Geological mapping and Geohazard monitoring from SAR

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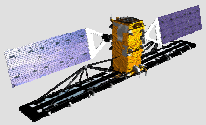
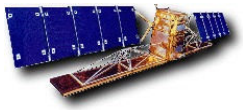
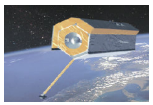
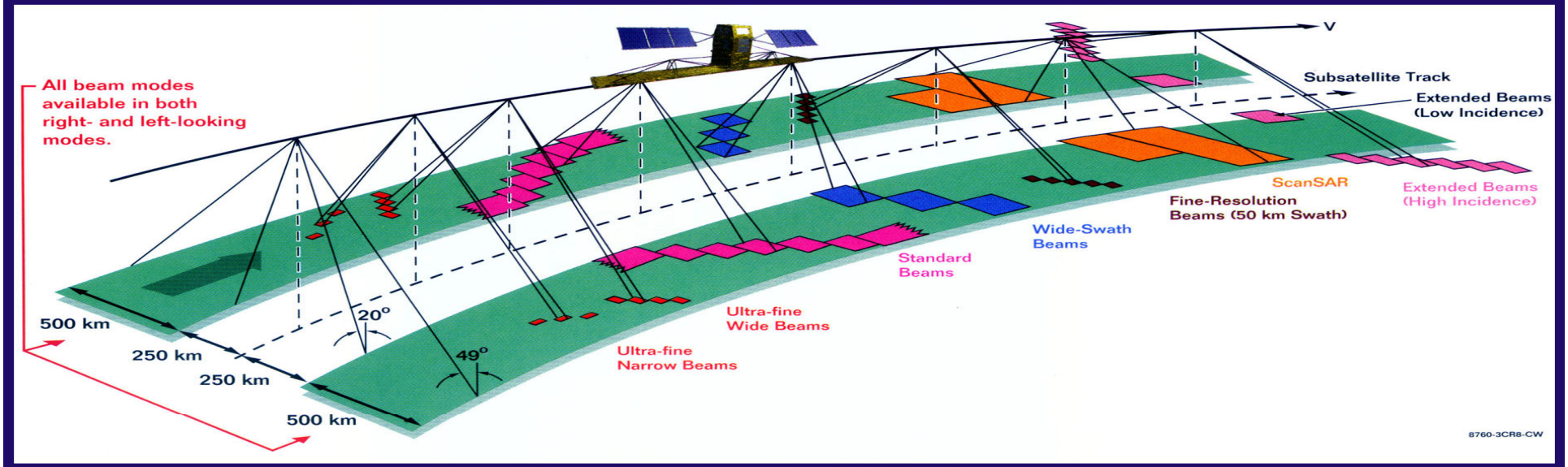
Outline

- Current SAR Systems
- Review of Current Geological Applications
  - Hydrocarbons: Exploration and Distribution
  - Mineral Exploration/ Mapping
  - Geological Hazard Monitoring
- Future trends and Research Gaps:

SAR System Summary

	Design Life	Imaging frequency	Spatial resolution	Polarization	Look direction	Status
RADARSAT-2 	7 years	C-Band, 5.405 GHz	3 to 100 meters	Single (HH, VV, VH, HV) Dual (HH/ HV, VV/VH) Polarimetric	Left- and right-looking	Launch 2007
RADARSAT-1 	5 years	C-Band, 5.3 GHz	10 to 100 m	Single HH	Right-looking	In operation (Since 95)
Envisat ASAR 	5 years	C-Band, 5.331 GHz	30 to 1000 meters	Single (HH, VV) Alternating (VV/HH, VV/VH, HH/HV)	Right-looking	In operation (Since 02)
TerraSAR-X 	5 years	X-Band, 9.650 GHz	1 to 15 meters	Single (HH, VV) Dual (VV/HH, VV/VH, HH/HV)	Left- and right-looking	Launch 2007
ALOS PALSAR	5 years	L-Band, 1.27 GHz	10 to 100 meters	Single (HH, VV) Dual (HH/ HV, VV/VH) Polarimetric (exp.)	Right-looking	Launch 2006

RADARSAT-2 Viewing Geometry

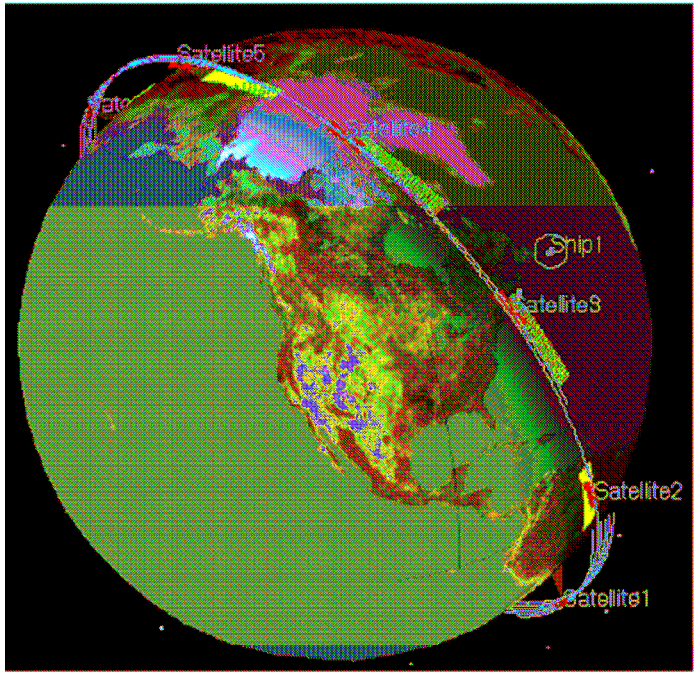


RADARSAT-2 will offer all the modes currently available with RADARSAT-1

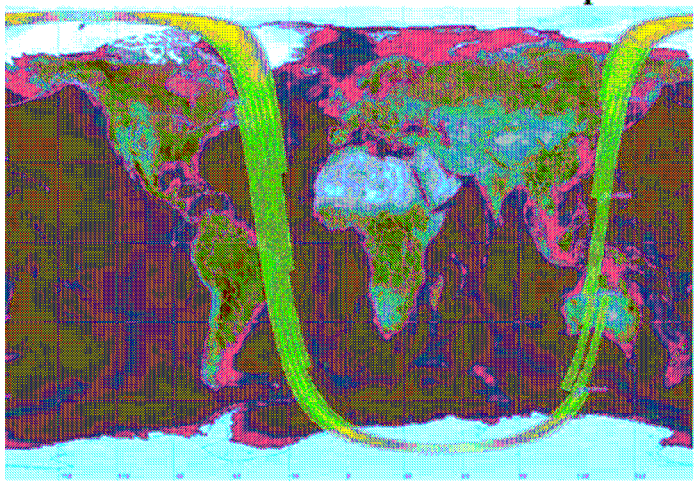
PLUS

- ***Selective Polarization (HH, VV, HV, VH) on all acquisition modes***
- ***Two full polarimetric modes (Standard QP and Fine QP)***
- ***Right or Left-looking modes available at all time***
- ***Triple Fine mode: 50 km swath, 11 x 9 m nominal resol.***
- ***Ultra Fine Wide mode: 20 km swath, 3 x 3 m resol.***
- ***Ultra Fine Narrow mode: 10 km swath, 3 x 3 m resol.***

RADARSAT-C Concept Overview



Constellation of six satellites 16 min apart

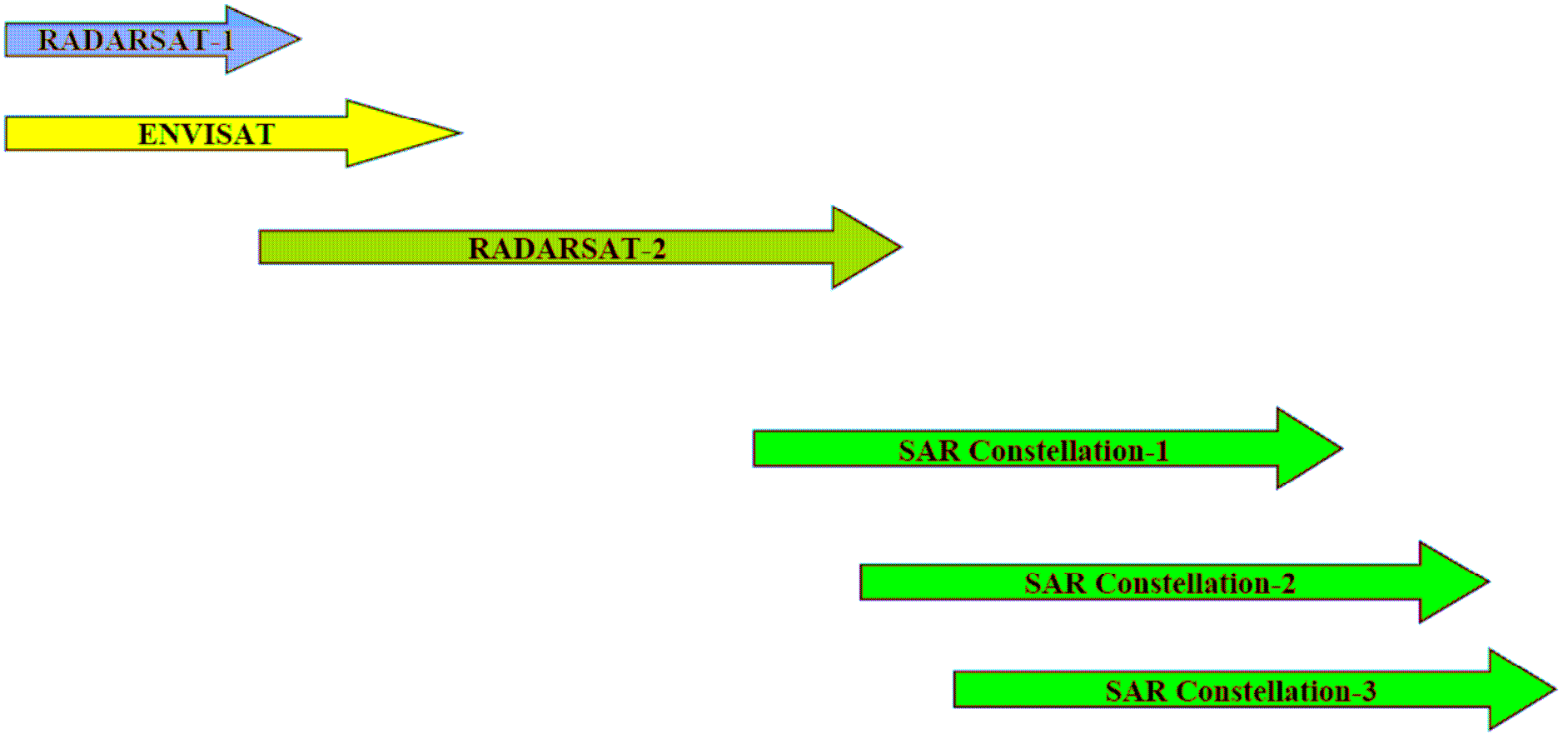


50 min coverage of east Atlantic

- Three to six satellites
- Minimum daily coverage of Canada at 50m
- Minimum daily global access
- Data analyzed in near real time
- Following satellites will tasked for specific identification
- Satellites equally spaced in same plane
- 2 to 4-day Coherent Change Detection using SAR interferometry
- Dual polarization data capability (constellation, but not necessarily each satellite)
- Gradual implementation with yearly launch
- Gradual replacement of aging satellites
- Fully reconfigurable

Canadian Space Agency | Agence spatiale canadienne

Timeline

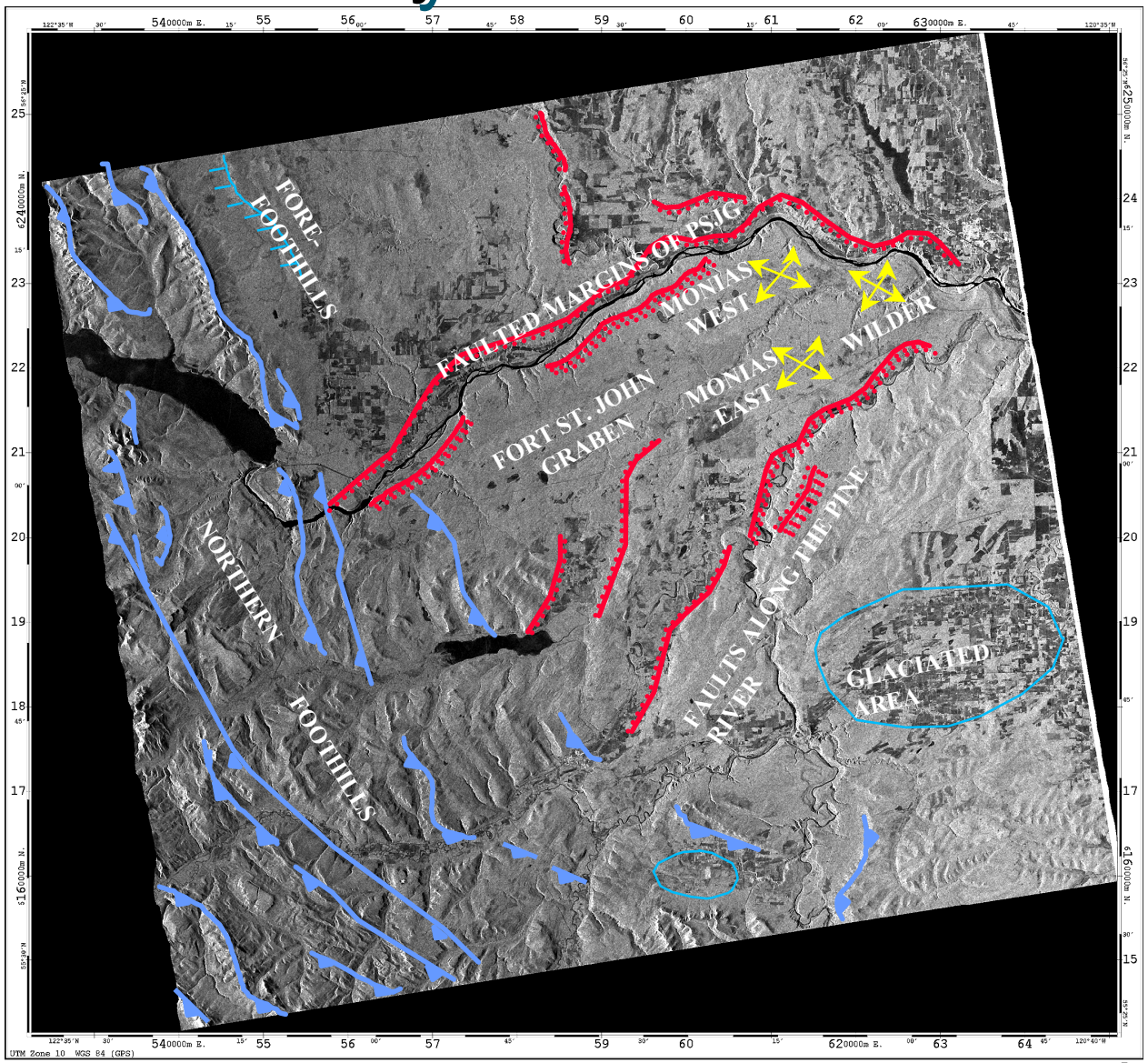


Mission Requirements (3)

- Spatial Resolution
  - Medium Resolution Mode (50m, 4 looks)
  - Low Resolution Mode (100 m, 8 looks)
  - High-Resolution Mode (5 m, 1 look)
  - Very High-Resolution Mode (< 3 m)
  - Dedicated Modes
- Swath
  - 350 km in medium resolution
  - 500 km low-resolution
  - 20-30 km in high-resolution
  - TBD km for CCD.

