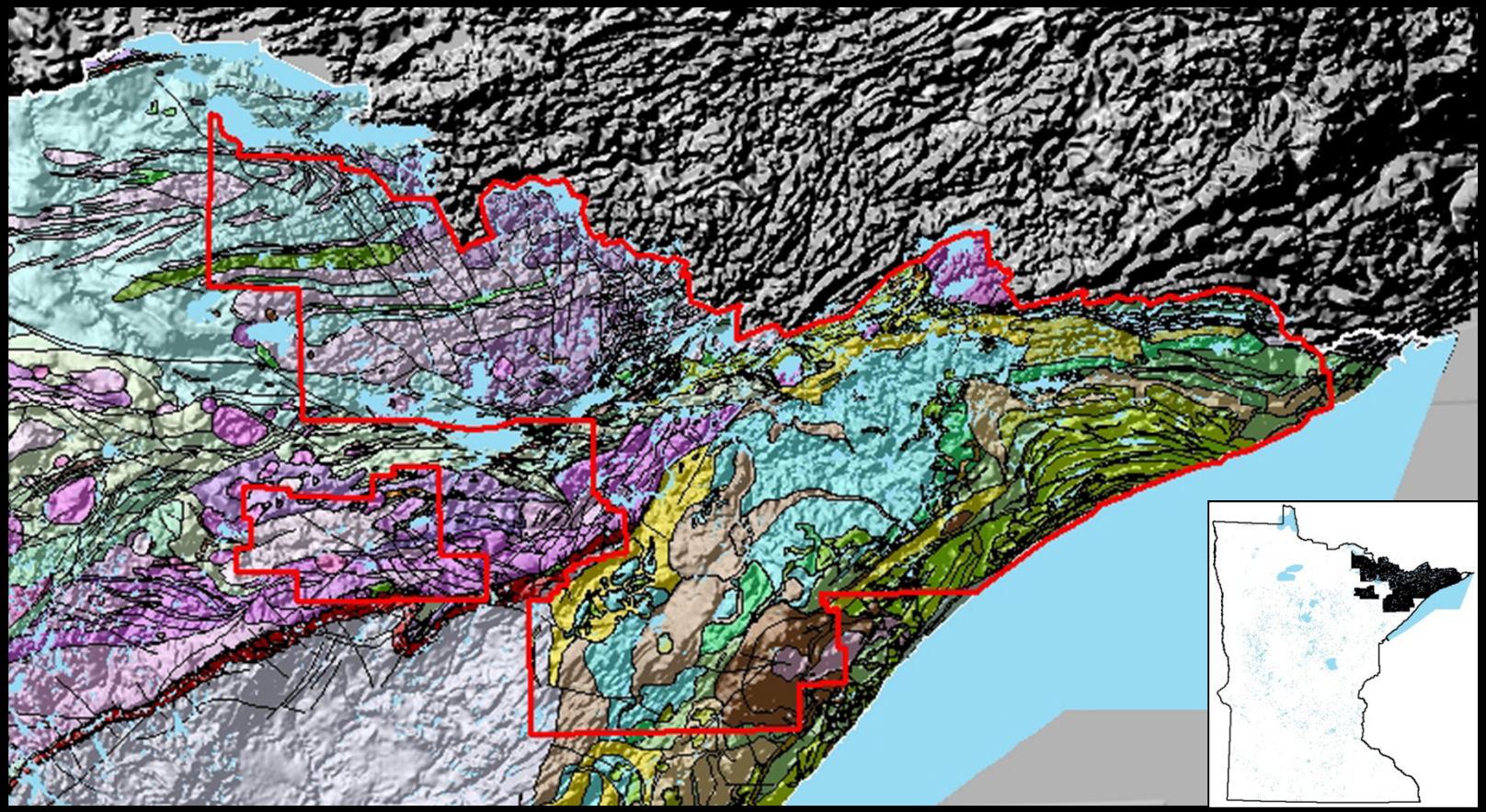
Geologic research and mapping in Superior National Forest

Mark Jirsa - Minnesota Geological Survey, University of Minnesota-Twin Cities, February 2012



Recent mapping funded by USGS STATEMAP element of National Geologic Mapping Program, the State Special Appropriation to the Minnesota Geological Survey, and the Precambrian Research Center-University of Minnesota, Duluth

OUTLINE

1. MINNESOTA GEOLOGICAL SURVEY
2. GEOLOGY PRIMER
3. HIGHLIGHTS OF MAPPING IN SNF
4. USE OF GEOLOGICAL DATA

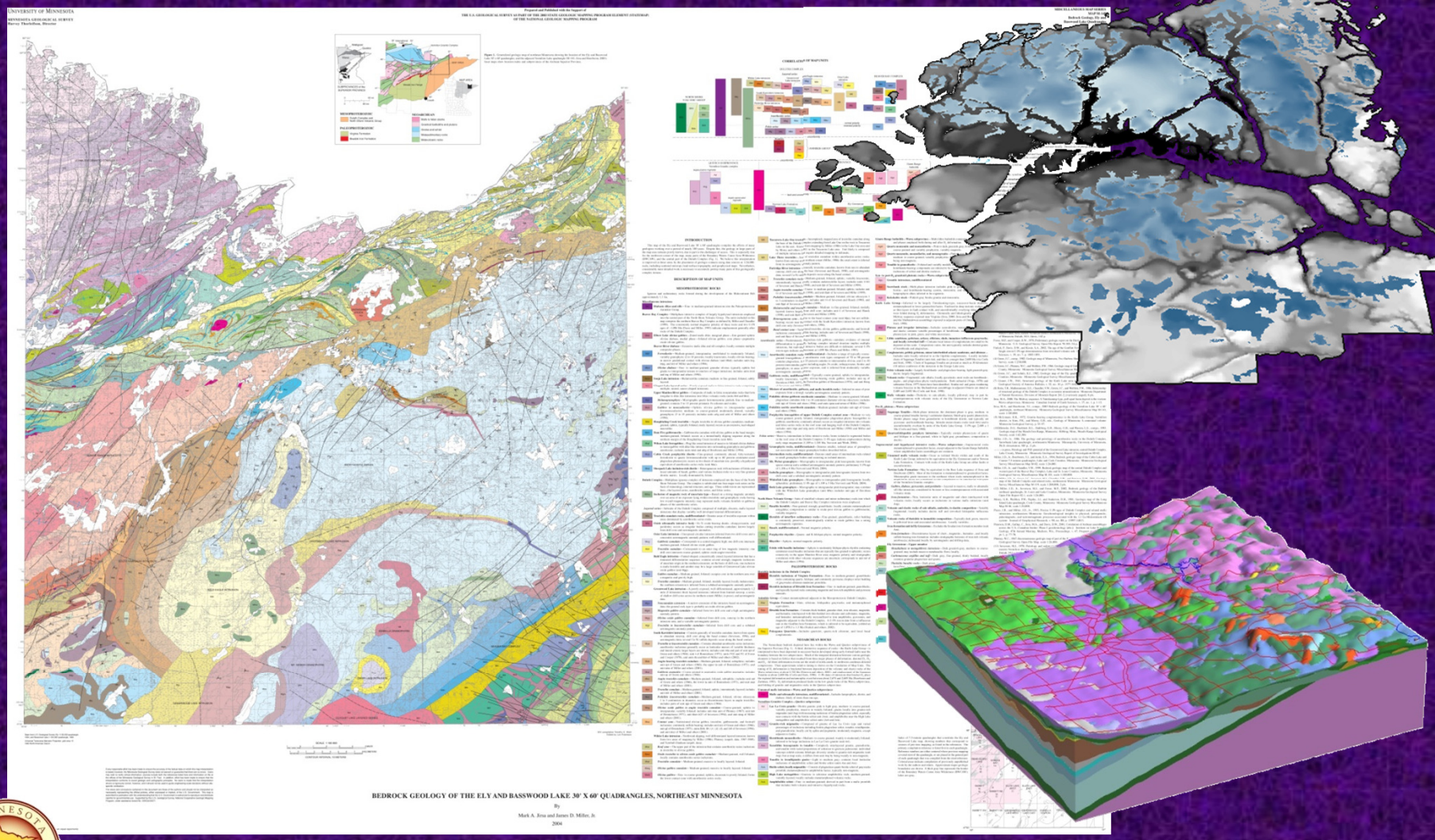
Minnesota Geological Survey

What we do and why

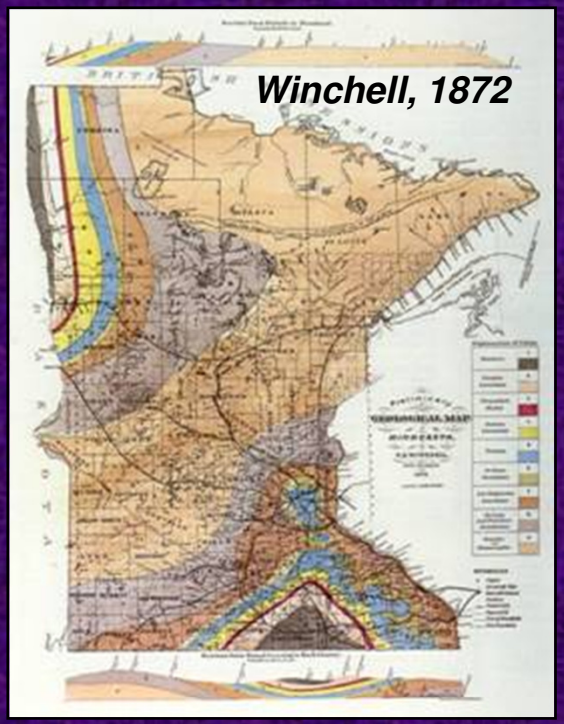
Provide systematic geoscience information to support stewardship of water, land, and mineral resources:

- **Water** (study the "container;" contributes to well siting and design, groundwater protection)
- **Land-use** (siting of land-fills, infrastructure, mines)
- **Mineral resources** (frac. sand, metallic minerals, quarry stone, aggregate, diamonds)

MGS primary output = maps and digital GIS products

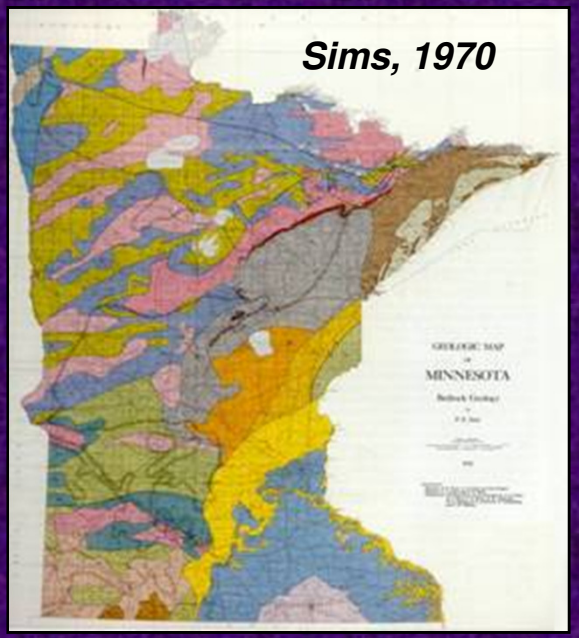


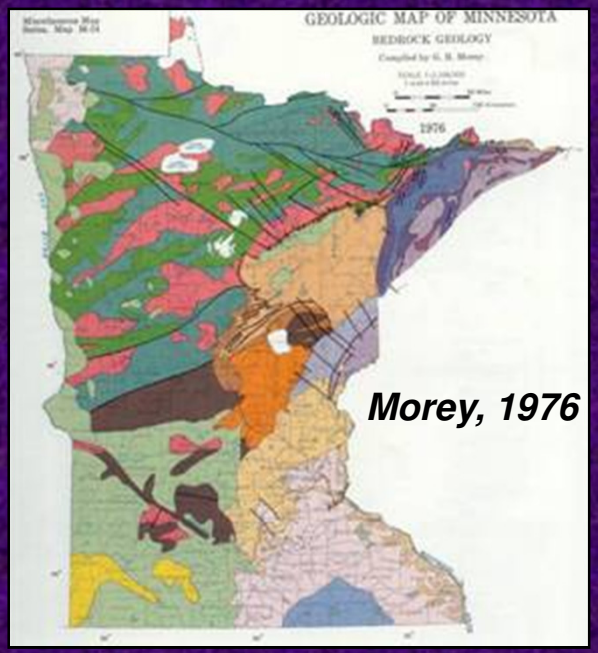
Owen, 1851


Winchell, 1872

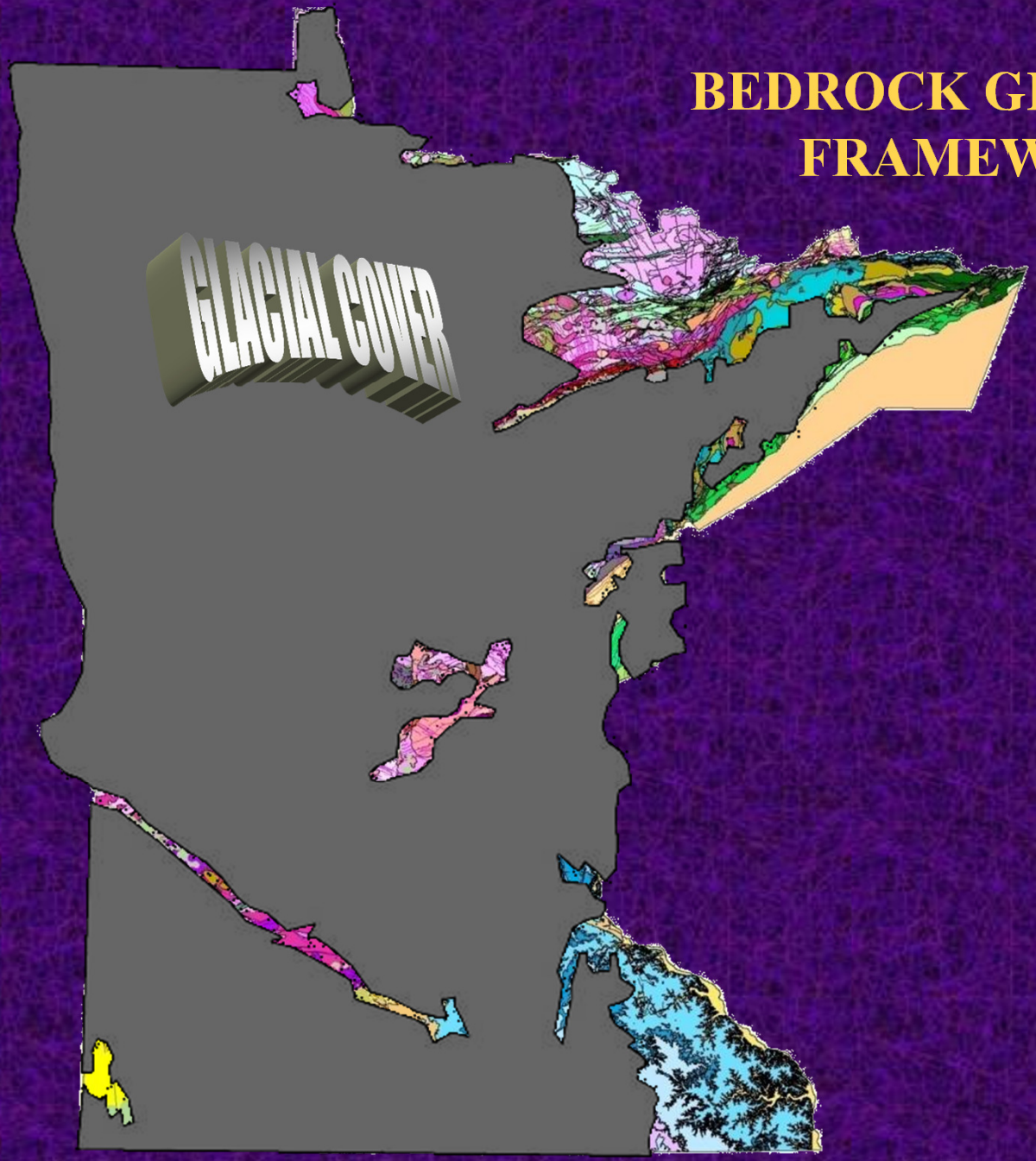
MAP OF
MINNESOTA
Winchell, 1900

Grout, 1932


Sims, 1970
GEOLOGIC MAP
OF
MINNESOTA

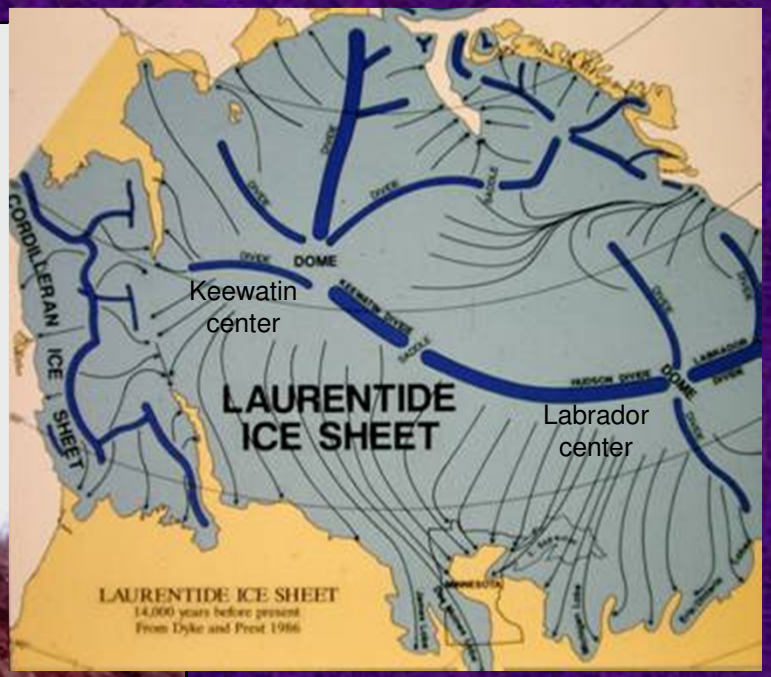

GEOLOGIC MAP OF MINNESOTA
BEDROCK GEOLOGY
1976
Morey, 1976

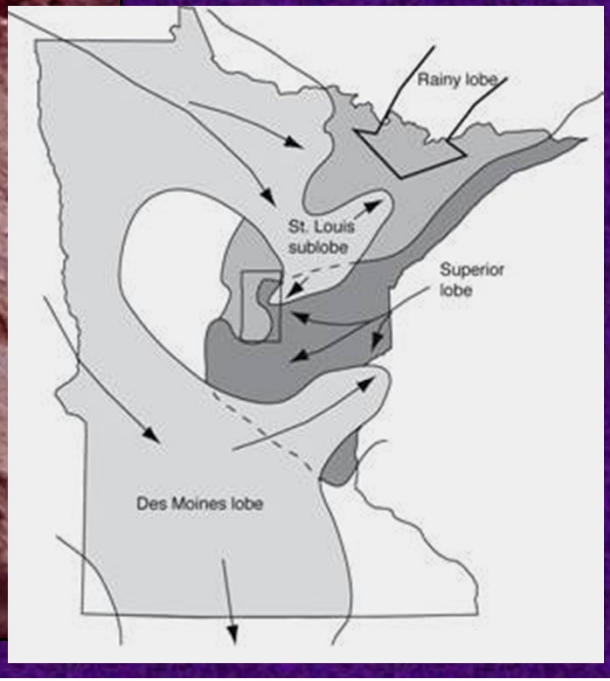
BEDROCK GEOLOGIC FRAMEWORK



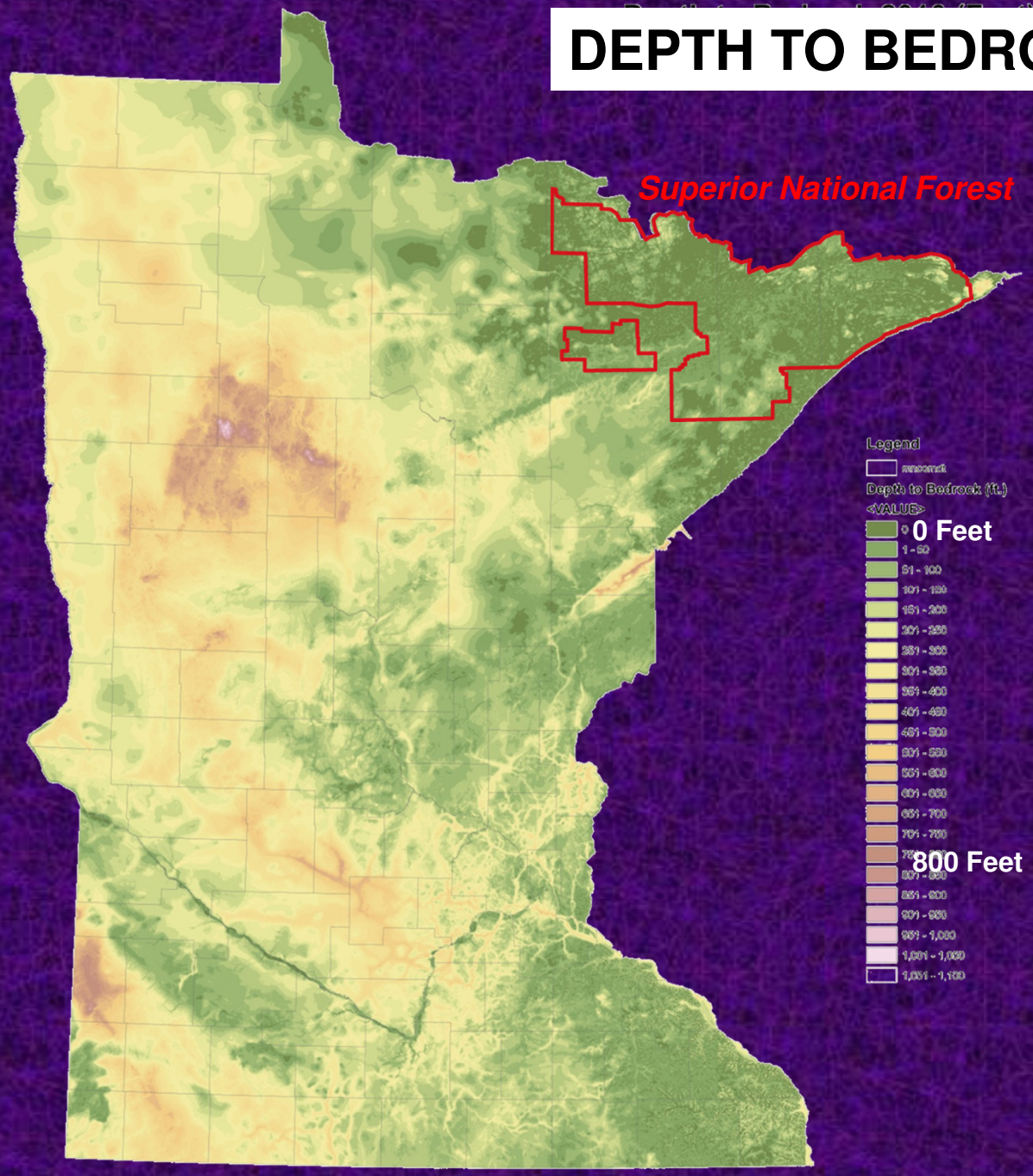
QUATERNARY GLACIAL SEDIMENTS

~2 Ma-12 ka





DEPTH TO BEDROCK 2010



ARCHIVED DRILL CORE AND DATA

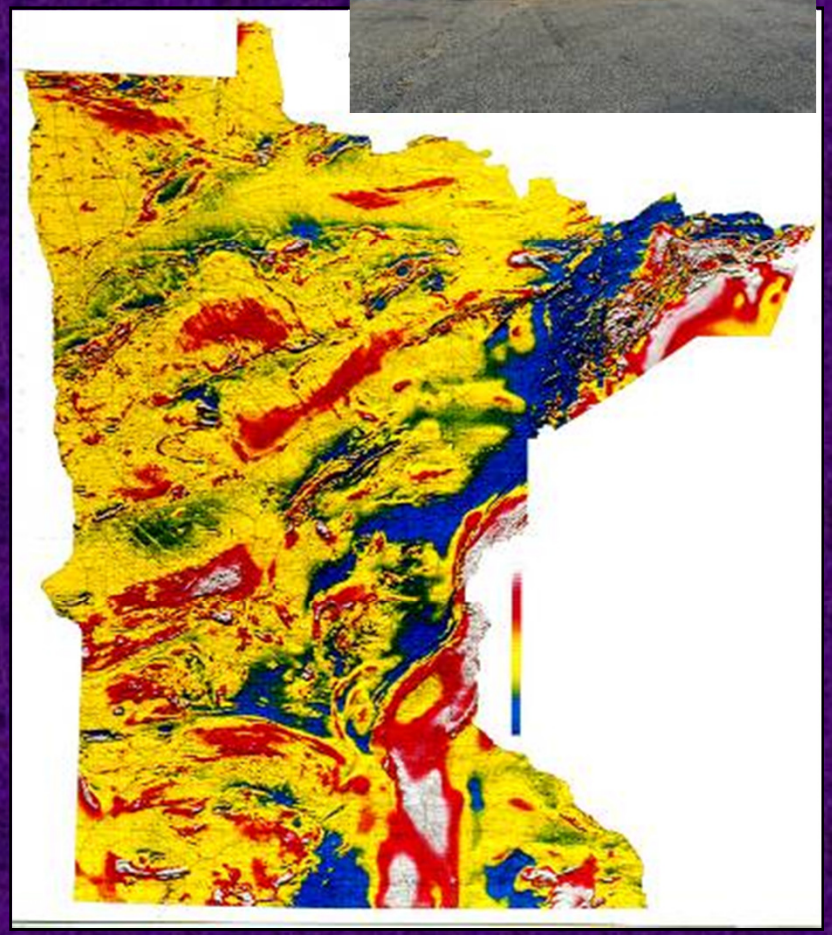
Location of core hole

Core Library, Hibbing

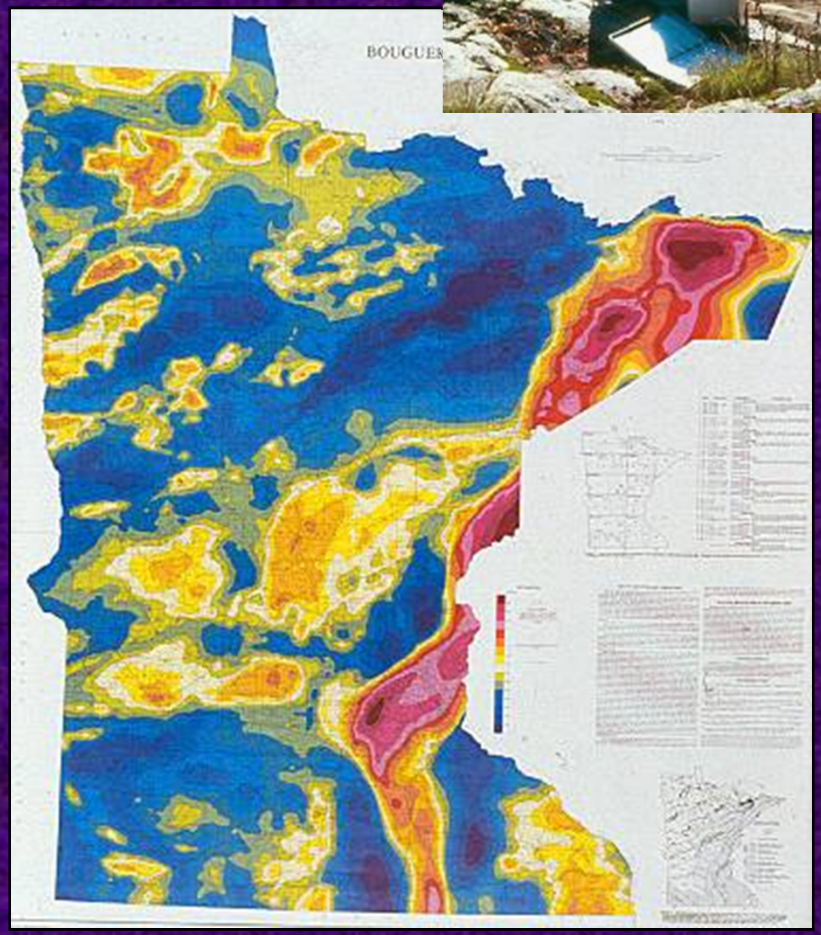
Drill Core

Core Library maintained by
Minnesota Department of Natural Resources,
Division of Lands and Minerals, Hibbing

