Exploration07

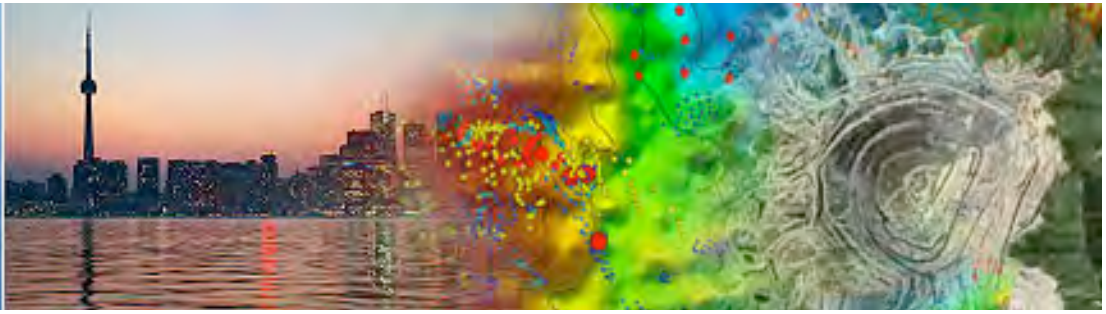
Workshop 3

Indicator Mineral Methods in Mineral Exploration

Sunday, September 9, 2007

Association of Applied Geochemists (AAG)

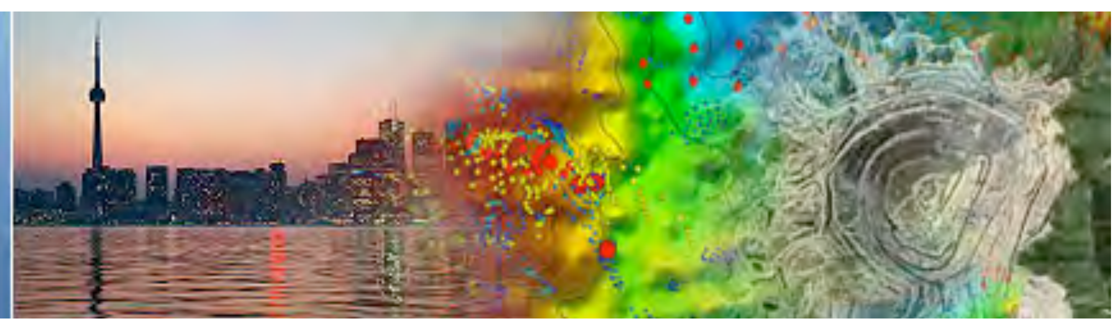
Convenors:
Harvey Thorleifson, MGS & Beth McClenaghan, GSC



9:00	Introduction	Harvey Thorleifson	*MGS*
9:30	Survey design	Chris Benn	*BHPB*
10:00	*Break*		
10:20	Processing methods	Beth McClenaghan	*GSC*
10:50	Mineral Chemistry	Bill Griffin	*GEMOC*
11:20	QA/QC	Mary Doherty	*ALS Chemex*
11:50	*Discussion*		
12:00	*Lunch*		
12:50	Precious metal exploration	Dave Kelley	*Zinifex*
1:20	Diamond exploration	Herman Grütter	*BHPB*
1:50	Base metal exploration	Stu Averill	*ODM*
2:20	Lab: field sampling	Mike Michaud	*ODM*
2:50	Exploration: India	Dean Pekeski	*Rio Tinto*
3:20	Public sector: Minnesota	Harvey Thorleifson	*MGS*
3:50	*Discussion*		

