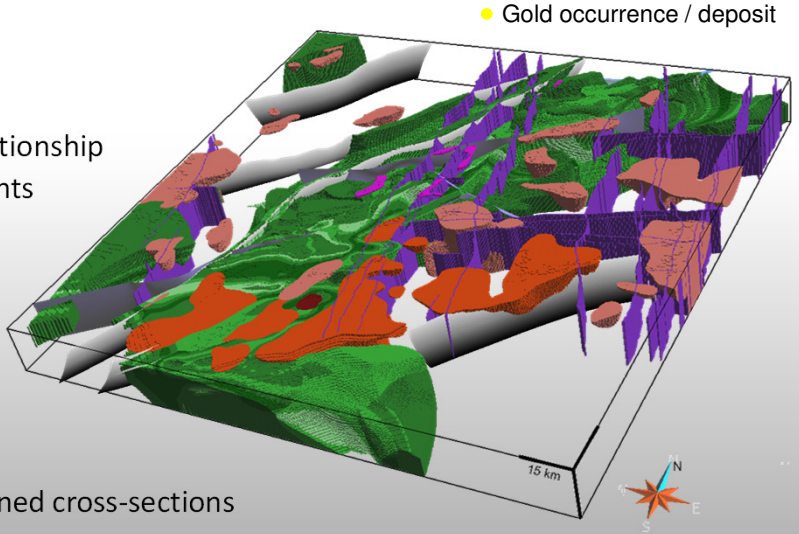
3D GIS and simple prospectivity map

- Field observations:
  - Stratigraphy
  - Fault cross-cutting relationship
  - Structural measurements
- Geological maps
- Structural geophysics:
  - 3D geometries
  - Undercover maps
  - Geophysically-constrained cross-sections



Perrouty et al. (2014 – Ore Geology Reviews)

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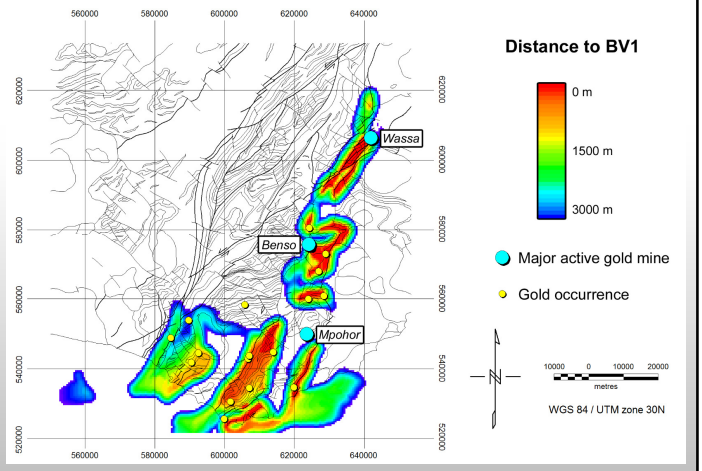

Perrouty et al. (2014 – Ore Geology Reviews)

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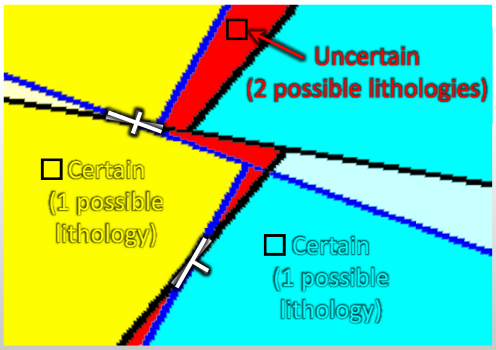
Uncertainty analyses

- Errors are associated with structural measurements *(e.g., operator, declination, natural variations)*