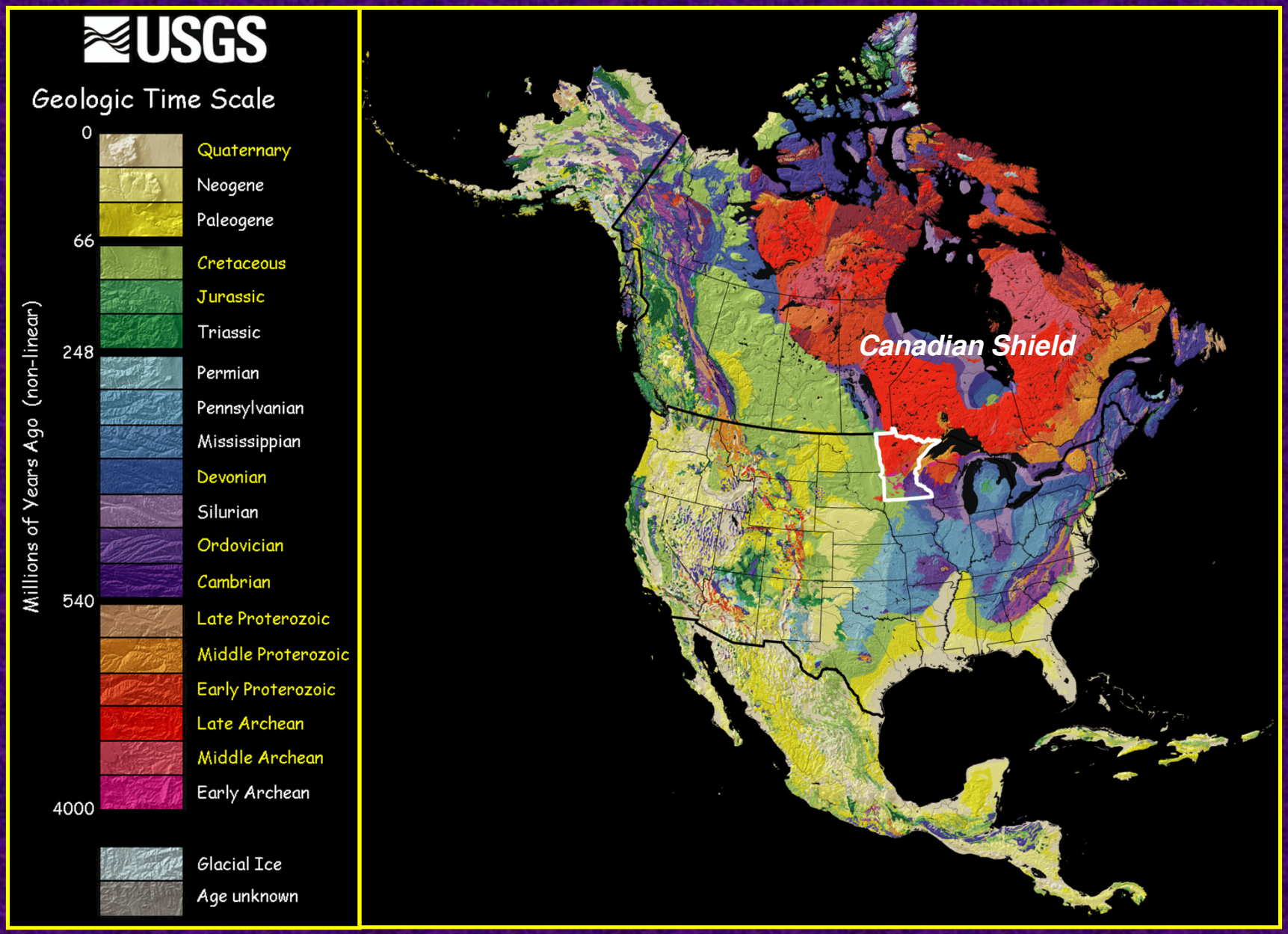
Magnetic Surveying



Gravity (density) Surveying



GEOLOGY PRIMER


USGS
Geologic Time Scale
Millions of Years Ago (non-linear)
0
66
248
540
4000
Quaternary
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Late Proterozoic
Middle Proterozoic
Early Proterozoic
Late Archean
Middle Archean
Early Archean
Glacial Ice
Age unknown
Canadian Shield

Simplified bedrock geology of SNF

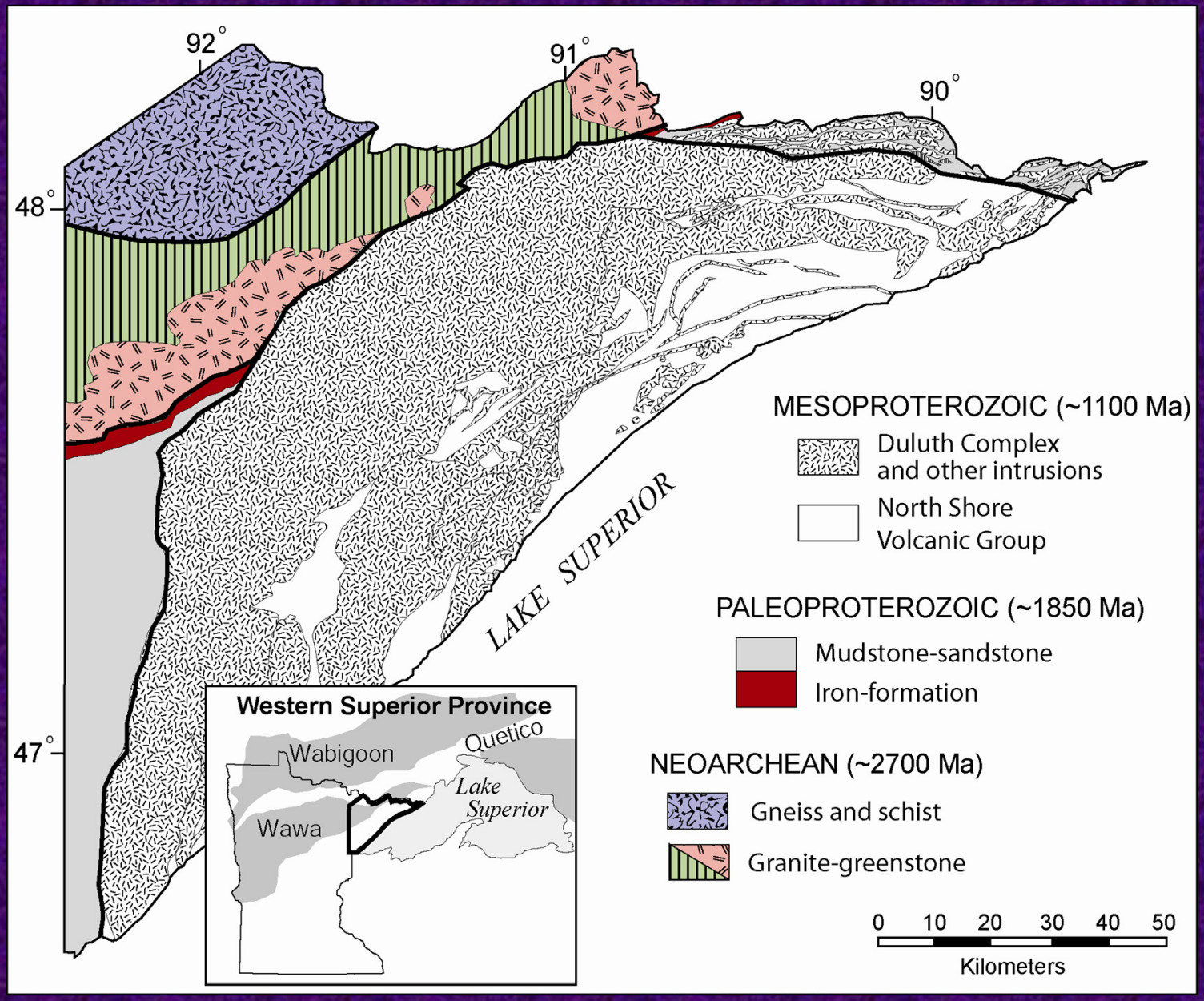
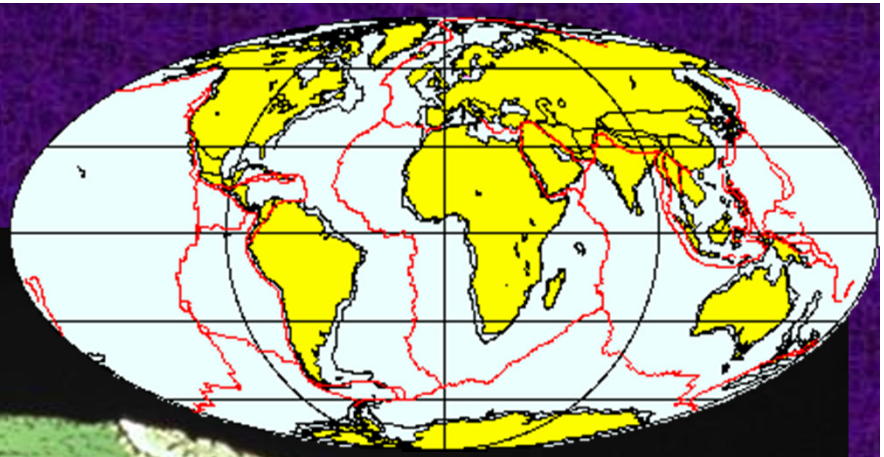
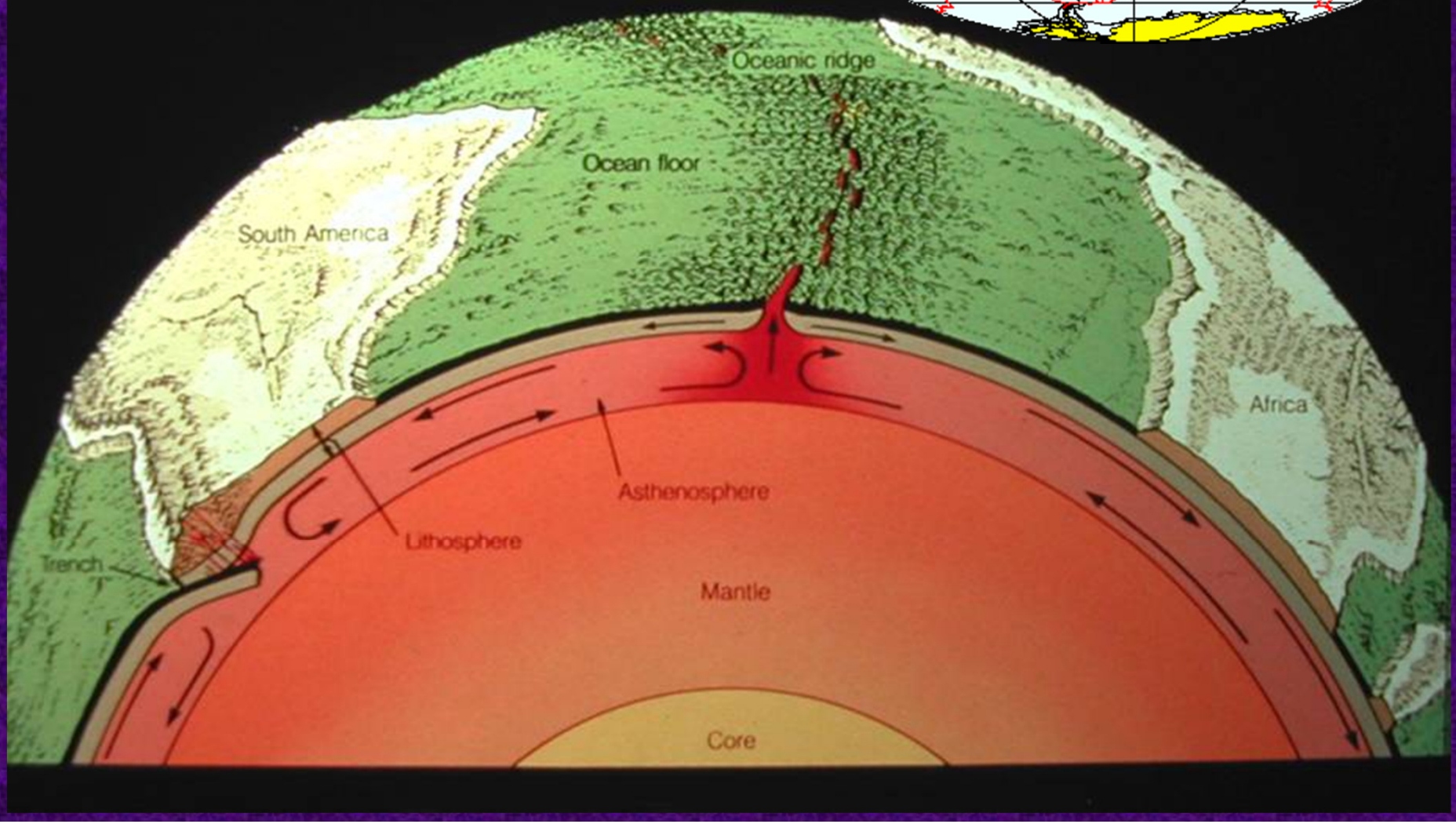


PLATE TECTONICS

The basic tenant of our science



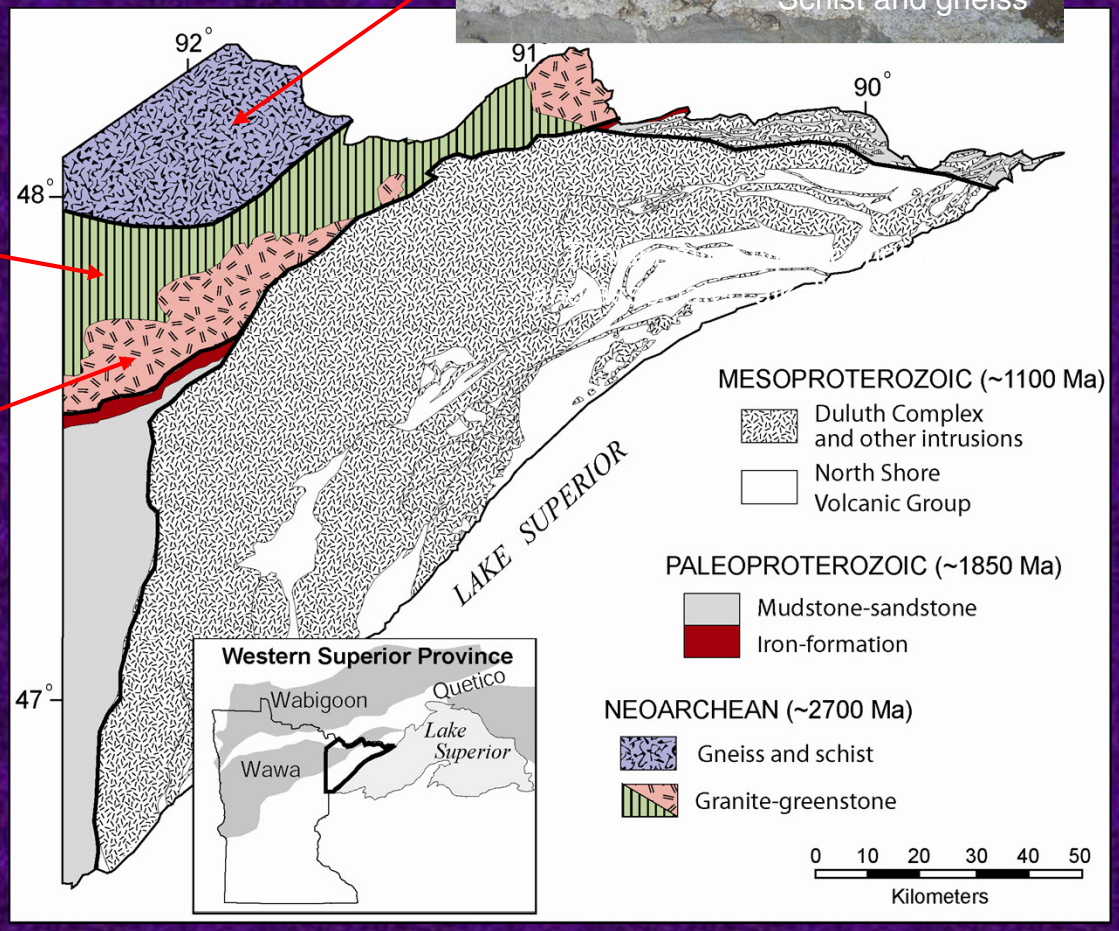


NEOARCHEAN (~2700 Ma)

Pillowed greenstone

Schist and gneiss

Granite and coeval mafic rocks



Accretion at collisional plate boundaries

(2.7 billion years ago)

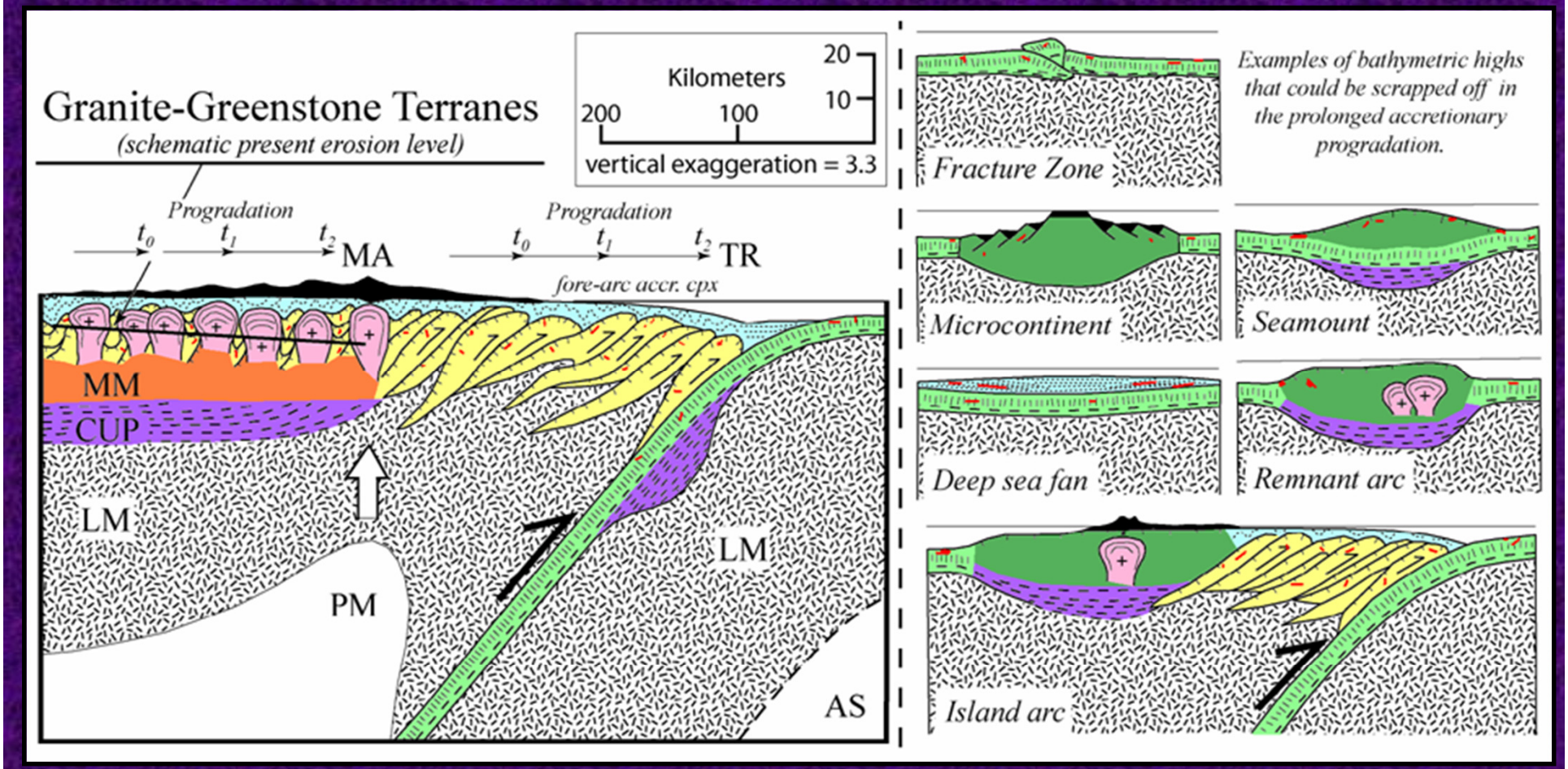
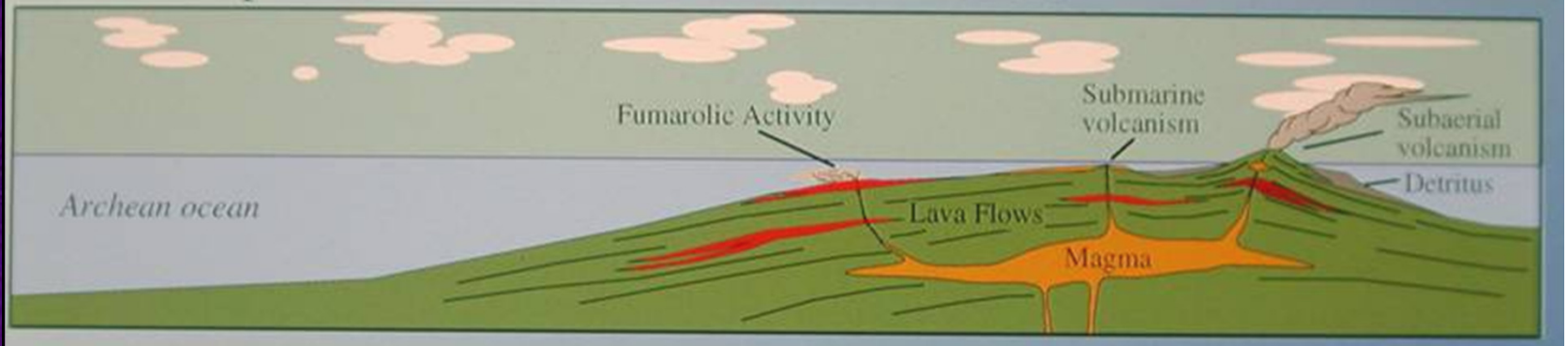
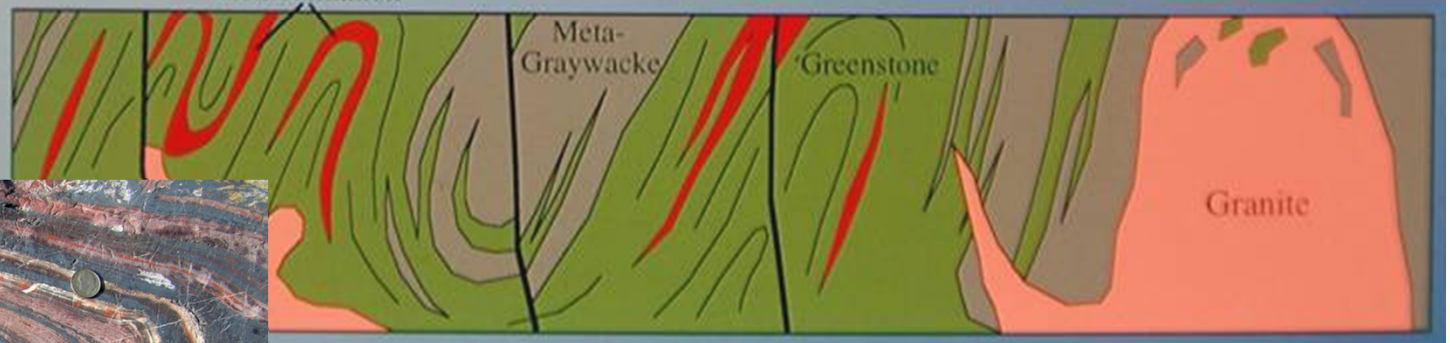


Image from J.D. Miller, Jr., MGS

Depositional Environment (≥ 2.6 Ga) - Submarine volcanogenic deposits at the flanks of volcanic arcs.