Indicator Mineral Methods
in Mineral Exploration: Introduction

Harvey Thorleifson
Minnesota Geological Survey



Mineral exploration

- Direct inspection
- Remote detection

Remote detection

- Exploration geophysics
- Exploration geochemistry
- Indicator mineral methods

Remote detection

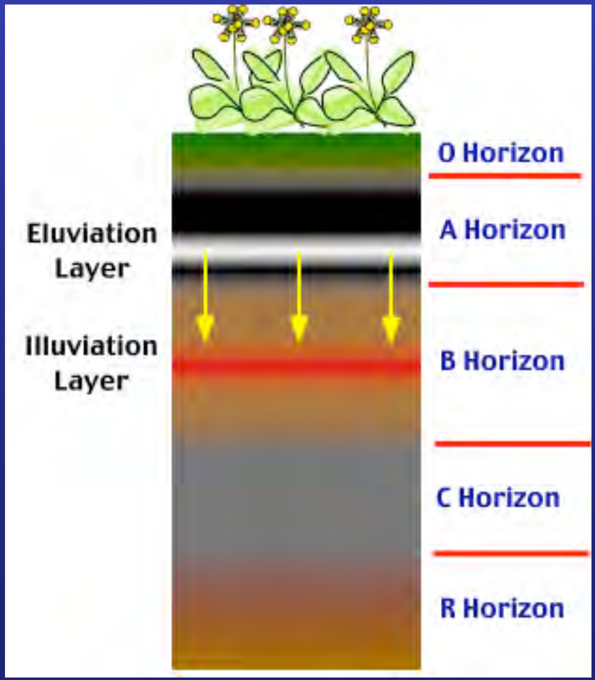
- Exploration geophysics
- Exploration geochemistry
  - Chemical signal
- Indicator mineral methods

Remote detection

- Exploration geophysics
- Exploration geochemistry
  - Chemical signal
- Indicator mineral methods
  - Clastic signal

Chemical signal

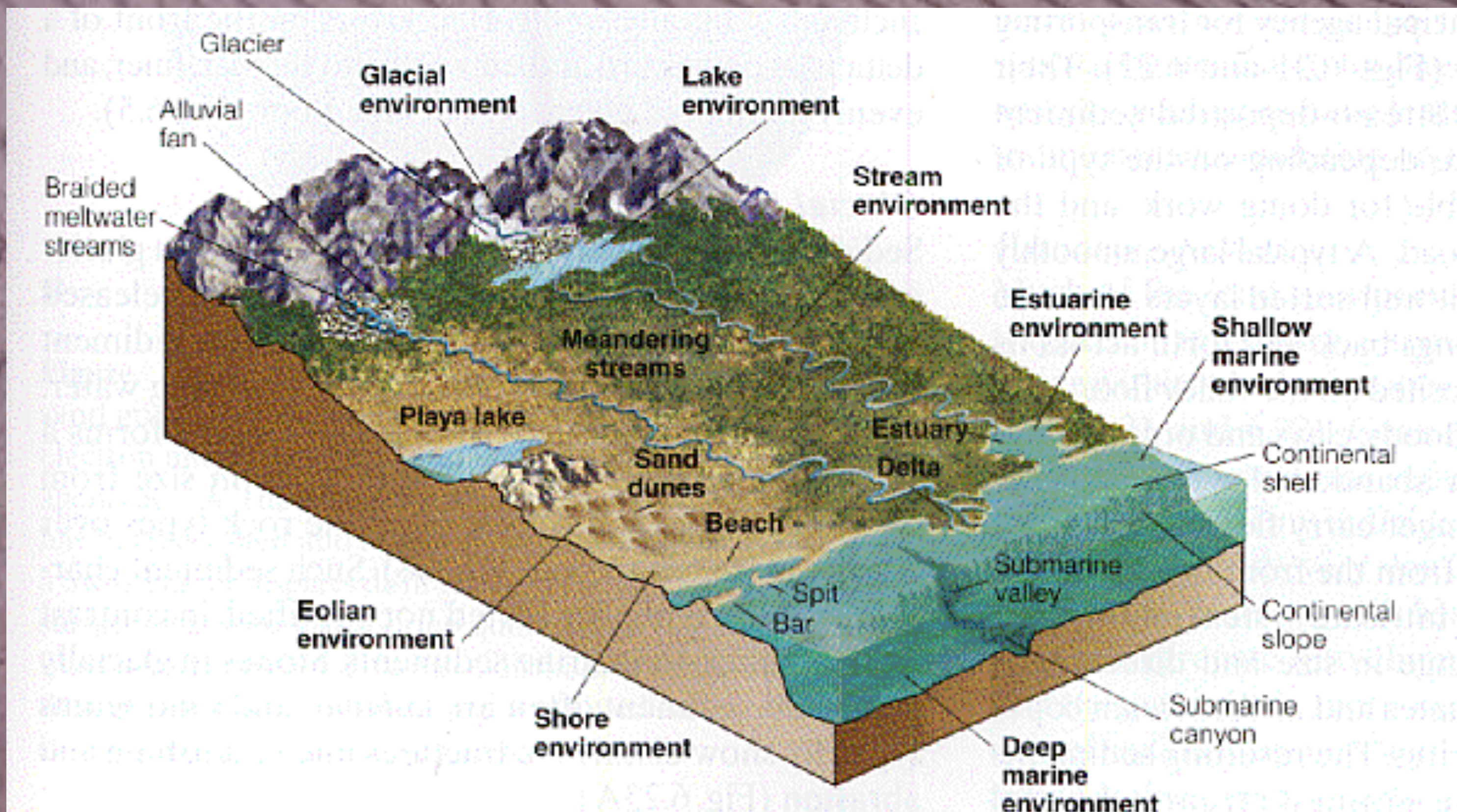
- Transported by aqueous &/or gaseous processes
- Detected in media such as A horizon, B, horizon, vegetation, or gases