Hydrocarbon Exploration

Halfway River: Alberta



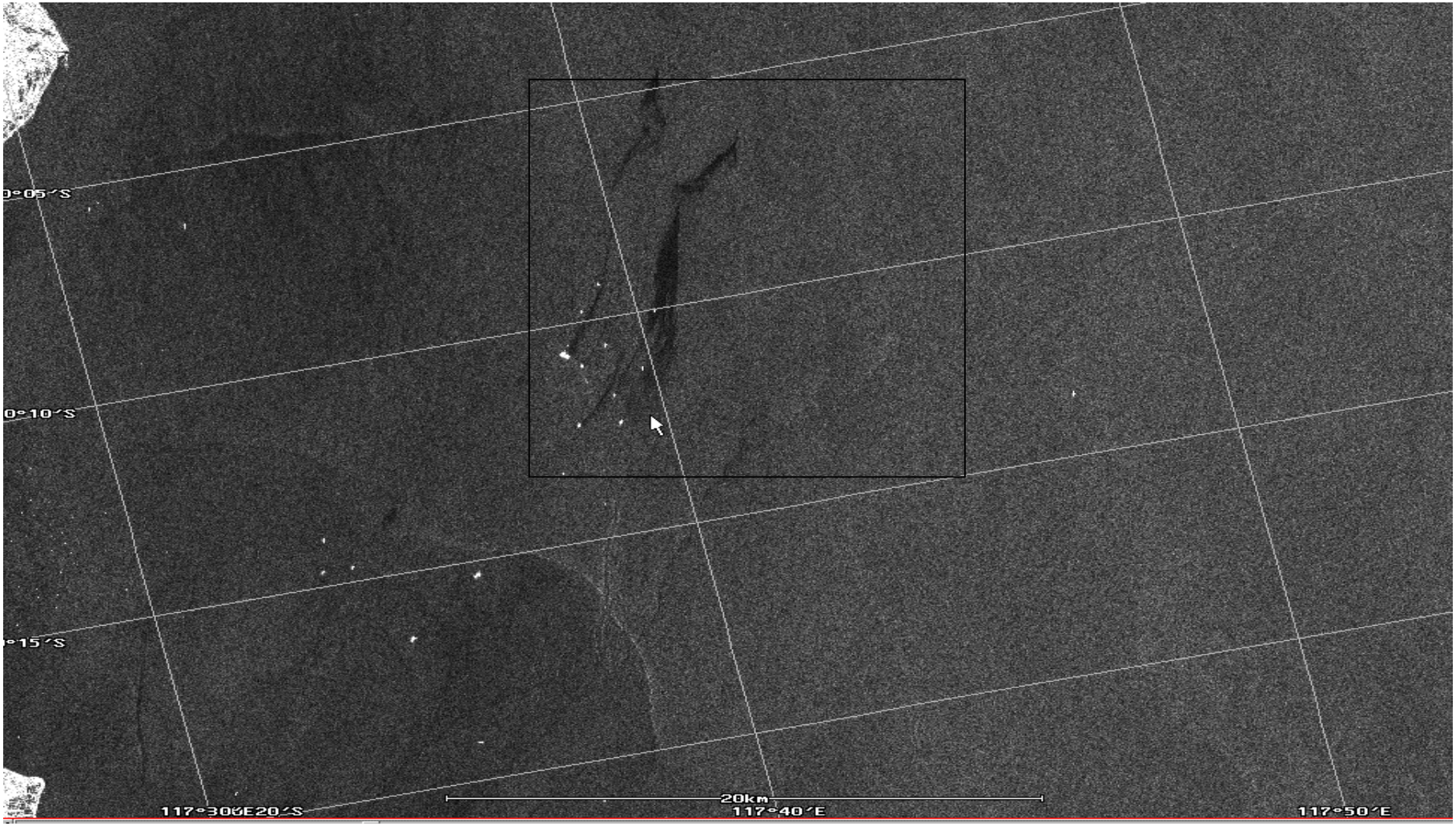
Orthorectified RADARSAT (S7) Charlie Lake, Canada

RUDP Image Courtesy of CSA (copyright 1996)

Kilometres 10 0 10 20 30

Miles 10 0 10

Ship detection and Oil Pollution Tracking

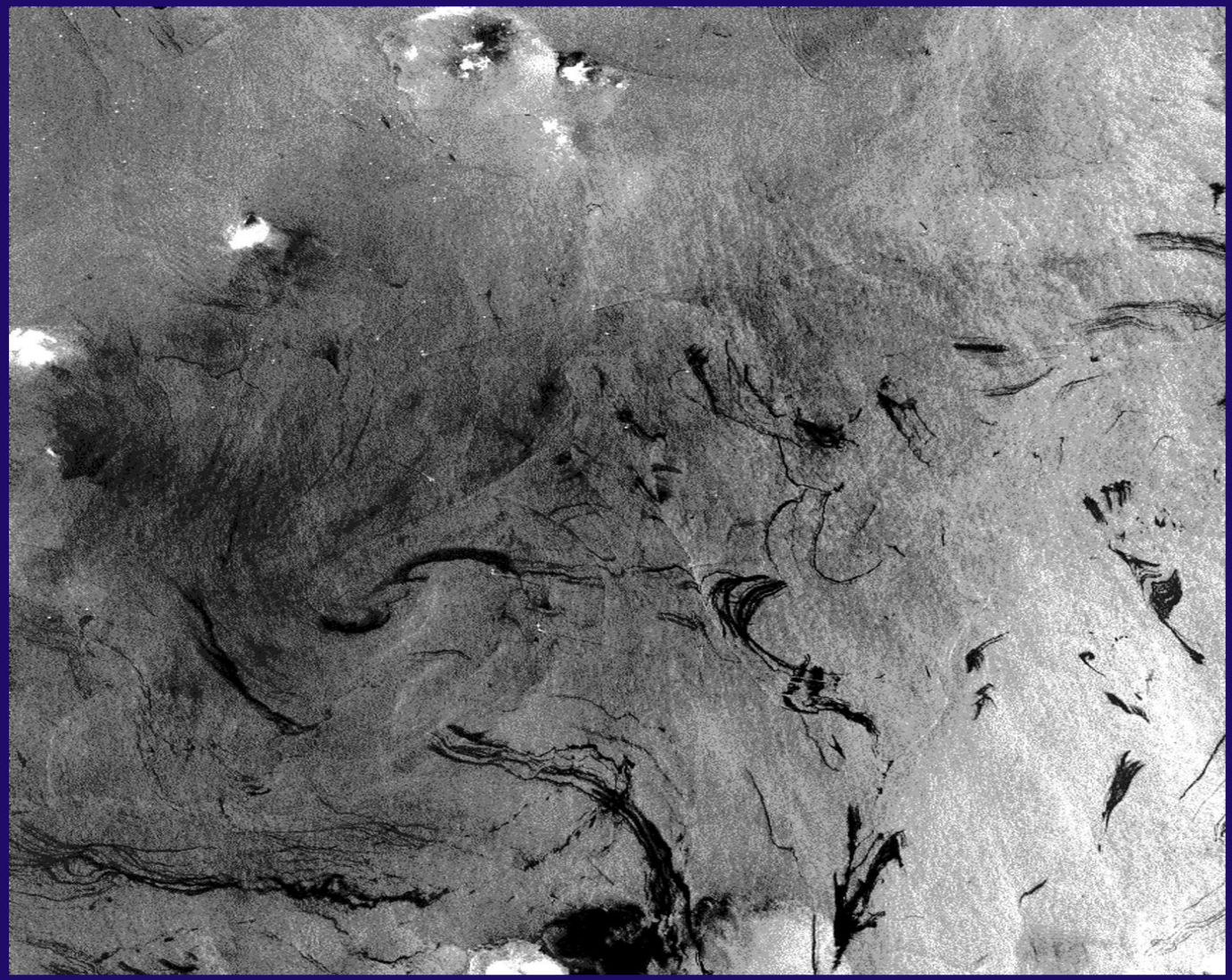


Natural Resources Canada | Ressources naturelles Canada

Geomatics Canada | Géomatique Canada

RADARSAT-1

Detection of Oil Seeps in the Gulf of Mexico



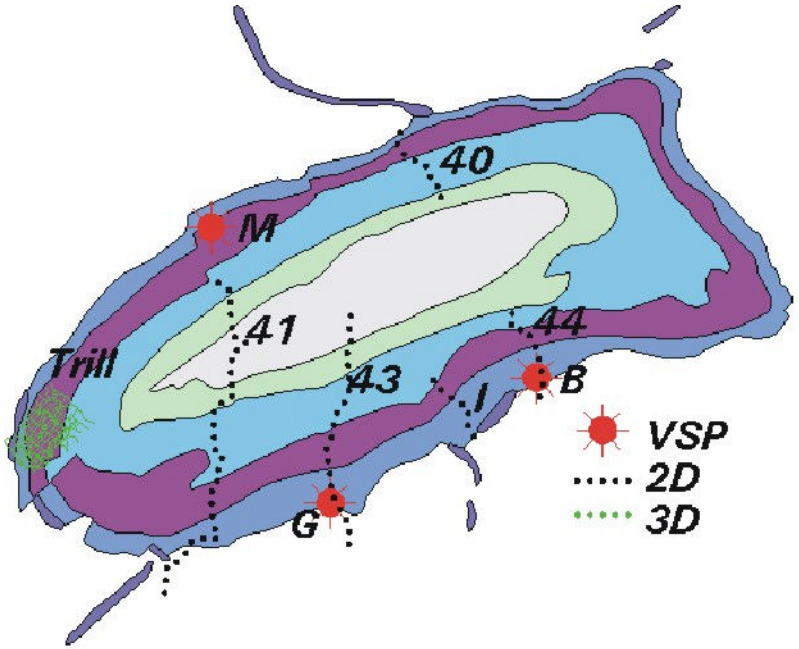
W2

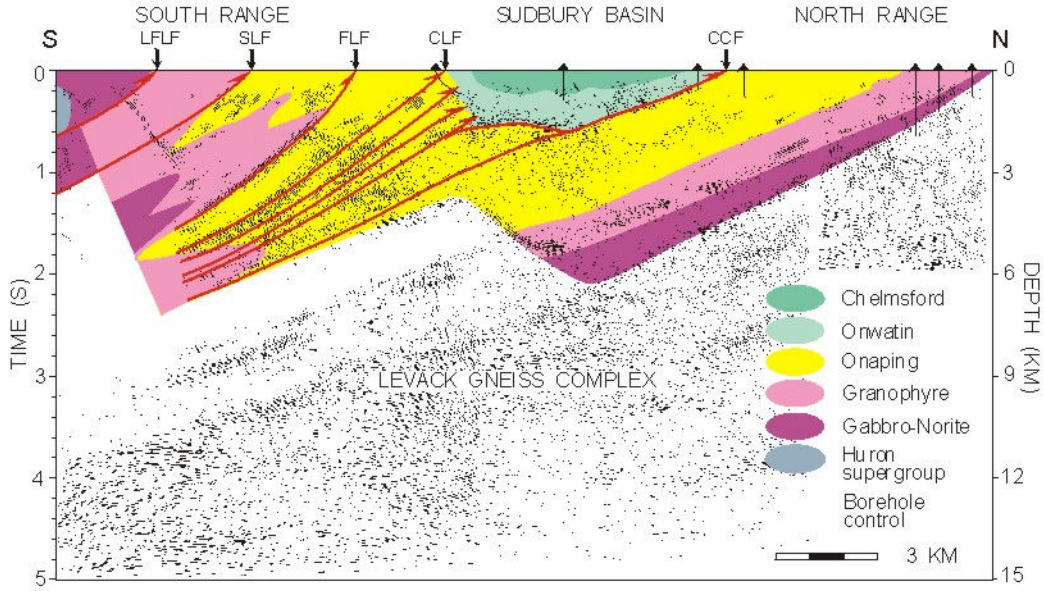
Image provided by RADARSAT International