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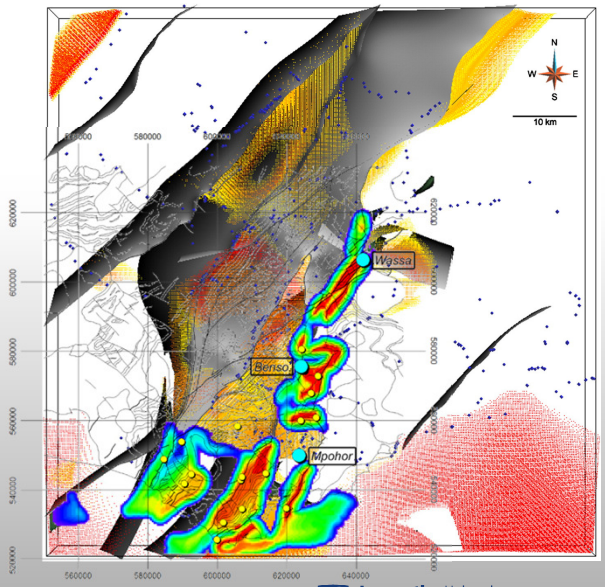
Uncertainty modeling

- Lithological variability for each cell in the Ashanti Belt model (volcanic sequence)
  - Low variability not displayed
  - Moderate variability in orange
  - High variability in red
  - *Outcrop structural data in blue*
- **=> Uncertainty modeling helps to assess the quality of a geological (or prospectivity) map/model**



Perrouty et al. (2014 – Ore Geology Reviews)

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Mapping using an "Automated" approach

Example in the Abitibi Greenstone Belt, Canada

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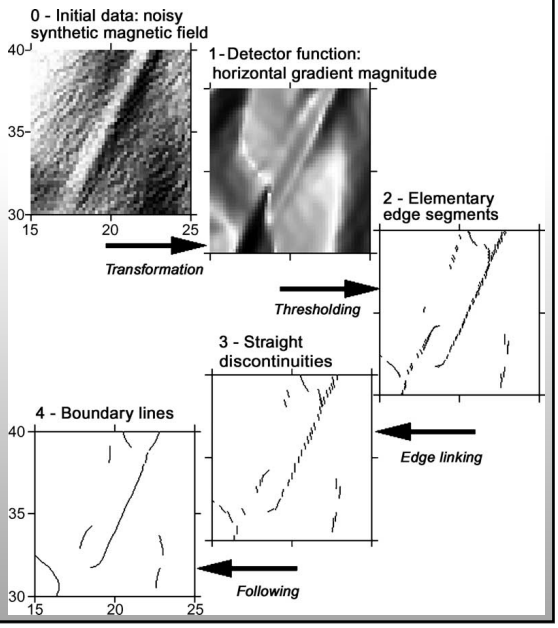
Automated-mapping approach

- Remote-sensing methods (i.e., automated image analysis)
  - Intensity, textures => lithology
- Edge detection methods (i.e., strong gradients identification)
  - Sharp contrast => contacts, faults



Debeglia et al. (2006 – Journal of Applied Geophysics)

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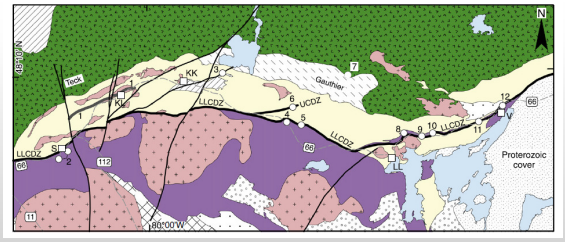
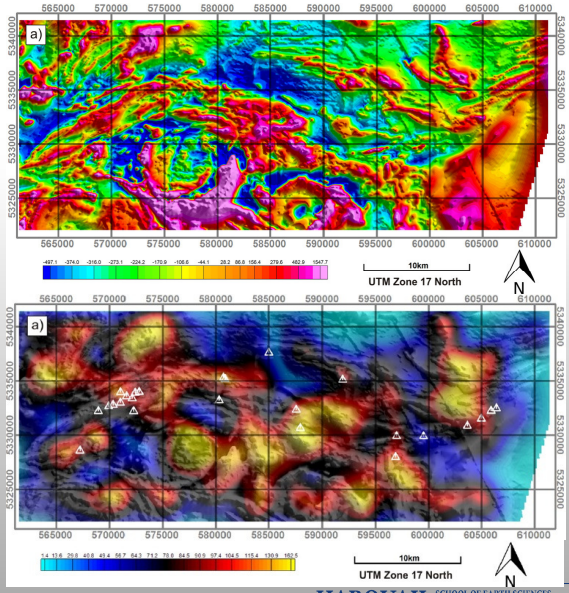
Automated-mapping