Occurrence - Strongly deformed, low-moderately metamorphosed lenses in granite-greenstone belts.



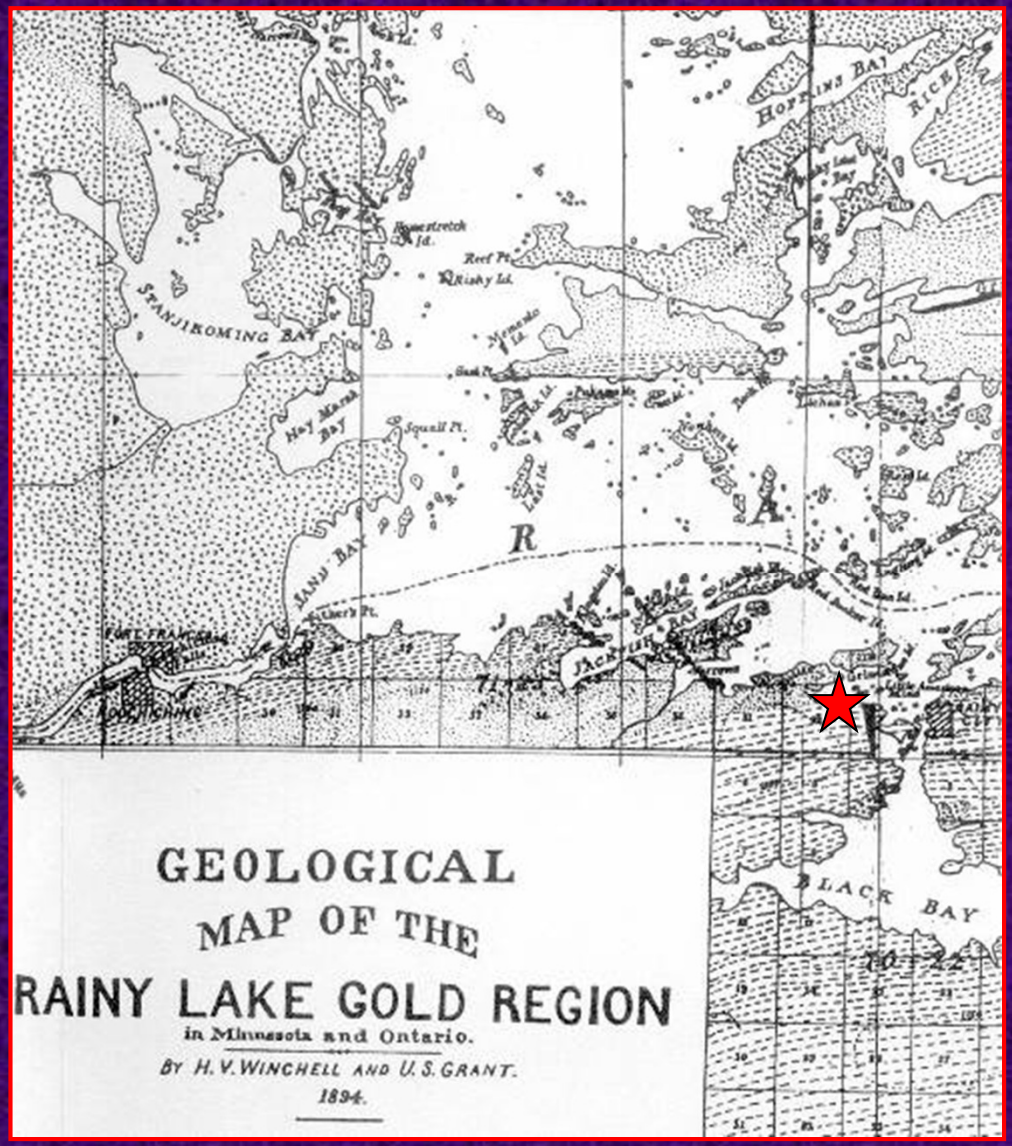
Soudan Iron Formation

EVOLUTION OF ACCRETED ISLAND ARCS

RAINY LAKE GOLD RUSH
1893-1901

LITTLE AMERICA ISLAND:

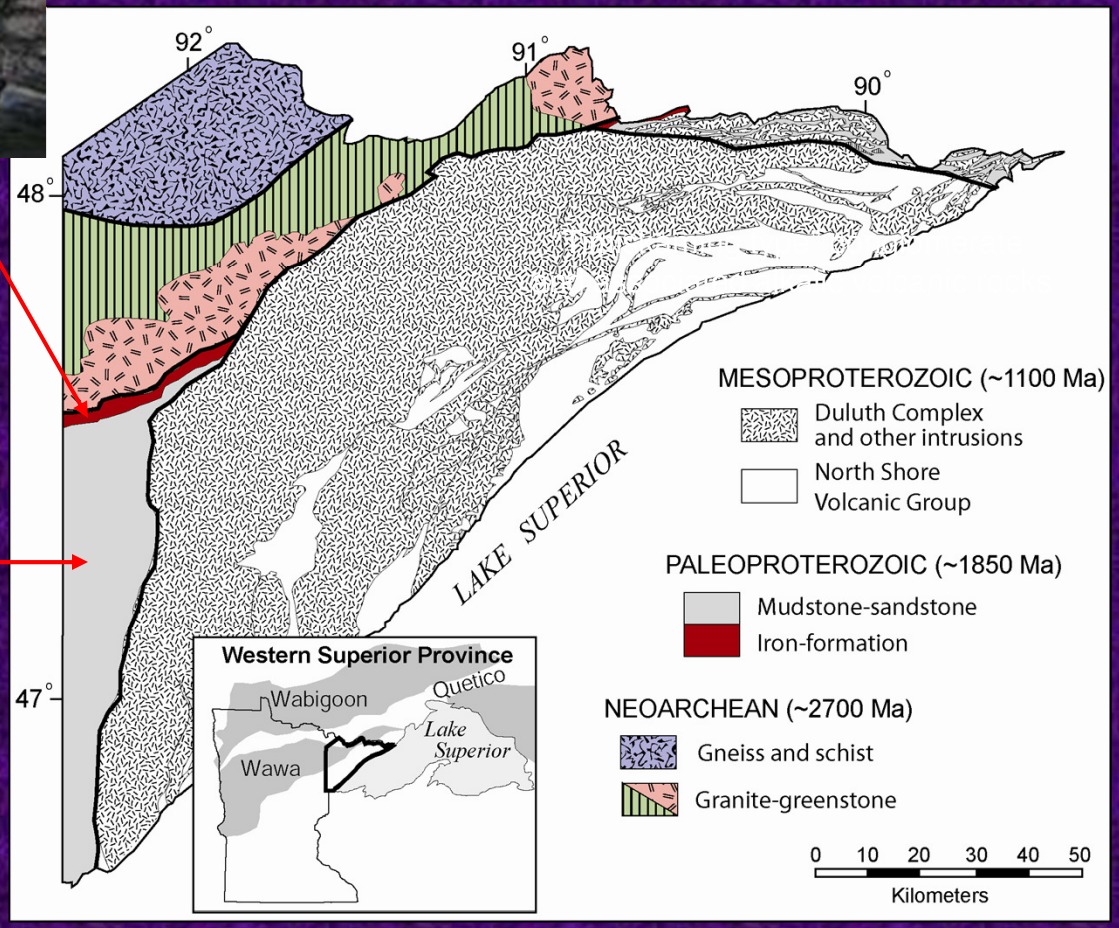
The first and only operating gold mine in Minnesota



PALEOPROTEROZOIC (~1850 Ma)

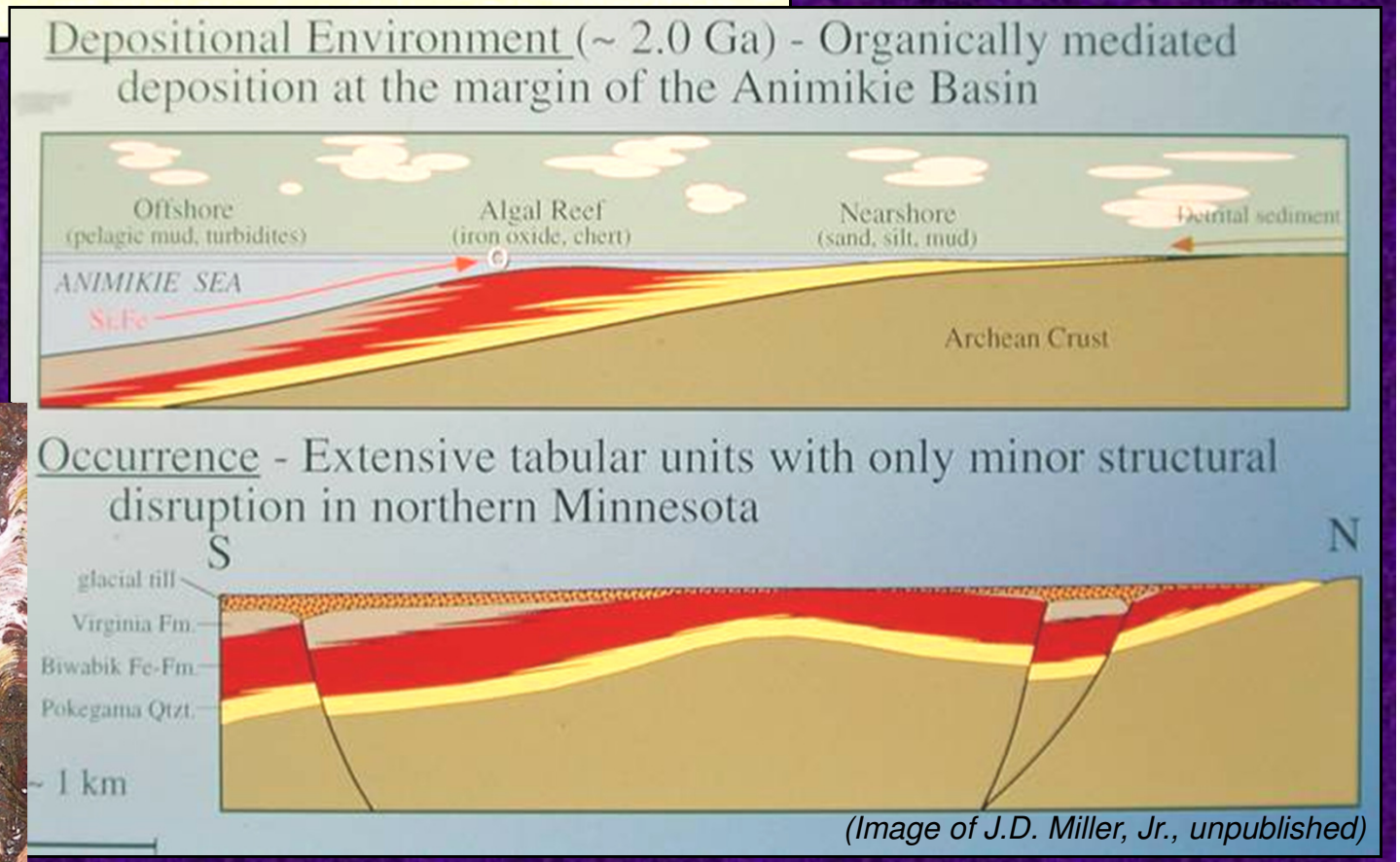
Biwabik Iron Formation

Thompson Formation-mudstone, sandstone



Tectonic setting

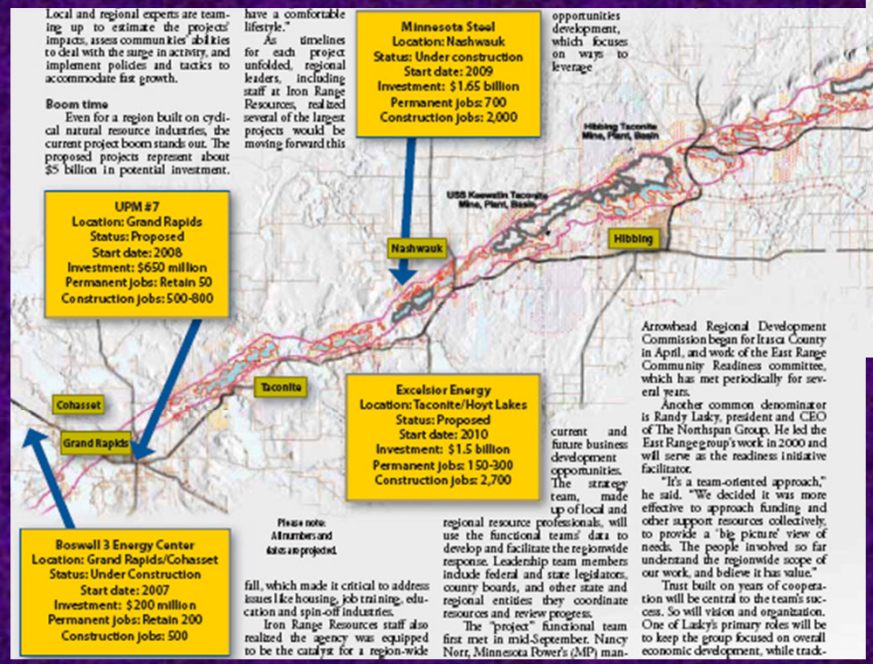
Depositional environment

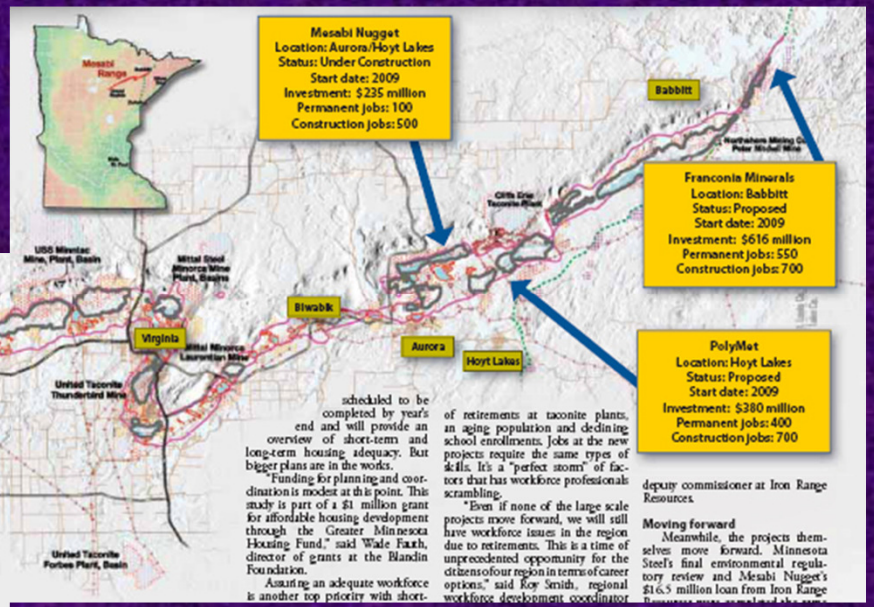


(Image of J.D. Miller, Jr., unpublished)

Stromatoloids (Cyanobacteria?)

New developments on and near the MESABI IRON RANGE





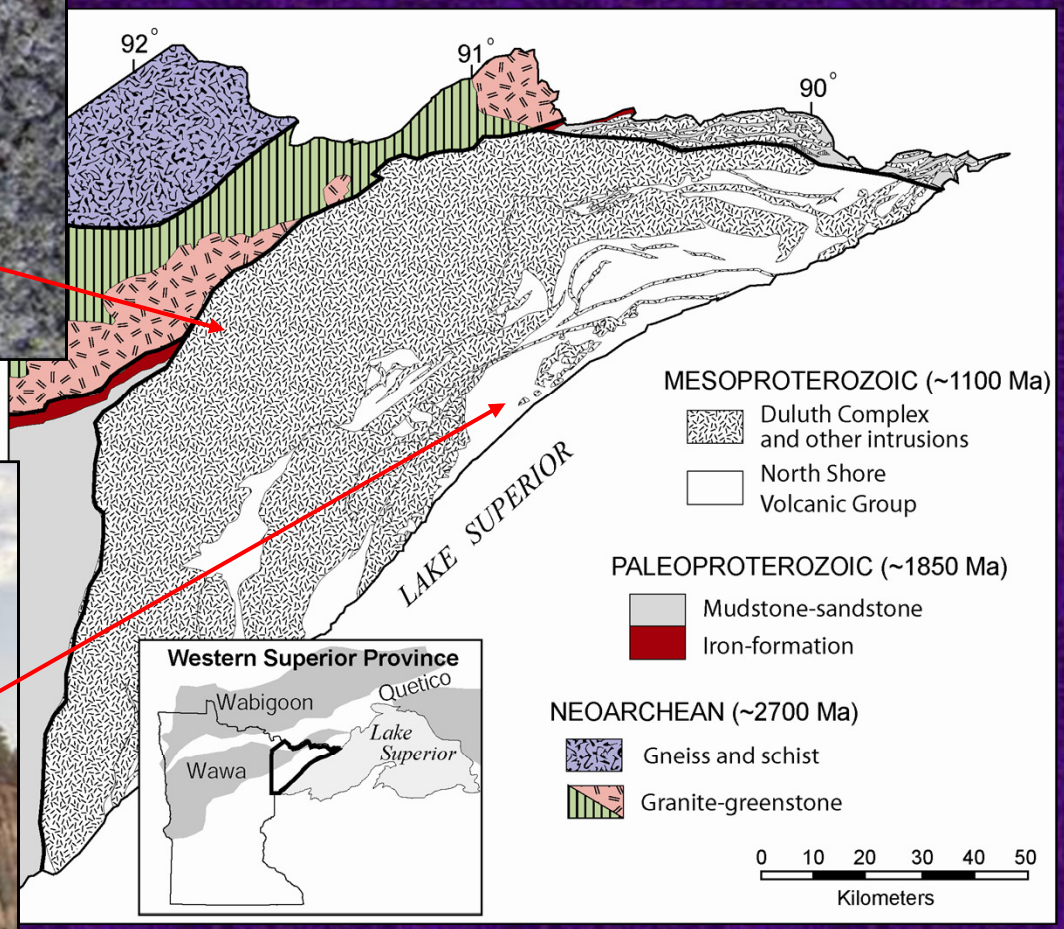
- 5 mines running at full capacity
- Planned mines and facilities
- Fe extraction from old mine waste

Source: Iron Range Resources "RangeView" w.2008-2009

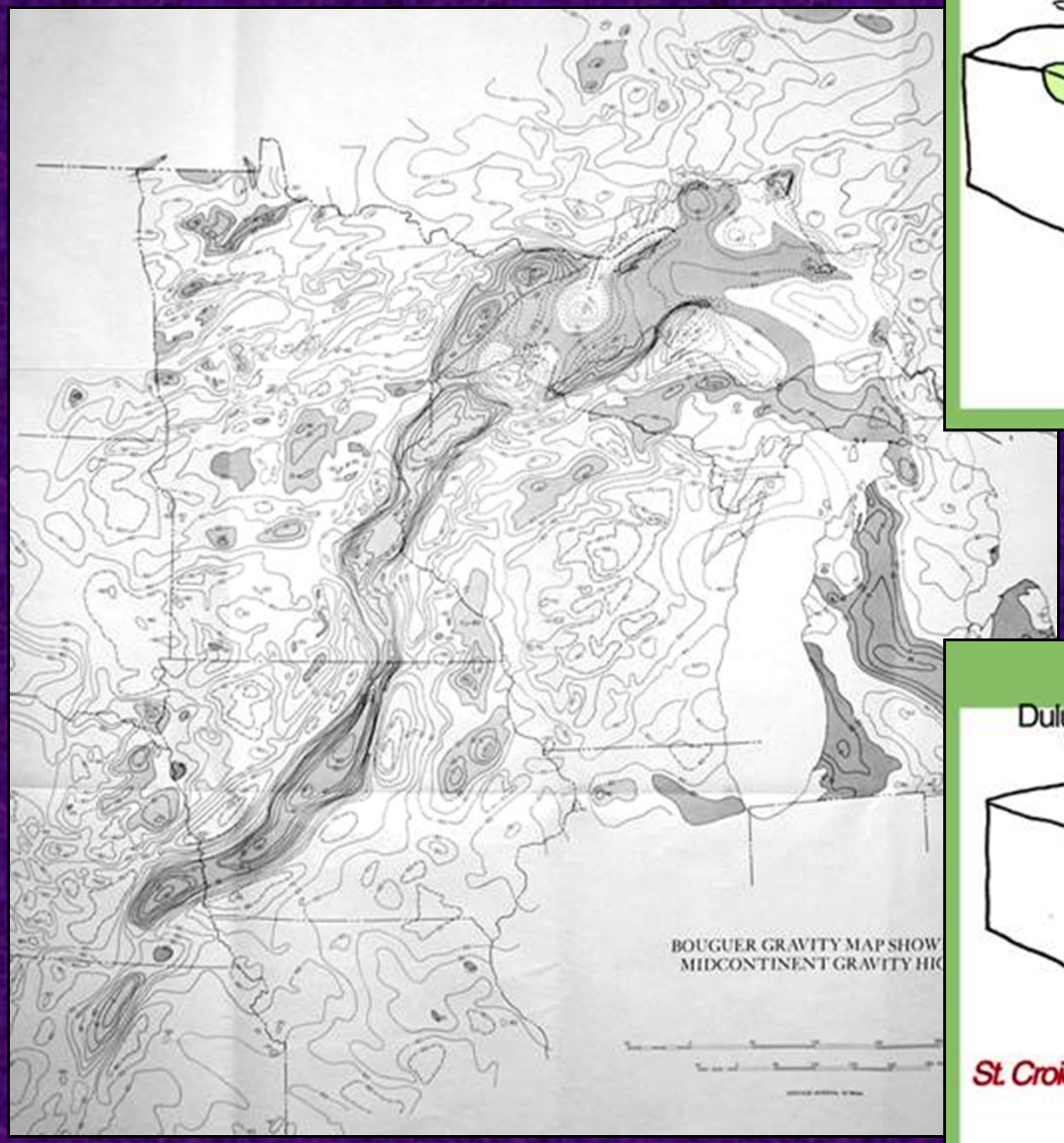
MESOPROTEROZOIC (~1100 Ma)

