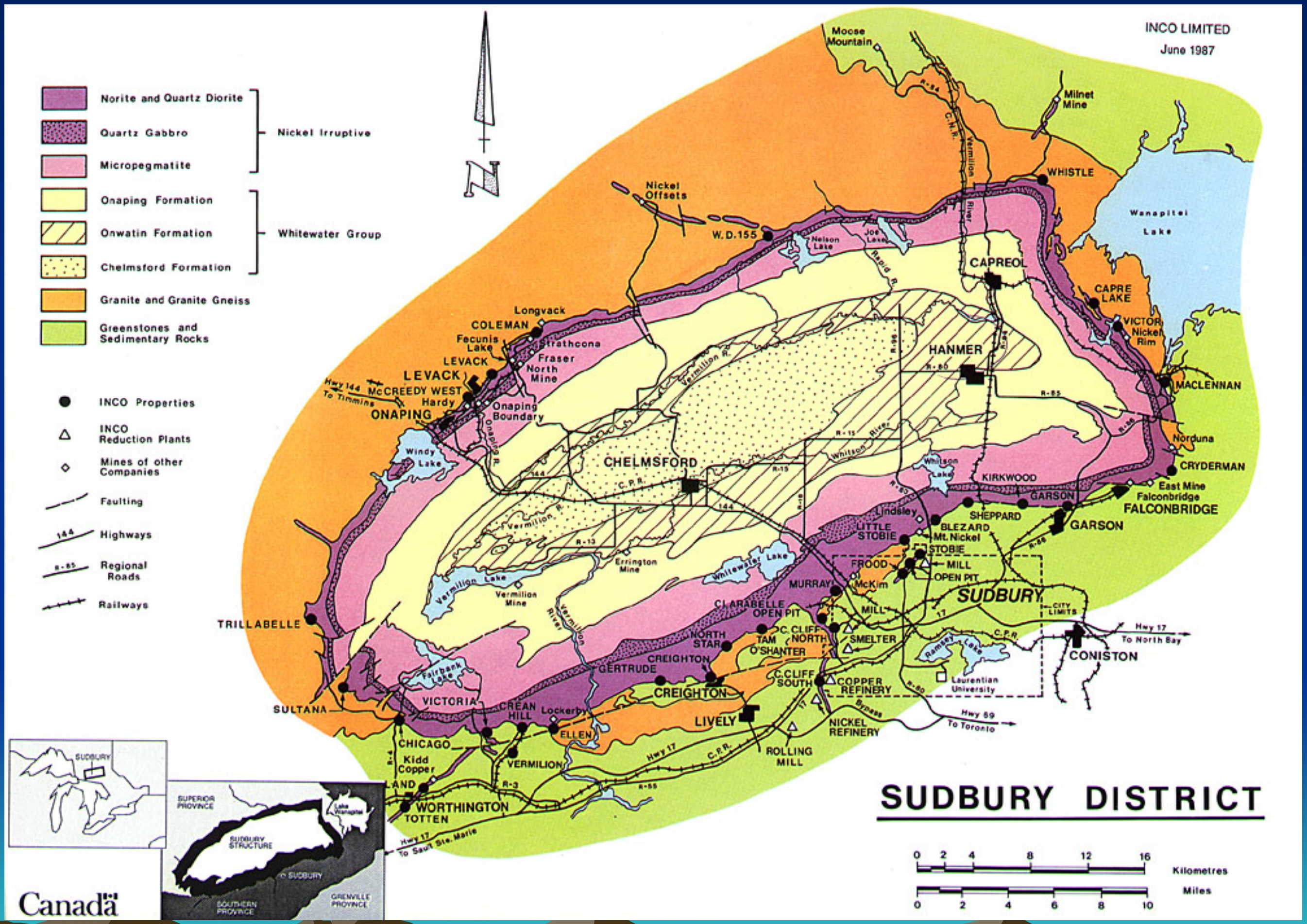
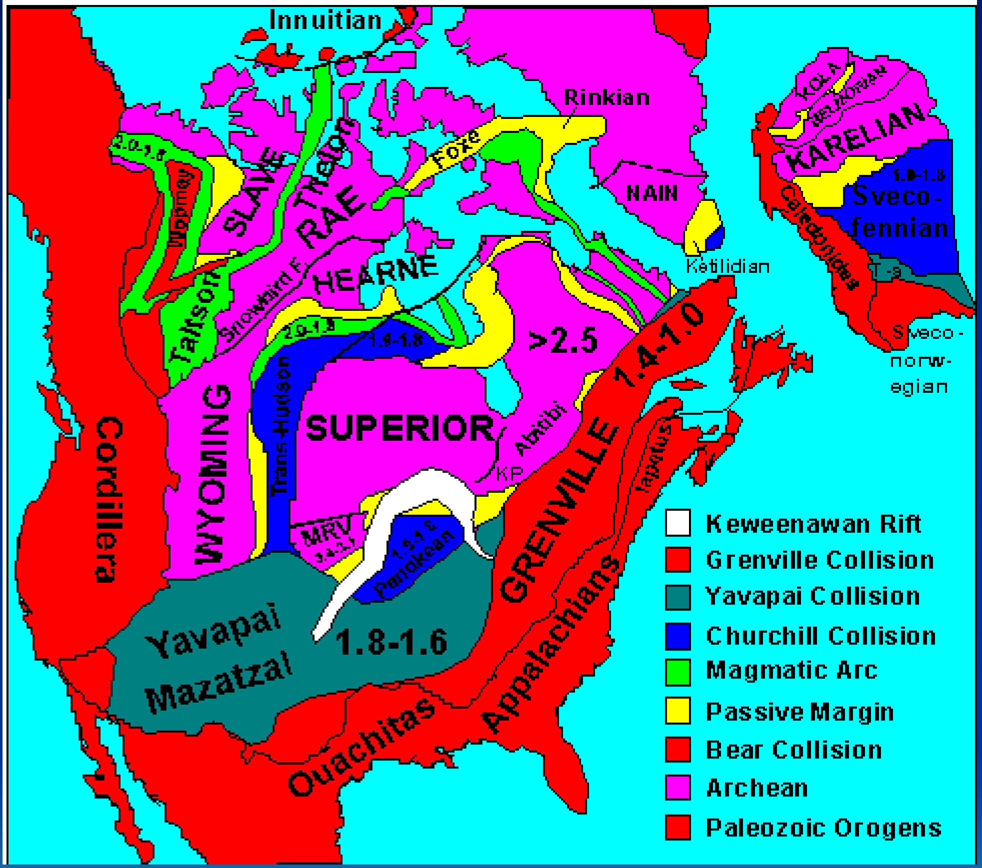
Geology of Sudbury Basin