- Example from the Kirkland Lake – Larder Lake area:



- Lineament detection →
- Orientation diversity heat map →



Holden et al. (2012 – Ore Geology Reviews)

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"Visual" and "Automated" integration

Characterization of a Gold Deposit Footprint,
Canadian Malartic, Superior Province

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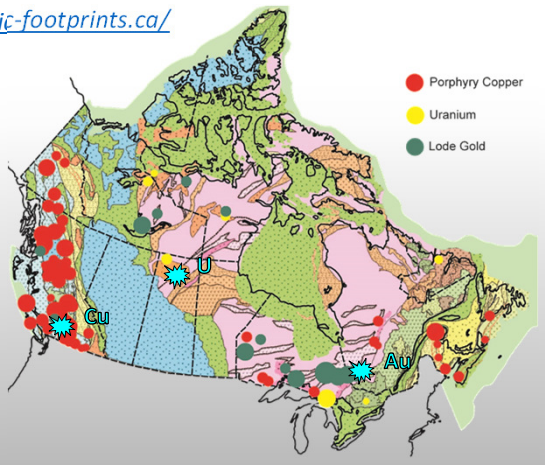
Integrated multi-parameter footprints

- **Footprints Project *(2013-2018)*** http://cmic-footprints.ca/
  - 3 world-class Canadian deposits:
    - *Highland Valley, Porphyry Cu*
    - *McArthur River-Millennium, Unconformity U*
    - *Canadian Malartic, Disseminated Au*
  - 51 partner organizations over 5 years
  - 43 HQP training (PDF, PhD, MSc, BSc)



Lesher et al. (2017 – Exploration 17)

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Natural Sciences and Engineering Research Council of Canada
Canada Mining Innovation Council
NSERC-CMIC Exploration Footprints Research Network

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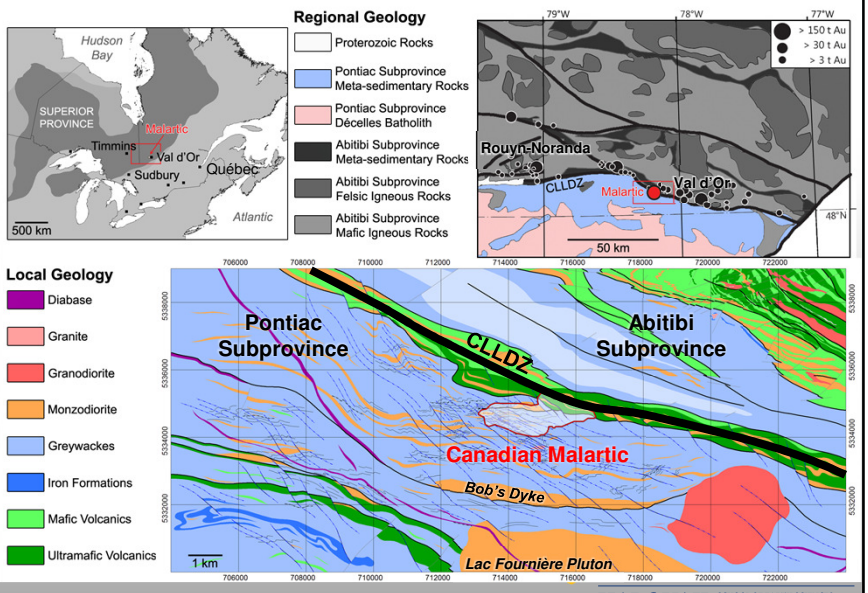
Canadian Malartic district