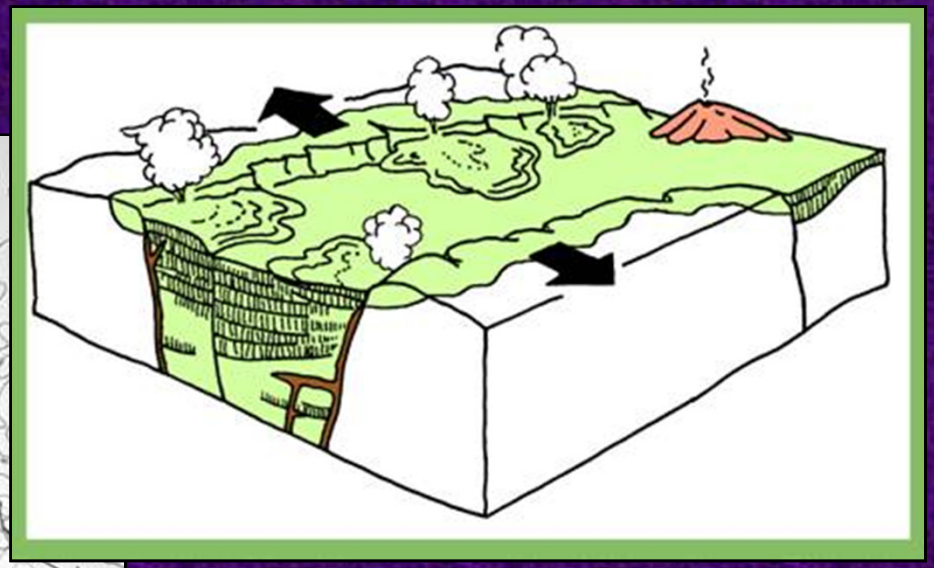
Duluth Complex

North Shore Volcanic Group

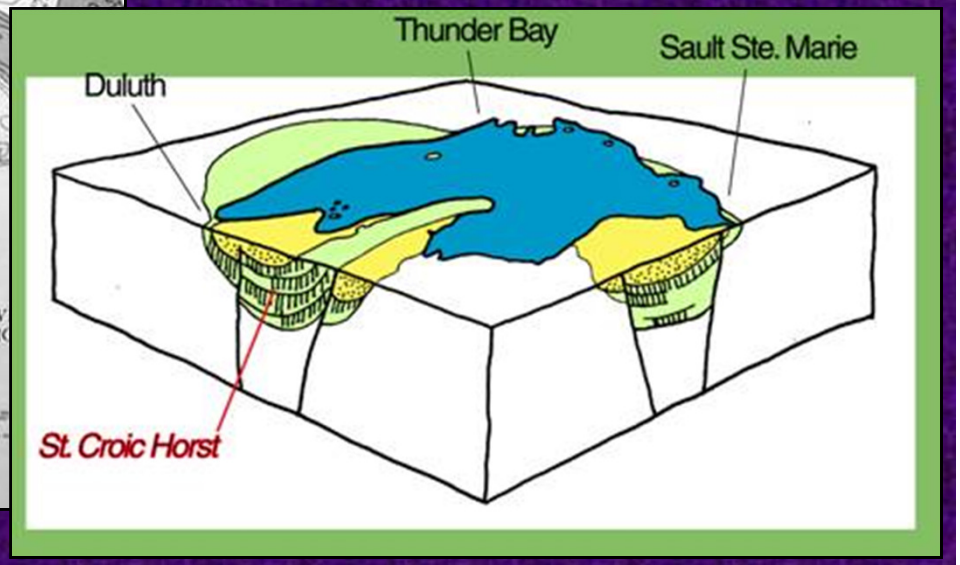


MESOPROTEROZOIC MIDCONTINENT RIFT

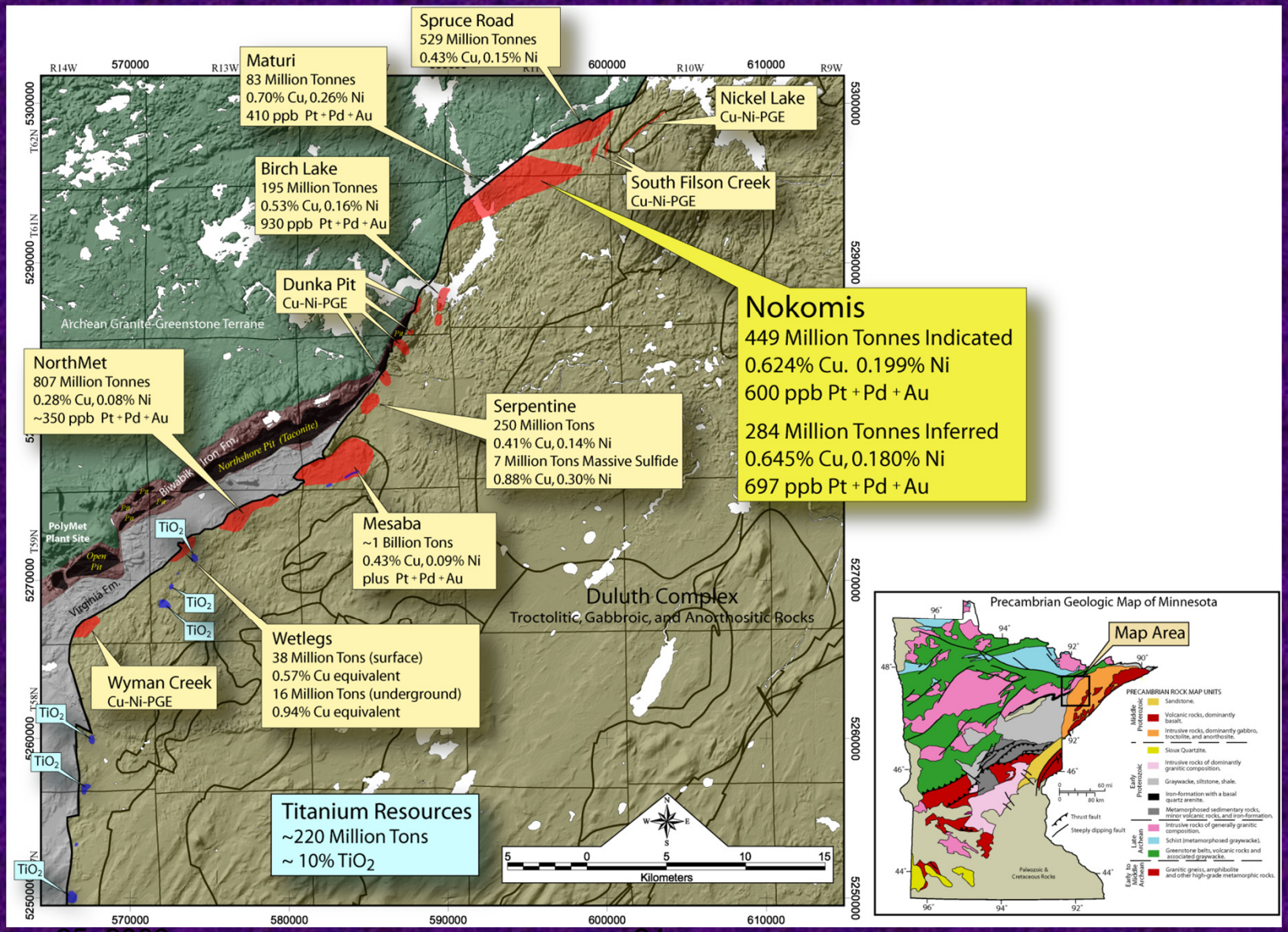




1109-1086 Ma



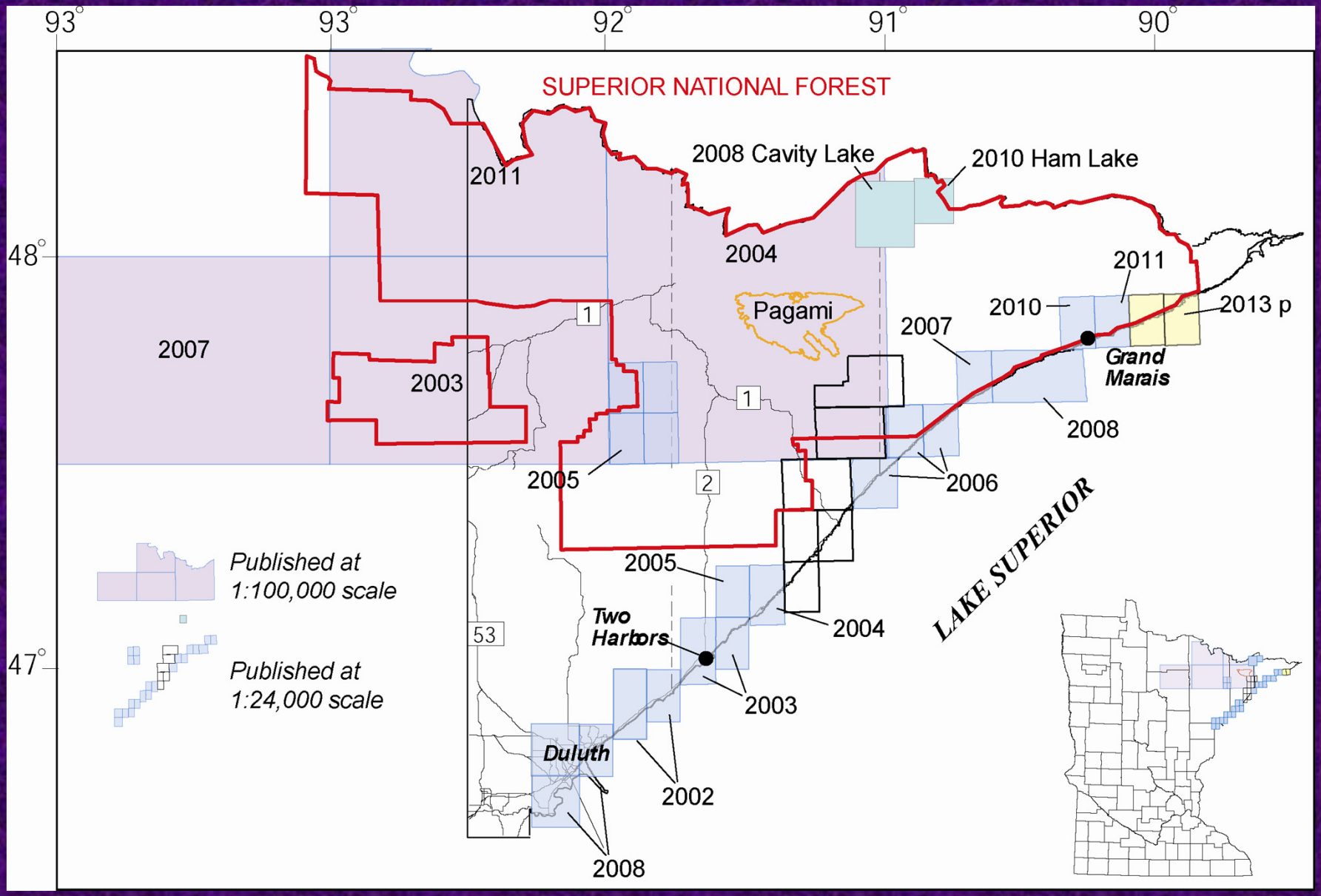
Poly-metallic mineral prospects/deposits



Imagery courtesy of Dean Peterson, Duluth Metals

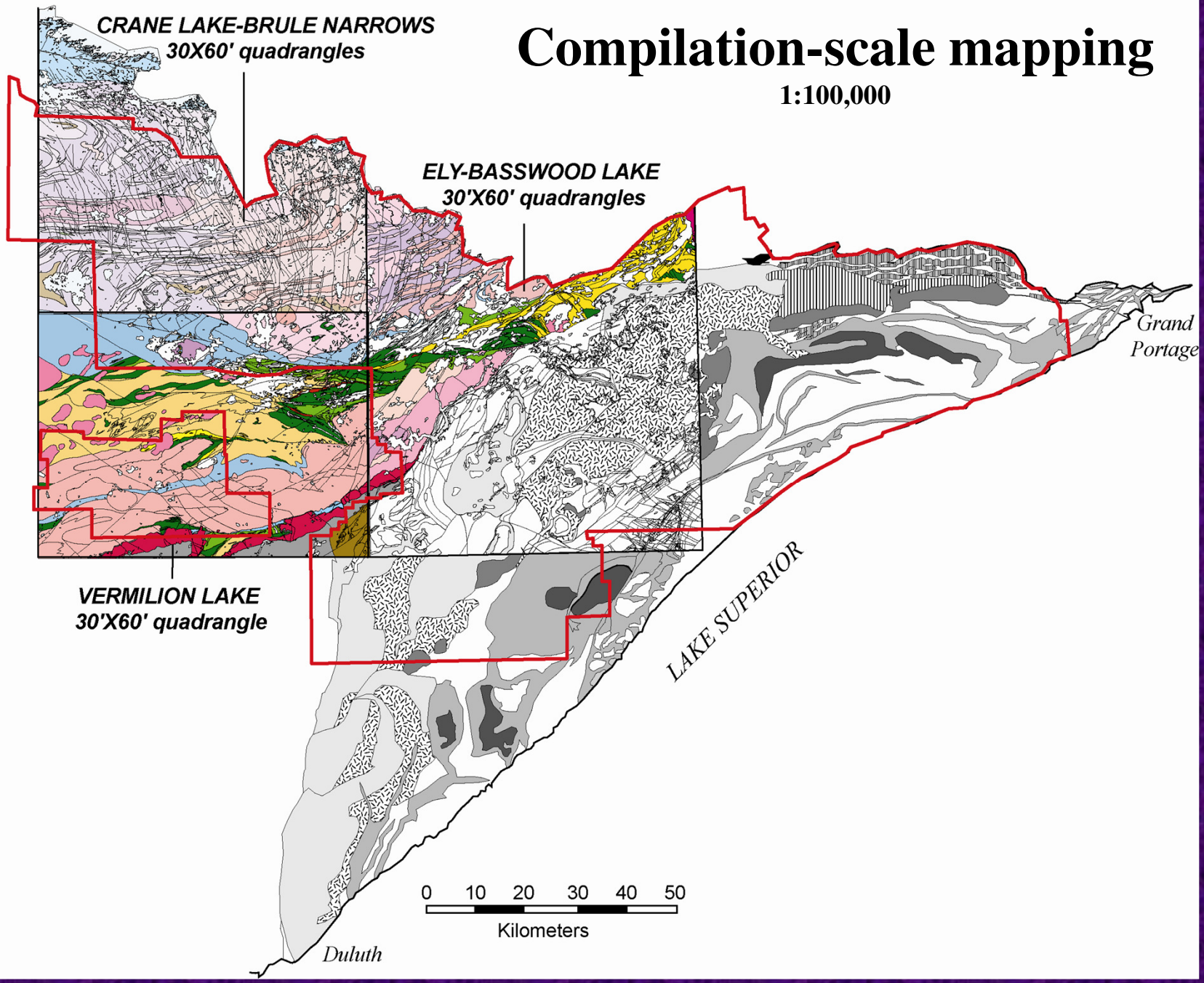
HIGHLIGHTS of MAPPING
in the
SUPERIOR NATIONAL FOREST

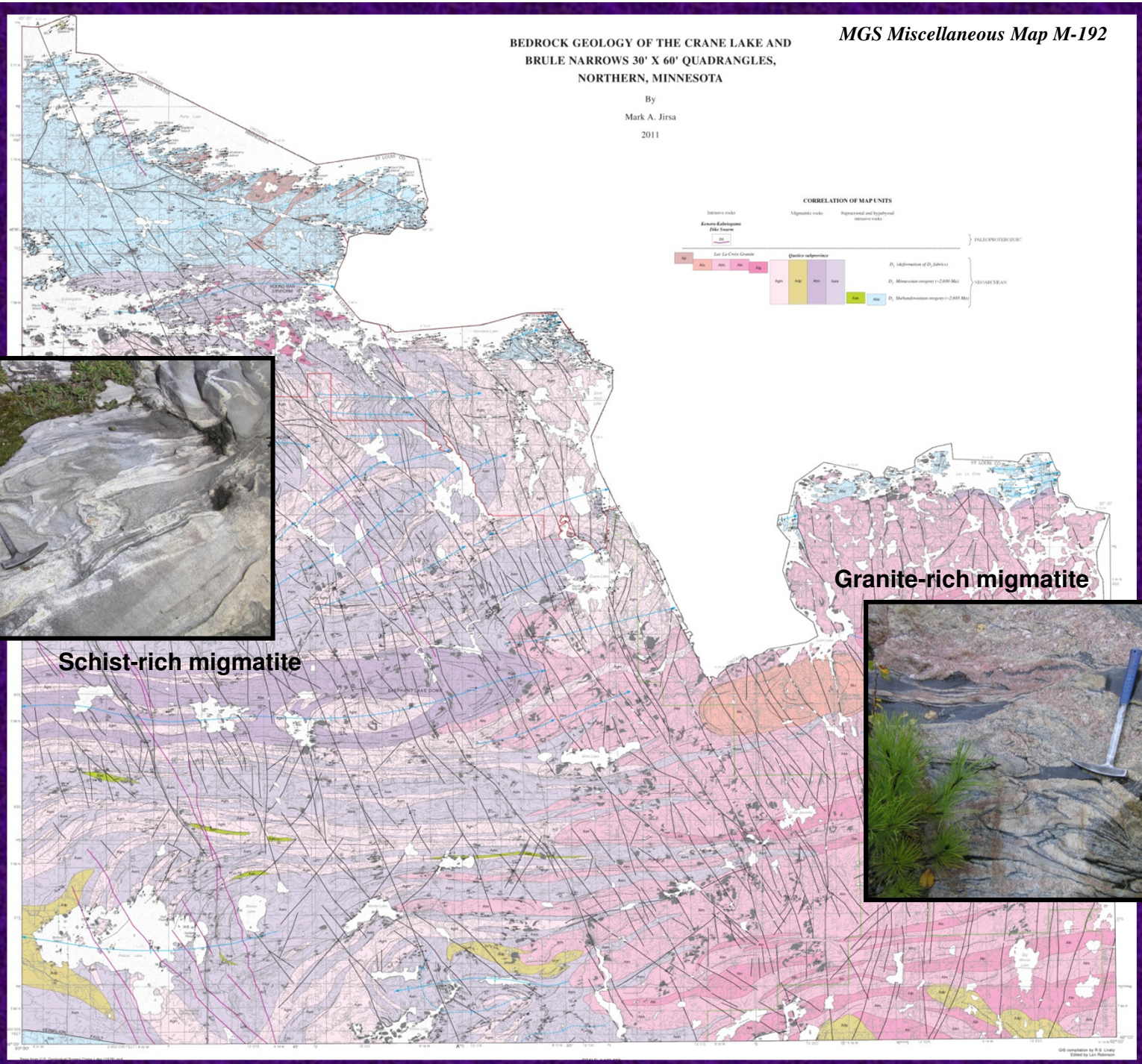
Recent geologic mapping in Superior National Forest



Compilation-scale mapping

1:100,000




MGS Miscellaneous Map M-192
BEDROCK GEOLOGY OF THE CRANE LAKE AND
BRULE NARROWS 30' X 60' QUADRANGLES,
NORTHERN, MINNESOTA
By
Mark A. Jirsa
2011
CORRELATION OF MAP UNITS
Granite-rich migmatite
Schist-rich migmatite

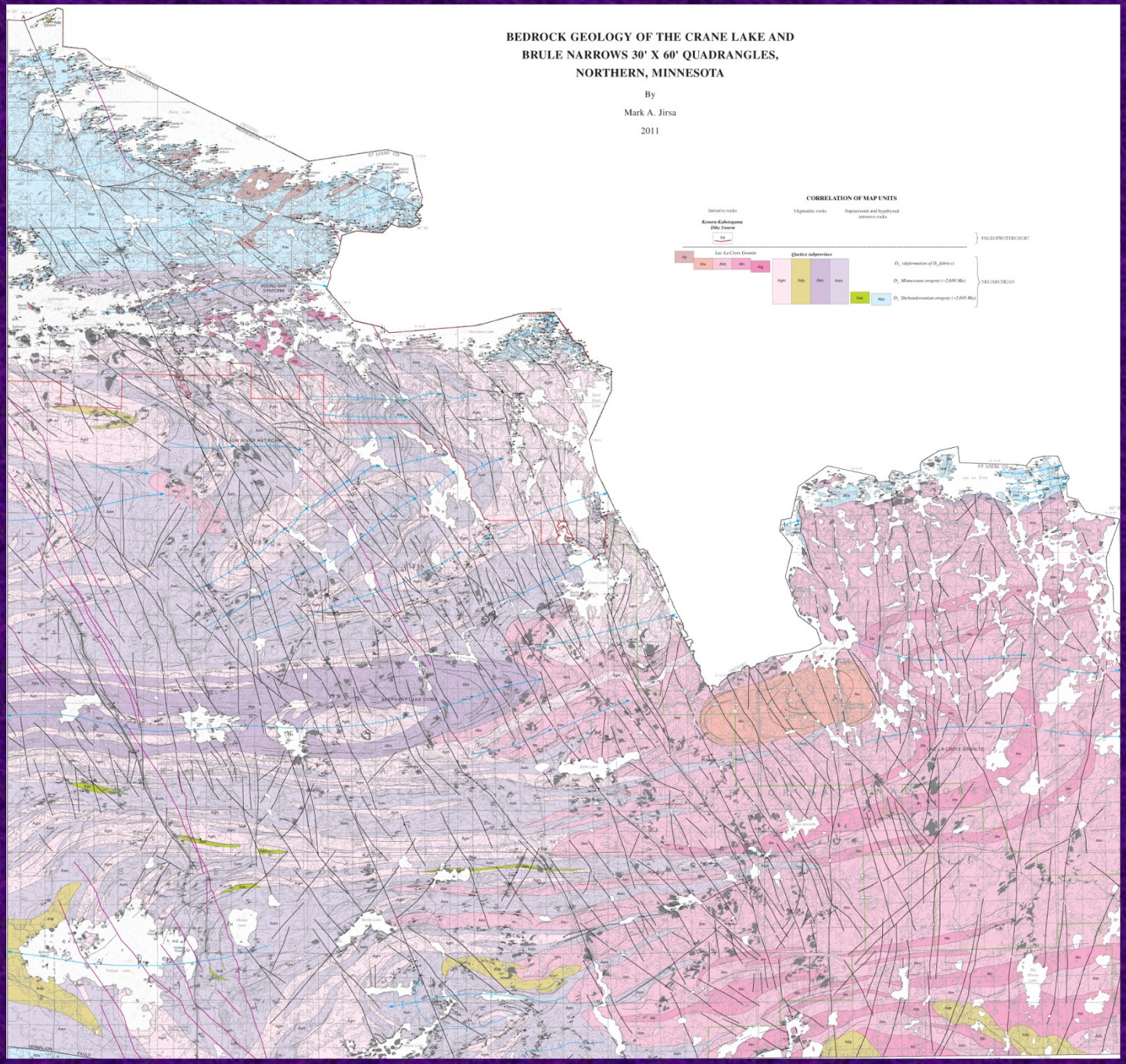
DERIVATIVE AEROMAGNETIC MAP OF CRANE LAKE-BRULE NARROWS QUADRANGLES
WHITE=magnetic
BLACK=non-magnetic