Sudbury Basin

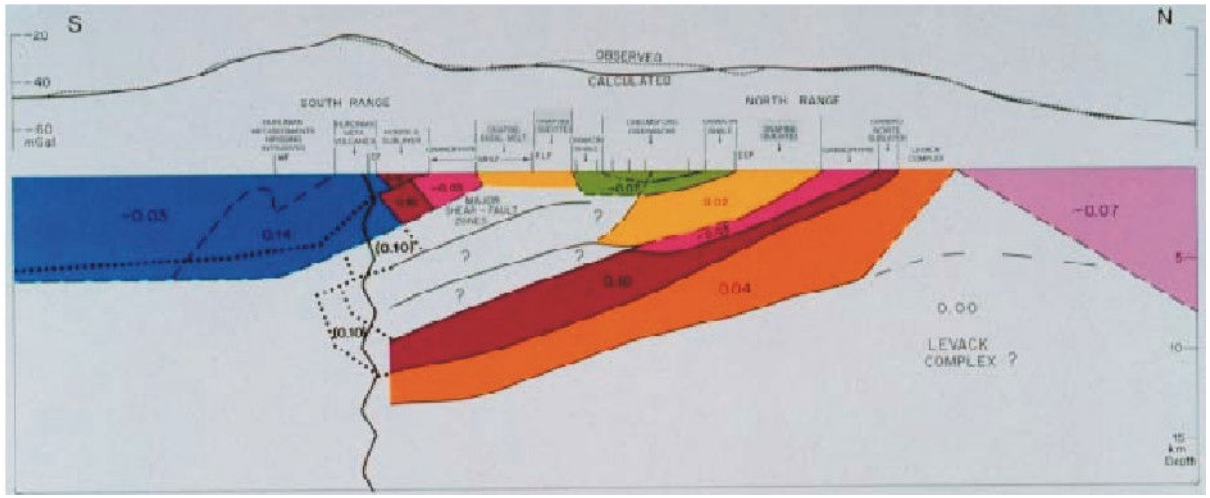
- World's oldest, largest, and best-exposed meteorite impact site
  - **1.8 billion years old**
  - **200-300 km original diameter**
- World class mineral deposits
  - **over 100 years of production worth more than $140 billion (contained metal in 2006 dollars)**
  - **Current production worth close to $2.5 billion per year**
  - **Significant new discoveries continue to be made**
- Large mining cluster
- The Basin is a CCRS supersite to develop a number of Geological Remote Sensing techniques.- evaluation of RADARSAT-1&2, and Hyperspectral (CSA) Envisat (ESA) and ALOS (JAXA) Terra SAR (DLR) missions.
- CCRS is providing high-res fused images to assist the GSC that are conducting high res mapping in the Basin (1:10-50K)

Sudbury Structure Studies

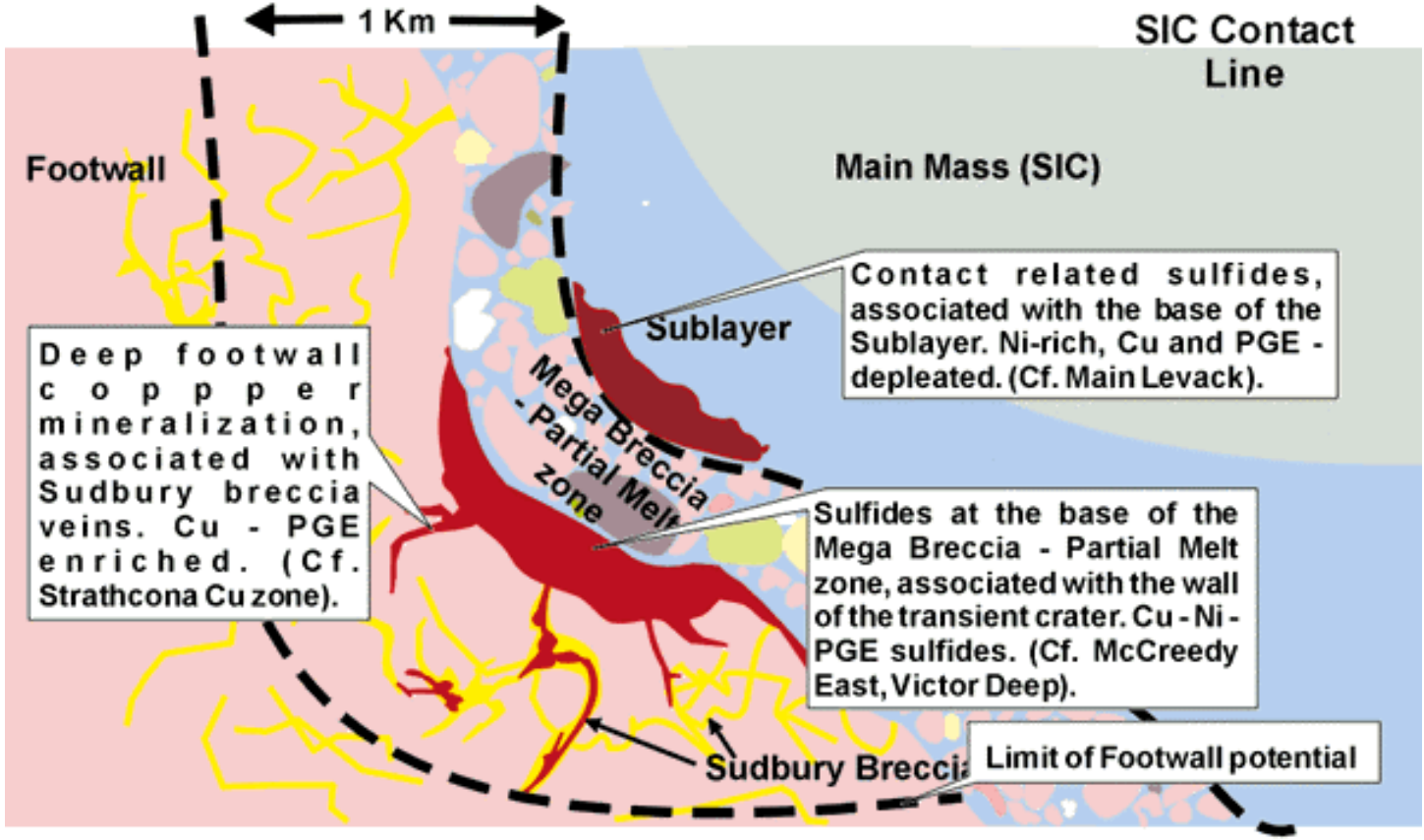




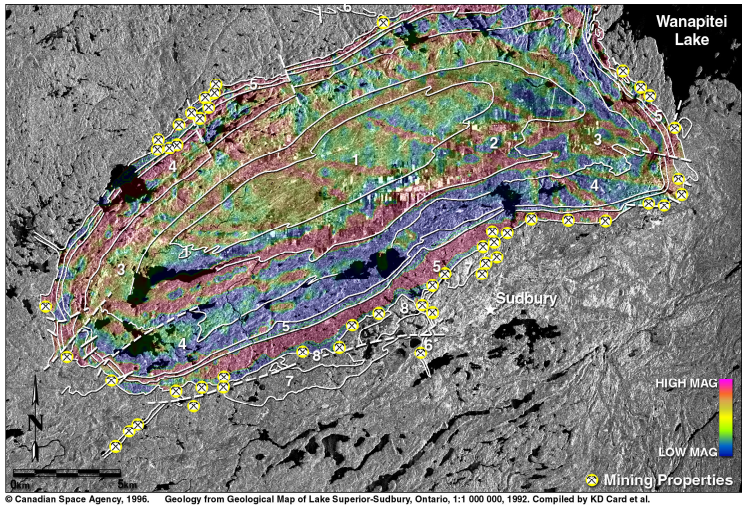
- GSC Compilations
- Included structural analysis of the 2D seismic, mag. and gravity data leading to currently accepted model of the deep basin geometry.



TYPICAL CROSS SECTION THROUGH NORTH RANGE ORE BODY

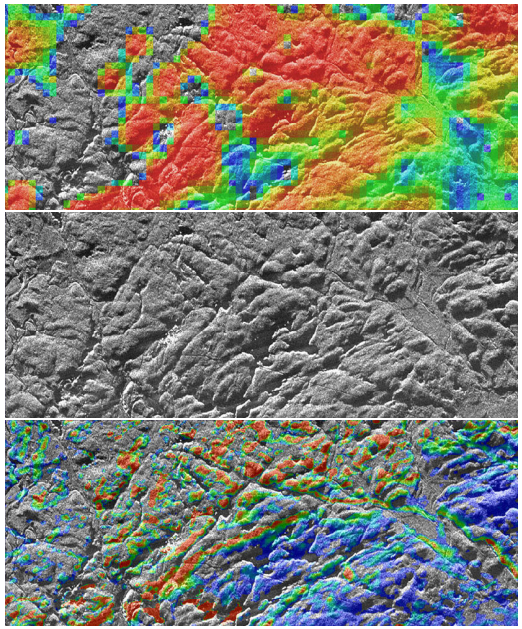


Integration of SAR and Magnetic Data



 Geology from Geological Map of Lake Superior-Sudbury, Ontario, 1:1 000 000, 1992. Compiled by KD Card et al.

RADARSAT Standard Mode and low resolution magnetic data



C-SAR + Mag (VG)
Mag originally gridded at 200 m

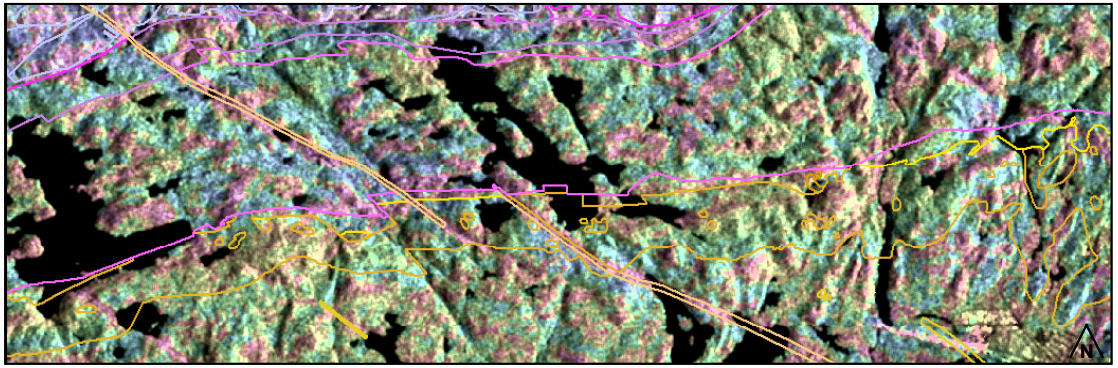
Airborne SAR
C-HH, Wide mode
Resolution 19 m
Pixel spacing: 15 m

0 km 5

C-SAR + Mag (VG)
Mag originally gridded at 25 m

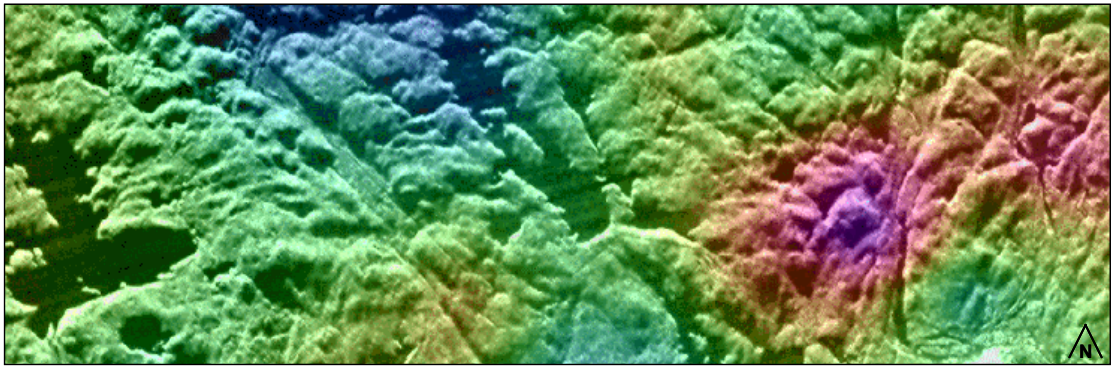
Magnetics
High
Low

Sudbury High Resolution Image Integration



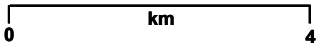
RADARSAT-1 Fine Mode integrated with magnetic vertical gradient and shaded relief

RADARSAT-1 data
Fine Mode mosaic - Beam 2/3 : 11-Nov-03 / 05-Dec-03
descending orbit, 6.25 m orig. pixel spacing
Magnetic data
20 m orig. pixel spacing
(courtesy Falconbridge)
Ontario Provincial DEM v. 1.1.0
20 m orig. pixel spacing
(courtesy Provincial Geomatics Service Centre)



SAR and geochemistry IHS Integration

Nickel in Soil



Updated geologic map

GEOLOGY

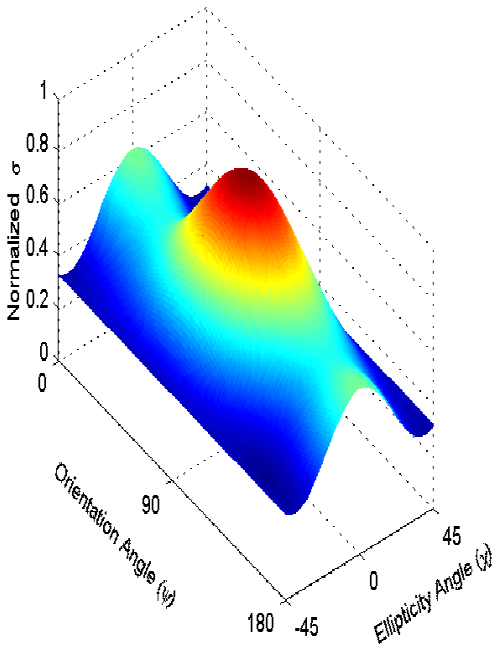
- Granite
- Basal Member Breccia
- Olivine Diabase
- Footwall Breccia
- Granophyre
- Gabbro
- Gneiss
- Black Member Breccia
- Metatextite
- Greyish-green Matrix
- Melt Body
- Quartz Gabbro
- Norite
- Siltsone / Limestone
- Wacke
- Pillow Basalt
- Diabase

Sudbury Breccia(25)- and Norite (8a)