Size

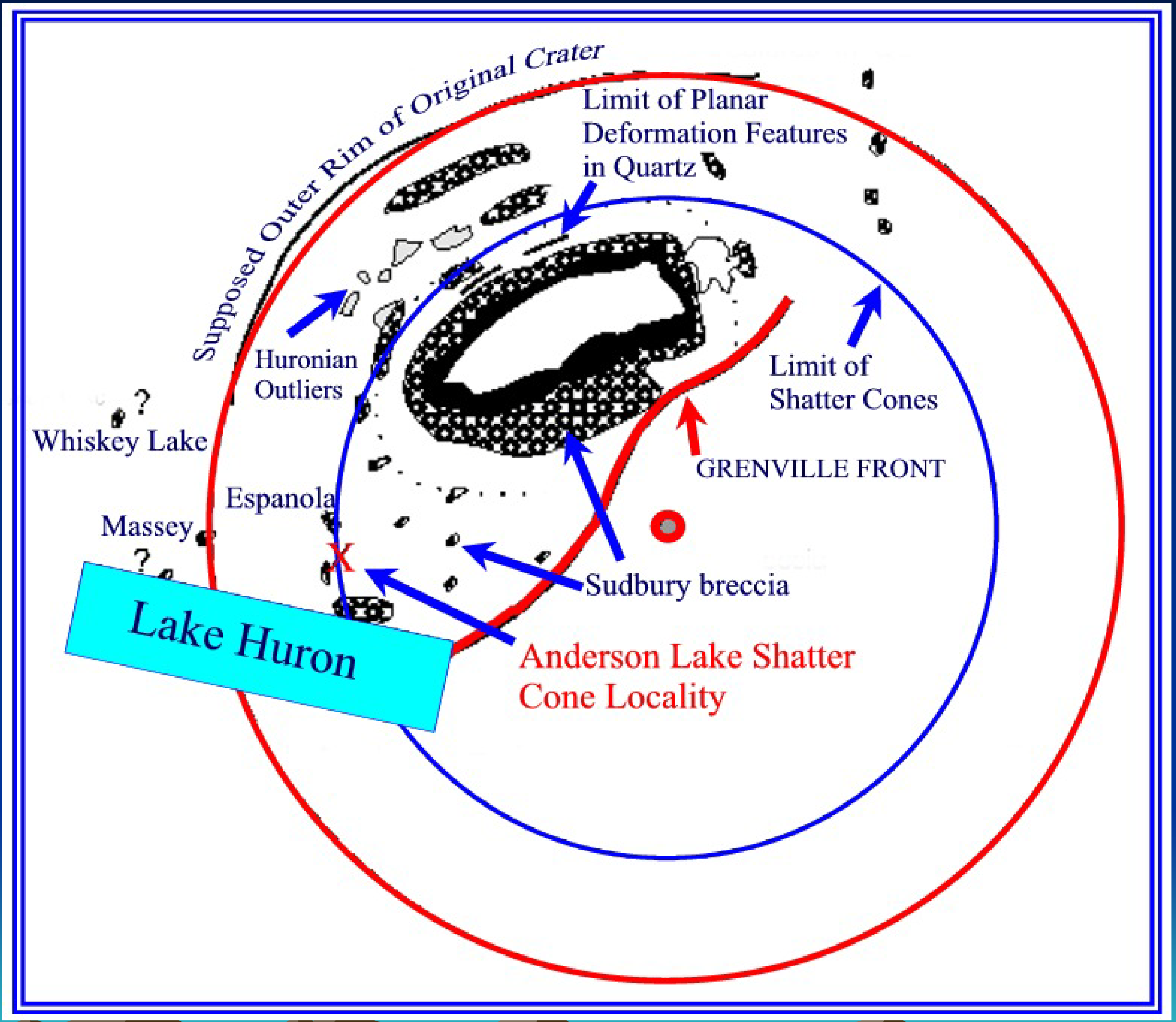
- Sudbury Basin is 62km long, 32 km wide and 15 km deep.\
- Also located near the confluence of 3 major plates in the North American Craton, the Superior, the Grenville and the Southern.



Innuitian
Rinkian
NAIN
Ketilidian
SLAVE
Thelon
RAE
Foxe
HEARNE
Snowbird F.
Taltson
Wopmay
2.0-1.8
Cordillera
WYOMING
Trans-Hudson
SUPERIOR
>2.5
Abitibi
KP
MRV
Penokean
Yavapai
Mazatzal
1.8-1.6
GRENVILLE
1.4-1.0
Appalachians
Iapetus
Ouachitas
KOLA
KARELIAN
Sveco-
fennian
Caledonides
Sveco-
norw-
egian
Keweenawan Rift
Grenville Collision
Yavapai Collision
Churchill Collision
Magmatic Arc
Passive Margin
Bear Collision
Archean
Paleozoic Orogens