BEDROCK GEOLOGY OF THE CRANE LAKE AND BRULE NARROWS 30' X 60' QUADRANGLES, NORTHERN, MINNESOTA

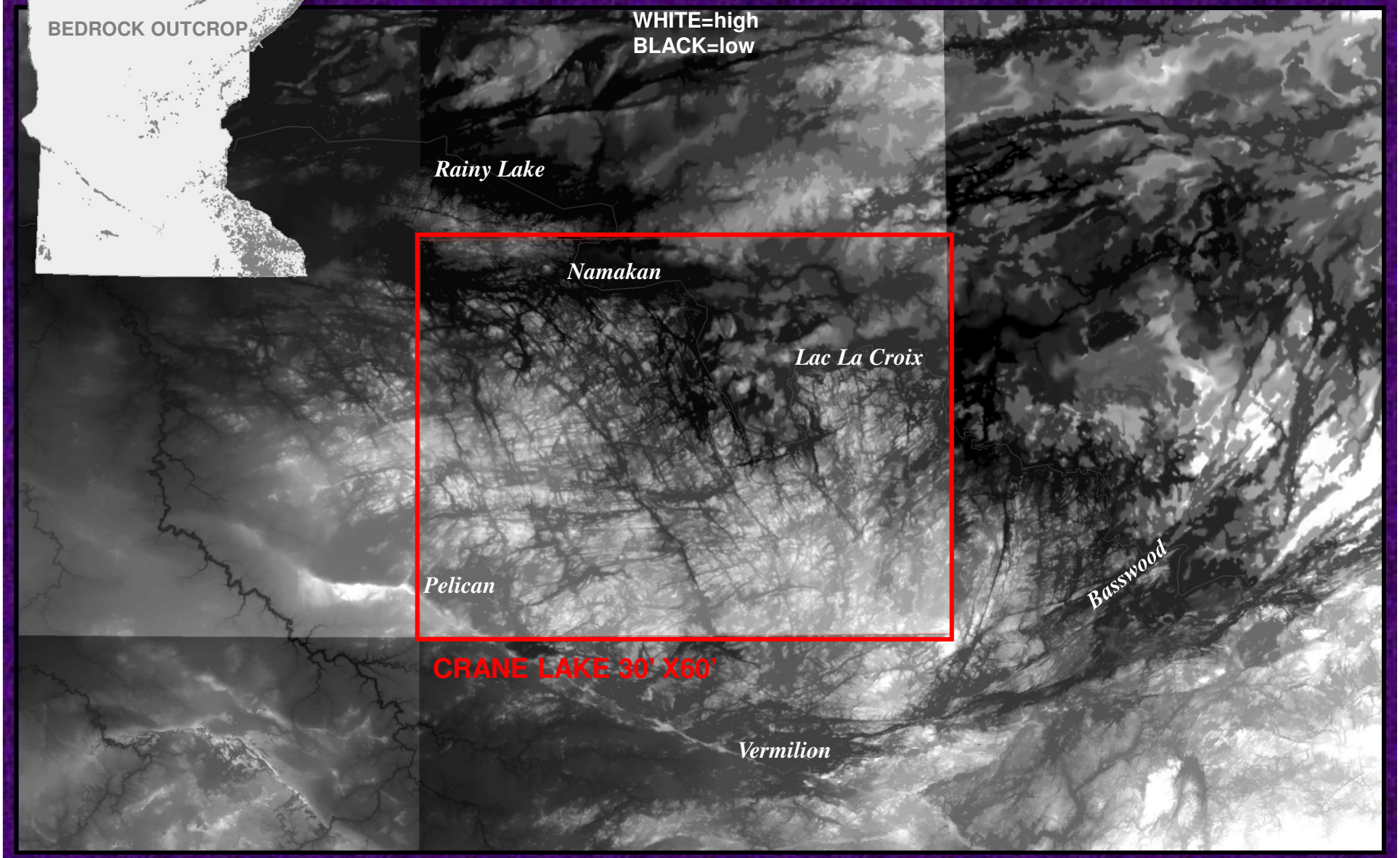
By

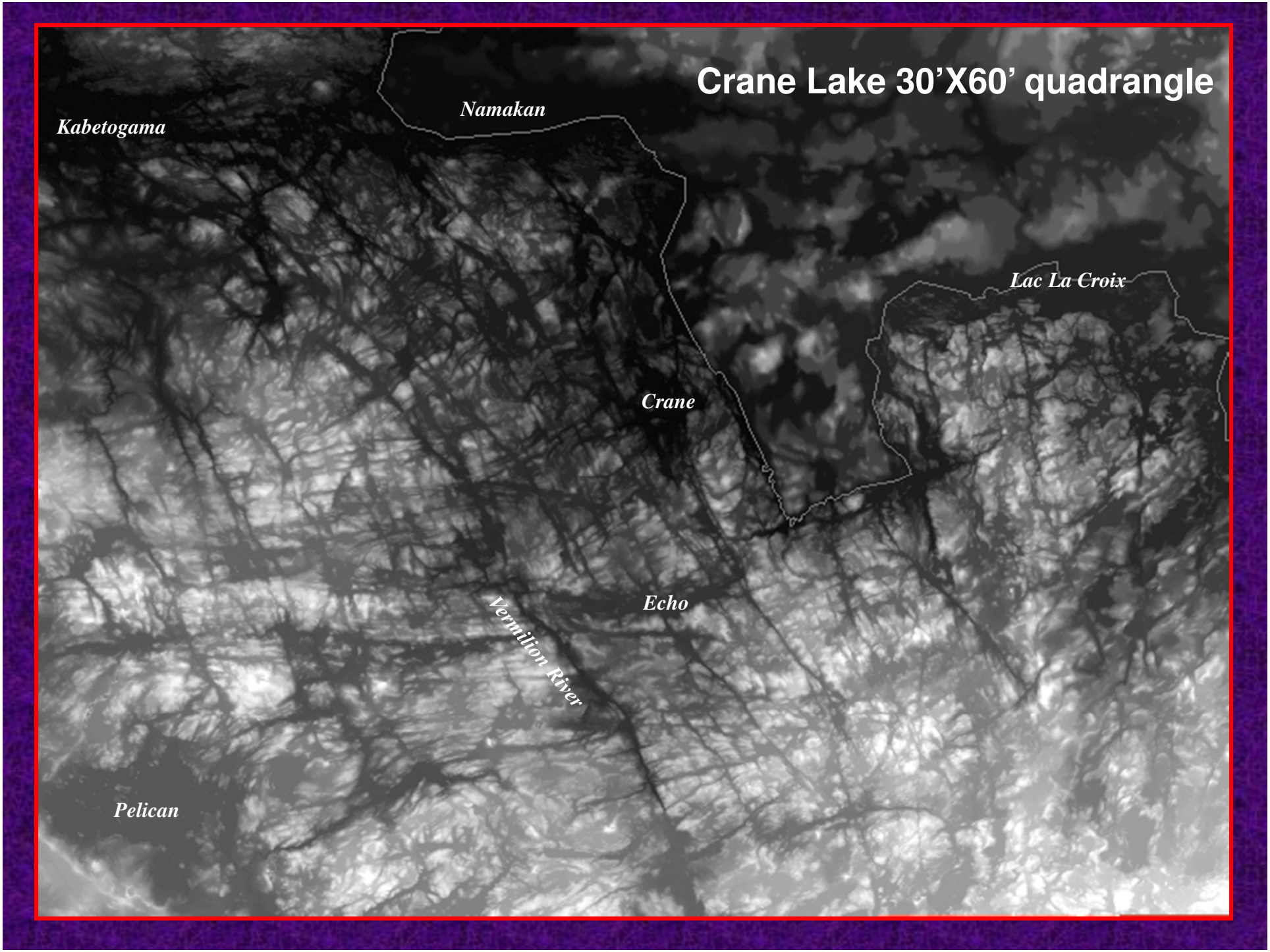
Mark A. Jirsa

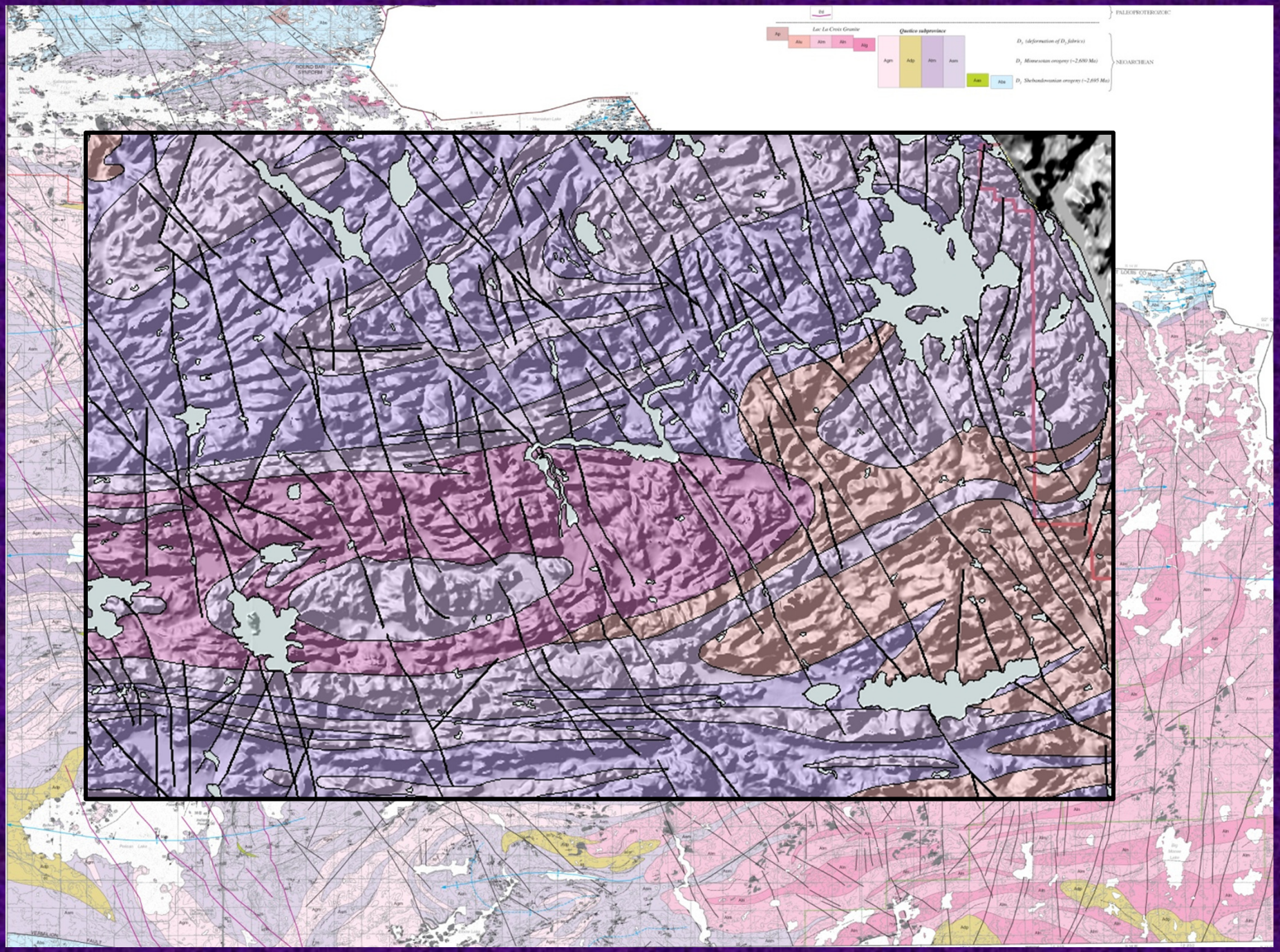
2011



Bedrock controls land-surface topography

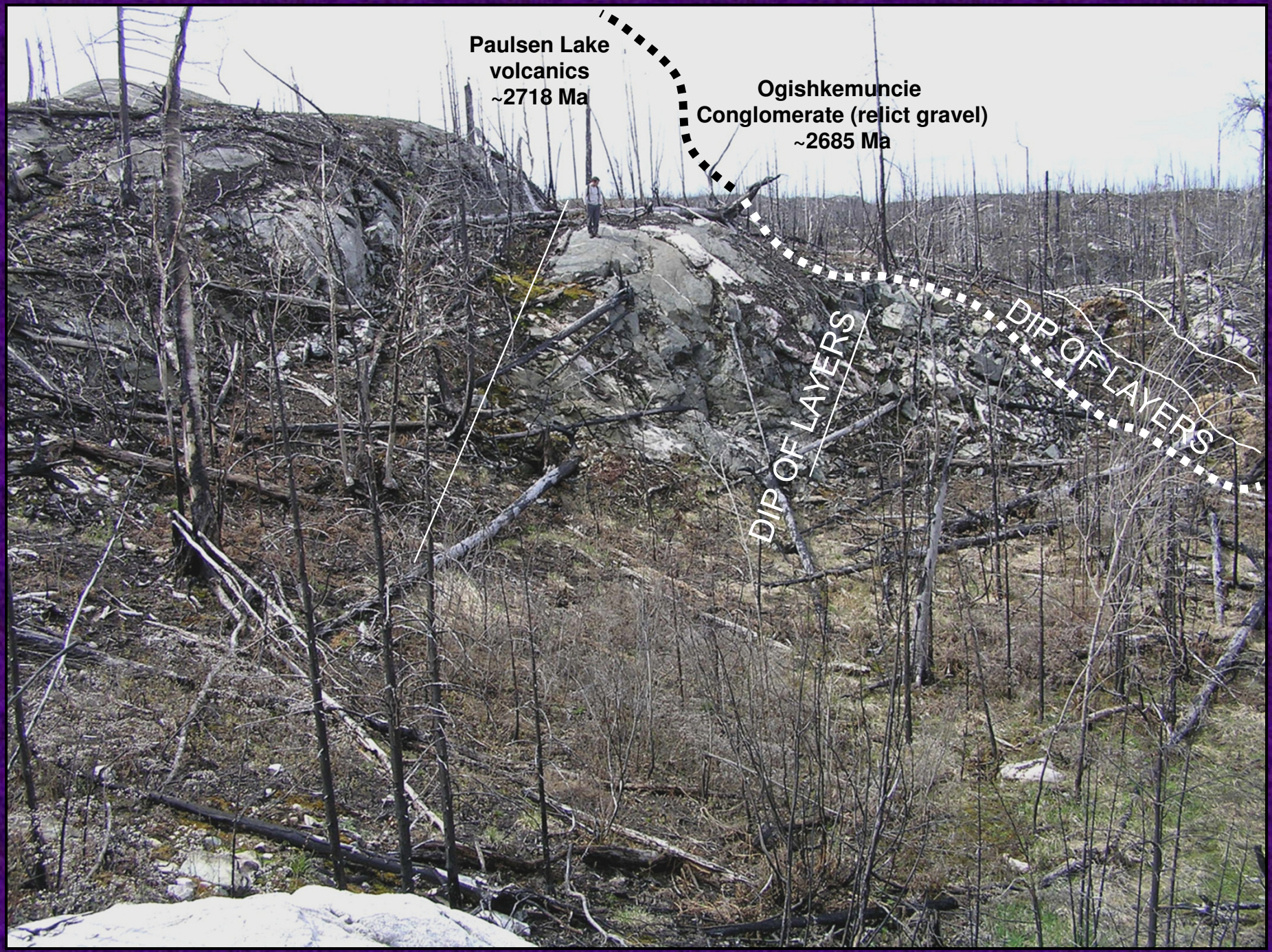



Crane Lake 30'X60' quadrangle
Kabetogama
Namakan
Lac La Croix
Crane
Echo
Vermilion River
Pelican

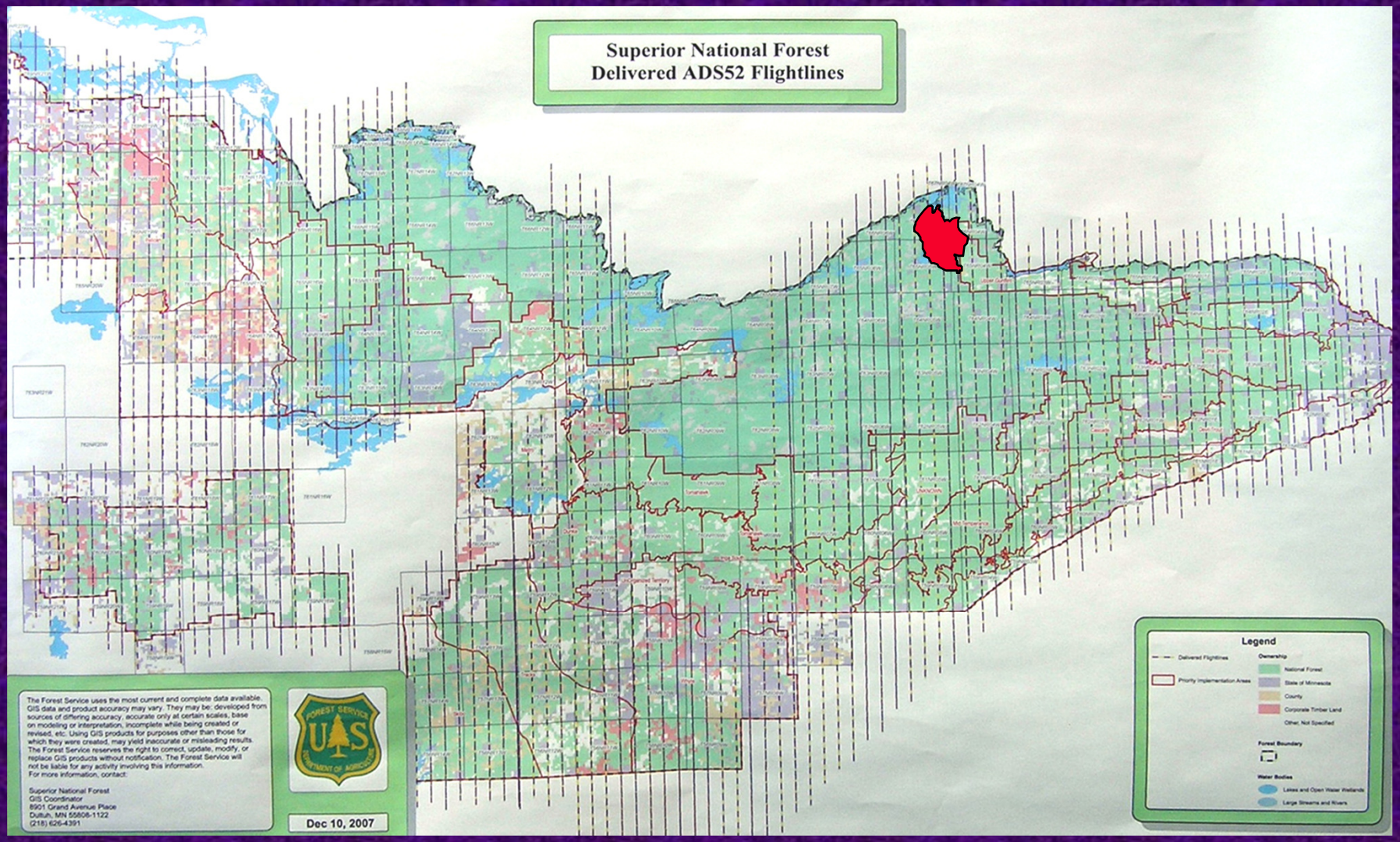

PALEOPROTEROZOIC
NEOARCHEAN
Lac La Croix Granite
Quetico subprovince
ROUND BAR SYNFORM
VERMILION FAULT

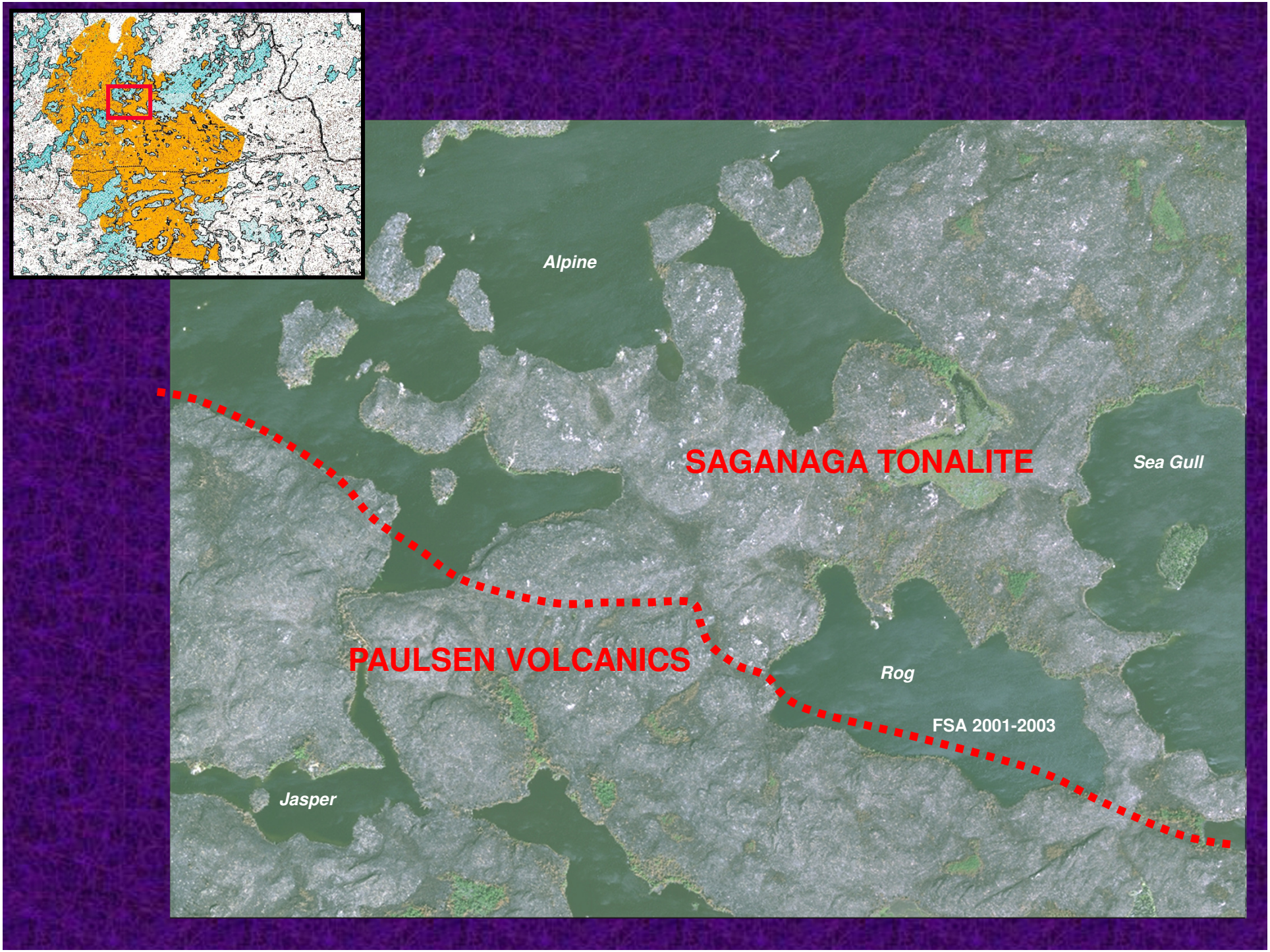
Geologic mapping in the burns

Wilderness News, Summer 2007 issue

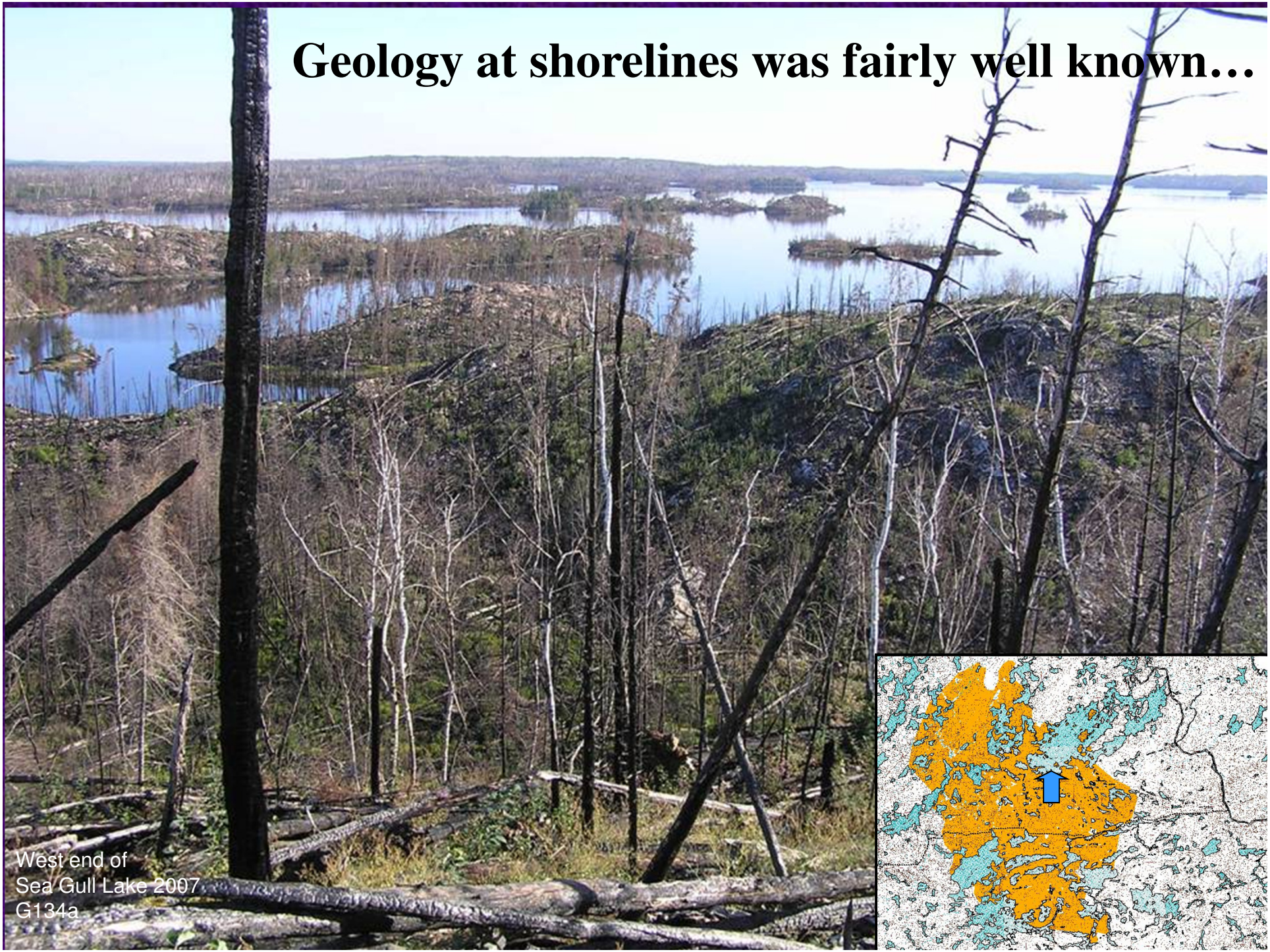

Paulsen Lake
volcanics
~2718 Ma
Ogishkemuncie
Conglomerate (relict gravel)
~2685 Ma
DIP OF LAYERS
DIP OF LAYERS

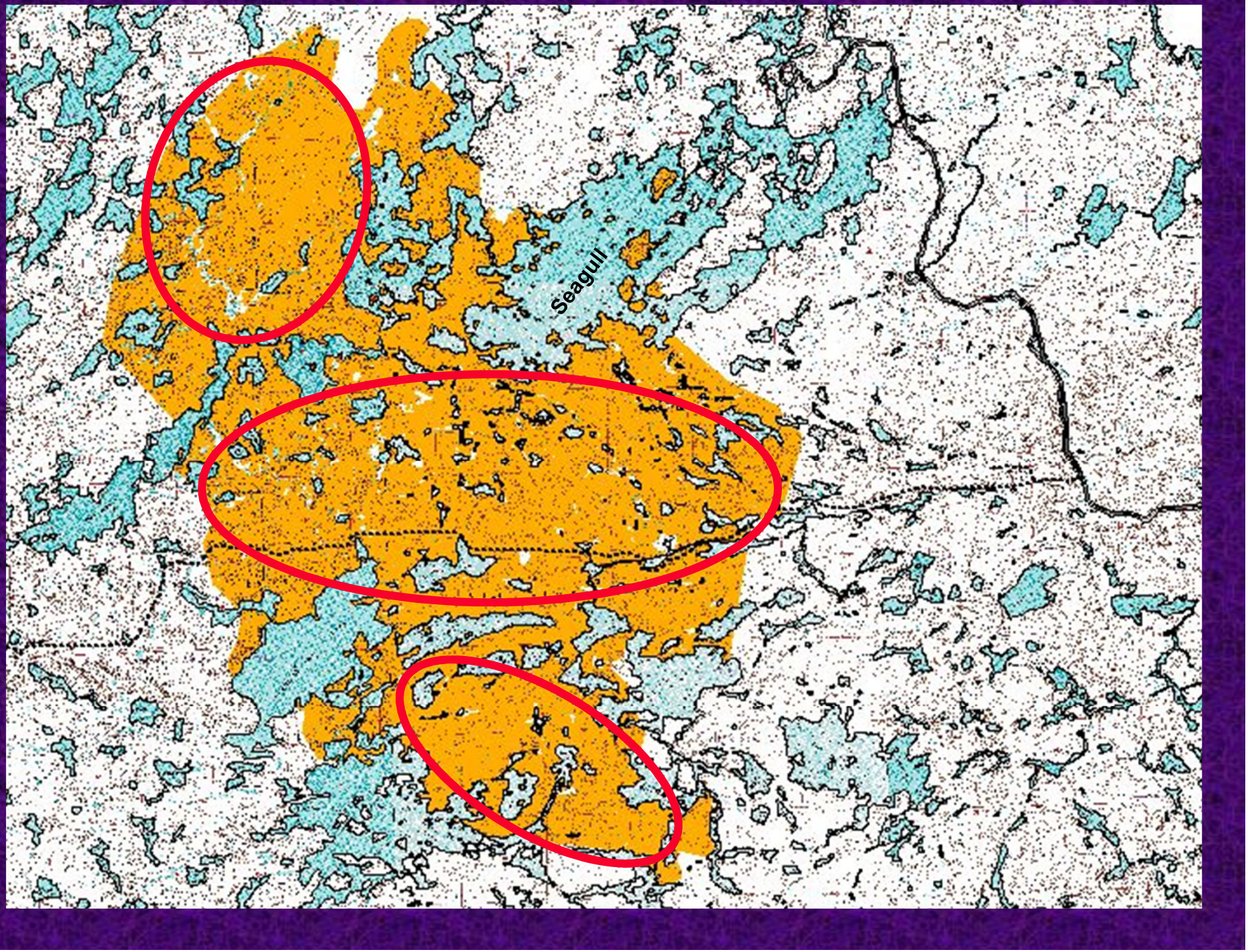
Flight lines for high-resolution air photography
Superior National Forest, July-August 2006