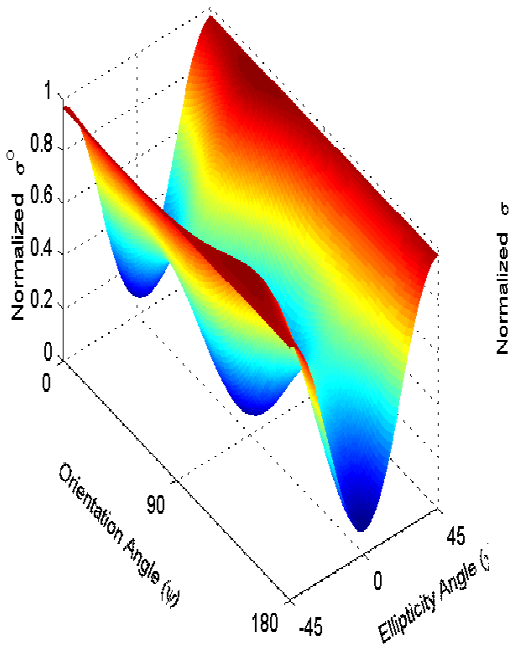
Area 25 : p39
Line 3 Pass 2 30-MAR-2004

Linear Pol (dB): σ^0_{HH} = -11.54 ; σ^0_{HV} =-22.57 ; σ^0_{VV} =-9.55
Circular Pol (dB): σ^0_{RR} = -14.40 ; σ^0_{LR} =-12.21 ; σ^0_{LL} =-14.52

CO-POL RESPONSE



CROSS-POL RESPONSE



Max Co-Pol: ($\psi = 90^0$; $\chi = 0^0$)
Min Co-Pol: ($\psi = 153^0$; $\chi = 36^0$)
Pedestal Height Co-Pol: 0.28

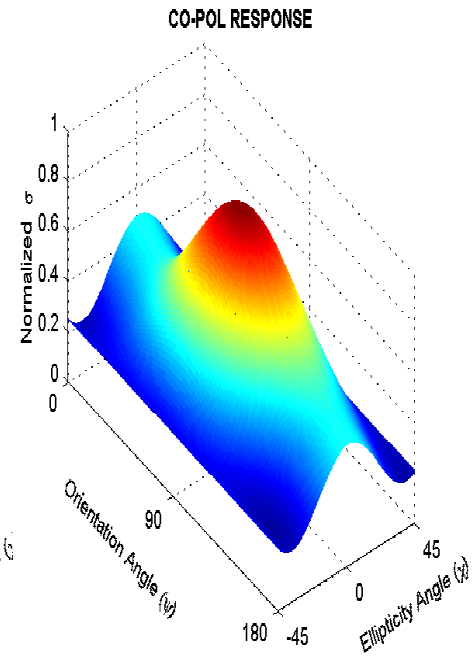
Incident angle: 44.39^0
Area center: [326 26151]
Number of samples: 17274

Max Cross-Pol: ($\psi = 135^0$; $\chi = 38^0$)
Min Cross-Pol: ($\psi = 0^0$; $\chi = 0^0$)
Pedestal Height Cross-Pol: 0.09

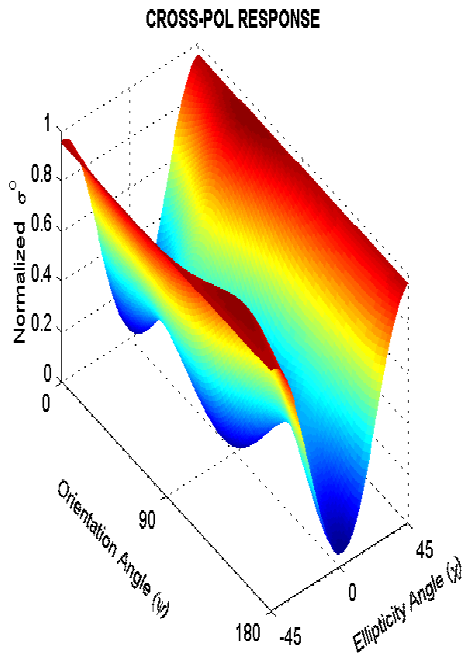
Area 9 : p8a
Line 3 Pass 2 30-MAR-2004

Linear Pol (dB): σ^0_{HH} = -14.57 ; σ^0_{HV} =-26.68 ; σ^0_{VV} =-11.45
Circular Pol (dB): σ^0_{RR} = -17.43 ; σ^0_{LR} =-14.10 ; σ^0_{LL} =-18.25

CO-POL RESPONSE



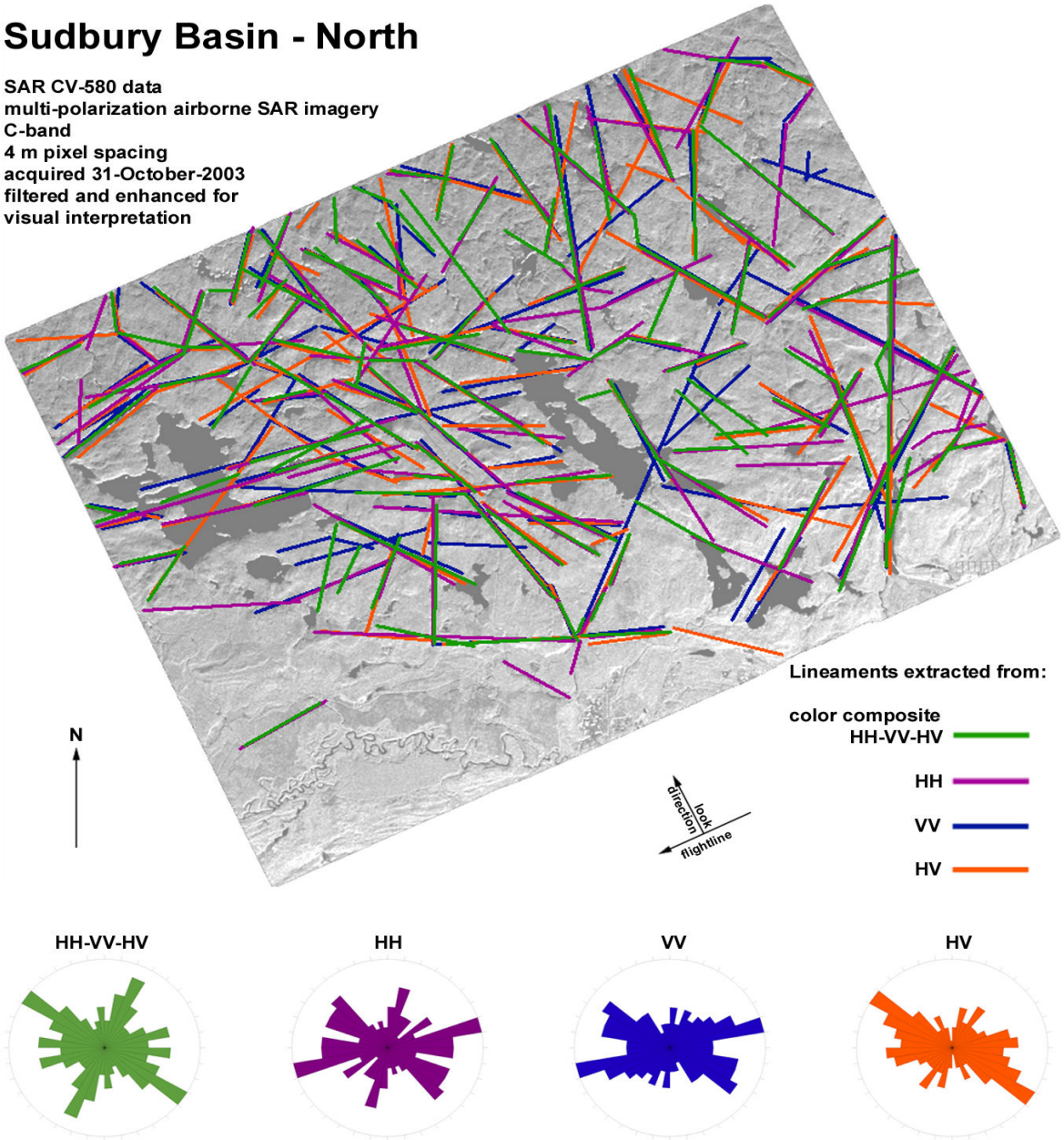
CROSS-POL RESPONSE



Max Co-Pol: ($\psi = 88^0$; $\chi = -1^0$)
Min Co-Pol: ($\psi = 153^0$; $\chi = 36^0$)
Pedestal Height Co-Pol: 0.16

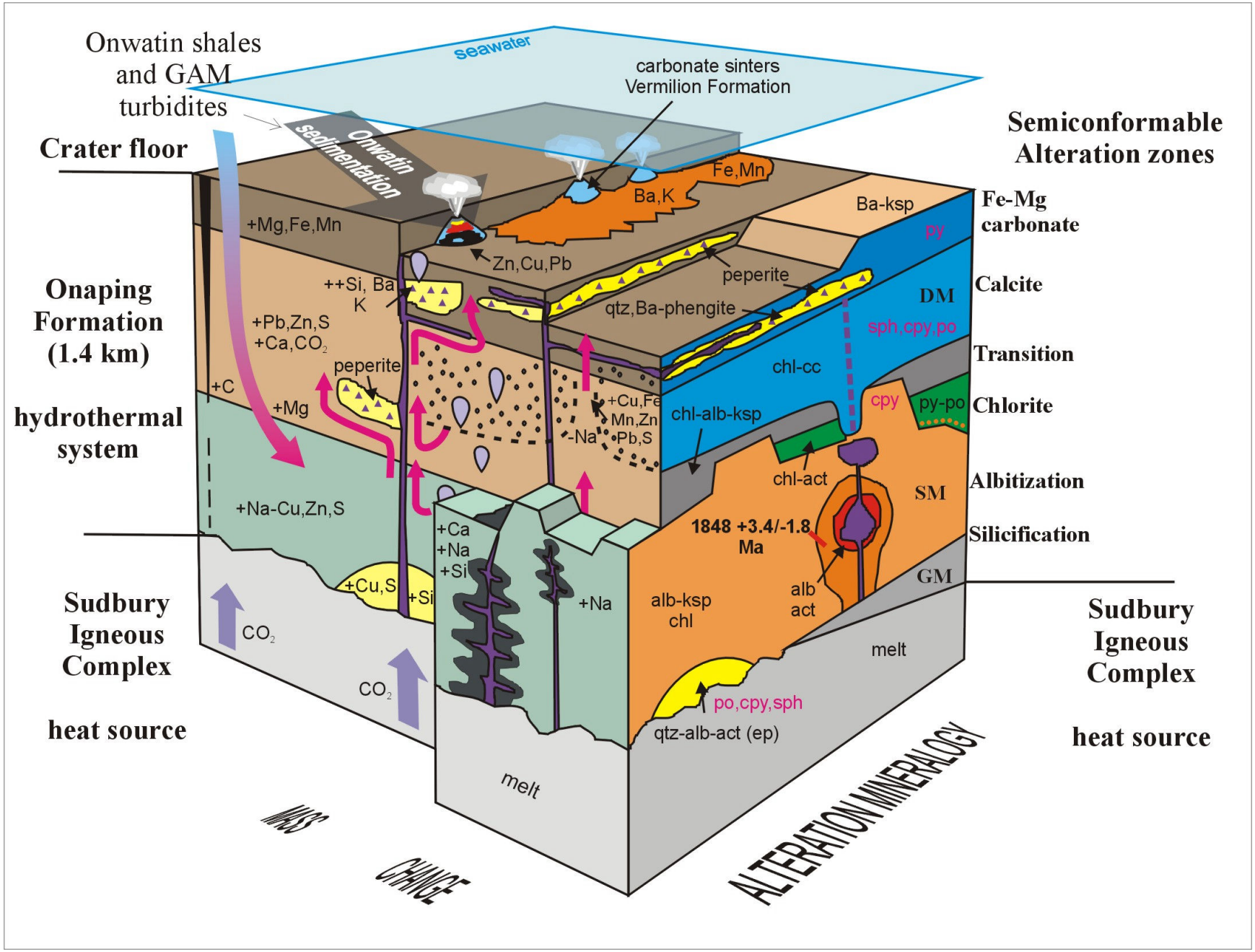
Incident angle: 45.72^0
Area center: [378 13776]
Number of samples: 383

Max Cross-Pol: ($\psi = 128^0$; $\chi = 38^0$)
Min Cross-Pol: ($\psi = 89^0$; $\chi = -1^0$)
Pedestal Height Cross-Pol: 0.05