Clastic signal

- Transported by mechanical processes
- Detected by sampling clastic sediments that have undergone minimal modification

Clastic sediments



Indicator minerals

- Ideally:
  - Coarse-grained
  - Specific to exploration target
  - Visually distinctive
  - Readily recovered
  - Adequately abundant
  - Adequately resistant

Indicator mineral methods

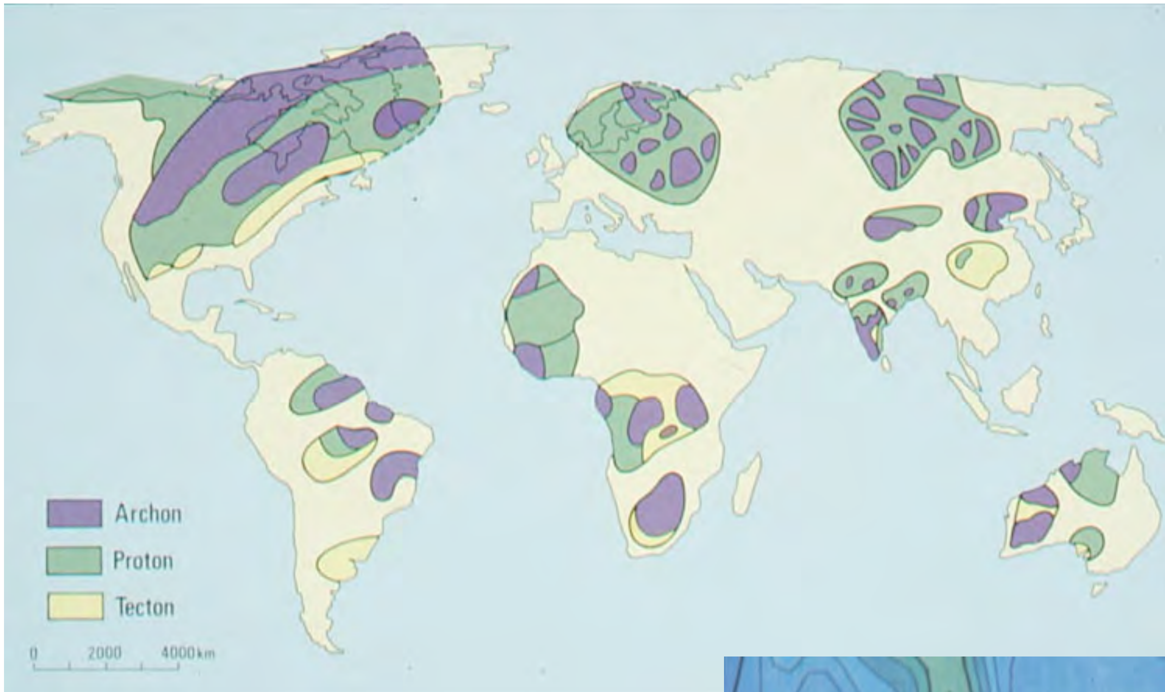
- Drift prospecting
- Drift exploration
- Tracing float
- Boulder tracing
- Stream sediment geochemistry
- Loaming
- Overburden sampling
- Till geochemistry
- Indicator mineral tracing