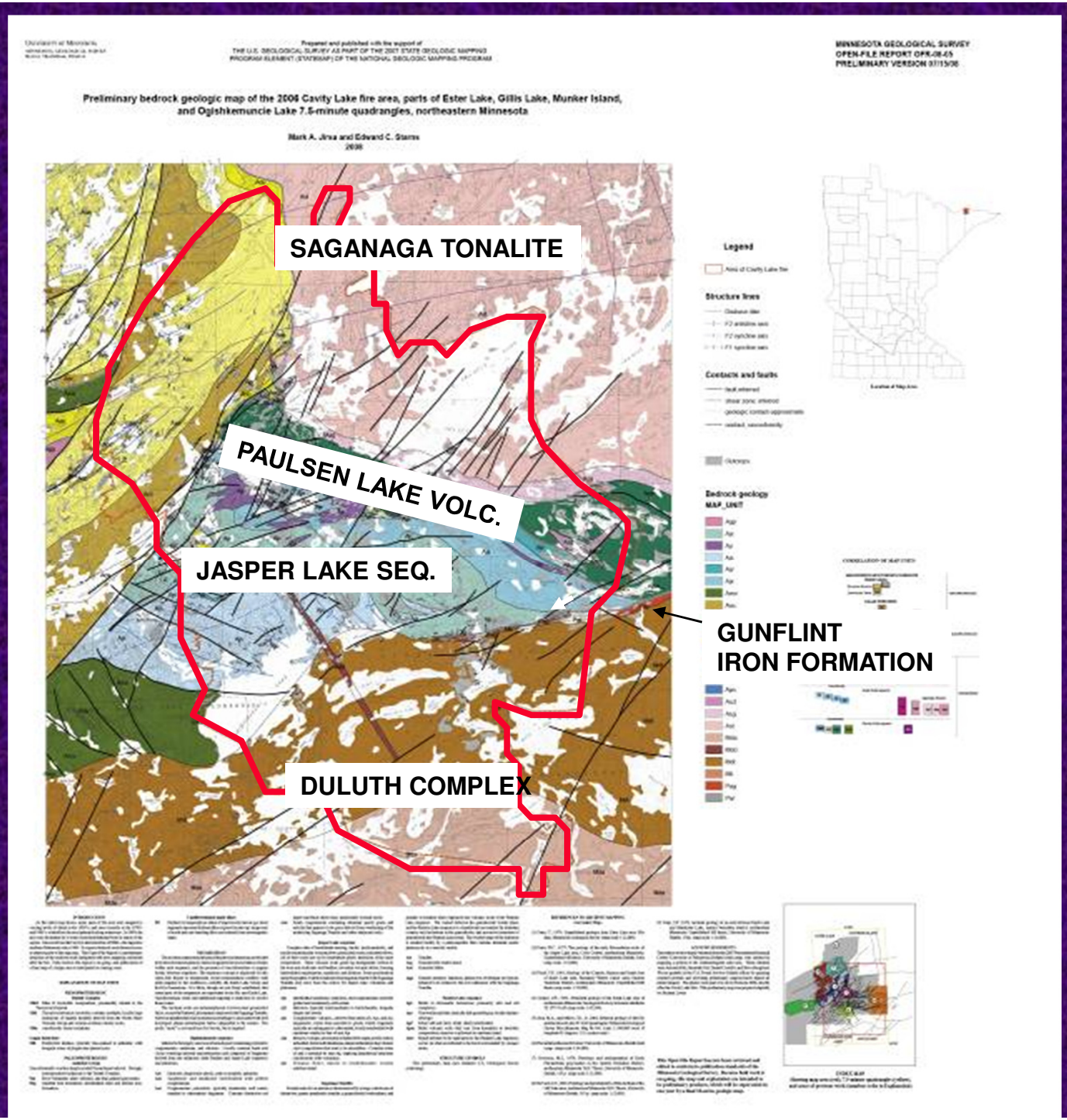



Alpine
SAGANAGA TONALITE
Sea Gull
PAULSEN VOLCANICS
Rog
FSA 2001-2003
Jasper

Geology at shorelines was fairly well known…

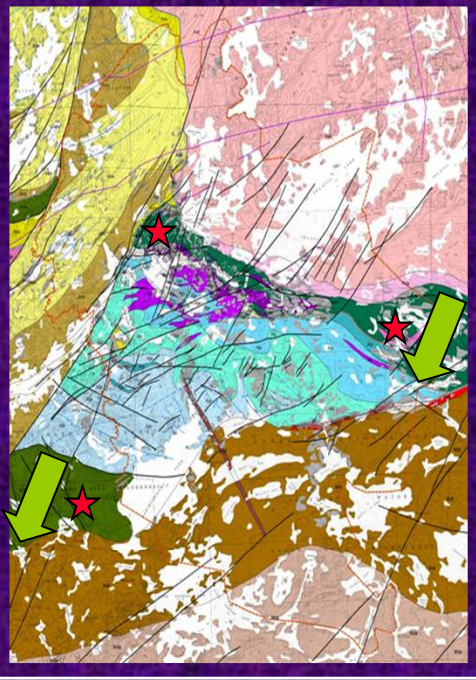



Seagull


MINNESOTA GEOLOGICAL SURVEY
OPEN-FILE REPORT OFR-08-05
PRELIMINARY VERSION 07/15/08
Preliminary bedrock geologic map of the 2006 Cavity Lake fire area, parts of Ester Lake, Gillis Lake, Munker Island, and Ogishkemuncie Lake 7.5-minute quadrangles, northeastern Minnesota
Mark A. Jirsa and Edward C. Stamo
2008
SAGANAGA TONALITE
PAULSEN LAKE VOLC.
JASPER LAKE SEQ.
GUNFLINT IRON FORMATION
DULUTH COMPLEX
Legend
Structure lines
Contacts and faults
Bedrock geology
MAP_UNIT

1 PAULSEN LAKE SEQUENCE

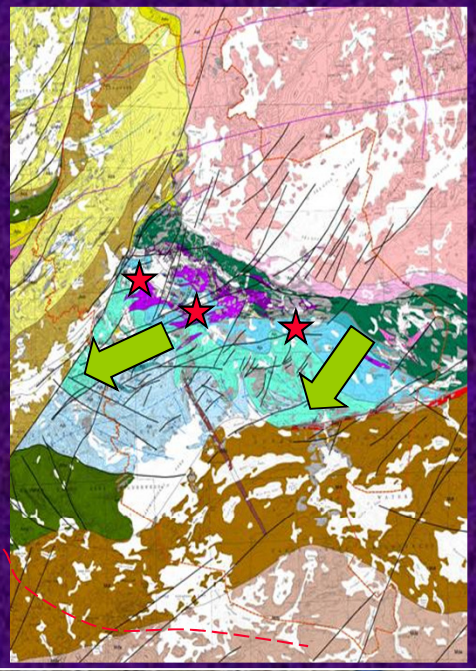
Metabasalt ~2720 Ma

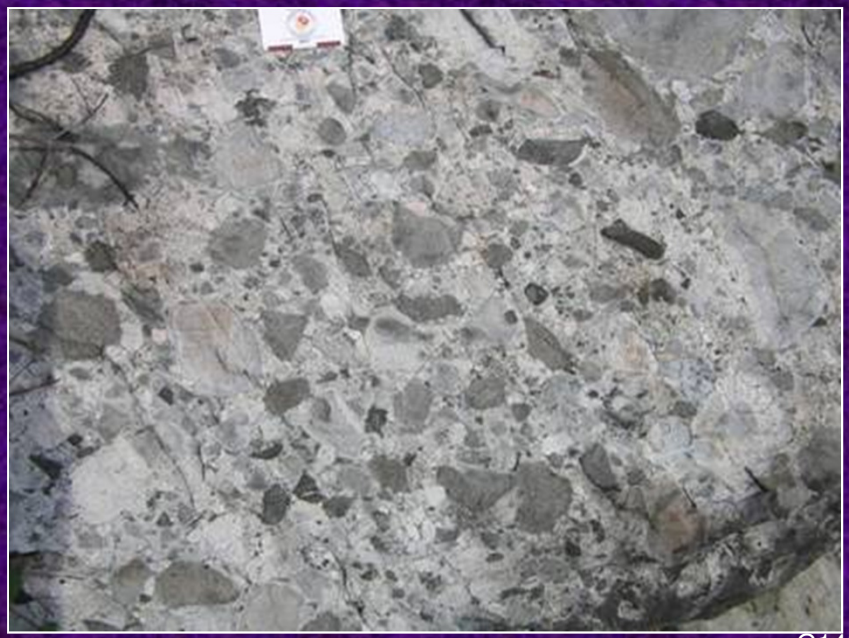


Stratigraphic younging

2 JASPER LAKE SEQUENCE

Volcanic and fragmental rocks (2690 Ma)



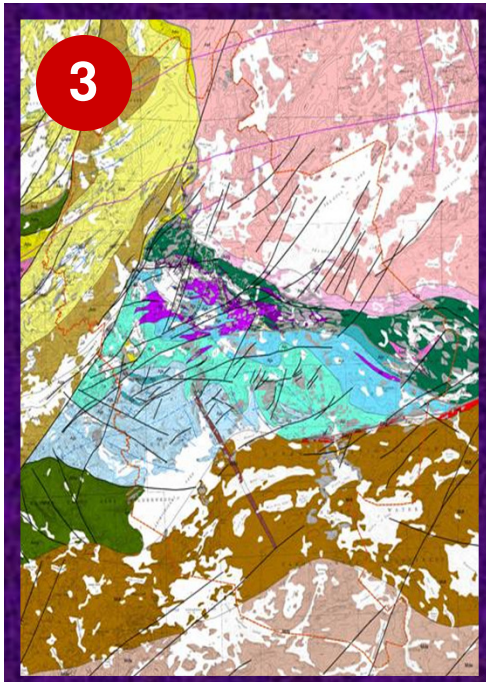


G145b

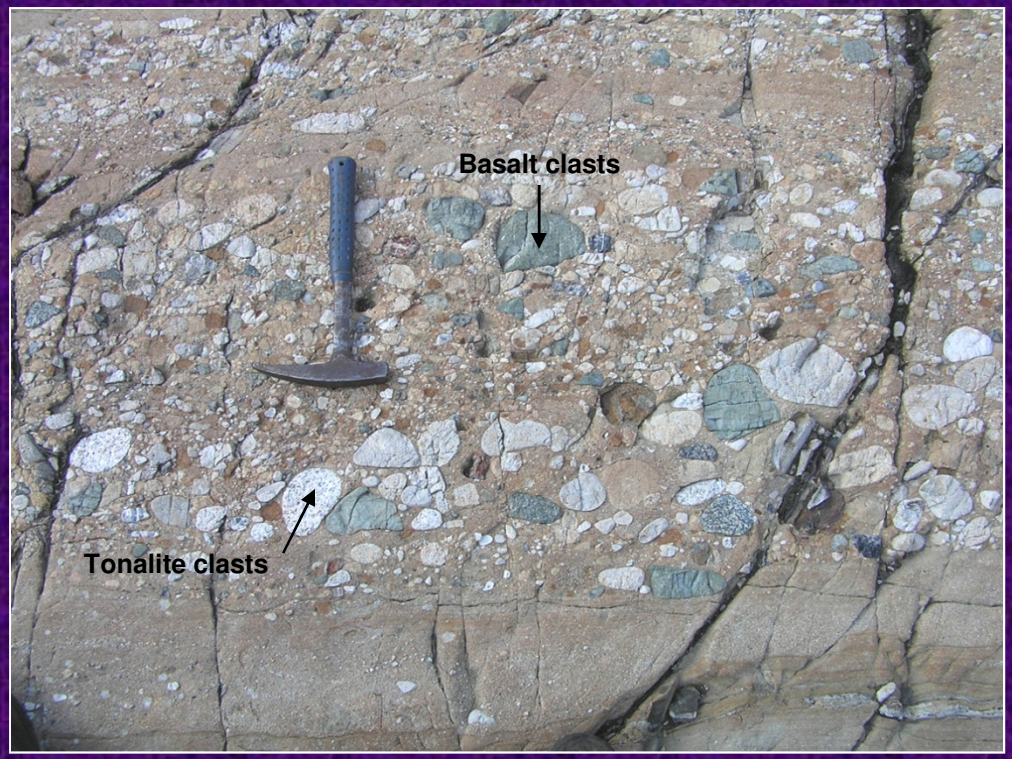
G278f

G175c

2
SAGANAGA TONALITE (2690 Ma)

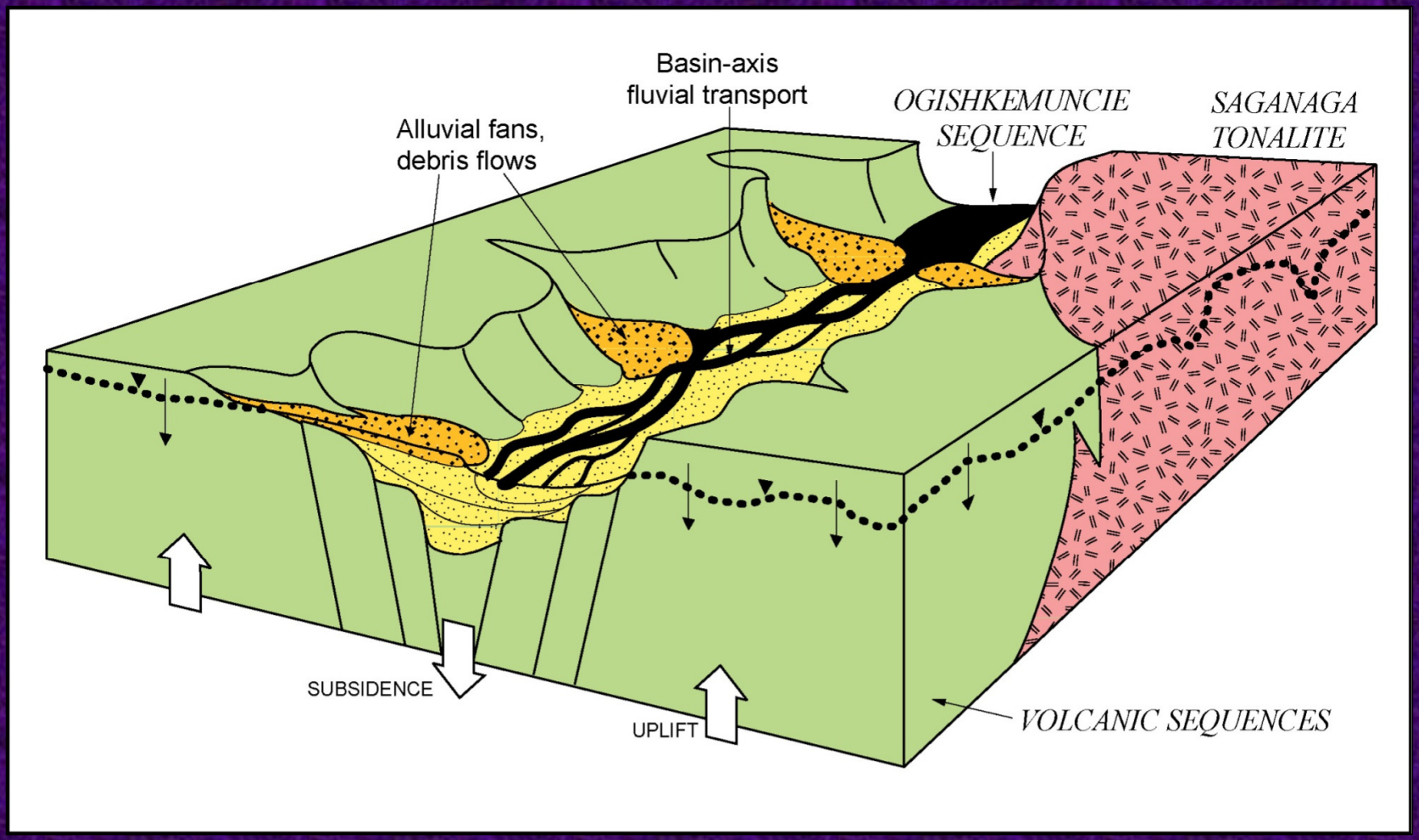


OGISHKEMUNCIE SEQUENCE Conglomerate and sandstone

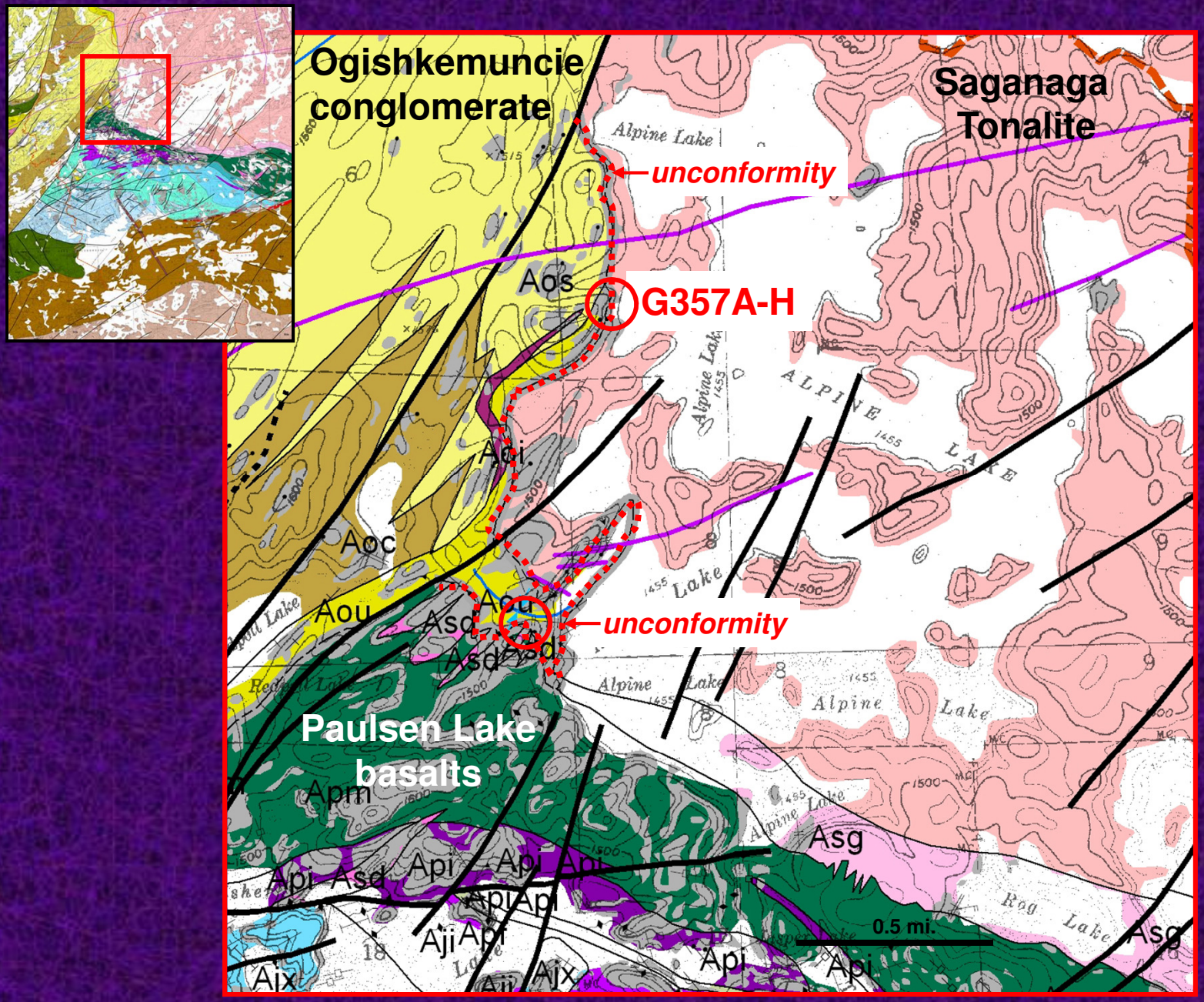


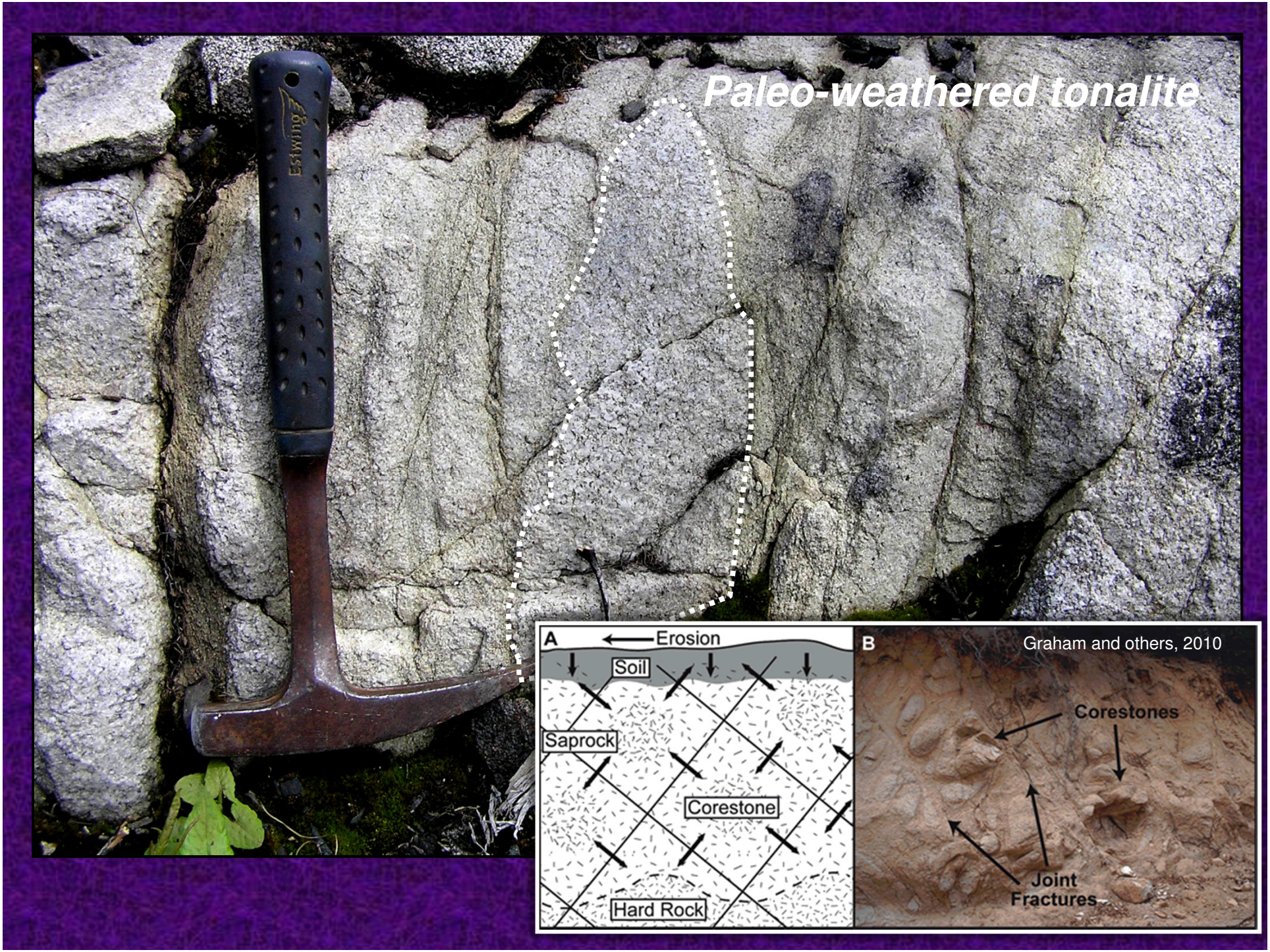
DEPOSITIONAL MODEL

3 *OGISHKEMUNCIE (conglomerate) SEQUENCE*



PALEOSAPROLITE ON SAGANAGA TONALITE



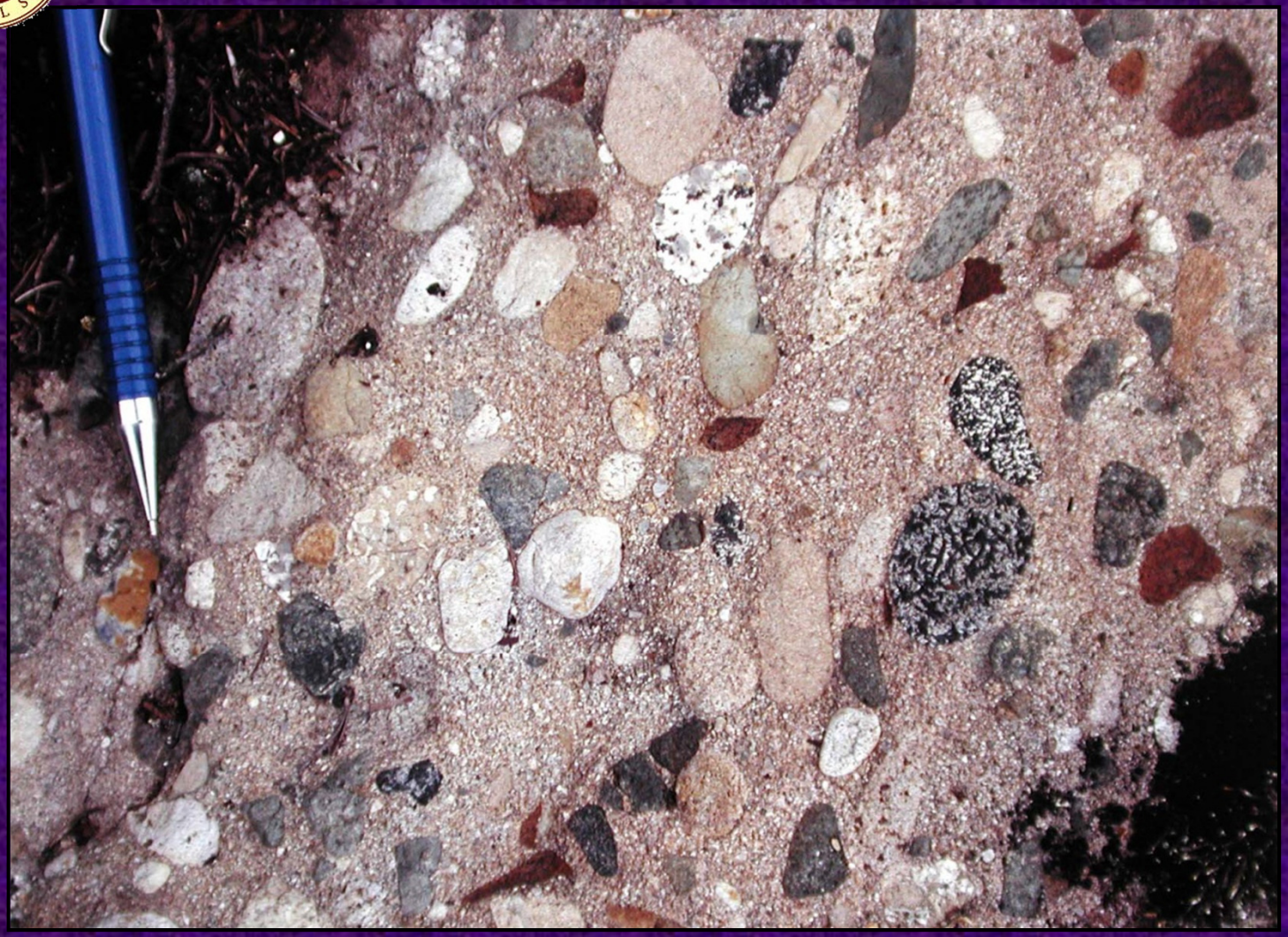

Paleo-weathered tonalite
Estwing
A
Erosion
Soil
Saprock
Corestone
Hard Rock
B
Graham and others, 2010
Corestones
Joint
Fractures