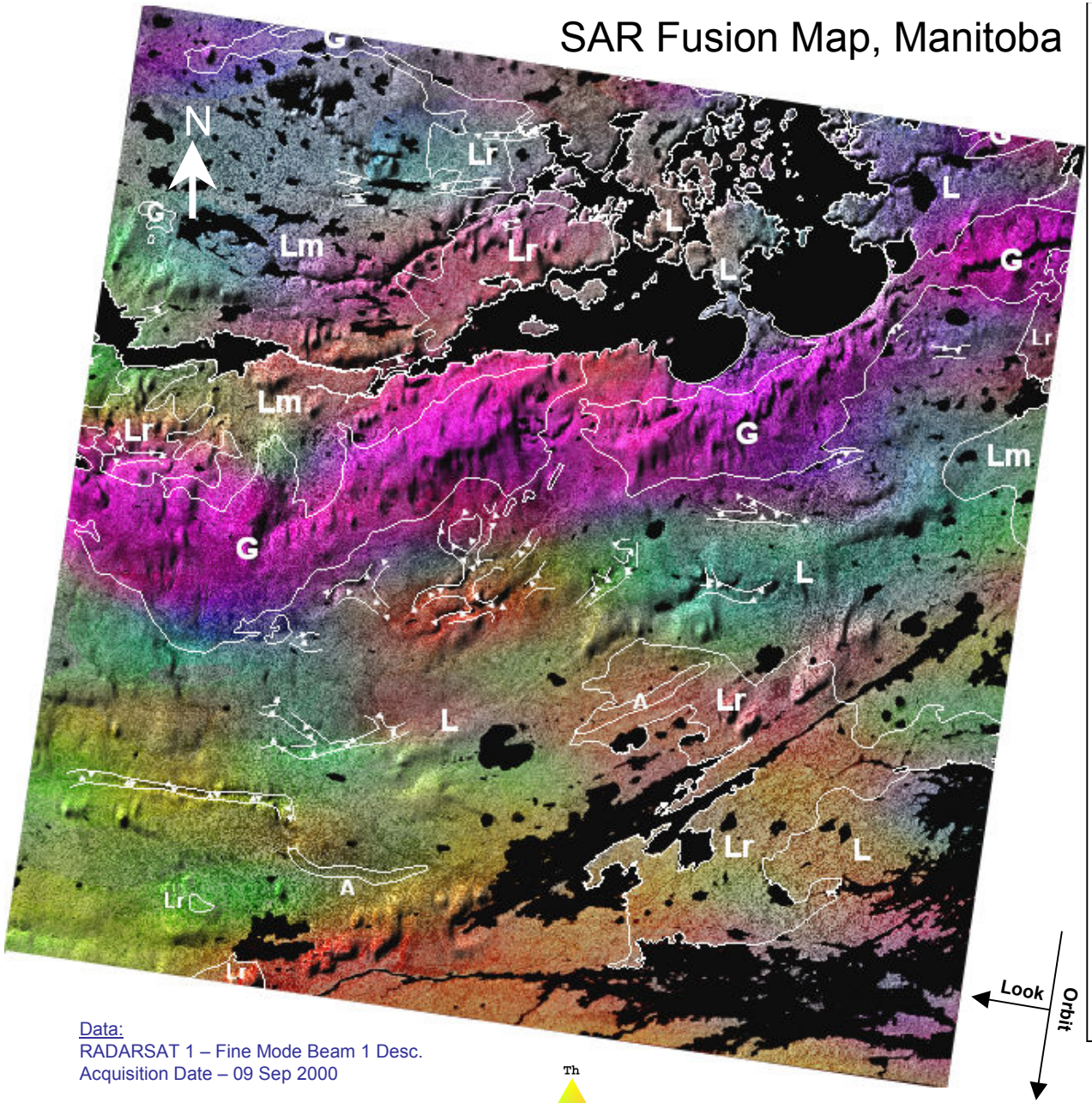


Polarimetric composite provide additional structural details (Singhroy 2005-CCRS)

Crater-fill hydrothermal alteration: Sudbury structure (Ames06)



SAR Fusion Map, Manitoba



LEGEND

QUATERNARY
HOLOCENE

NONGLACIAL ENVIRONMENT

A — ALLUVIAL DEPOSITS: gravel sand, and silt 1-10 m thick; occurs as terrace and plains that were formarly stream floodplains and deltas

PROGLACIAL AND NONGLACIAL ENVIRONMENTS

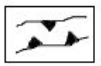
L — GLACIOLACUSTRINE BASIN DEPOSITS: clay, silt,2-15 m thick; commonly grey and verved where thisck but massive and brownish near surface and where thin; forms a nearly unbroken blanket in low relief areas or occupied basins between bedrock hills

Lm — Discontinuous veneer, 1-2 m thick; largely overlying till and including areas of till and rock

Lr — Discontinuous veneer, 1-2 m thick; largely overlying rock and including abundant rock outcrops

GLACIAL AND PROGLACIAL ENVIRONMENTS

G — GLACIOFLUVIAL ICE CONTACT DEPOSITS: sand and gravel with variable sorting and stratification; locally contains or is overlain by gravelly diamicton; 15-90 m thick; occurs mainly as major kame moraine systems consisting of broad kettled ridges formed as interiobate moraines and as isolated kames and eskers; surface of features in many areas reworked by lacustrine processes and locally overlain by beach ridges

 Abandoned or underfit channel (large, small)

MAP 1603A
SURFACE GEOLOGY MAP
1:500 000
GEOLOGY by R.W Klassen and J.A. Netterville 1971-1973

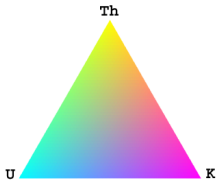
Look

Orbit

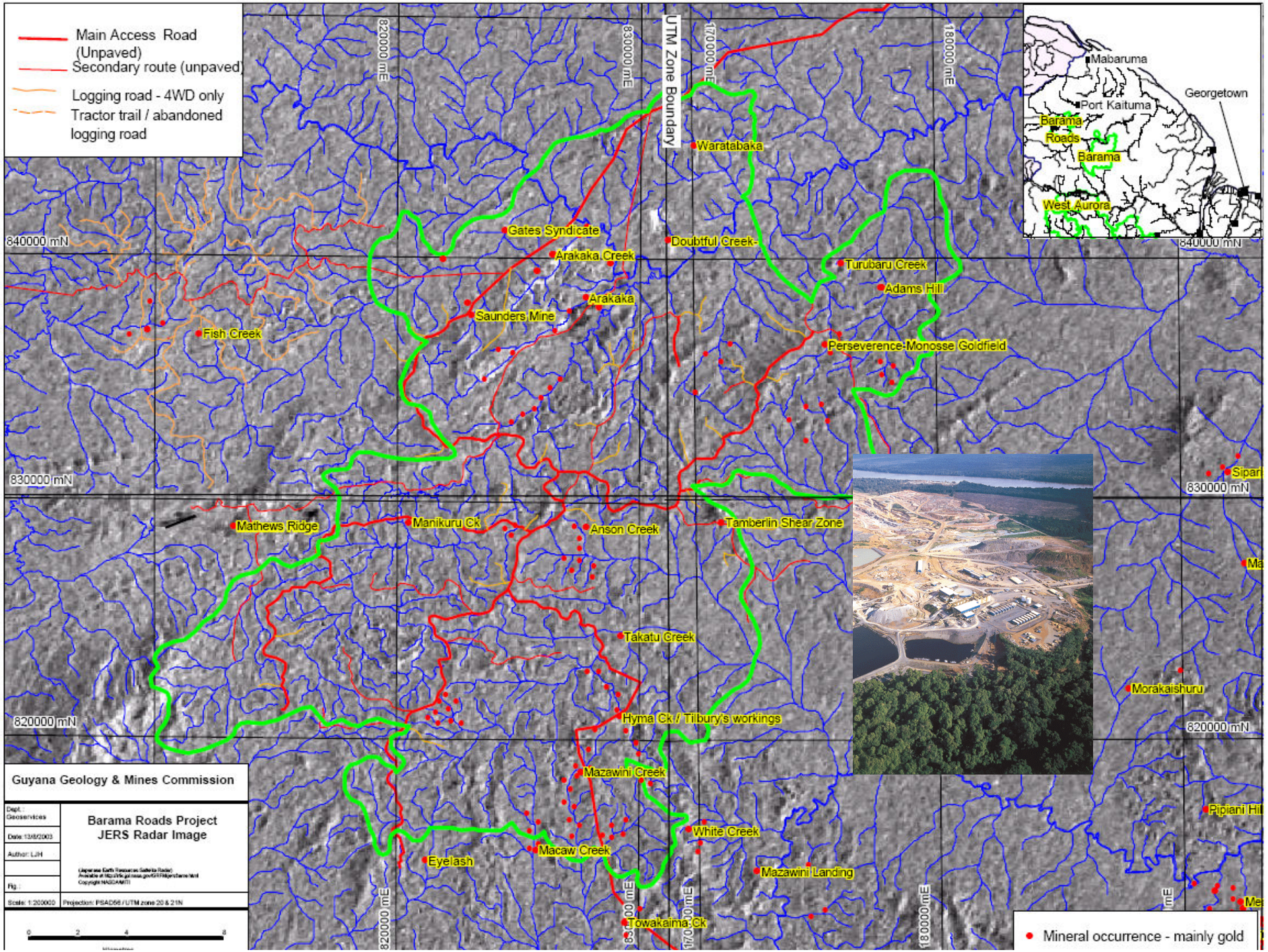
Data:
RADARSAT 1 – Fine Mode Beam 1 Desc.
Acquisition Date – 09 Sep 2000

GSC Airborne Radiometric Data (K-Th-U)

Shaded Relief from CDED 250 000 DEM



1:100 000 Scale
Kilometres 1 0 1 2 3 4 5 6 7


Main Access Road (Unpaved)
Secondary route (unpaved)
Logging road - 4WD only
Tractor trail / abandoned logging road
UTM Zone Boundary
820000 mE
830000 mE
170000 mE
180000 mE
840000 mN
830000 mN
820000 mN
Mabaruma
Georgetown
Port Kaituma
Barama Roads
Barama
West Aurora
Waratabaka
Gates Syndicate
Doubtful Creek
Arakaka Creek
Arakaka
Saunders Mine
Fish Creek
Turubaru Creek
Adams Hill
Perseverence-Monosse Goldfield
Mathews Ridge
Manikuru Ck
Anson Creek
Tamberlin Shear Zone
Takatu Creek
Hyma Ck / Tilbury's workings
Mazawini Creek
White Creek
Macaw Creek
Eyelash
Mazawini Landing
Towakaima Ck
Morakaishuru
Pipiani Hill
Guyana Geology & Mines Commission
Barama Roads Project
JERS Radar Image
Mineral occurrence - mainly gold

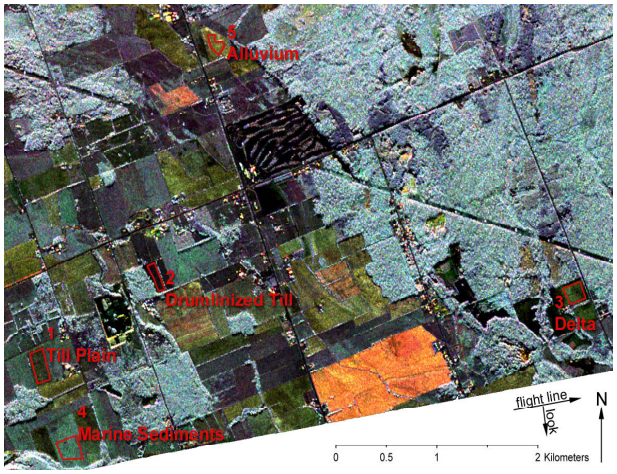
Natural Resources Canada | Ressources naturelles Canada

BATHURST ISLAND
POLAR BEAR PASS
Lithology from SAR

RADARSAT-1 C-HH

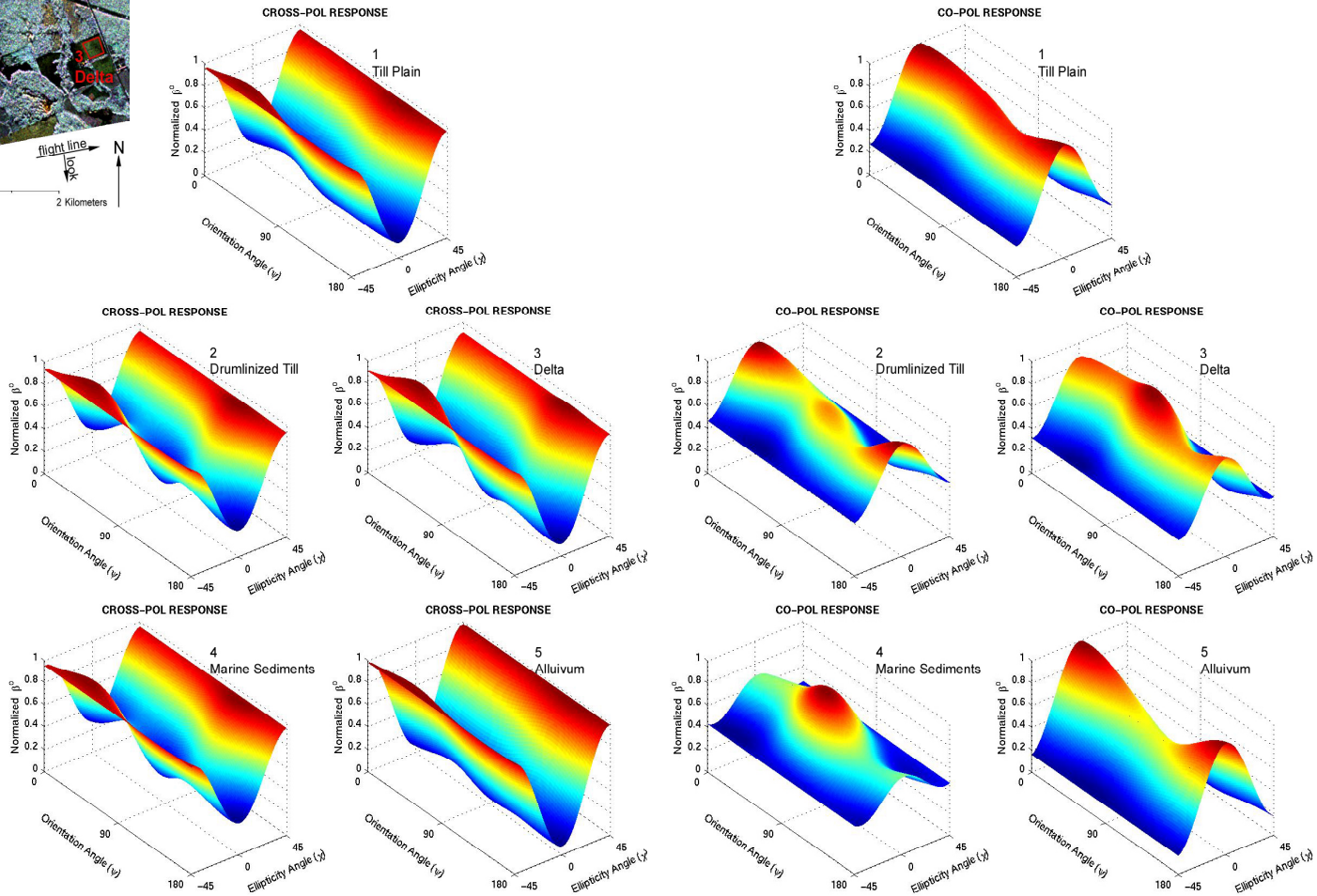
Standard beam (S7)
21-March-96
$\theta = 45° - 49°$
Res. : 20 m (rg) x 27 m (az)
Pixel spacing : 32 m