- **18.6 Moz Au**
- Oxidized intrusion-related deposit (Helt et al., 2014)
- Stockwork-disseminated system (De Souza et al., 2015)
- South of the CLLDZ (Cadillac Larder Lake Deformation Zone)



Perrouty et al. (2017 – Ore Geology Review)

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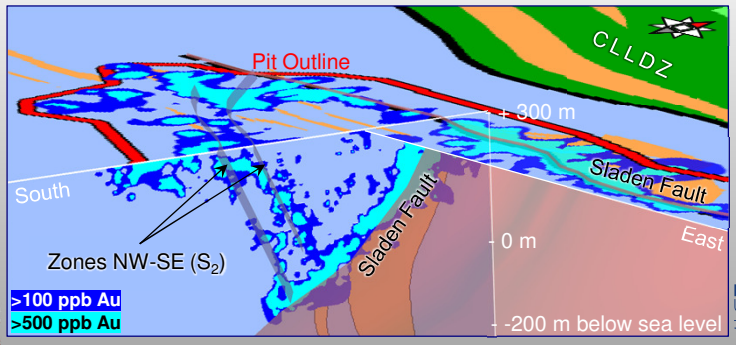
Geological setting

- 3 deformation events: **D_1** - isoclinal F_1 folds, pressure-solution cleavage (S_1)
  D_2 - close s-shaped F_2 folds, NW-SE biotite cleavage (S_2)
  D_3 - subtle crenulation cleavage (S_3)

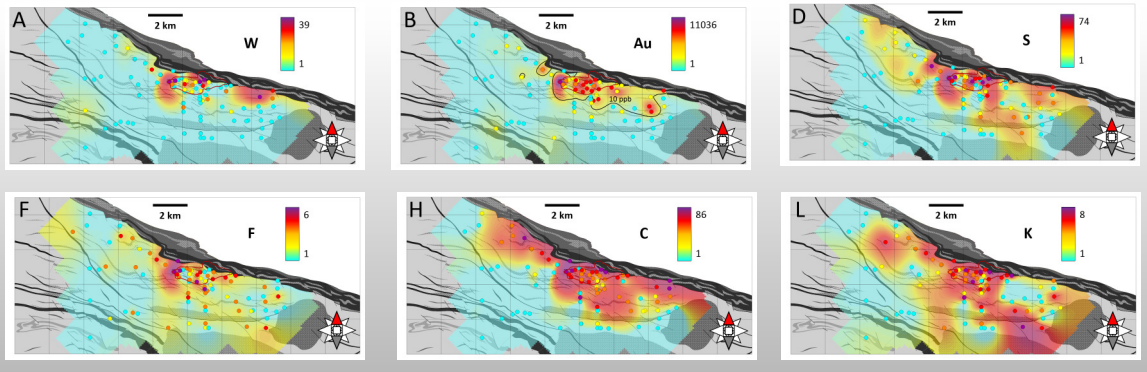
- Syn-D_2 mineralization at 2664 ± 11 Ma *(De Souza et al., 2015)*



Perrouty et al. (2017 – Ore Geology Review)

89 hydrothermal alteration haloes

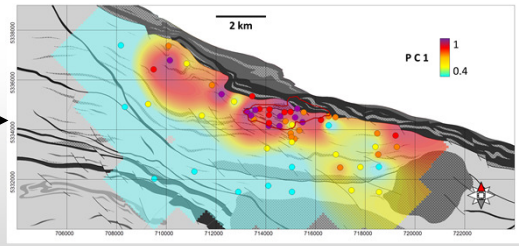
- Examples in mafic dykes *(concentration gain factor calculated using the multiple protolith method of Maclean, 1990)*



Perrouty et al. (submitted)

How to integrate these alteration haloes?