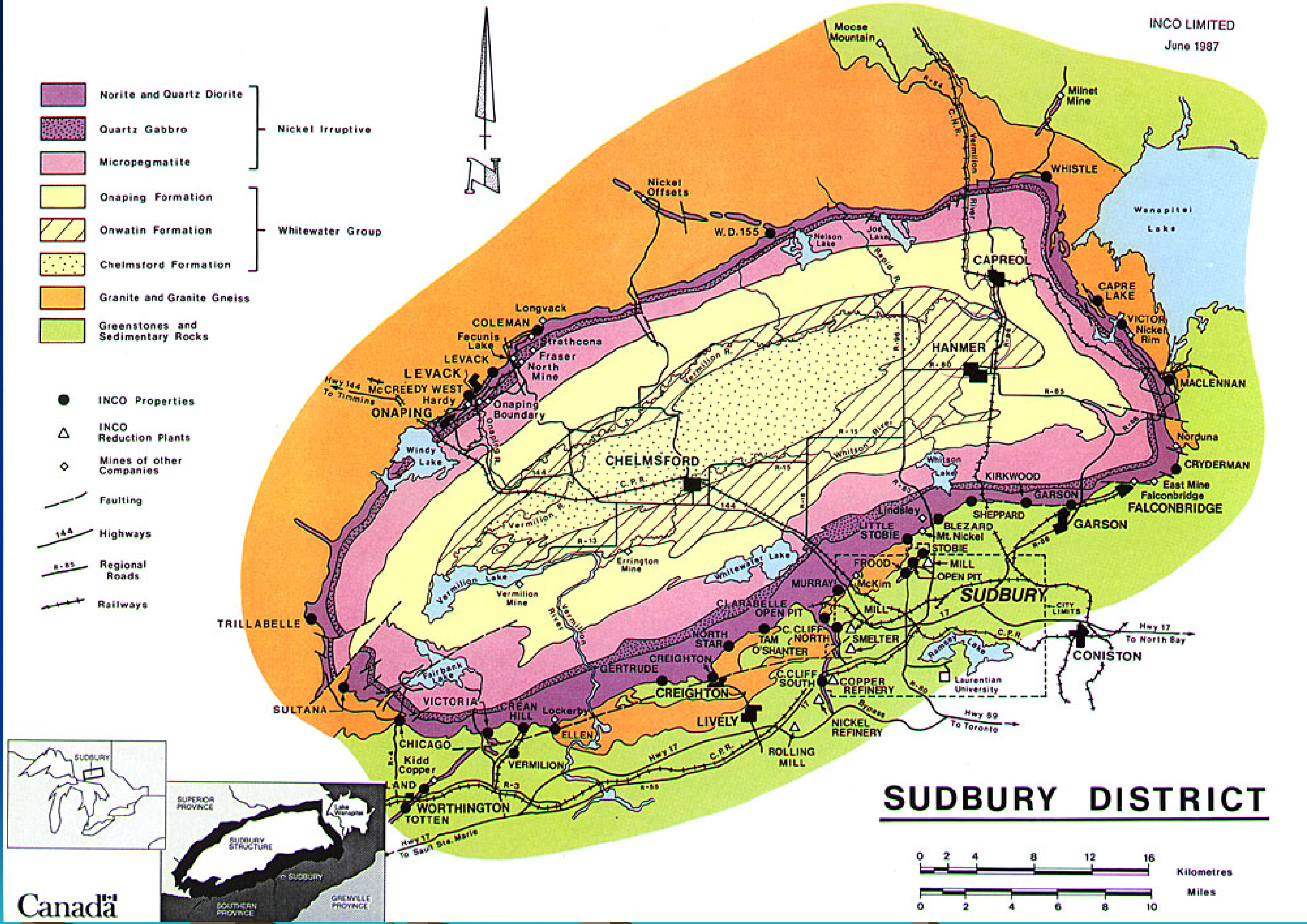
Origins

- The Sudbury Basin or Structure was formed by the impact of a 10 km meteorite.
- This is the second largest impact crater in the world.
- The original crater is guessed to be about 250 km in diameter.
- Impact occurred about 1.85 billion years ago.
- Original crater altered by subsequent geologic processes


Supposed Outer Rim of Original Crater
Limit of Planar Deformation Features in Quartz
Huronian Outliers
Whiskey Lake
Limit of Shatter Cones
GRENVILLE FRONT
Espanola
Massey
Sudbury breccia
Lake Huron
Anderson Lake Shatter Cone Locality

Sudbury Igneous Complex

- Localized around the rim of the basin.
- Formed by the recrystalization of the impact melt (i.e. magma)
- Made up of mafic norite, felsic norite, quartz gabbro, and granophyre
- Source of most of the ores being mined due to slow cooling of magma.