Polarimetric Signatures of Surficial Materials

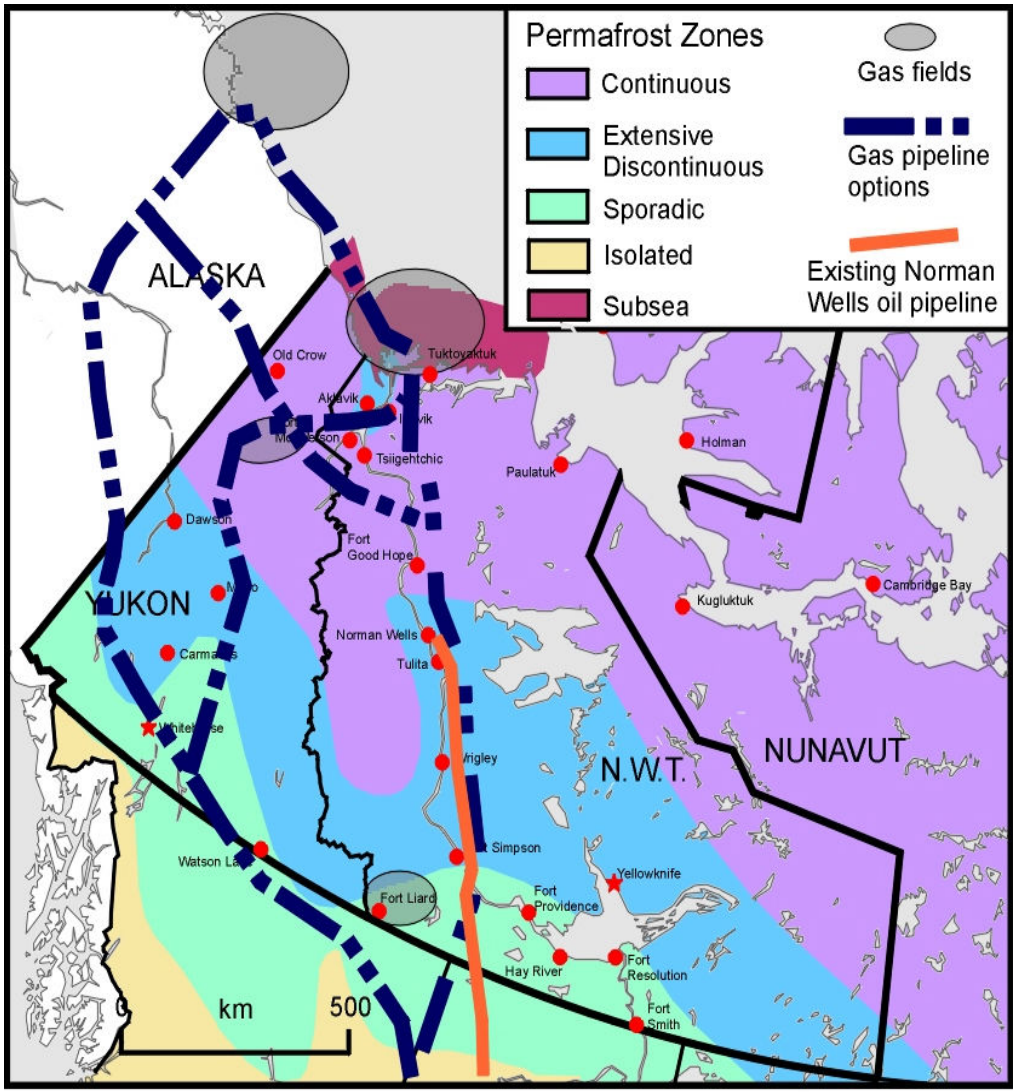


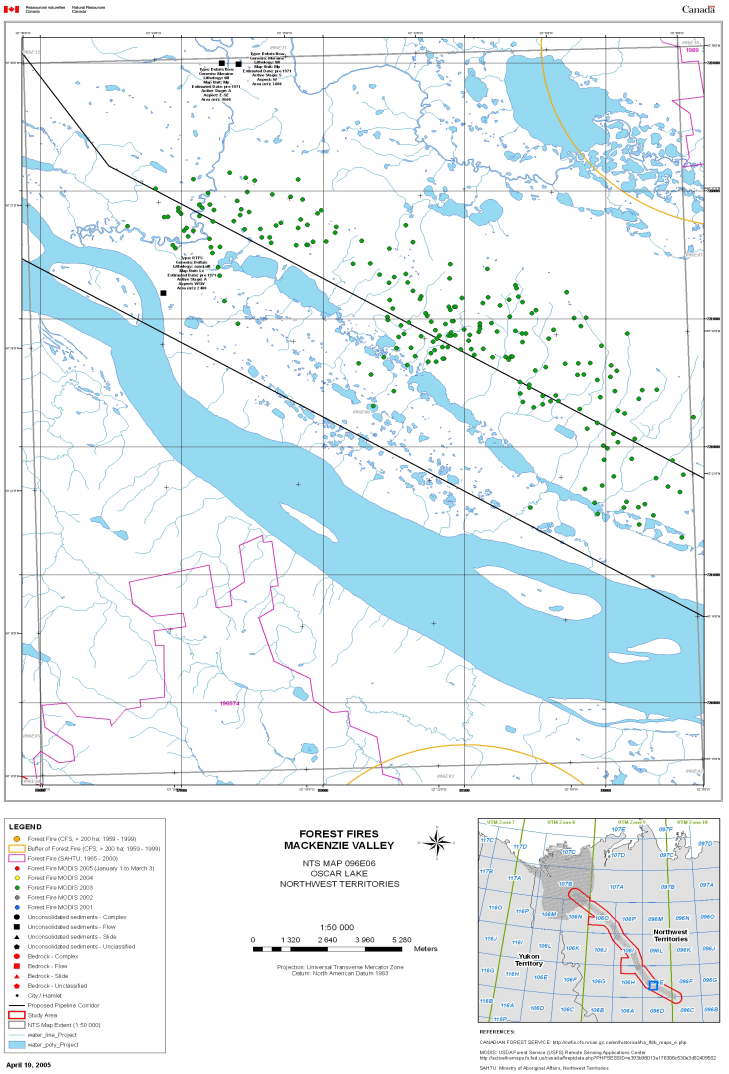
HH-VV-VH color composite of airborne CV-580 C-band data acquired in November 1999. Test sites of different surficial material are highlighted in red.

Polarimetric signatures extracted form the polarimetric SAR CV-580 data for cross-pol (left) and co-pol (right) responses over selected test sites




2005 6 14

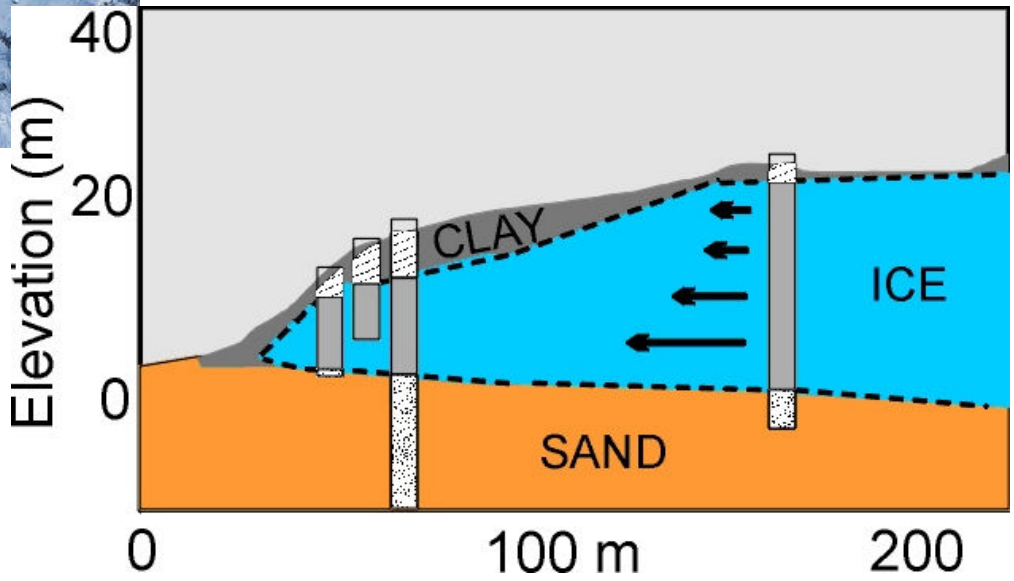

Permafrost Zones
Continuous
Extensive Discontinuous
Sporadic
Isolated
Subsea
Gas fields
Gas pipeline options
Existing Norman Wells oil pipeline
ALASKA
YUKON
N.W.T.
NUNAVUT
Old Crow
Tuktoyaktuk
Aklavik
Tsiigehtchic
Holman
Paulatuk
Dawson
Fort Good Hope
Kugluktuk
Cambridge Bay
Norman Wells
Tulita
Carmacks
Whitehorse
Wrigley
Simpson
Watson Lake
Fort Liard
Fort Providence
Yellowknife
Hay River
Fort Resolution
Fort Smith
0
km
500


Canada
LEGEND
FOREST FIRES
MACKENZIE VALLEY
NTS MAP 096E06
OSCAR LAKE
NORTHWEST TERRITORIES
1:50 000
0 1 320 2 640 3 960 5 280
Meters
Projection: Universal Transverse Mercator Zone
Datum: North American Datum 1983
April 19, 2005
Yukon Territory
Northwest Territories
REFERENCES:

Slope Stability and Deformations

Deep seated failures

Creep



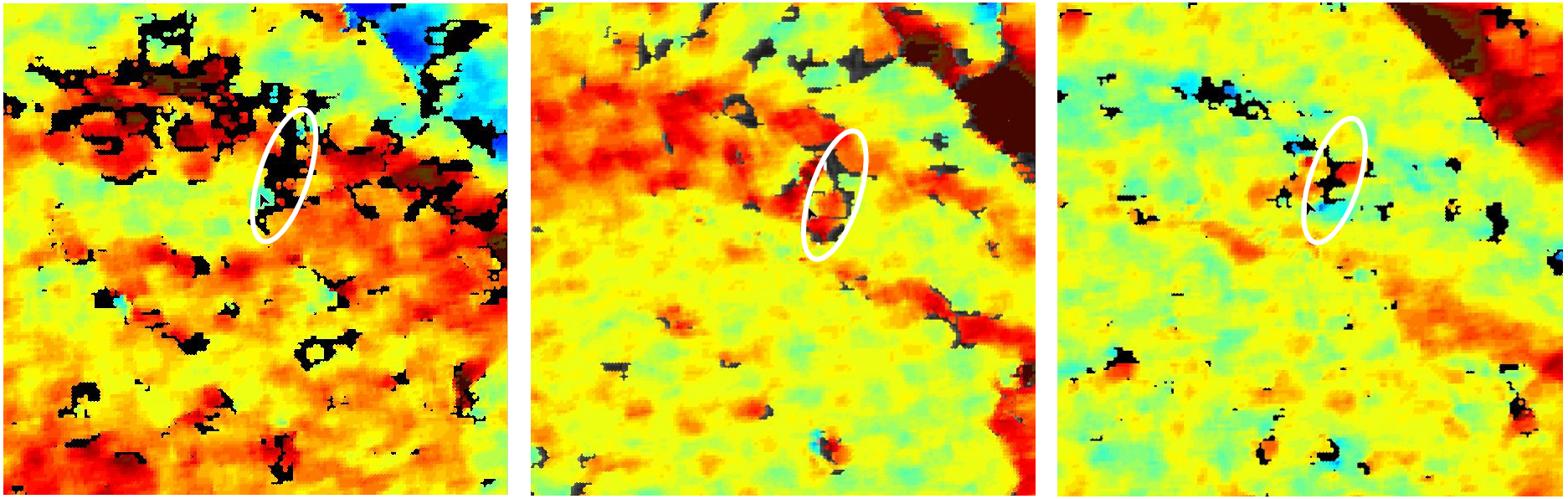
Results: Permafrost activity (red)