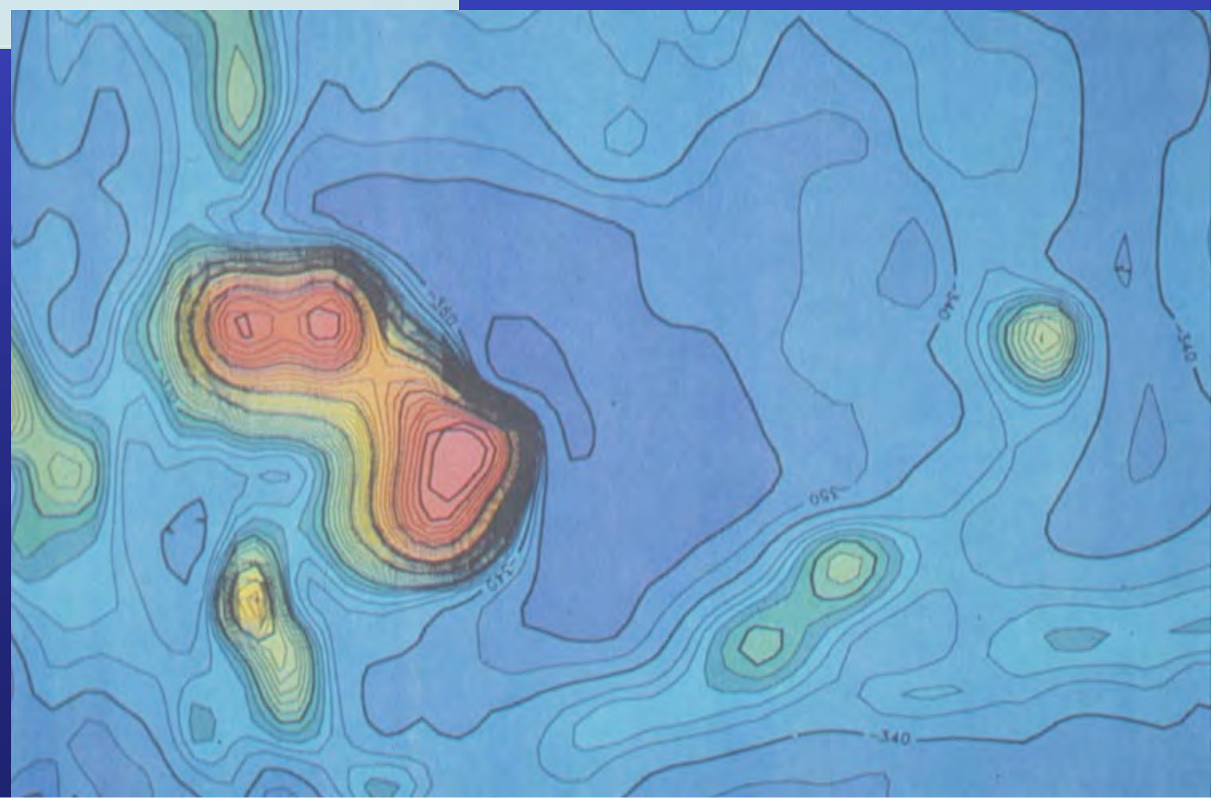
Indicator mineral surveys

- Exploration, mapping, research
- Regional reconnaissance
- Follow-up
- Assessment of geophysical targets
- *In situ* mineral chemistry

Objective

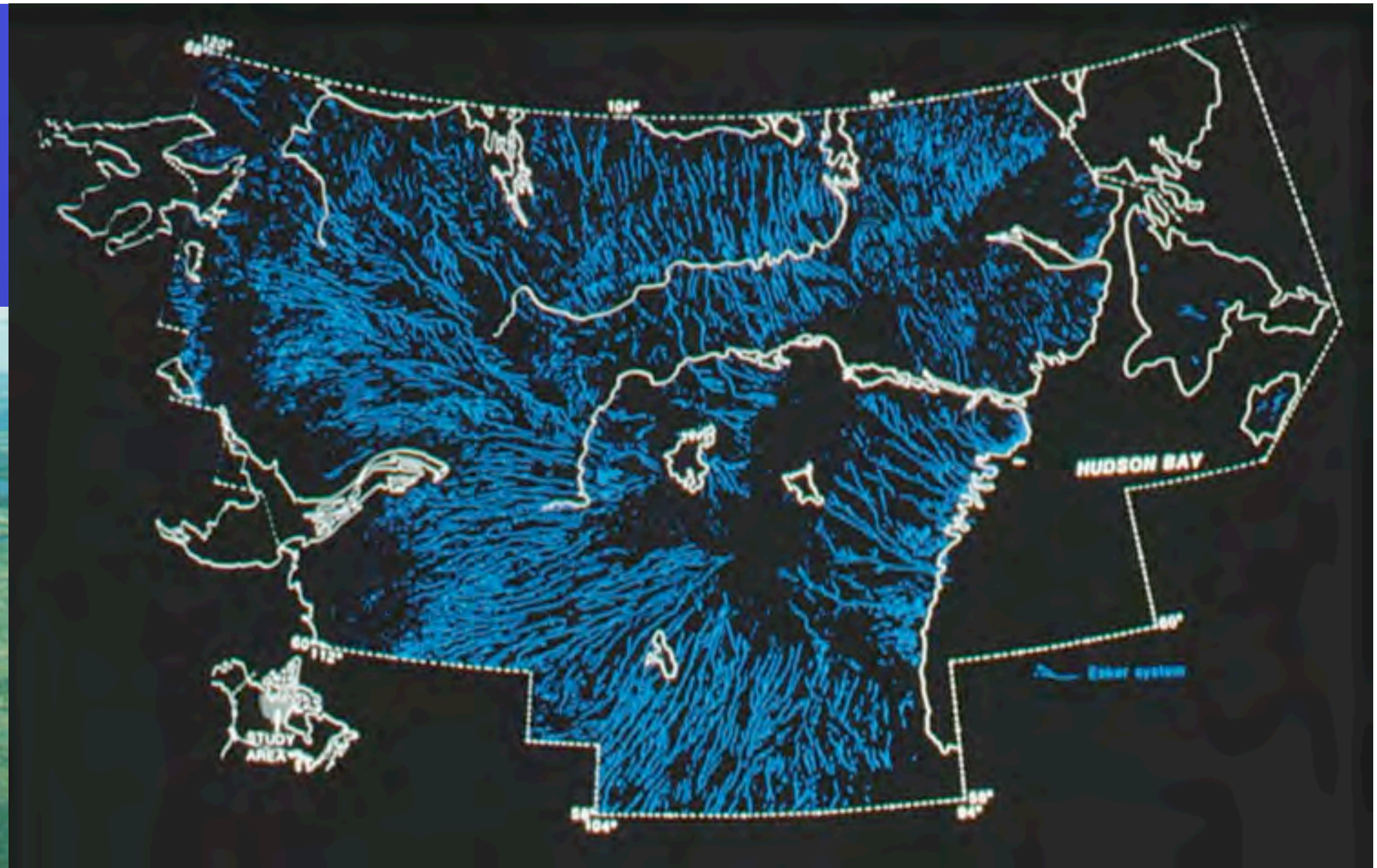
- Region or target
- Commodity or commodities