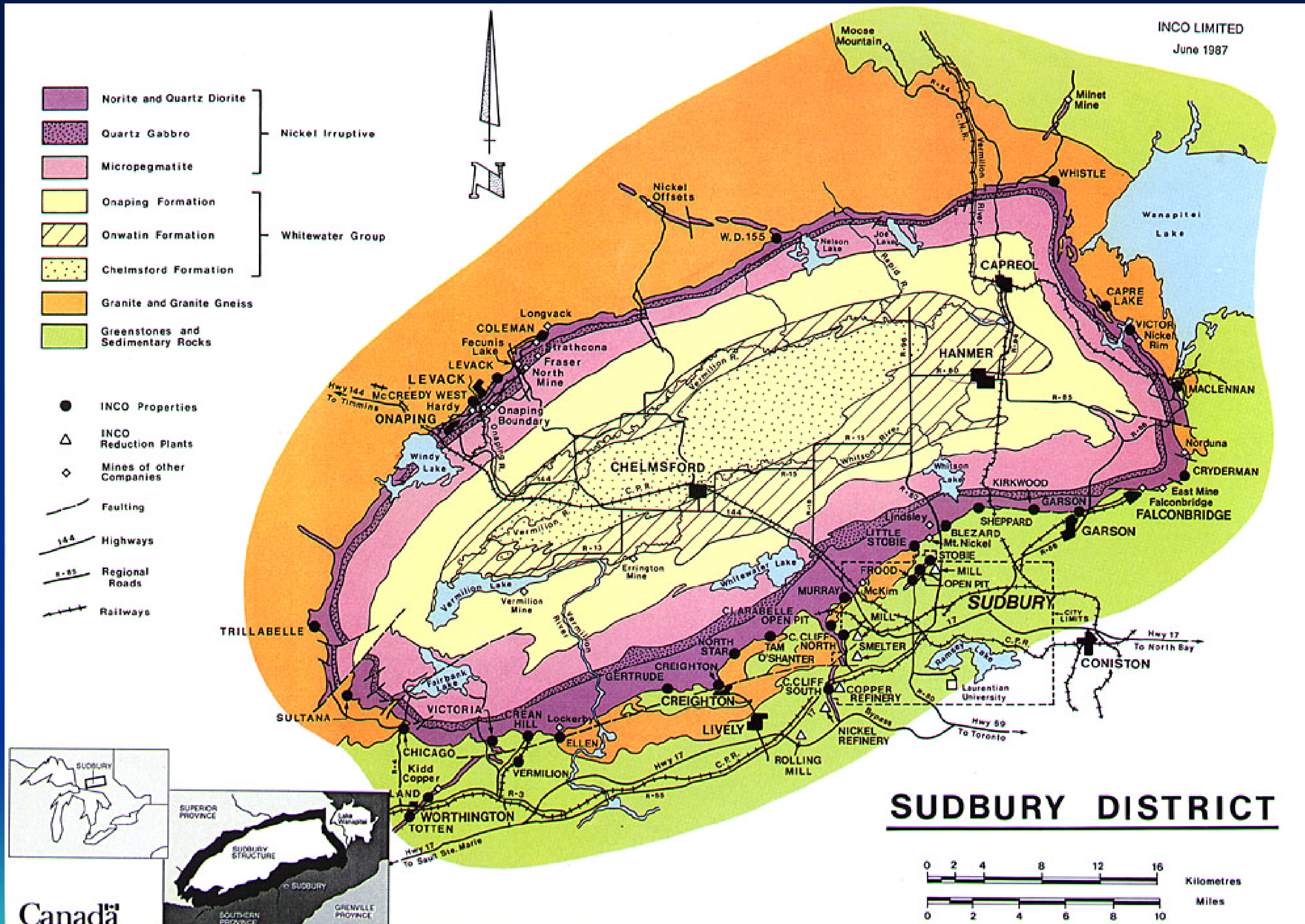
SUDBURY DISTRICT
INCO LIMITED
June 1987
Norite and Quartz Diorite
Quartz Gabbro
Micropegmatite
Nickel Irruptive
Onaping Formation
Onwatin Formation
Chelmsford Formation
Whitewater Group
Granite and Granite Gneiss
Greenstones and Sedimentary Rocks
INCO Properties
INCO Reduction Plants
Mines of other Companies
Faulting
Highways
Regional Roads
Railways
Kilometres
Miles
CHELMSFORD
CAPREOL
HANMER
SUDBURY
CONISTON
LIVELY
LEVACK
ONAPING
COLEMAN
WHISTLE
MACLENNAN
CRYDERMAN
FALCONBRIDGE
GARSON
CREIGHTON
TRILLABELLE
SULTANA
WORTHINGTON
TOTTEN
Wanapitei Lake
Windy Lake
Vermilion Lake
Whitewater Lake
Canada

Sudbury Igneous Complex

- Two plutons, the Creighton and Murray, both of granite were brought to the surface after the impact.
- Both are along the south rim of the basin