Deformation maps on ASC mode: 3 ~consecutive pairs

24 days
30-Jul-06 / 23-Aug-06

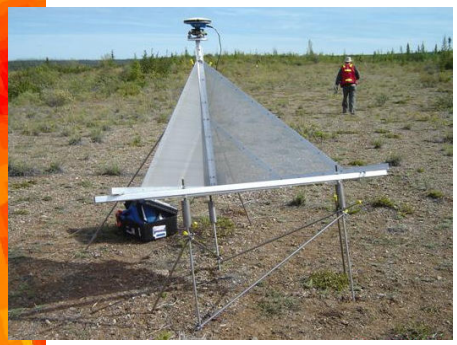
24 days
23-Aug-06 / 16-Sep-06

24 days
26-Sep-06 / 20-Oct-06

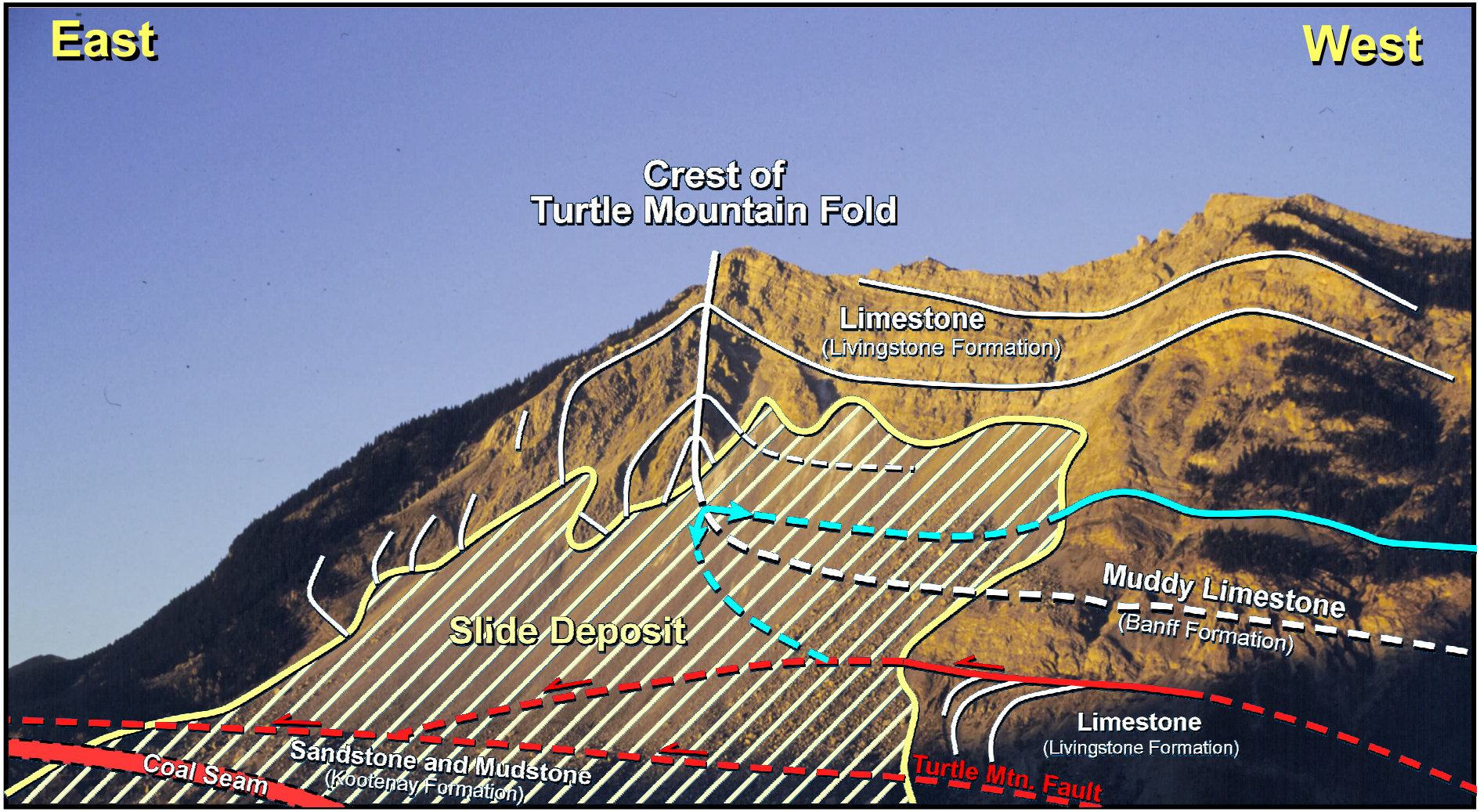


3D view – Permafrost activity (red)

Corner reflector



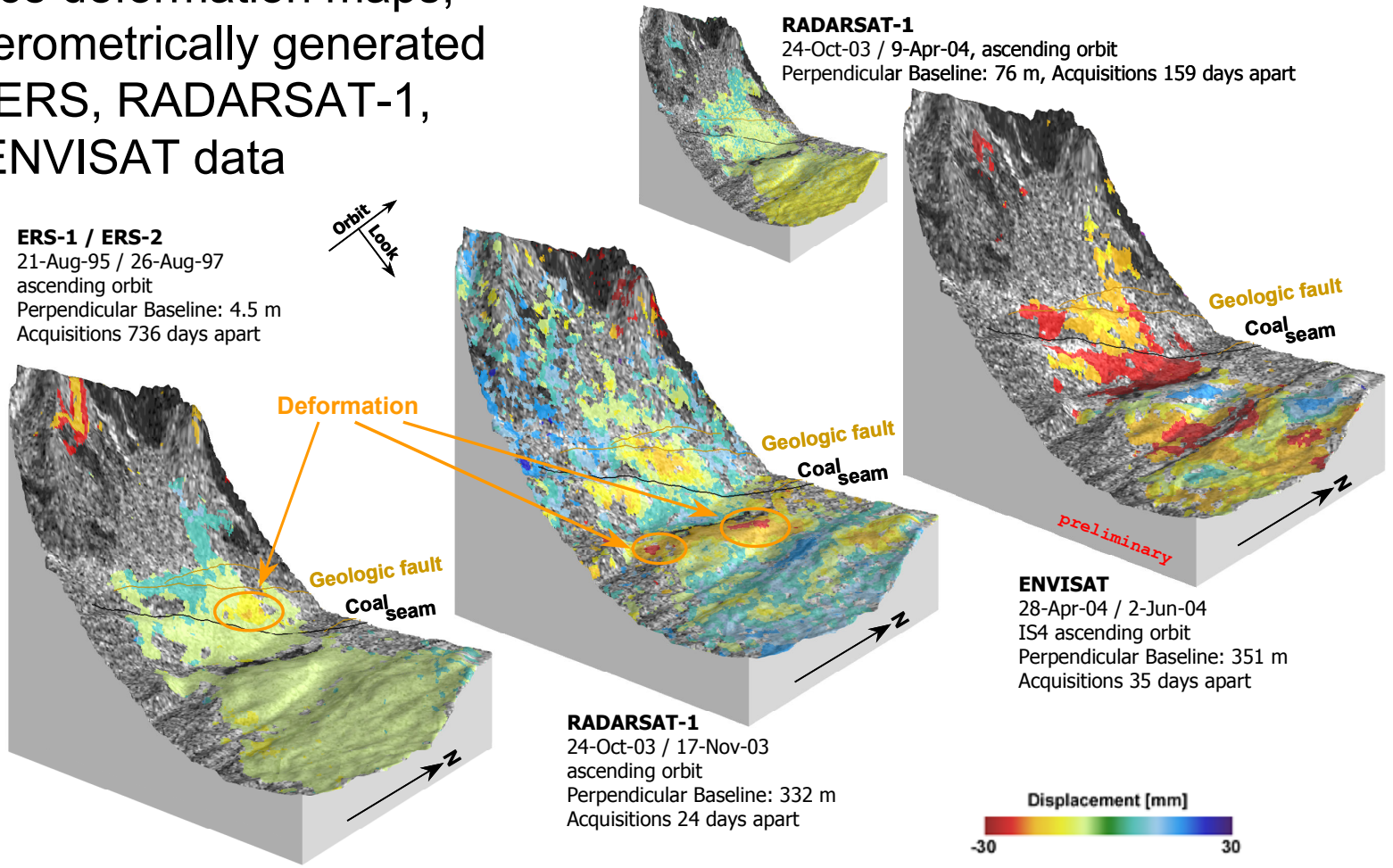
View from Interpretive Centre



Multi-interferogram Approach: Frank Slide Alberta :Trans Canada Highway:

InSAR images are used as part of the integrated monitoring program.

Surface deformation maps, interferometrically generated from ERS, RADARSAT-1, and ENVISAT data

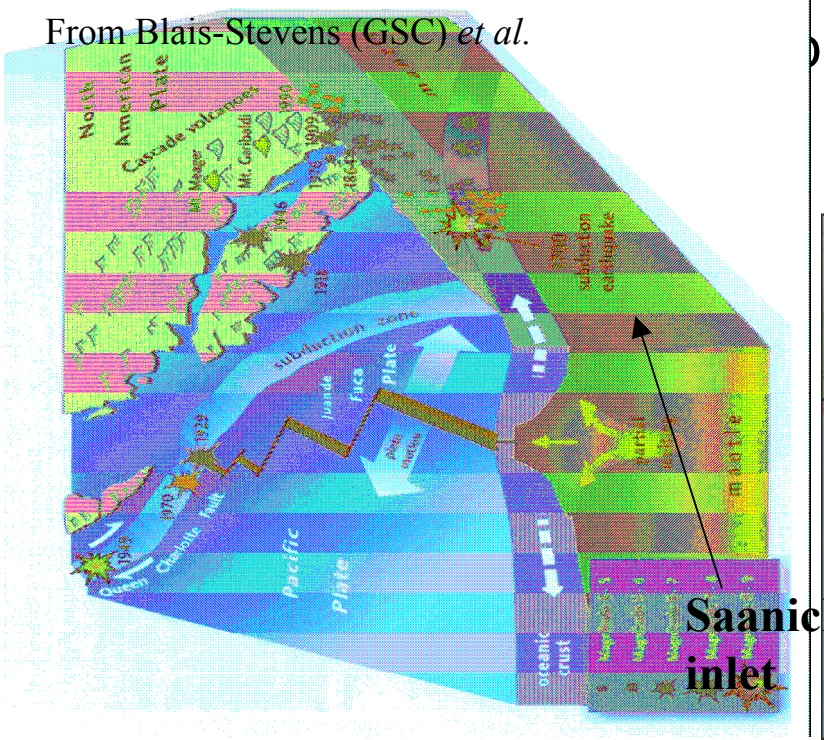


Deformation values are only shown where scene coherence exceeds 0.5 (ERS, ENVISAT) or 0.3 (RSAT) respectively.

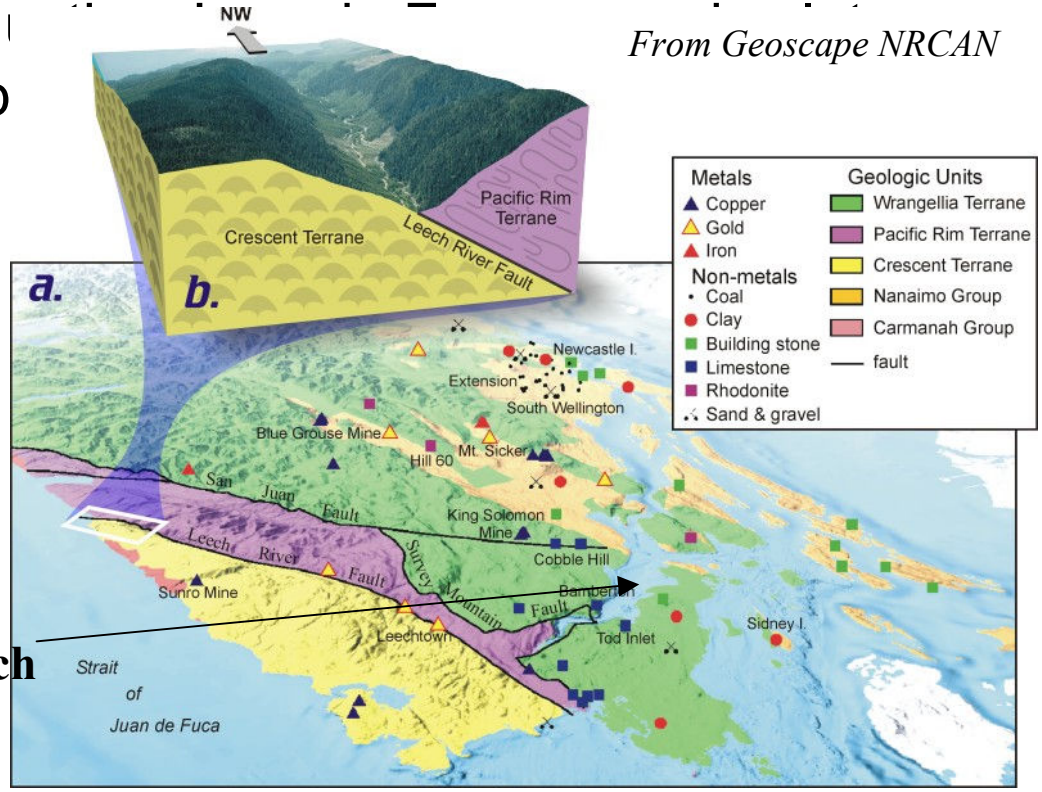
CTM-InSAR Vancouver Island

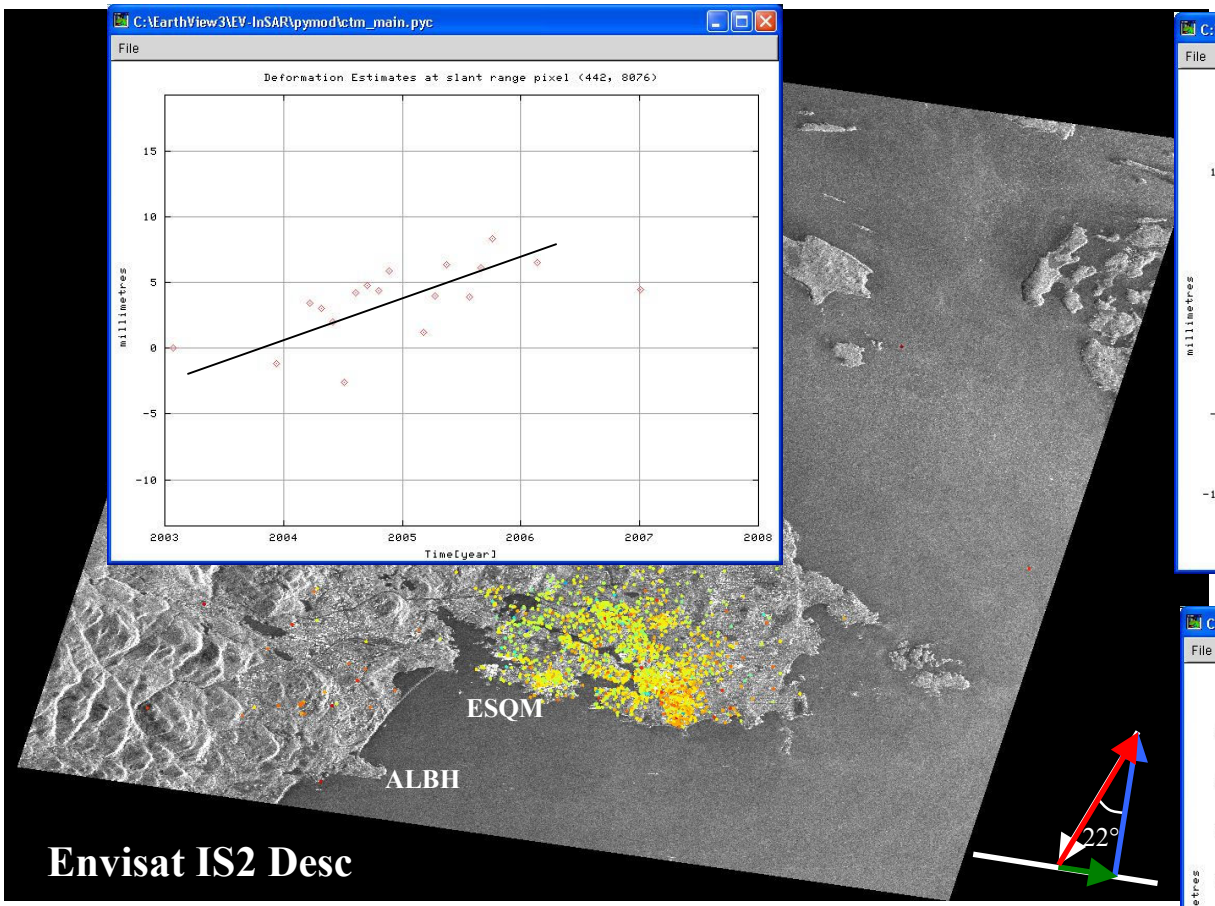
- Very seismic active region (subduction, strike-slip faults)
- The Leech River Fault is a deep rooted thrust fault possibly originating near the subd