Neoarchean Weathering and Atmospheric pO_2

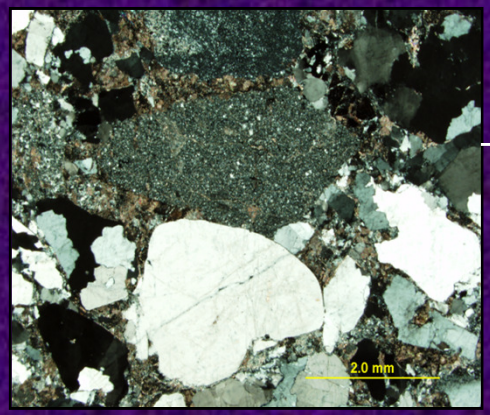
Mark Jirsa
Minnesota Geological Survey

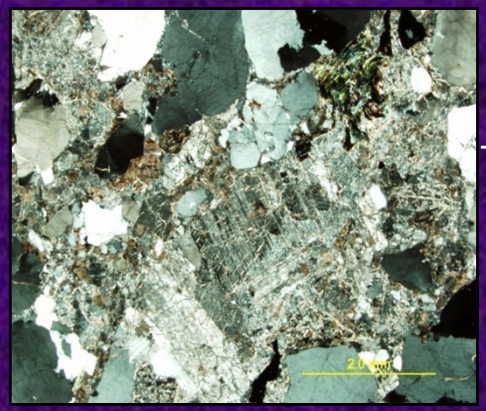
and

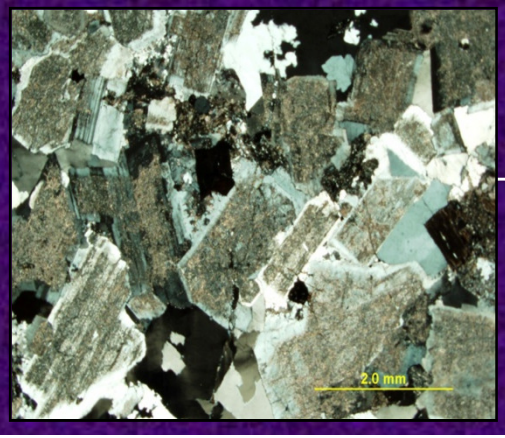
Steven G. Driese
Baylor University, Texas



SUMMARY of WEATHERING PROFILE of tonalite







Saprolitic tonalite

Conglomerate with "clayey" saprolite clasts and lithic fragments

"Fresh" tonalite

CONCLUSIONS

Based on comparison* of weathered vs. unweathered rock

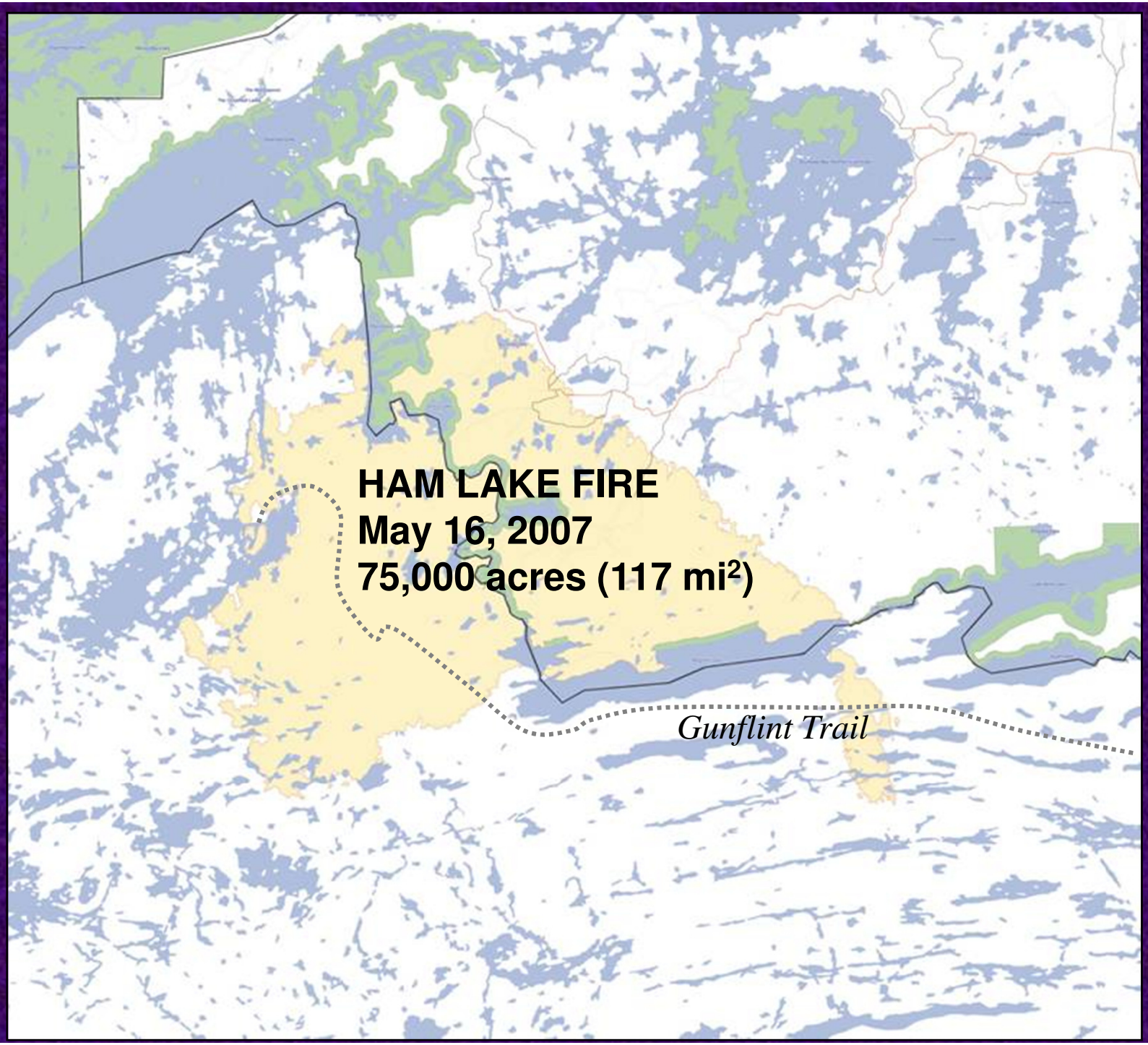
Driese and others, 2011; Precambrian Research v. 189, p. 1-17

1) **Field and microscopic evidence supports the interpretation of ~2690 Ma weathering and paleosol development.**

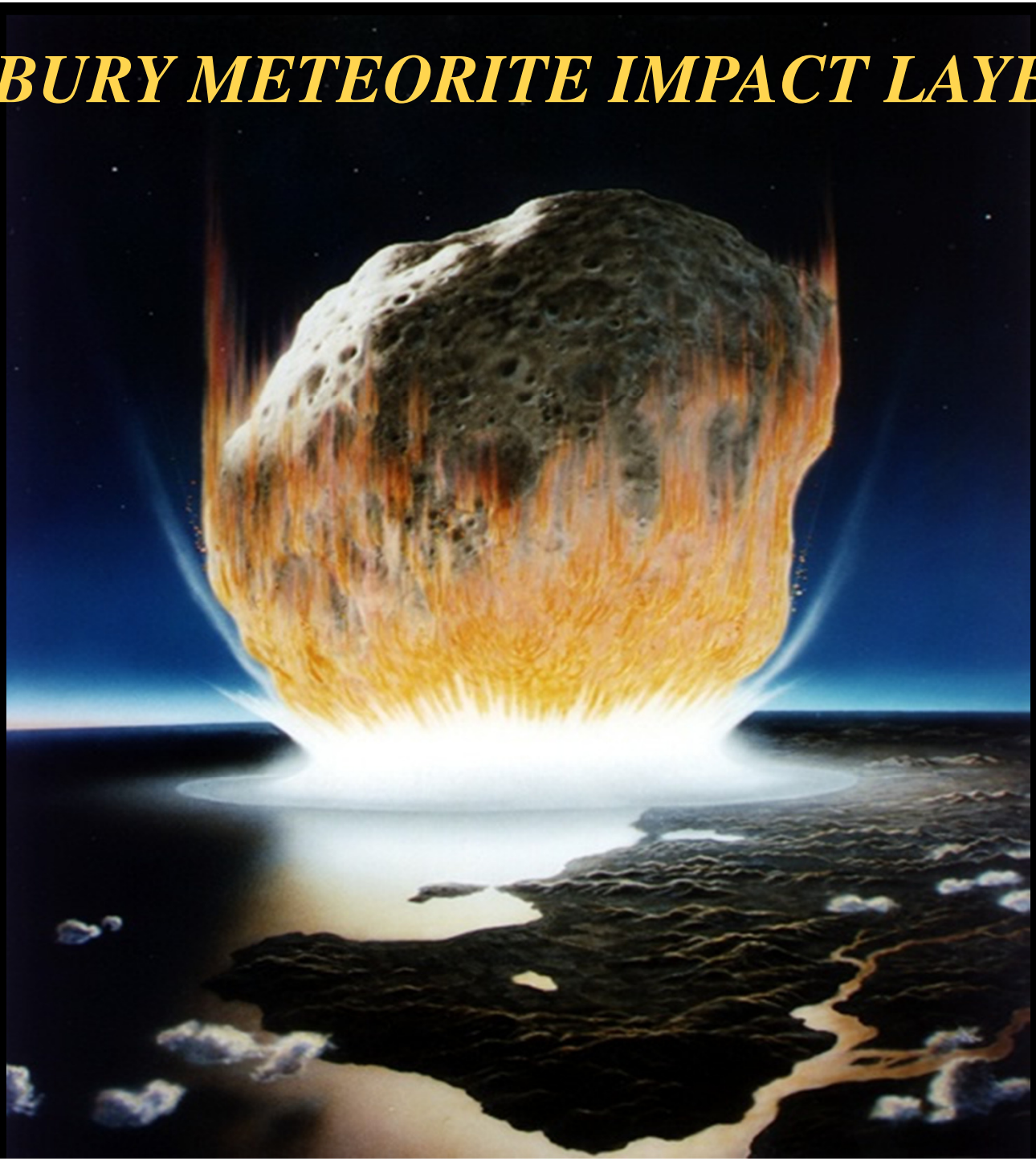
2) **Major and trace element geochemistry indicates that primitive microbes contributed to the weathering process *(earliest indications of terrestrial life).***

3) **Geochemistry implies weakly oxygenated paleoatmosphere.**

*Comparative texture, mineralogy, major and trace element compositions


HAM LAKE FIRE
May 16, 2007
75,000 acres (117 mi²)
Gunflint Trail

SUDBURY METEORITE IMPACT LAYER



SUDBURY METEORITE IMPACT EVENT

*Of 174 confirmed structures:**

2nd largest

4th oldest

BY CRATER SIZE

1. Vredefort (S. Africa) 300 km
2. ***Sudbury (Ontario) 250 km***
3. Chicxulub (Mexico) 170 km

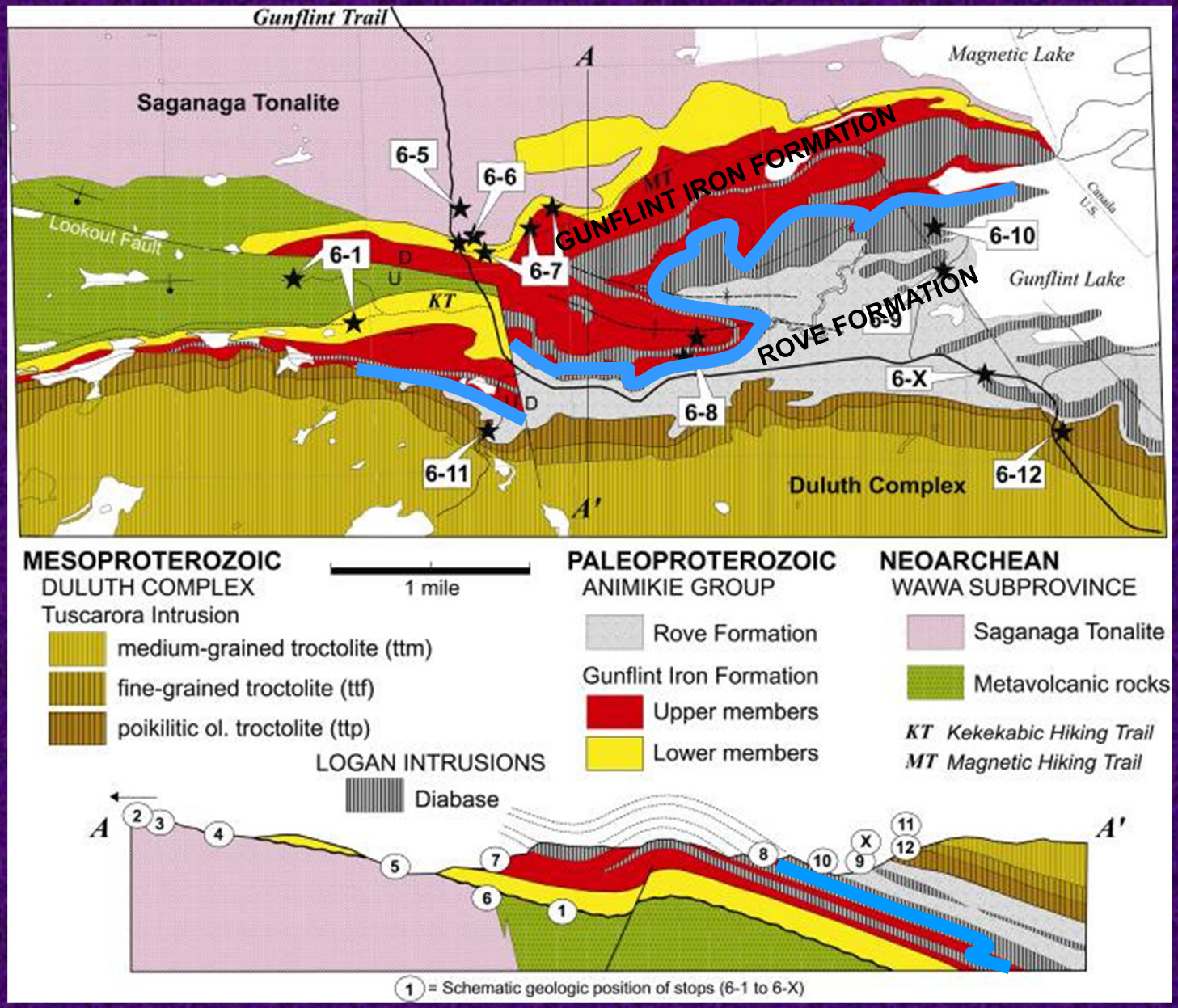
BY AGE

1. Suarjarvi (Finland) ~2400 Ma
2. Vredefort (S. Africa) 2023 Ma
3. Yarrabubba (Australia) ~2000 Ma
4. ***Sudbury (Ontario) 1850 Ma***

117. Chicxulub (Mexico) 65 Ma

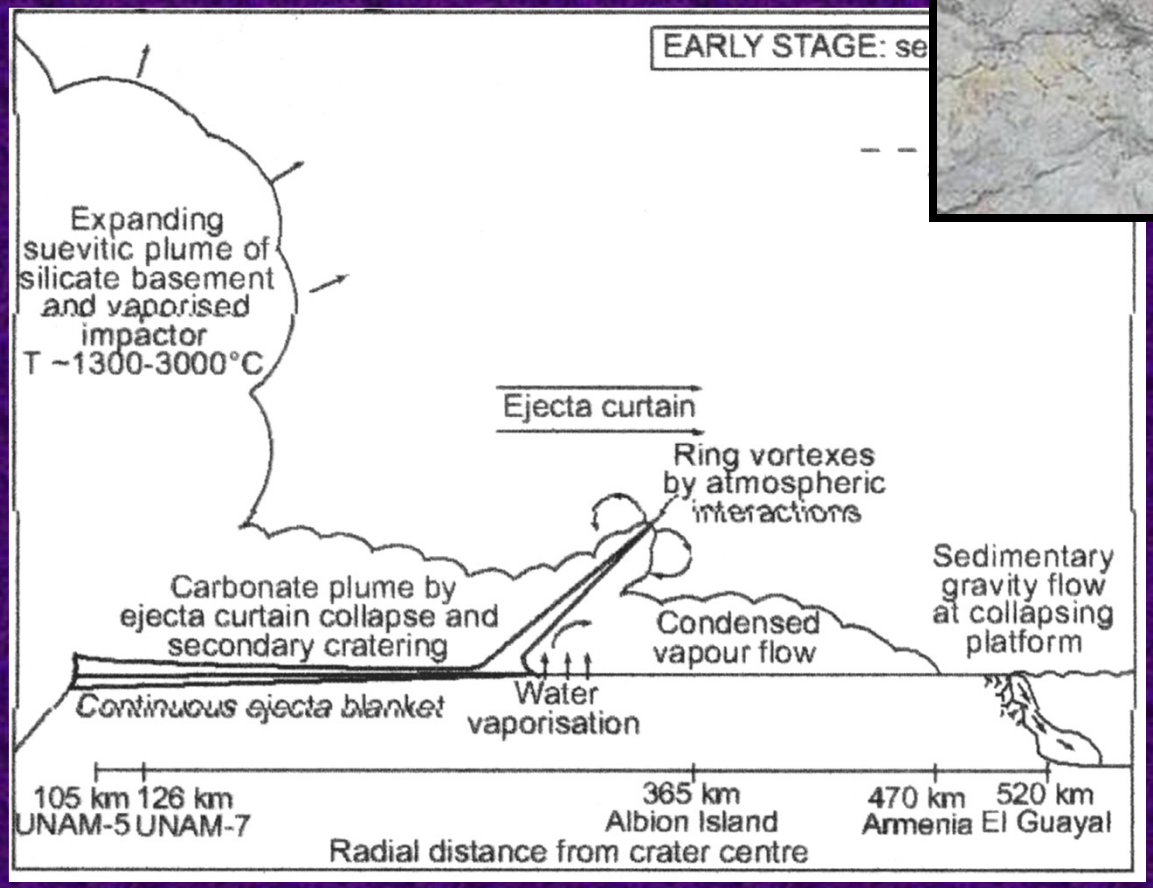
*www.unb.ca/passc/ImpactDatabase

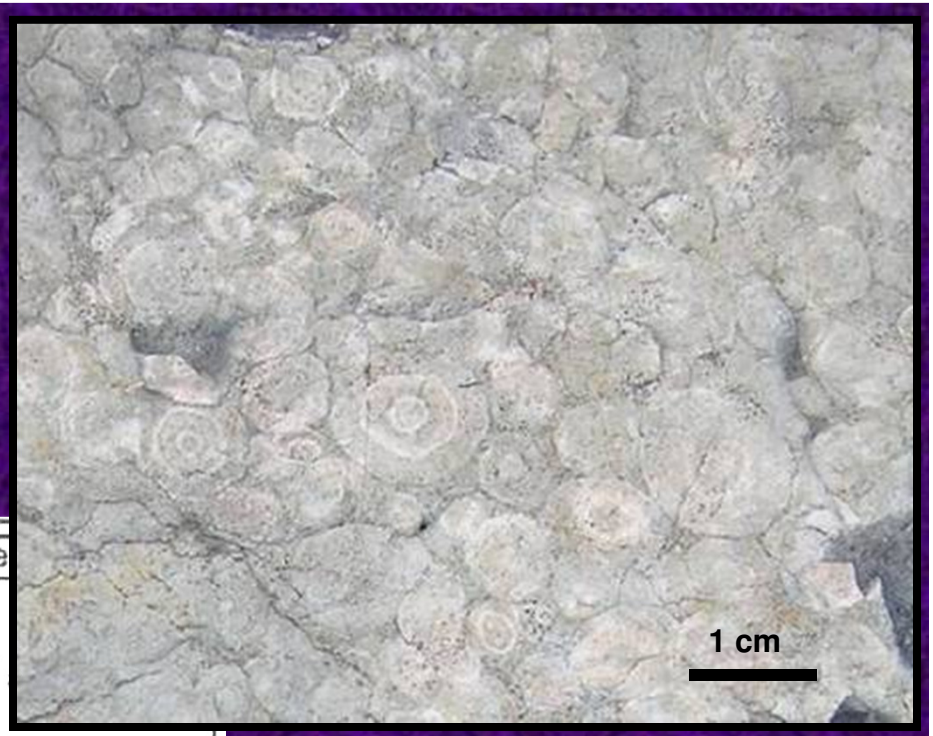
SUDBURY IMPACT LAYER

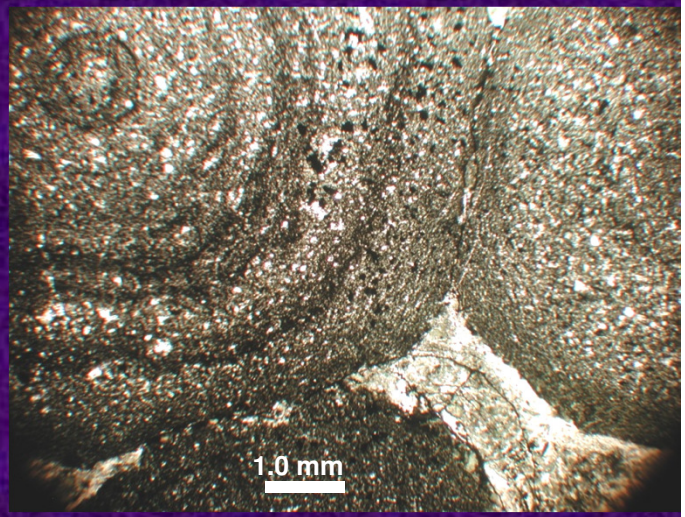


Accretionary Lapilli

Concentrically layered granular spheres formed in turbulent, impact cloud from ejected ash, melt droplets, and vapor