The Whitewater Group

- Made up of breccia at the lowest layer.
- Also includes mudstone, siltstones.
- Very mineral rich and good for agriculture after weathering.
- This covers the floor of the basin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Highways
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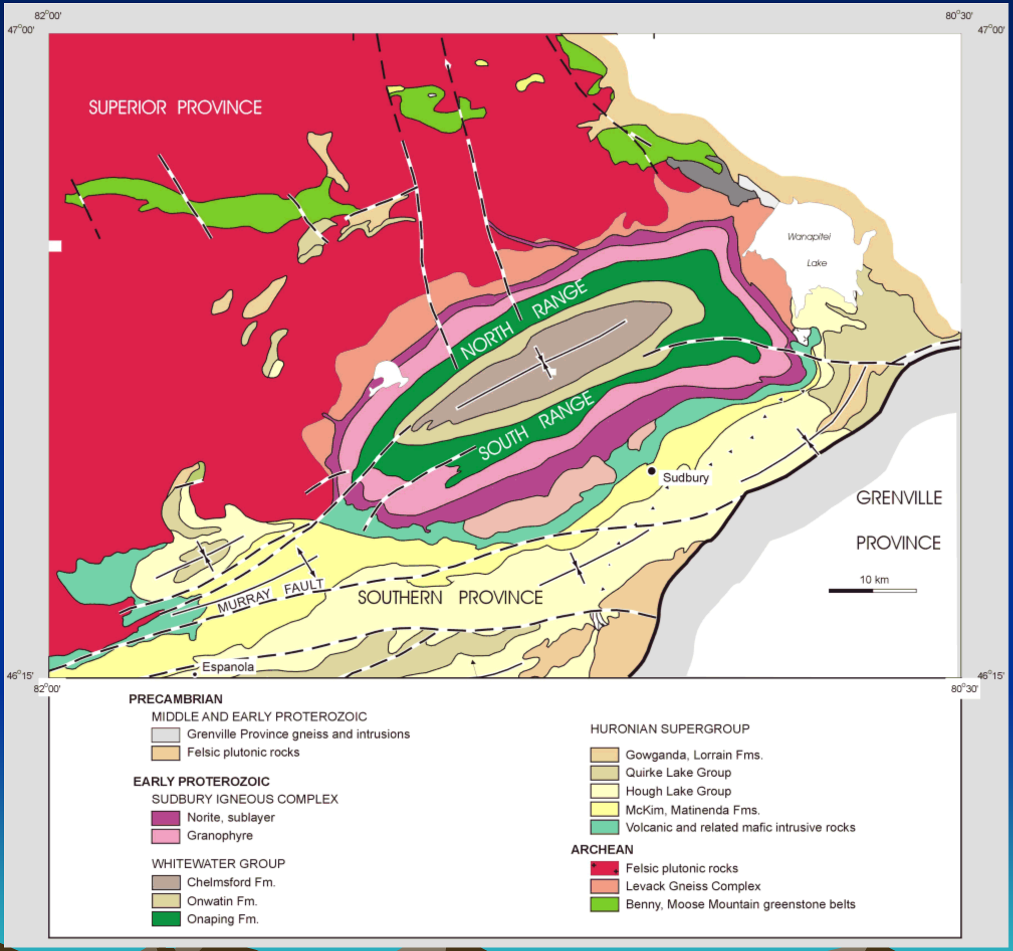
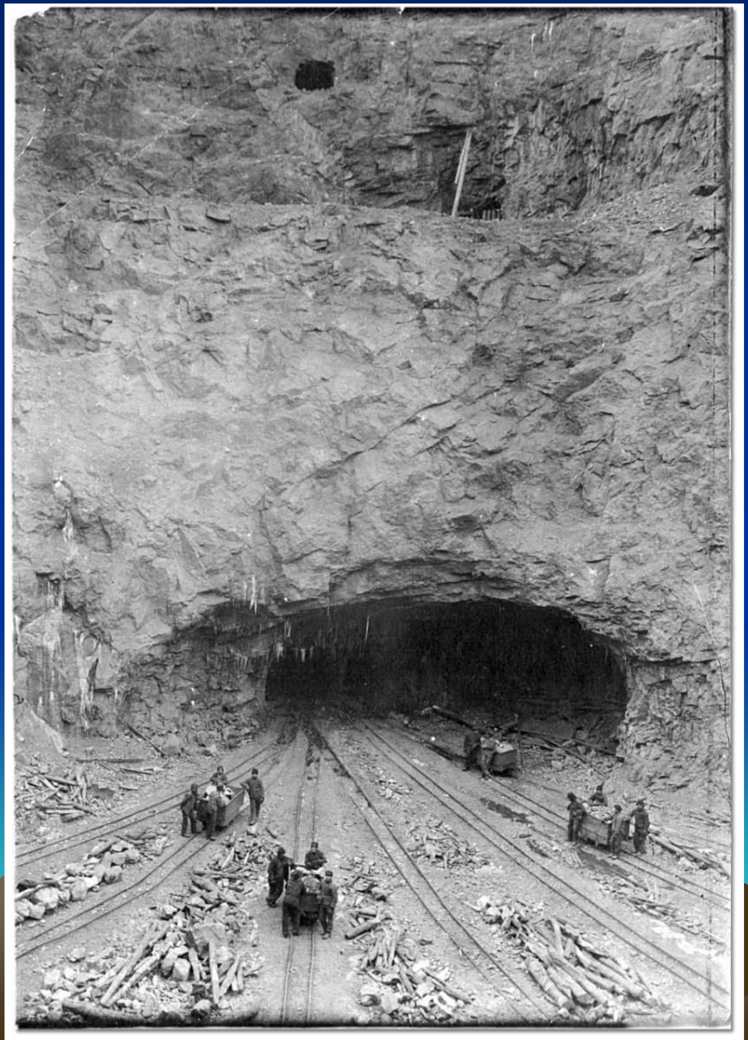
Railways
N
Moose Mountain
Milnet Mine
WHISTLE
Nickel Offsets
W.D.155
Nelson Lake
CAPREOL
Wanapitei Lake
CAPRE LAKE
VICTOR Nickel Rim
MACLENNAN
HANMER
Longvack
COLEMAN
Fecunis Lake
Strathcona
LEVACK
Fraser
North Mine
LEVACK
McCREEDY WEST
Hardy
ONAPING
Onaping Boundary
Hwy 144 To Timmins
Windy Lake
CHELMSFORD
Norduna
CRYDERMAN
KIRKWOOD
East Mine
Falconbridge
FALCONBRIDGE
GARSON
SHEPPARD
GARSON
Lindsley
BLEZARD
Mt. Nickel
LITTLE STOBIE
STOBIE
FROOD
MILL
OPEN PIT
McKim
SUDBURY
CITY LIMITS
MURRAY
Whitewater Lake
Errington Mine
Vermilion Lake
Vermilion Mine
TRILLABELLE
CLARABELLE OPEN PIT
MILL
SMELTER
NORTH STAR
TAM O'SHANTER
C.CLIFF NORTH
C.CLIFF SOUTH
COPPER REFINERY
Ramsey Lake
Laurentian University
CONISTON
Hwy 17 To North Bay
CREIGHTON
GERTRUDE
CREIGHTON
LIVELY
NICKEL REFINERY
Hwy 69 To Toronto
Fairbank Lake
SULTANA
VICTORIA
CREAN HILL
Lockerby
ELLEN
CHICAGO
Kidd Copper
VERMILION
ROLLING MILL
LAND
WORTHINGTON
TOTTEN
Hwy 17 To Sault Ste. Marie
SUDBURY DISTRICT
Kilometres
0 2 4 8 12 16
Miles
0 2 4 6 8 10
SUDBURY
SUPERIOR PROVINCE
SUDBURY STRUCTURE
SUDBURY
SOUTHERN PROVINCE
GRENVILLE PROVINCE
Canada

Faults



82°00'
80°30'
47°00'
47°00'
SUPERIOR PROVINCE
Wanapitei
Lake
NORTH RANGE
SOUTH RANGE
Sudbury
GRENVILLE
PROVINCE
10 km
MURRAY FAULT
SOUTHERN PROVINCE
Espanola
46°15'
46°15'
82°00'
80°30'
PRECAMBRIAN
MIDDLE AND EARLY PROTEROZOIC
Grenville Province gneiss and intrusions
Felsic plutonic rocks
EARLY PROTEROZOIC
SUDBURY IGNEOUS COMPLEX
Norite, sublayer
Granophyre
WHITEWATER GROUP
Chelmsford Fm.
Onwatin Fm.
Onaping Fm.
HURONIAN SUPERGROUP
Gowganda, Lorrain Fms.
Quirke Lake Group
Hough Lake Group
McKim, Matinenda Fms.
Volcanic and related mafic intrusive rocks
ARCHEAN
Felsic plutonic rocks
Levack Gneiss Complex
Benny, Moose Mountain greenstone belts

Mining and Rock Stability Issues in the Sudbury Mining District



Creighton Mine 1905

Why is Stability in Mining Important?

- Safety is #1 issue.