Archon
Proton
Tecton
0 2000 4000 km



Media

- Stream sediments
- Shoreline sediments
- Glaciofluvial sediments
- Till


HUDSON BAY
Esker system
STUDY AREA
104°
60°

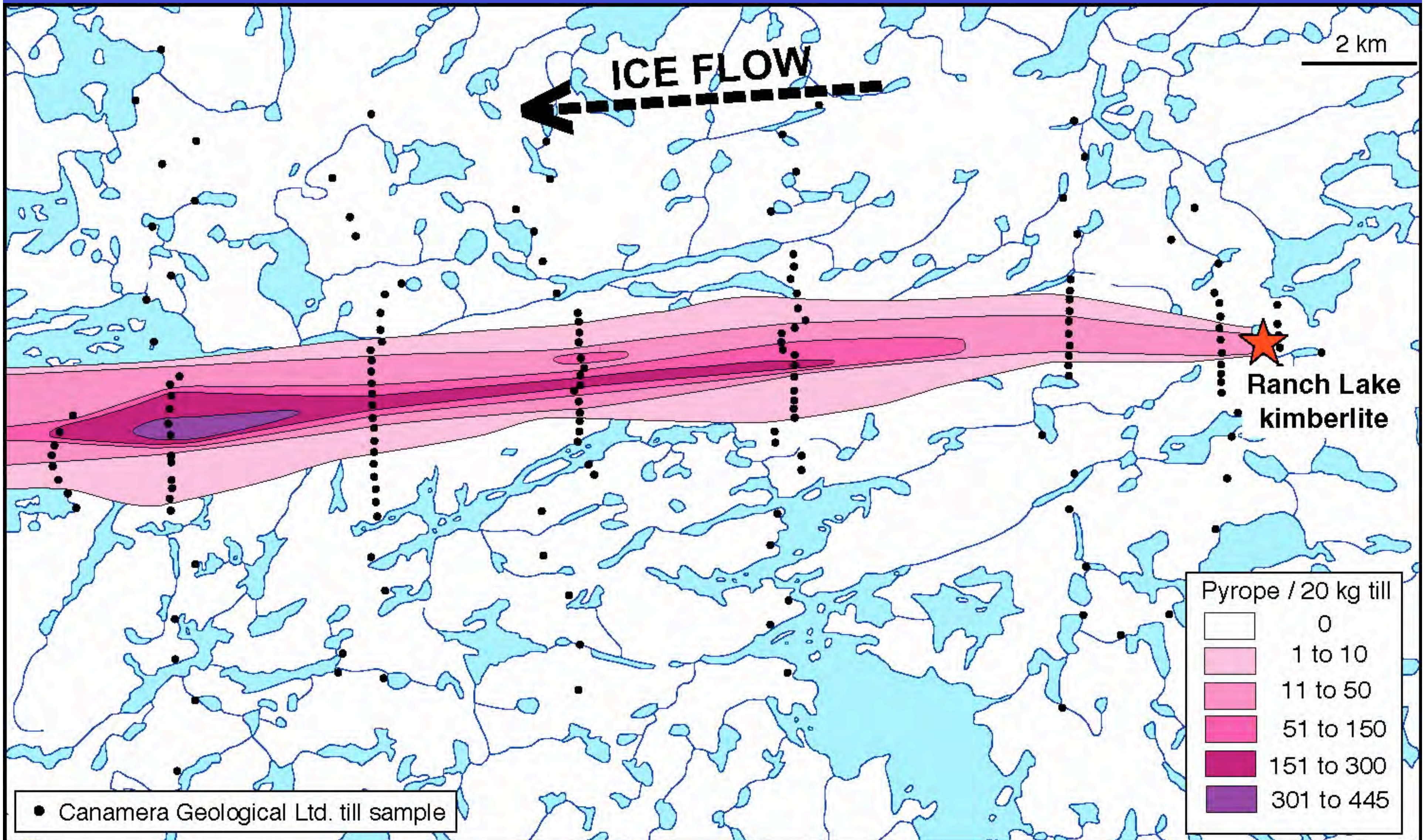

cm
Southeastern Manitoba