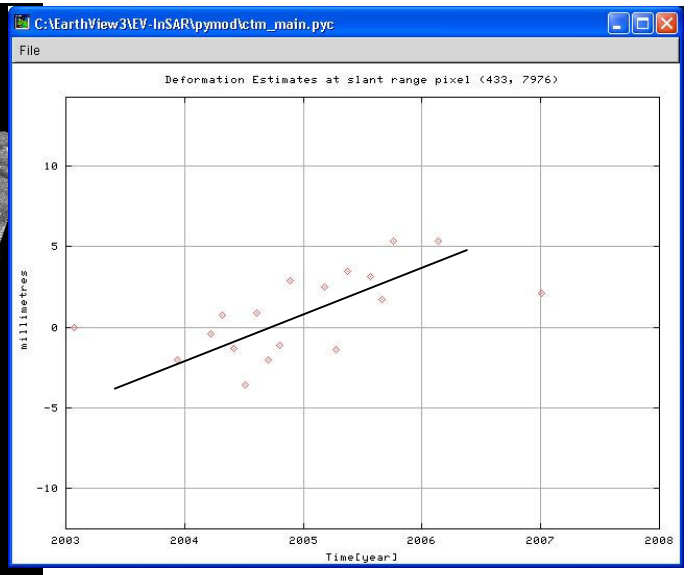
From Blais-Stevens (GSC) *et al.*

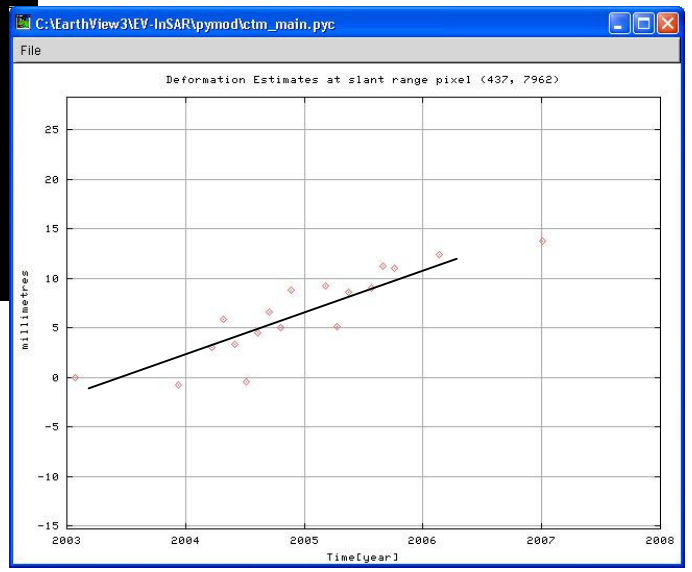


From Geoscape NRCAN



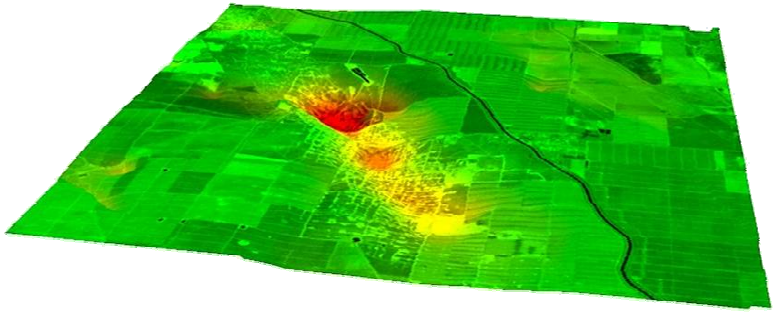




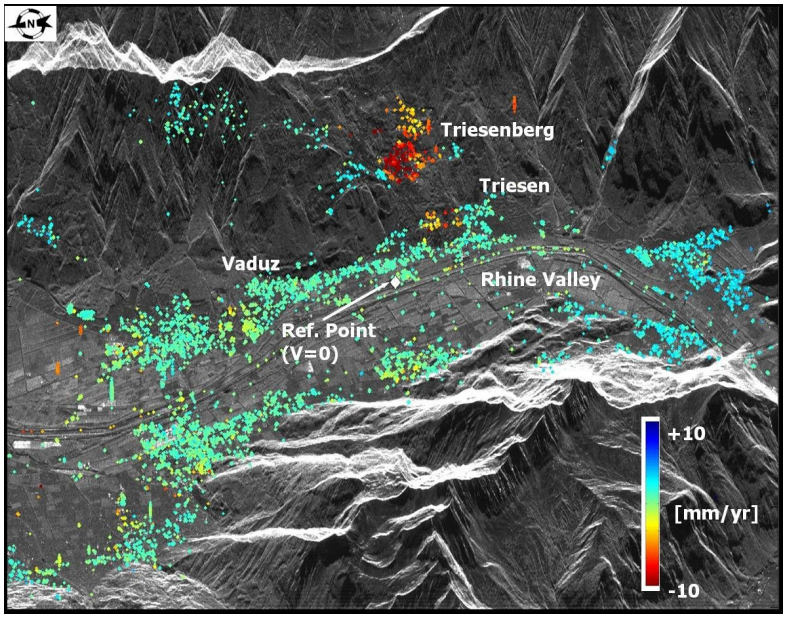


- Deformation rate ~3±1mm/yr in slant
- By triangulation => Vert.= 2.8±0.9mm/yr
  => Horiz.=1.1±0.4mm/yr

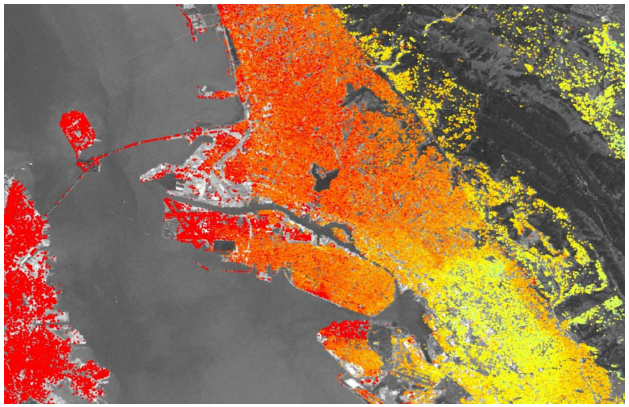
InSAR Examples
(Feretti 06)



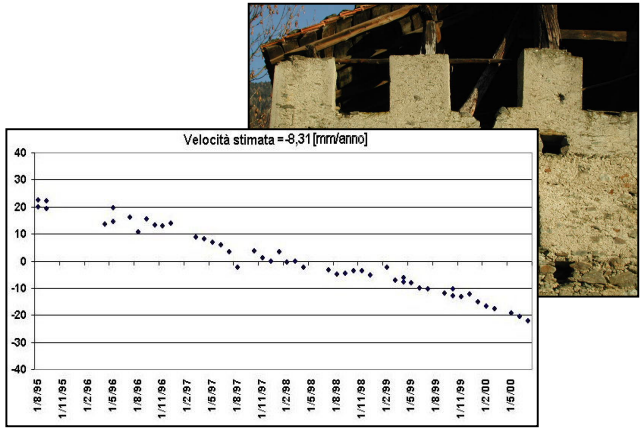
Subsidence Montoring



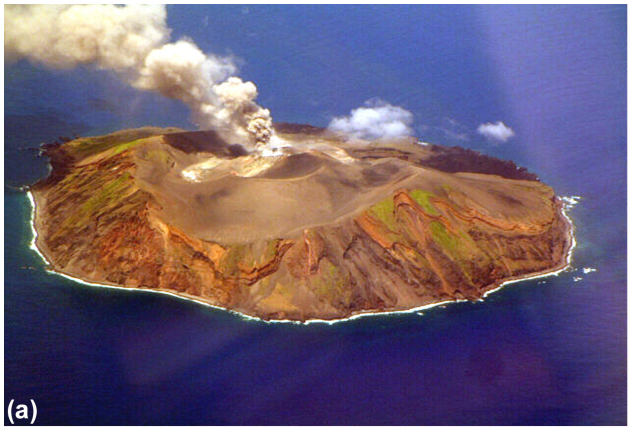
Slow Landslides Montoring

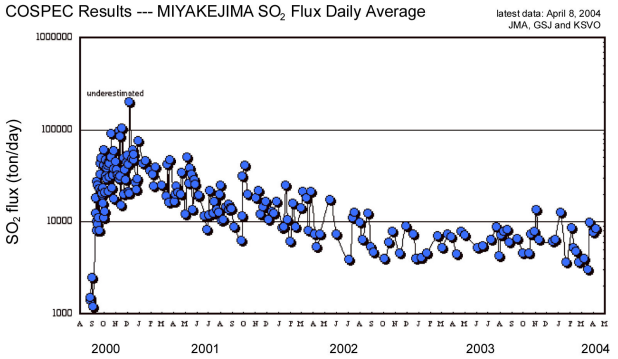


Tectonics

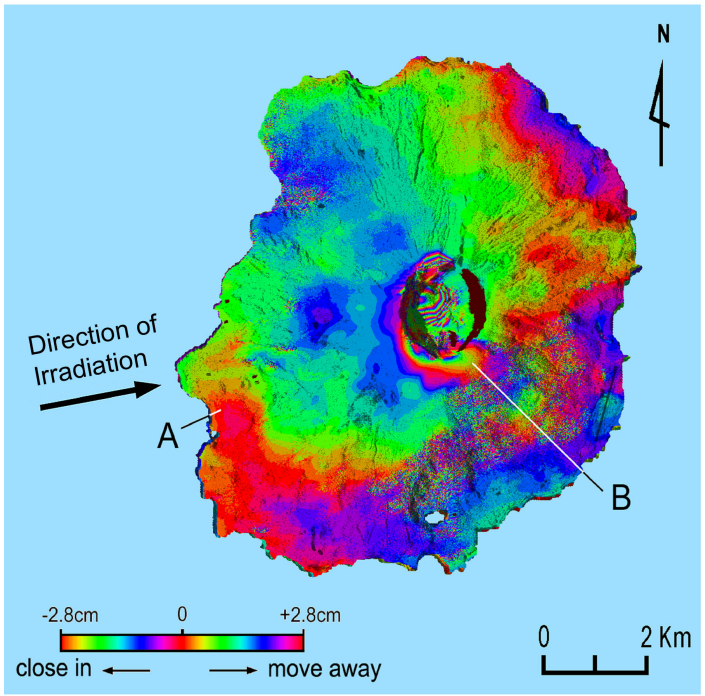


Single Building Monitoring



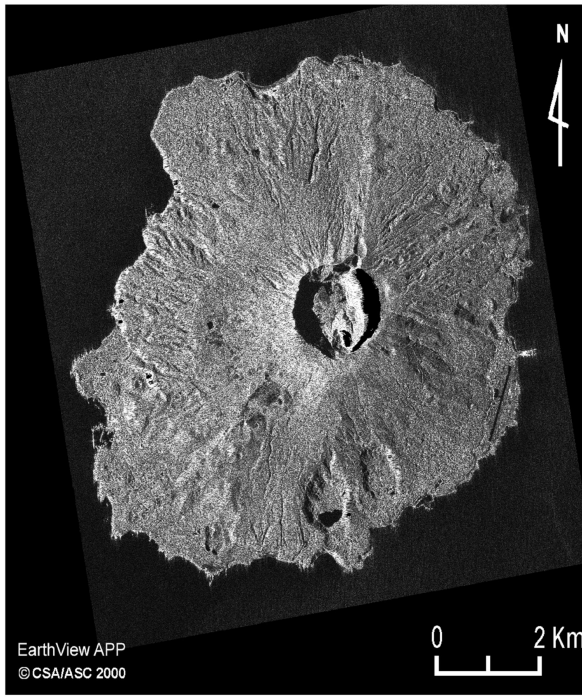


(b)



RADARSAT D-InSAR 2000 11/10 & 2000 12/04

(c) INTERFEROGRAM



RADARSAT 42A F3f 2000 11/10

(d) MASTER IMAGE

Future SAR Research for Geological Applications

InSAR

Non linear motion components especially on complex landslides

Phase unwrapping problems related fast motion and accurate DEM

Field Corner reflector insatallation in remote areas: One size does not fit all.

No satellite today dedicated to InSAR . *New SAR systems* will reduce the current difficulties and limitations.

Need a multi-interferogram approach –a multi-image strategy can overcome most of the difficulties encountered in InSAR analysis. (i) atmospheric effects, (ii) baseline indetermination, (iii) identification of coherent areas

A *time series of data is better than a single value:* (i) for geohazard monitoring; (ii) more reliable and higher accuracy data

Geological Mapping

Need for *polarimetric signatures of geological materials/rocks* from single, dual pol and quad pol images

Need to evaluate C X L for geological mapping with availability of RADARSAT, Envisat, Terra SAR and ALOS

Need to develop textural classifiers for geological surfaces.