  October 7th, 2007, Creighton Mine in Sudbury district experienced 3.7 magnitude quake.

  -Result was rockbursts

  -Rockbursts a main cause of accidents in mines and particularly in the Sudbury District

Seismic Events in Sudbury Mines

- Causes and Consequences
- How Problems are being addressed

Mining Induced Seismic Activity and Rockbursts

- Preexisting stress fields can release energy in the form of seismic events
- Can lead to rockbursts
  - Rockbursts reported in Sudbury as early as 1935

Result of a rockburst

Rockbursts

- Two Categories
  - Type I : Direct result of mining excavation
  - Type II : Occur at a distance away from mining, not in direct contact with applied stresses

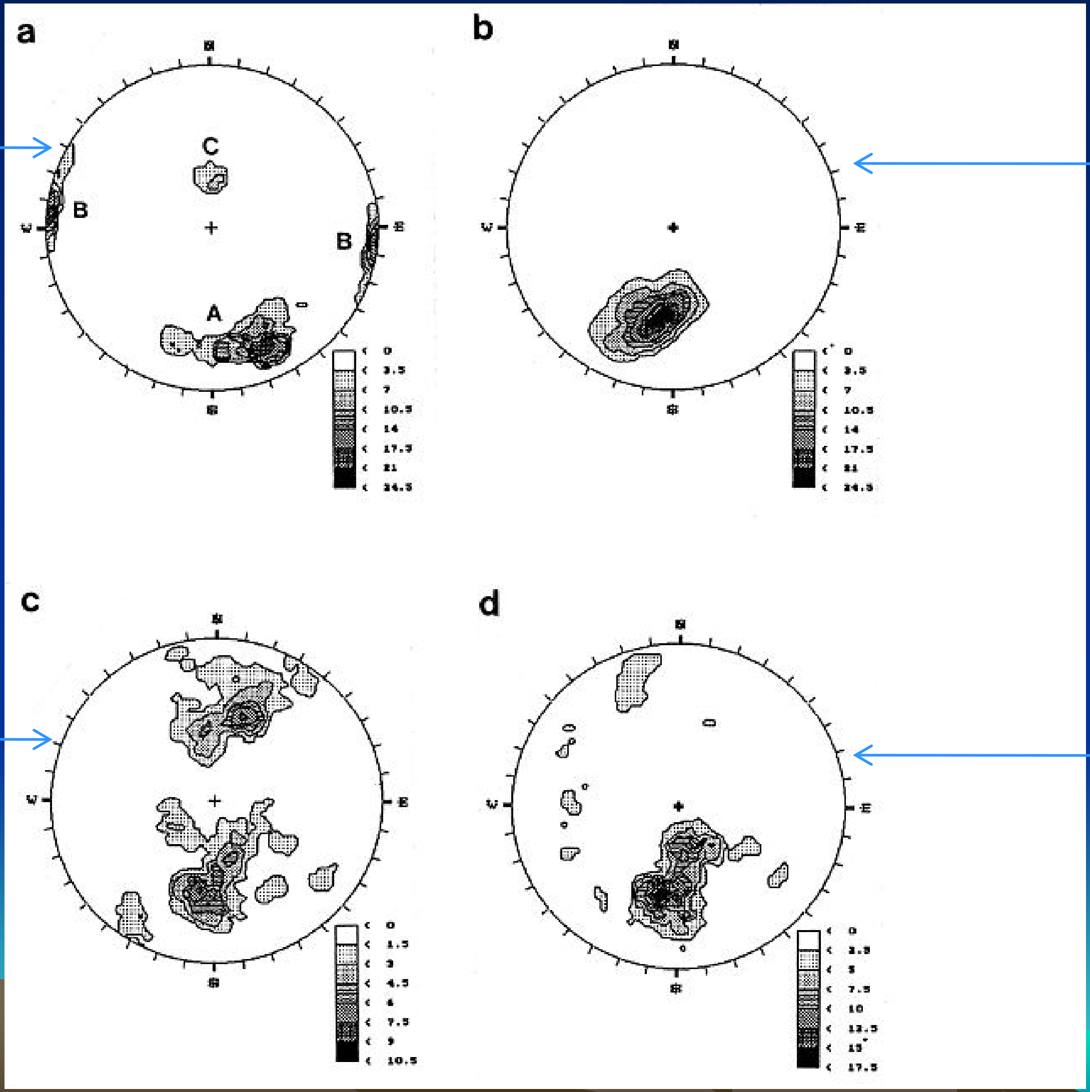
Behavior of Microseismic Events

- Microseismic events align themselves with geologic structure; i.e. they follow the fault orientation.
- This was determined from study of the Strathcona Mine in the Sudbury district