Site: A
Depth: m


cm
Southeastern Manitoba
Site: 92TCA-A
Depth: 24.4 m

Spacing & layout

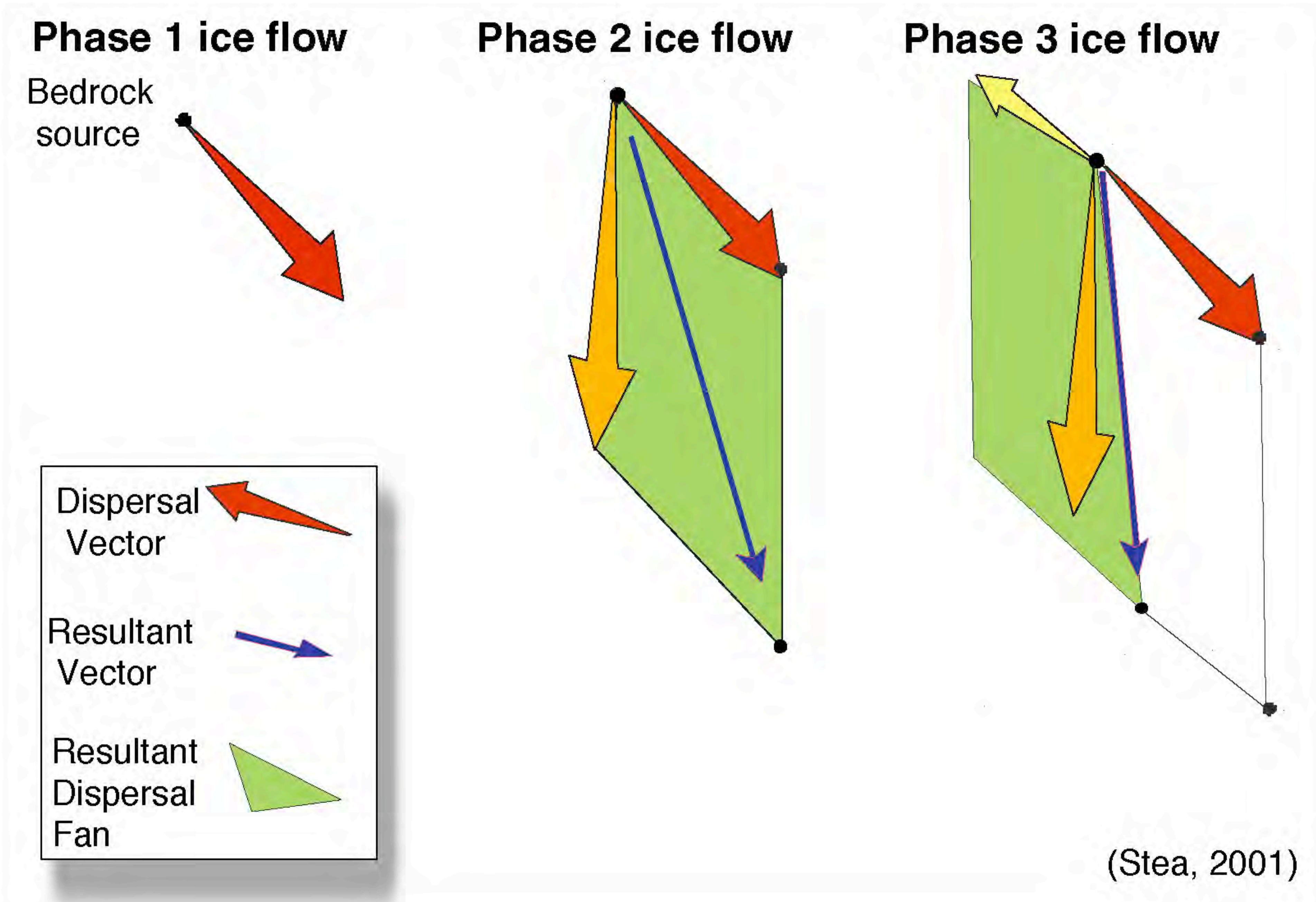
- Can vary by orders of magnitude
  - 10’s of km
  - 1 km
  - 0.1 km
- Layout
  - Grid
  - Transect