- Visual integration / geological interpretation
  - Sizes, shapes, structural controls
- Principal Component Analysis:



- Machine learning:
  - Support Vector Machine (Bérubé et al., submitted)
  - Random Forest (Bérubé et al., in prep)
  - Hypercube (Feltrin et al., in prep)
  - etc...

Product

- "Integrated map" *(NOT a final product)*

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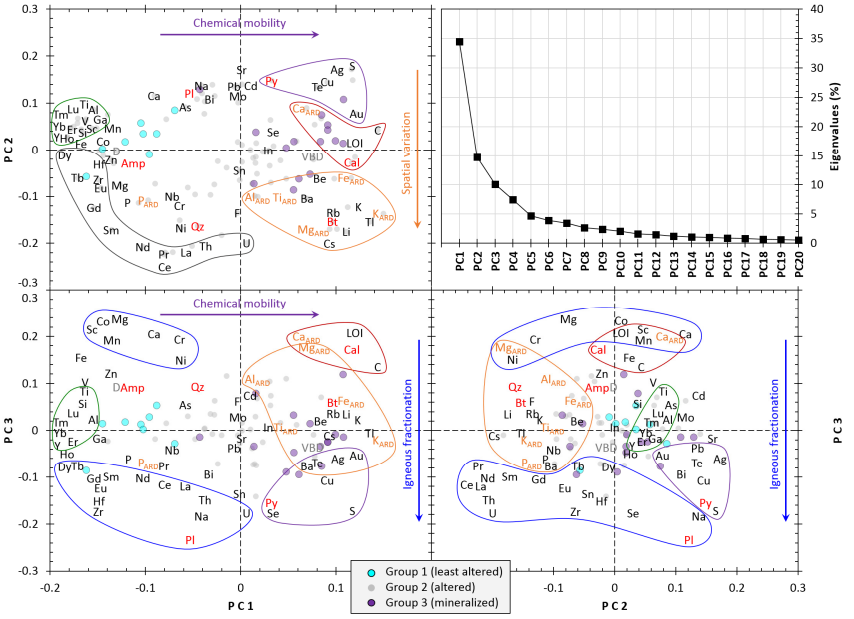
Principal Component Analysis

- **PC1** (35%): **Au-S-C-Tl-Li-LILEs chemical mobility**
- PC2 (15%): Spatial variation (footprint size)
- PC3 (10%): Igneous fractionation of the mafic dykes



Perrouty et al. (submitted)

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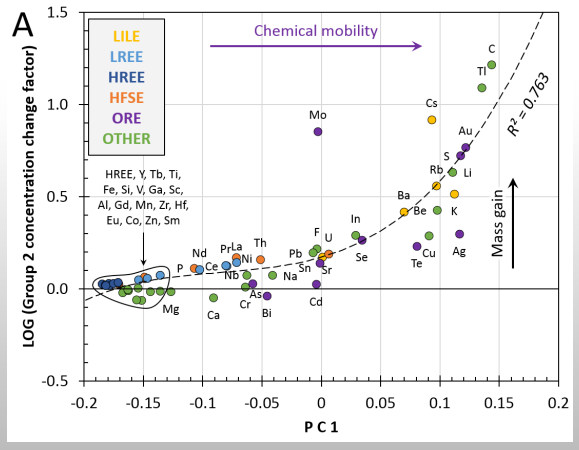
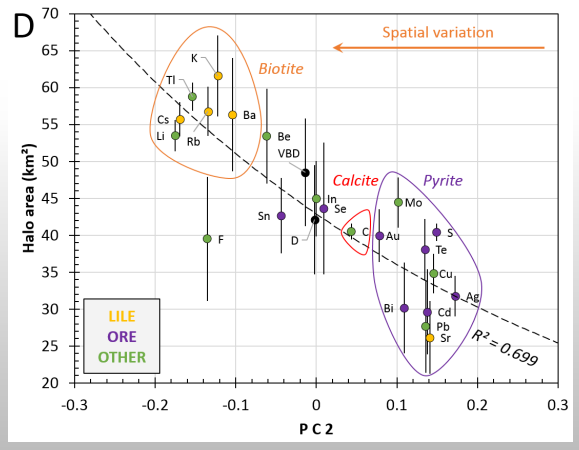
Validation of the PCA interpretation