Stereonets showing seismic alignment with fault orientation

Fracture poles

Orientation of seismicity



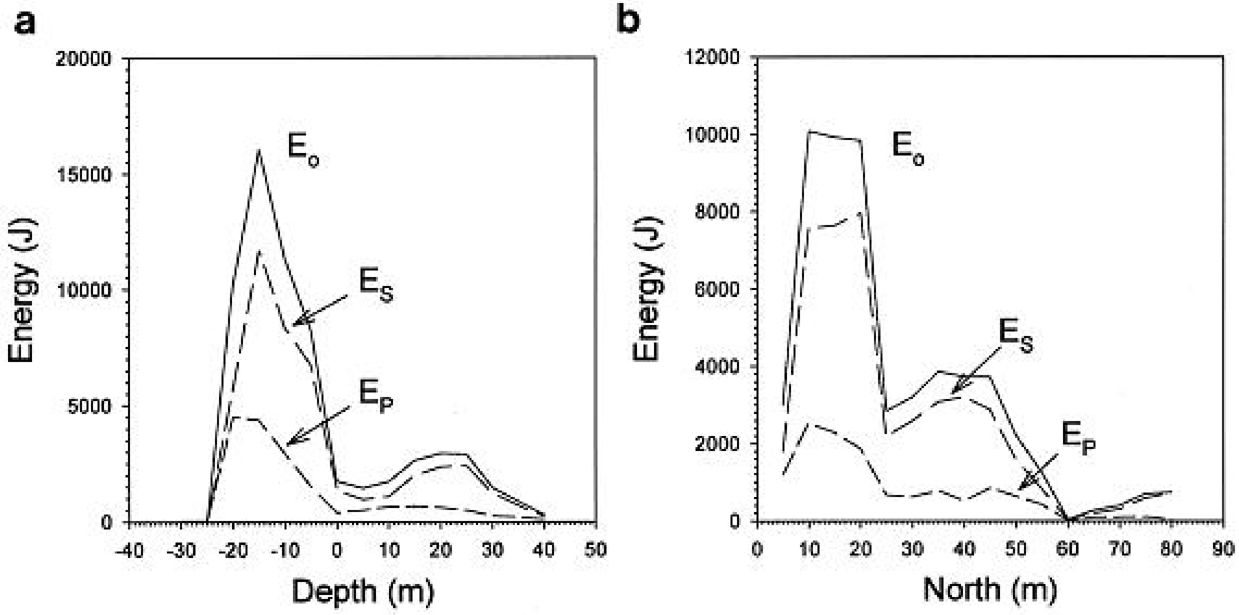
Fault-plane solutions

Failure planes

Behavior of Microseismic Events

- Wave energy (P and S waves) gives insight to behavior
- From same study of Strathcona Mine, three energy regions were discovered:
  - (1) P-wave dominated
  - (2) S-wave dominated
  - (3) Combination

Energy Regions in Strathcona Mine



Implications of Energy Regions

- Events close to excavation dominated by *non-shear failure.*
- Events further away dominated by *shear failure.*

Solutions to Rock Stability Issues

- “Bulk” Method of mining has become popular
  - 95% of ore from Creighton Mine obtain by this method
  - Specific method: “Slot-Slash”
    - Used by Vale Inco

“Slot-Slash” Mining Method

- Mininmizes number of needed blasts
- Increases number of available blasting faces
- Reduces seismicity

Vale Inco at the Creighton Mine in Sudbury

Safety Measures

- Procedure after excavation:
  - Vale Inco implemented following procedure for Creighton Mine:
    - Exit vicinity
    - Allow for seismic decay
      - Most mining induced seismicity from slipfaults right after blast

Telemining in Sudbury District

- Excavations are made remotely
  - Keeps miners out of potential hazardous situations like rockbursts
- Complications:
  - Difficult to implement due to current rock structure
    - Needs to be modified for accomadations.

Telemining Technology

Conclusion

- Rock stability and microseismic events not uncommon in Sudbury
- Research and emerging technology is increasing safety and efficiency

Environmental Affects

- Three main factors in environmental damage:
  - Roast Yards
  - Logging
  - Smelting

Roast Yard

- First step to processing nickel-copper ore
- Fumes are dispersed at ground level
- Ore heated in air
  - Sulfide oxidizes
- Ore burns for 2+ months
  - Sent to furnace for smelting

Logging

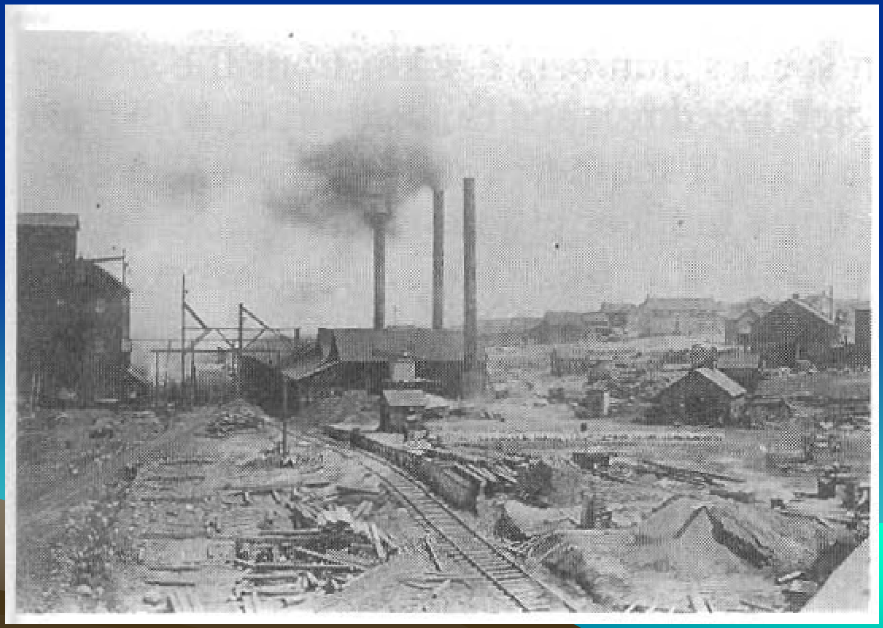
- Heavy logging to support burning

FIGURE 2.2. White pine stumps on a barren stony hillside, 3.2 km northeast of the Copper Cliff smelter.

FIGURE 2.3. White cedar stumps on a barren peat area, Happy Valley, close to the Falconbridge smelter.

Smelting

- Stacks disperse fumes over a large area
- Smelter fumes contain:
  - Copper particles
  - Nickel particles
  - Sulfur dioxide
- Fumes affect the landscape long term



Vegetation damage

- First assessment, 1945: Murray and Haddow
  - Tree foliage severely burned
    - 35km NE
    - 20km N
    - 20 km S
  - Higher mortality/decreased growth
    - White pine: up to 40 km
    - Floor species: up to 20 km

Vegetation damage

- 1974: Whitby and Hutchinson
  - Proved that soil inhibits plant growth
    - Toxic components were water-soluable
      - -Copper
      - Nickel
      - Aluminum
      - Cobalt (at lower levels)

Vegetation damage

- 1981: Amiro and Courtin (coinciding with Struik's (1973))
  - Provide first detailed quantitative description of vegetation surrounding smelters
    - "Barren" area
      - Soil pH < 4.0
      - Land closest to smelters
    - "Semi-barren" area
      - Land more distant from smelters