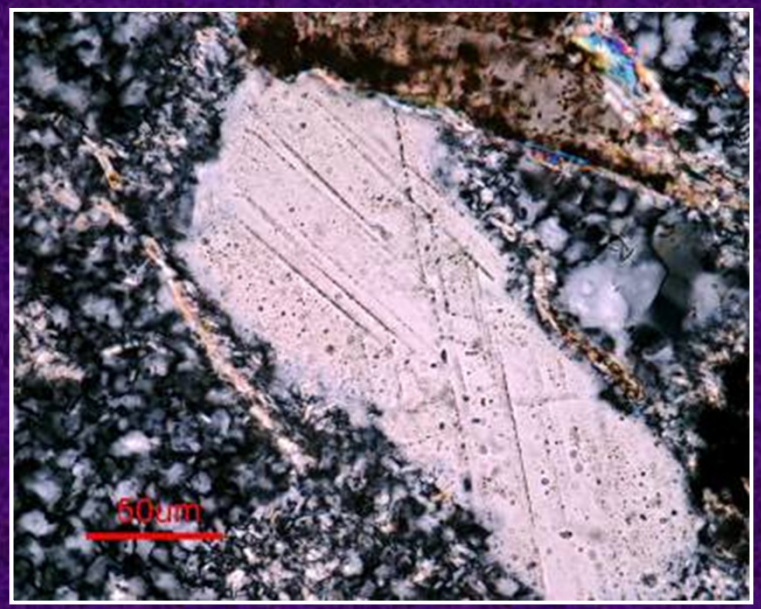


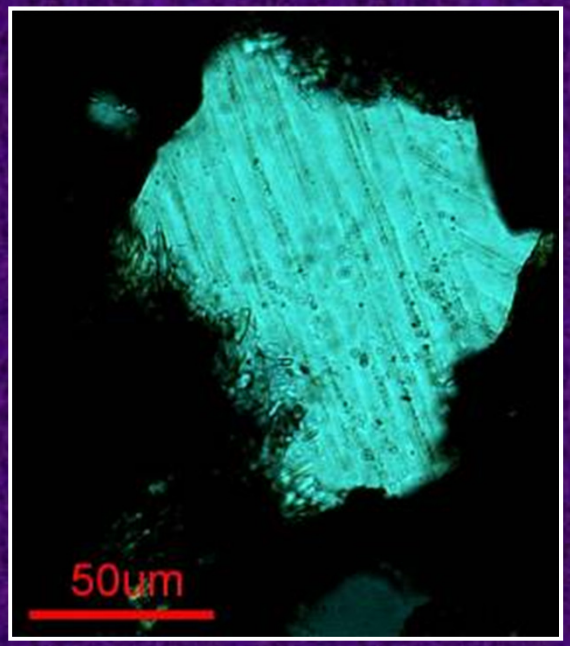




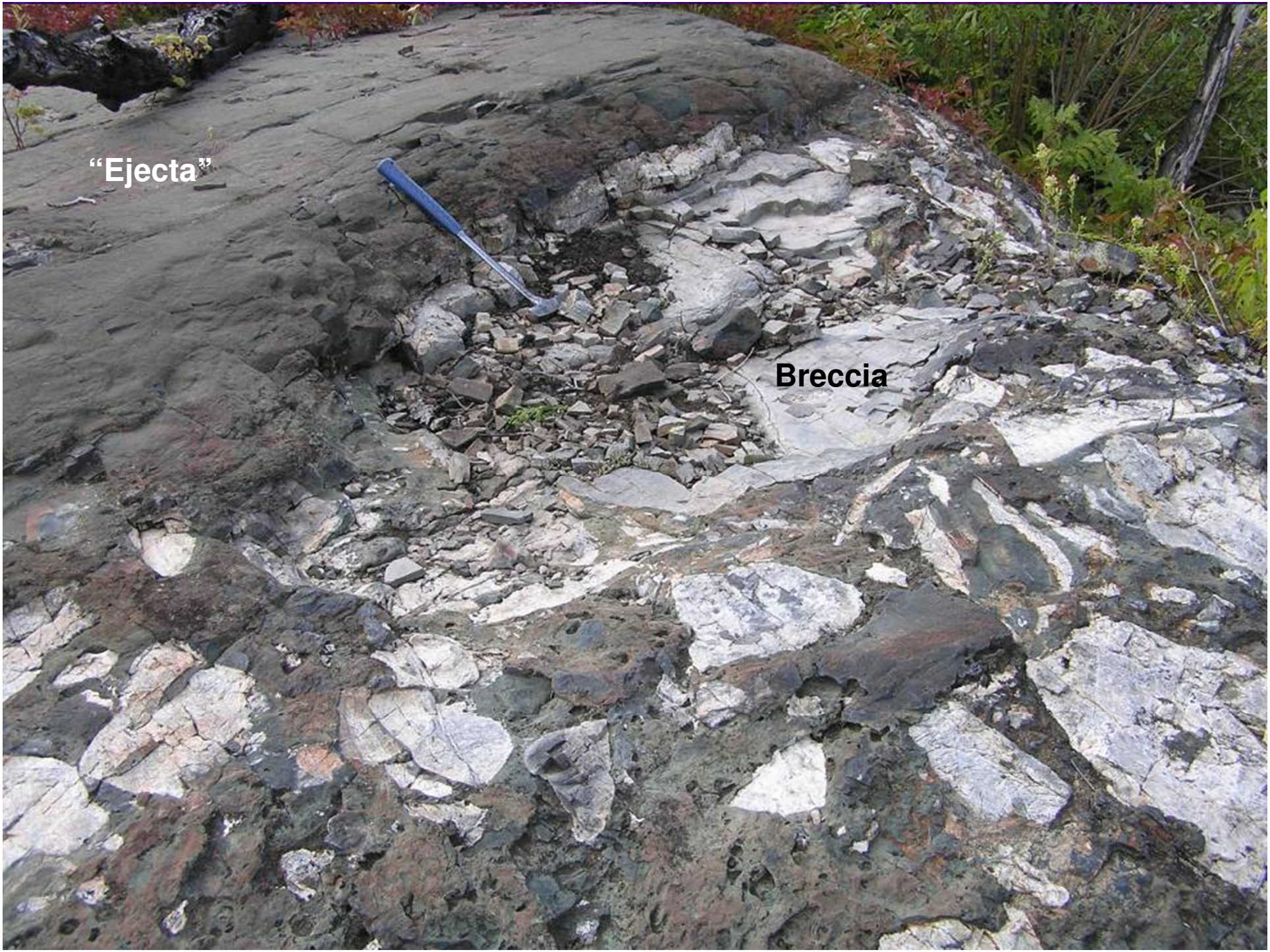
Salge, 2007; Chicxulub

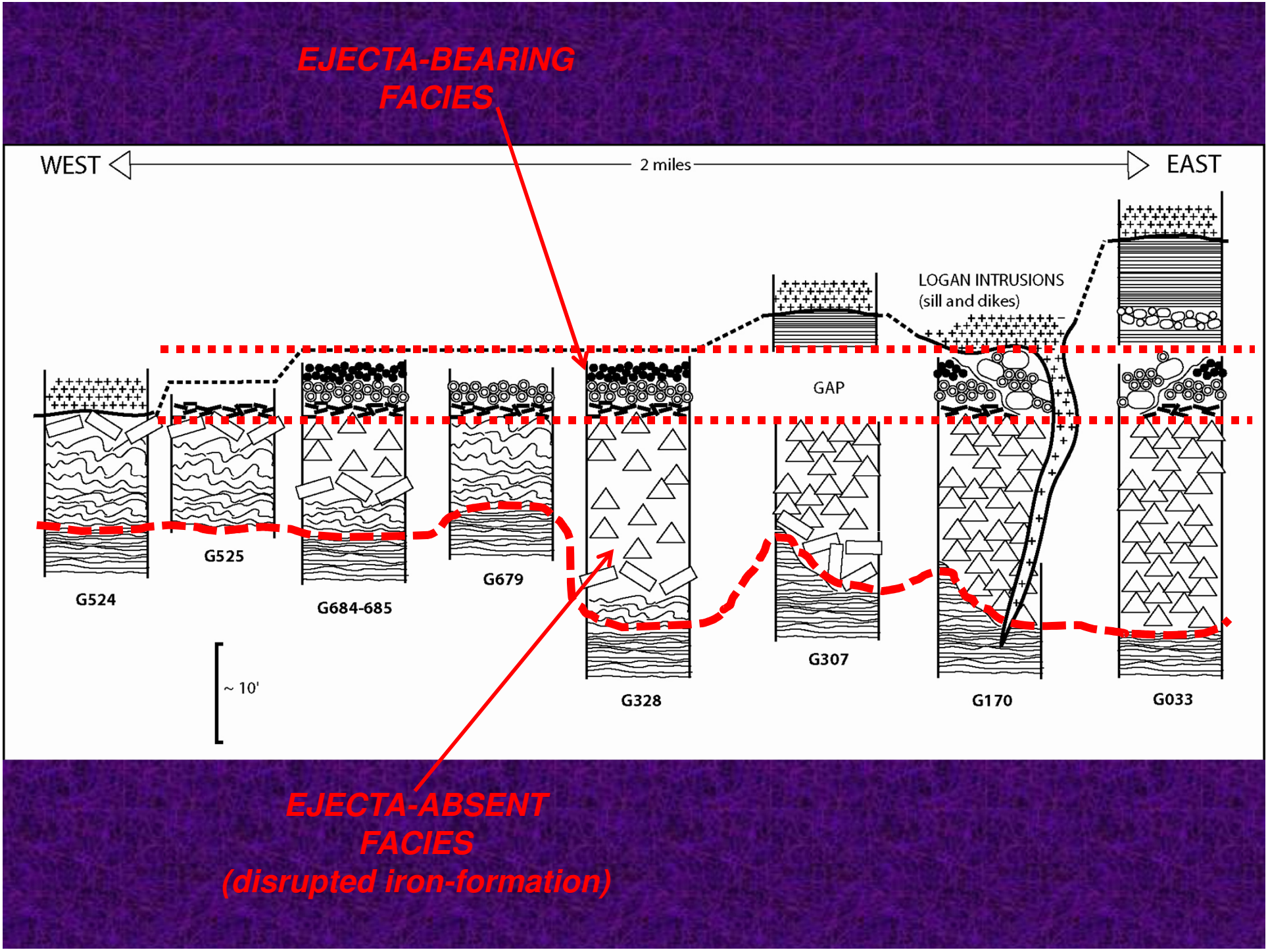
"SHOCKED QUARTZ" and DEVITRIFIED GLASS



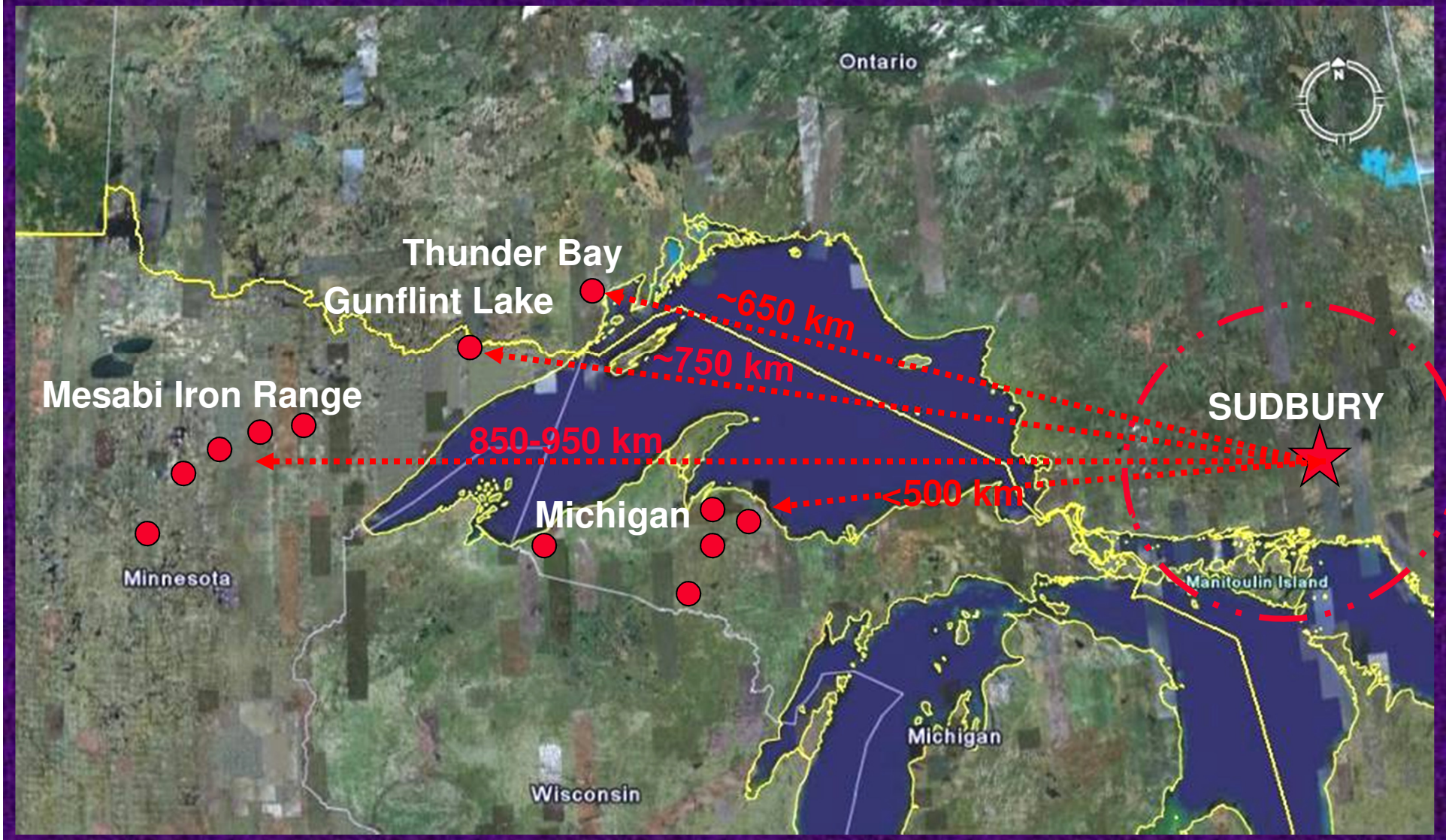


Imagery from Bill Addison and Bill Cannon


"Ejecta"
Breccia


EJECTA-BEARING FACIES
WEST
2 miles
EAST
LOGAN INTRUSIONS
(sill and dikes)
GAP
G524
G525
G684-685
G679
G328
G307
G170
G033
~ 10'
EJECTA-ABSENT FACIES
(disrupted iron-formation)

"SUDBURY IMPACT LAYER"
Localities in the Lake Superior Region



Google Earth 2008

CONTEXT FOR INTERPRETATION…

www.lpl.arizona.edu/impacteffects

Collins and others, 2005

CALCULATED ARRIVAL TIMES FOR EFFECTS AT GUNFLINT LAKE
(770 km from Sudbury target zone)

1) ~13 seconds—***Fireball***

2) ~2-3 minutes—***Earthquake*** (magnitude >13 at Sudbury)

(New data estimates magnitude 13 at Chicxulub)

3) ~5-10 minutes—***Airborne ejecta arrives*** (~1-3 m thick , fragments < 1 cm)

4) ~40 minutes—***Air blast*** (compression wave, wind speeds >1400 mph)

5) ~1-2 hours—***Tsunami*** (likely the first of several)

6) Post-impact ***environmental changes*** (almost certainly GLOBAL)

EVENT → RESULT → GEOLOGIC EVIDENCE

1) EARTHQUAKE →Brecciated and folded substrate

2) EJECTA SURGE → microbreccia, and SUEVITE PLUME → fall-out of layered lapilli and gritstone

3) TSUNAMI (reworks upper breccia and lapilli)→ Rounded breccia with lapilli

CHICXULUB IMPACT ESTIMATES

Projectile diameter: **12.00 km (= 7.45 miles)**
Projectile Density: **3000 kg/m^3**
Impact Velocity: **20.00 km per second**

Final Crater Diameter: **154 km (= 95.4 miles)**
Final Crater Depth: **1.35 km (= 0.836 miles)**
Target melted or vaporized is 4660 km^3 = 1120 miles^3
Melt pool thickness is **808 meters (= 2650 feet)**.

Marcus, Melosh, and Collins, 2010

Estimate of impact-generated S-waves at Chicxulub:

>15m vertical ground motion at 1000km from target
>1m vertical ground motion at 7000km from target

Schulte and others, 2011 (Sedimentology)

IMPORTANCE OF EJECTA STUDY

1) Unique and global time-line for depositional events.

2) No other impact deposit is this old and this complete

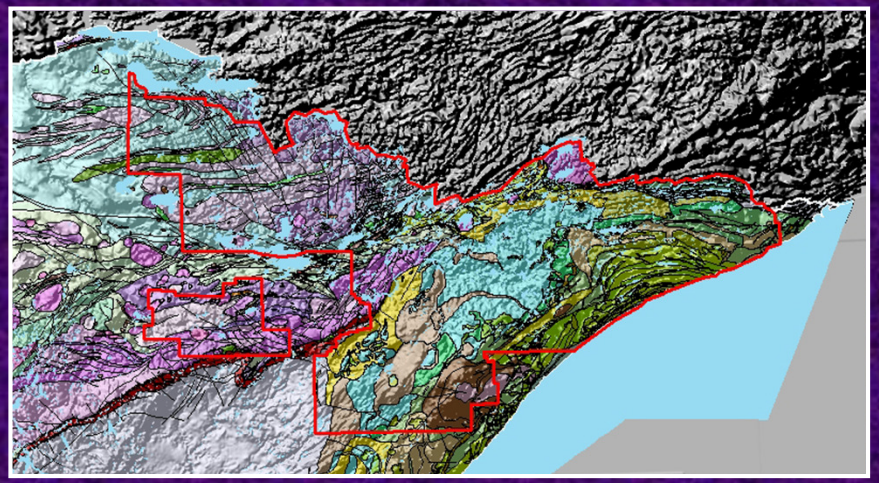
3) Ejecta blanket reveals something about the depositional environment.

4) Ejecta blanket relates to size and composition of impactor.

5) Each locality adds incrementally to the story of terrestrial impact.

USE OF GEOLOGIC DATA

from the Superior National Forest



1) Contributes to understanding of early crust

2) Improves the evolving geologic picture of BWCA

3) Can extrapolate features to other regions

4) Bedrock relates to regional topography, hydrology, and biology

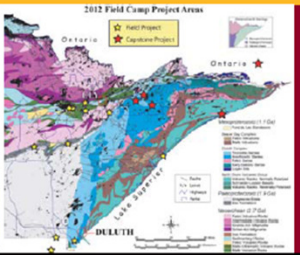
5) Provides cursory data for property valuations

6) Comprises the "base layer" for Environmental Impact Studies

7) Perfect "training ground" for geology students

Precambrian Research Center
University of Minnesota Duluth

University of Minnesota Duluth
PRECAMBRIAN
July 8 - August 17, 2012



Shield Yourself! **Join us for the sixth season of the "most unique geology field camp in North America". The Precambrian Research Center at the University of Minnesota Duluth offers a six-week field camp in the picturesque forests northeastern Minnesota, including the Boundary Waters Canoe Area Wilderness. This camp highlights mapping methods best suited to field studies of the diverse Precambrian terranes comprising the Canadian Shield.**

"Those who see the most rocks win" (Murray Hitzman, Professor, Colorado School of Mines, Society of Economic Geologist Newsletter, v. 84, January 2011)

A major goal of this camp is to address the alarming shortage of geologists adequately trained in basic field mapping skills, especially in the unique and challenging terranes of the Precambrian.

This field camp is open to **undergraduate** juniors and seniors from accredited geology programs, as well as graduate students and professional geologists (if space is available). Students interested in pursuing field-based **graduate research** of Precambrian geology or in seeking entry-level jobs in the **minerals exploration industry** will particularly benefit from this field camp. Many of our former students have secured employment in the minerals industry or have gone on for post-graduate degrees in geology.

Program Description

COST: **$3200** includes tuition, fees, room, and board. No additional non-resident fees.

CREDITS: Students will receive 6 semester-based, transferable credits for this UMD undergraduate course (GEOL 4500, Sec. 2).

PREREQUISITES: Students will be required to have taken a semester of petrology and structural geology or equivalent courses.

FACILITIES: Students will be housed in dormitories and provided most meals in cafeterias at the University of Minnesota Duluth during weeks 1, 2 & 6 and at Vermilion Community College in Ely, MN during weeks 3 & 4. The capstone mapping projects (week 5) will involve primitive camping or cabin lodging.

To Apply

Application forms and additional information may be obtained from the PRC field camp webpage:
www.d.umn.edu/prc/fieldcamp

QUESTIONS?
CONTACT:
Dr. Jim Miller, PRC director
EMAIL:
prc@d.umn.edu
TELEPHONE:
218-720-4355
ADDRESS:
Precambrian Research Center
UMD-Natural Resources Research Institute
5013 Miller Trunk Highway
Duluth MN 55811

Field Camp Highlights

- Field mapping in diverse Precambrian terranes, including:
  - Deformed metasedimentary rocks
  - Layered mafic intrusions
  - Plateau lavas and subvolcanic intrusions
  - Banded iron-formation sequences
  - Archean granite-greenstone belts
  - Large-scale Archean shear zones
- Mapping at various scales - outcrop (1:250) to quadrangle (1:24,000)
- Recognizing metamorphic grade, deformational fabrics, alteration assemblages, and ore mineralization in the field
- Acquisition and interpretation of field geophysical data
- Glacial deposit mapping and introduction to drift prospecting
- Drill core logging of iron formation, gabbro and greenstone
- Drift mapping in an underground iron mine (1/2 mile below surface)
- GIS compilation of field data (in ArcGIS) and digital map-making (Illustrator)
- CAPSTONE MAPPING PROJECT – Field parties of 3-6 students and an instructor conduct detailed mapping in diverse geological terranes during week 5; most projects involve backwoods field work, primitive camping, and canoeing in a wilderness setting.

Staff

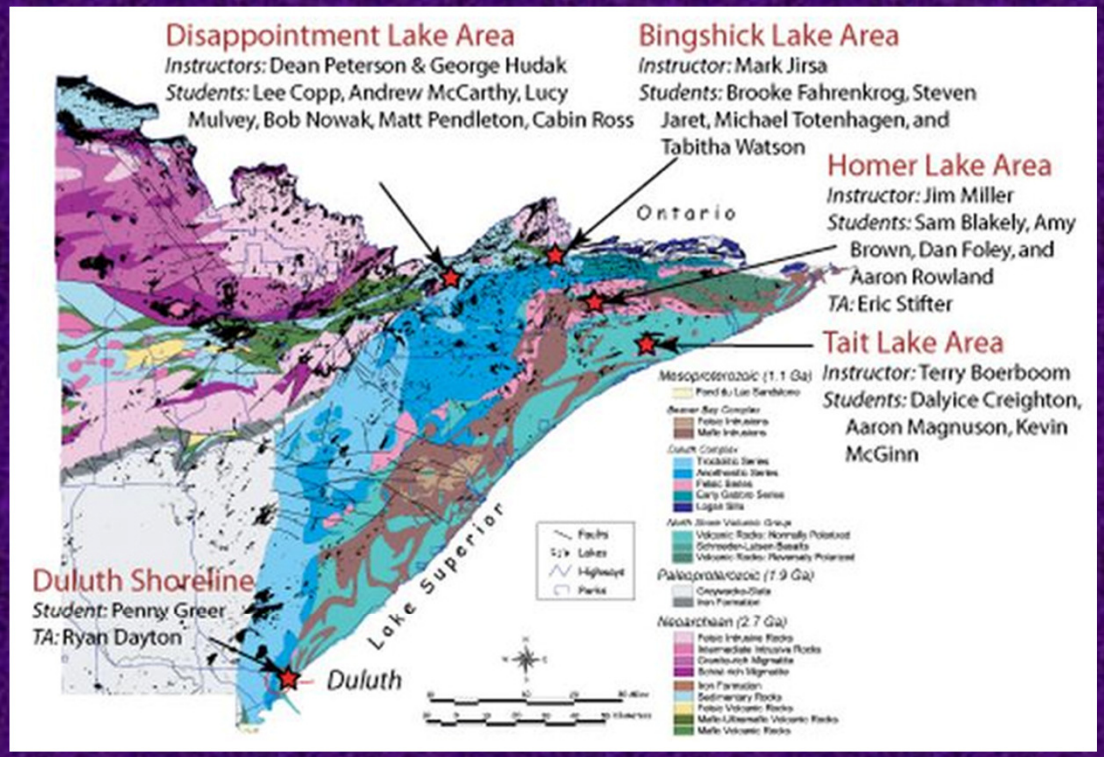
The PRC field camp is staffed by professional field geologists with over 200 years of combined mapping experience in Precambrian terranes.

Jim Miller, Igneous Petrology/Econ Geology, Dept of Geological Sciences-UMD
George Hudak, Volcanology/Econ Geology, Natural Res Research Inst-UMD
Dean Peterson, Economic Geology, Duluth Metals Ltd
Terry Boerboom, Precambrian Geology, Minnesota Geological Survey
Mark Jirsa, Precambrian Geology, Minnesota Geological Survey
Phil Larson, Glacial Geology/Economic Geology, Duluth Metals Ltd
Marsha Patelke, Sedimentology/Stratigraphy, Natural Res Research Inst-UMD
Mark Severson, Economic Geology, Natural Resources Research Inst-UMD
Nigel Wattrus, Geophysics, Dept of Geological Sciences-UMD

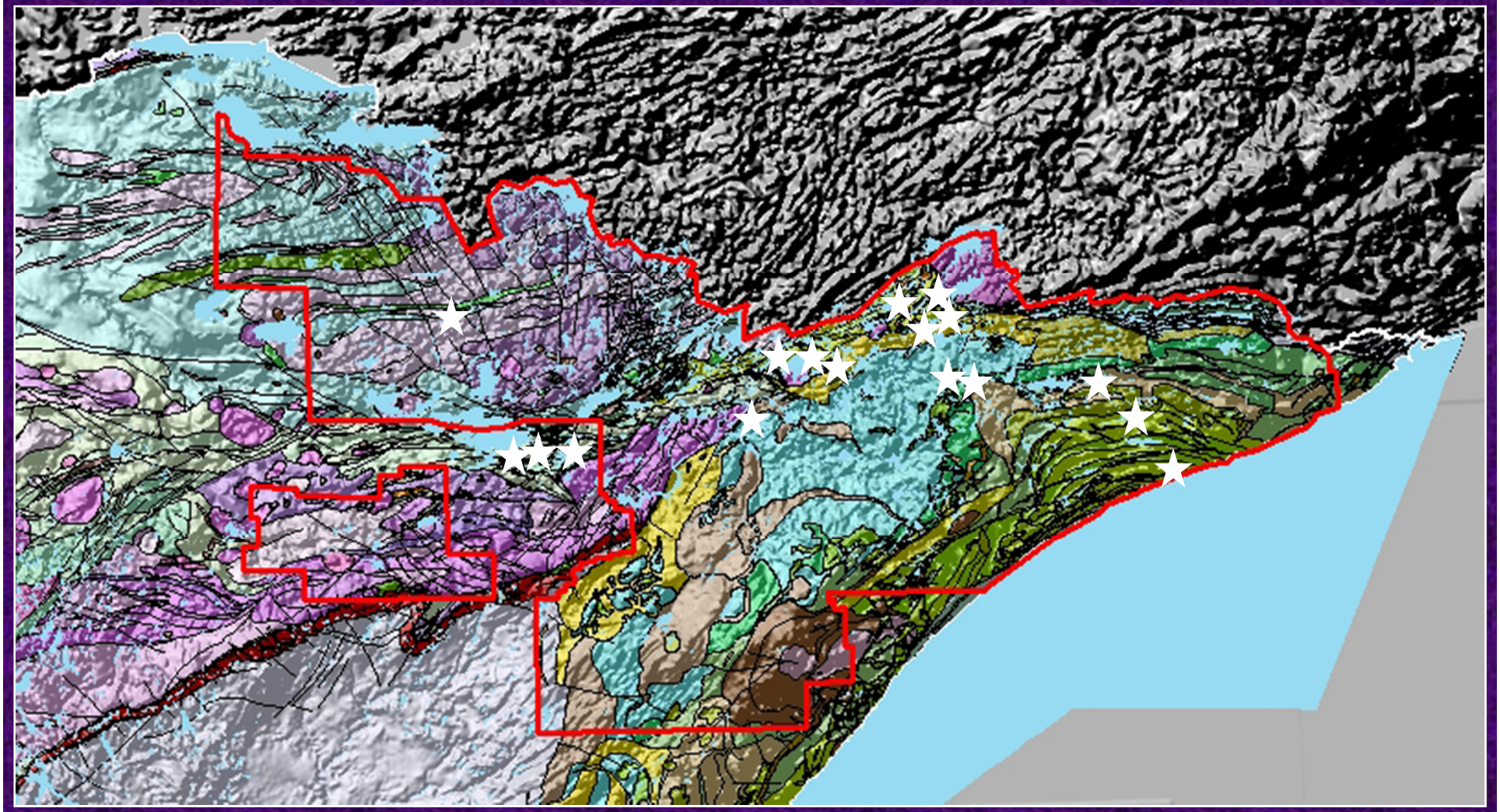
www.d.umn.edu/prc

FIELD CAMP

CAPSTONE MAPPING



★ Capstone mapping projects 2007-2011



WHAT'S NEXT?

Dunka Pit, Mesabi Iron Range, 2006

1) Regional-scale mapping has been conducted in most areas; however, DETAILED MAPPING in complex and critical areas is on-going.

2) Quaternary (glacial sediments) geology may be useful