Perrouty et al. (submitted)

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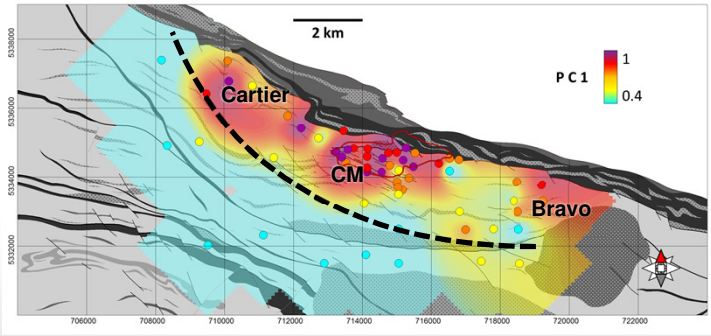
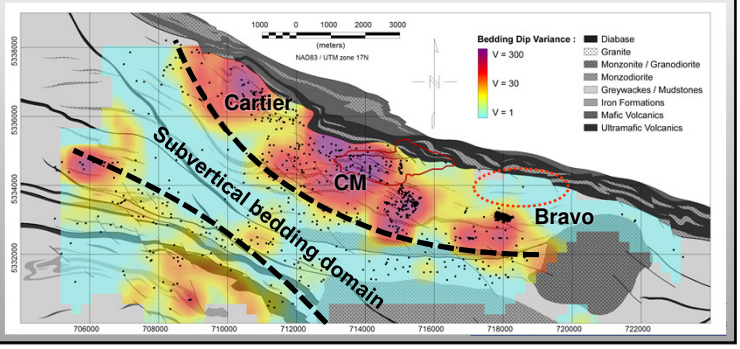
Final interpretation

- PC1 represents a multi-parameter integrated footprint of the Canadian Malartic gold deposit



- Element mobility (and gold mineralization) is mainly controlled by F_1-F_2 joint fold hinge zone (i.e., zones of structural complexity)



Perrouty et al. (2017 & submitted)

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GIS for prospectivity …

Ore Geology Reviews 71 (2015) 477–483

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/oregeorev

Editorial

Introduction to the Special Issue: GIS-based mineral potential modelling and geological data analyses for mineral exploration

Alok Porwal [a,b,*], Emmanuel John M. Carranza [c]

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[b] Centre for Exploration Targeting, University of Western Australia, Crawley 6009, WA, Australia
[c] Department of Earth and Oceans, James Cook University, Townsville, Queensland, Australia

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Conclusions

- GIS tools are largely underused for geological mapping and gold exploration in Canada and elsewhere
- A huge amount of 2D and 3D geological and structural data can be extracted from an integrated interpretation of multiple GIS layers (e.g., mapping in the Ashanti Greenstone Belt)
- Both “Visual” and “computer-based” approaches should be understood and interpreted by a “geologist brain” to deliver a better final product (e.g., Canadian Malartic footprint)

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As an exploration geologist you need to:

- Understand the raw data processing behind each layer of the GIS (e.g., geophysical maps, computer-based integrated maps)
- Be able to interpret each layer individually in term of lithology, structures, metamorphism, alteration, etc...
- Be able to visually integrate the information from different layers to build your geological exploration model
- Consider geological uncertainty and think in 3D *(i.e., a fault strike and dip in one outcrop may not be representative of the regional trends)*
- Always validate your GIS interpretation with several field observations and broad geological knowledge

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Thank you …

WAXI - West African Exploration Initiative
IXOA - L'Initiative d'Exploration Ouest Africaine

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