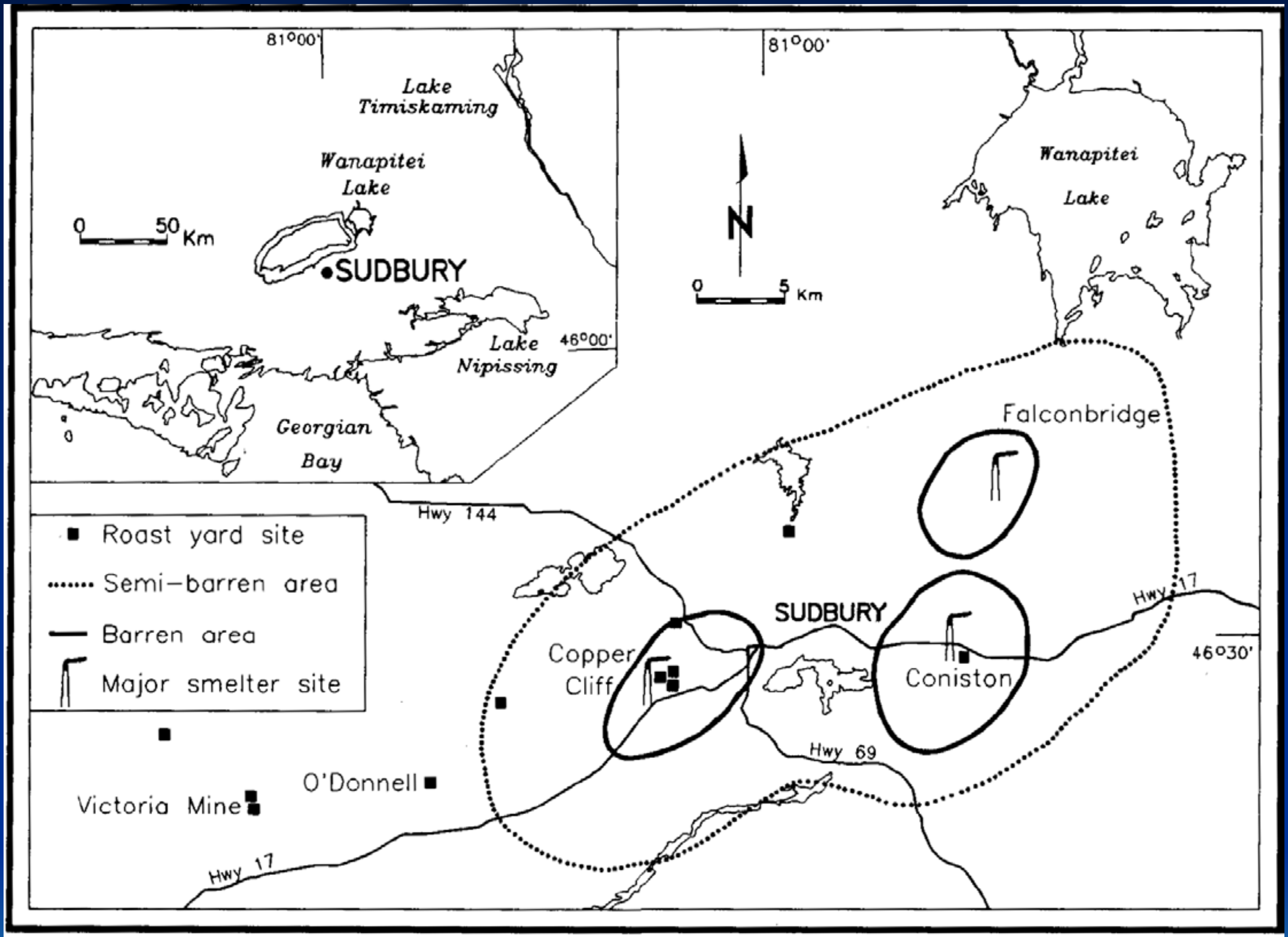


FIGURE 2.7. The location of the Sudbury Basin and the major sites of roasting and smelting activity and Struik's (1973) "zones of site and vegetational stability" based on air photographs.

Impacts

- Logging
  - Erosion
  - Extreme frost action
- Metal Deposition
  - Toxicity
  - Soil pH interaction with nickel and copper
- Sulfur dioxide fumes
  - Sulfuric acid → acid rain
  - Soil pH relative to fume zone

Logging

- Soil erosion begins
  - Glacial till restrains/protects complete erosion of many areas
    - Coarse material (stones and boulders) still in place today
  - Frost action
    - Caused additional washing out of fines

Metal Deposition

- Metal contamination
  - Toxicity
    - Copper and nickel concentrations higher near smelters
    - Soil pH also higher near smelters
  - pH and nickel/copper interaction

TABLE 2.1. Chemical characteristics of surface soils from the sulfur dioxide fumigation zones described by Dreisinger and McGovern (1971), as illustrated in Figure 2.8. Sampling was conducted in 1969 with 10 sites sampled in each zone.

Fumigation zone	Mean pH ± SD	Mean total copper (mg/kg ± SD)	Mean total nickel (mg/kg ± SD)
Heavy	3.8 ± 0.3	1250 ± 500	1930 ± 900
Moderate	4.3 ± 0.1	900 ± 300	750 ± 300
Light	4.7 ± 0.1	320 ± 80	400 ± 120
Perceptible	5.0 ± 0.2	200 ± 30	420 ± 120
None	5.0 ± 0.2	100 ± 20	200 ± 30

Sulfur Dioxide Fumes

- Largest affect on environment
  - Impacts largest area of land
  - Long term impacts
- Damages land and water environments
  - Land damage: peaked in 1960s
  - Water damage: peaked in 1970s

Sulfur Dioxide Fumes

- Contributes to erosion issues
  - Destroys both tree and floor plant life
- Some plant life thrives in high pH soil
  - White birch
  - Wild blueberry

Today

- New technology has greatly improved the area
  - Improved desulphurization
  - Furnace developments in smelters

- In 1993 SO_2 emissions were less than one fifth (55 kt) of the 1970 output (320 kt) (Falconbridge)

- SO_2 reduction by 87% from 1972 to 1994 (INCO)

Questions???