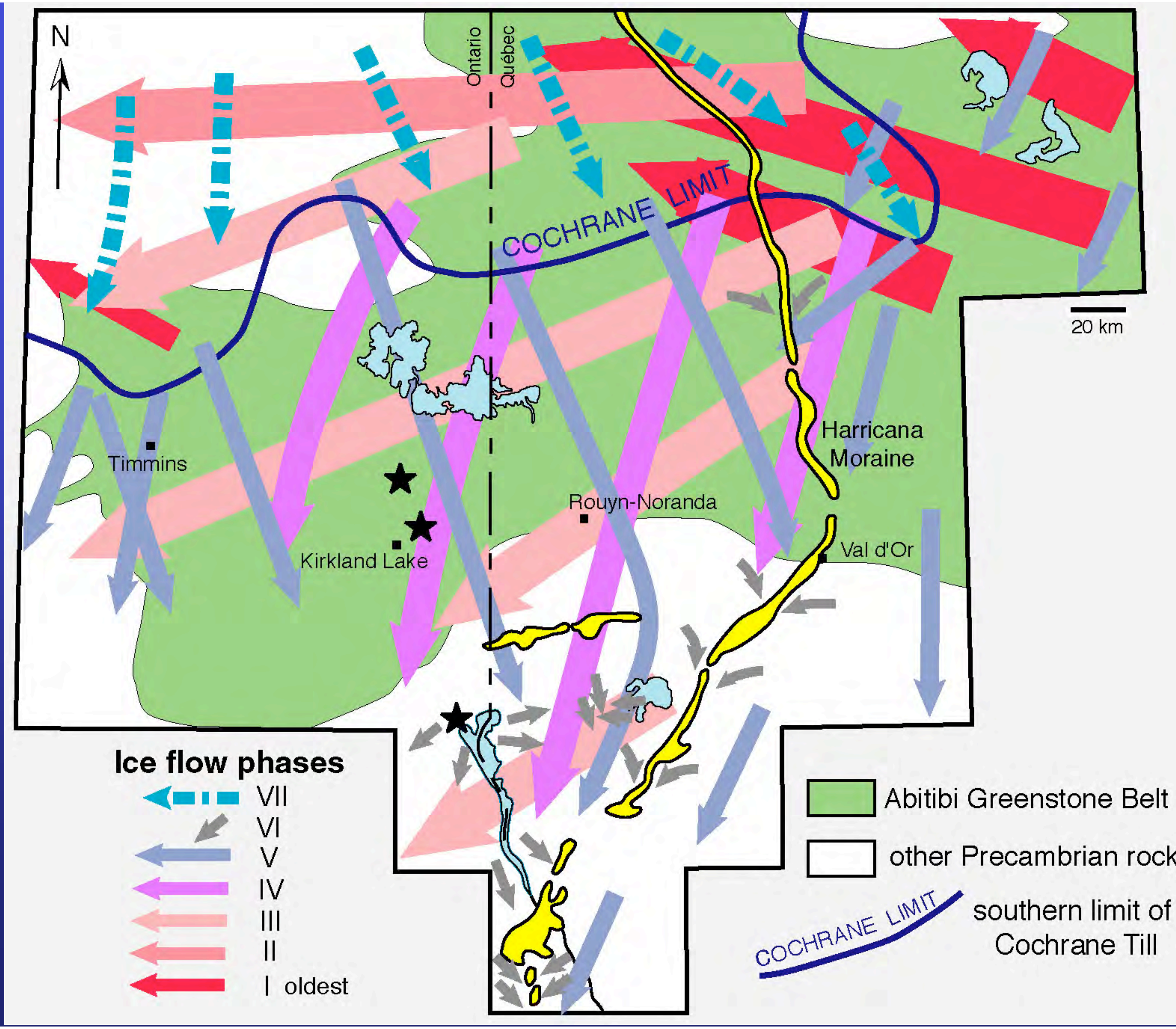
Ribbon shaped train: one direction

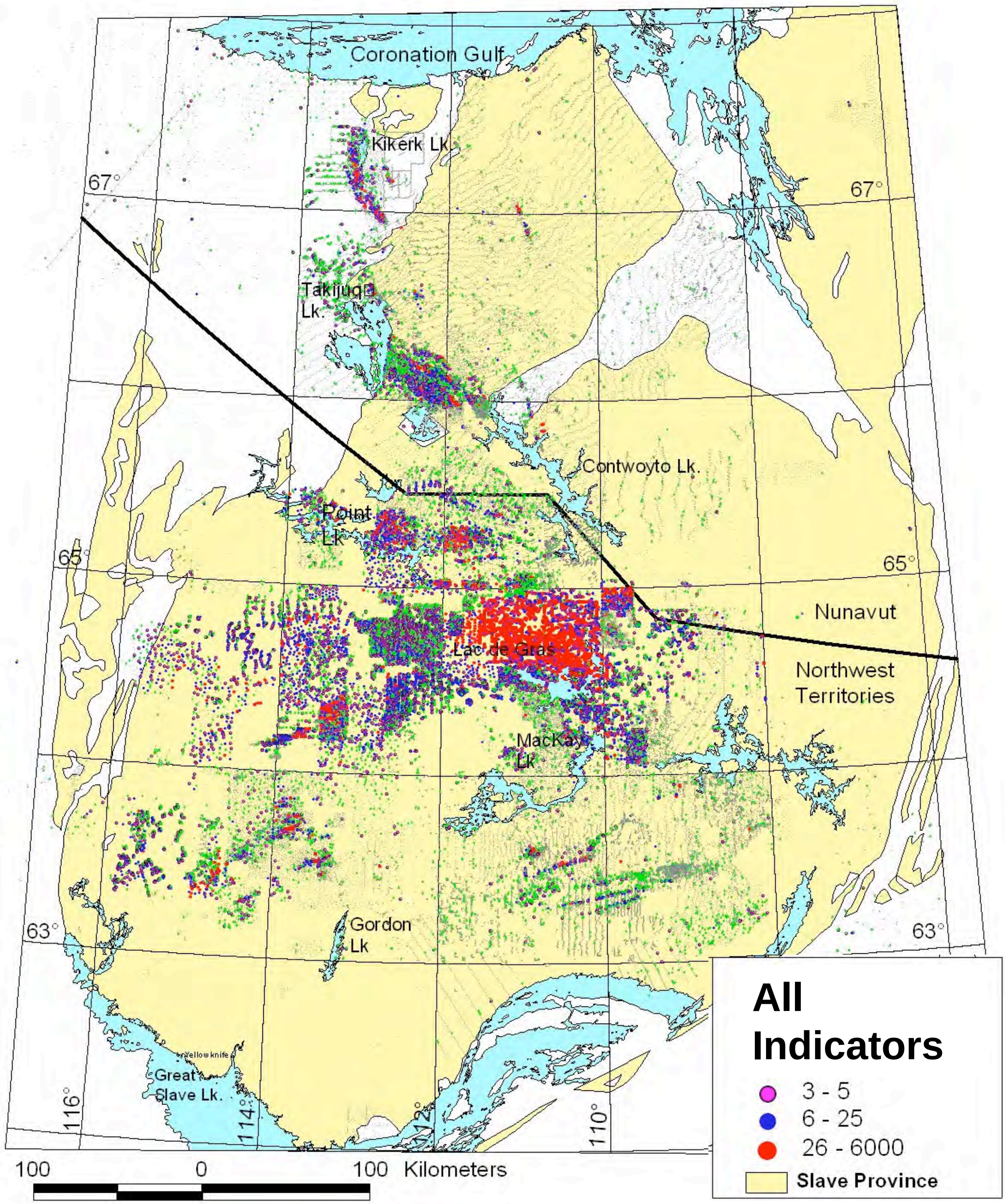


(McClenaghan et al.,. 2001)

Ranch Lake, NWT,
pyrope grains in till


Phase 1 ice flow
Phase 2 ice flow
Phase 3 ice flow
Bedrock source
Dispersal Vector
Resultant Vector
Resultant Dispersal Fan
(Stea, 2001)

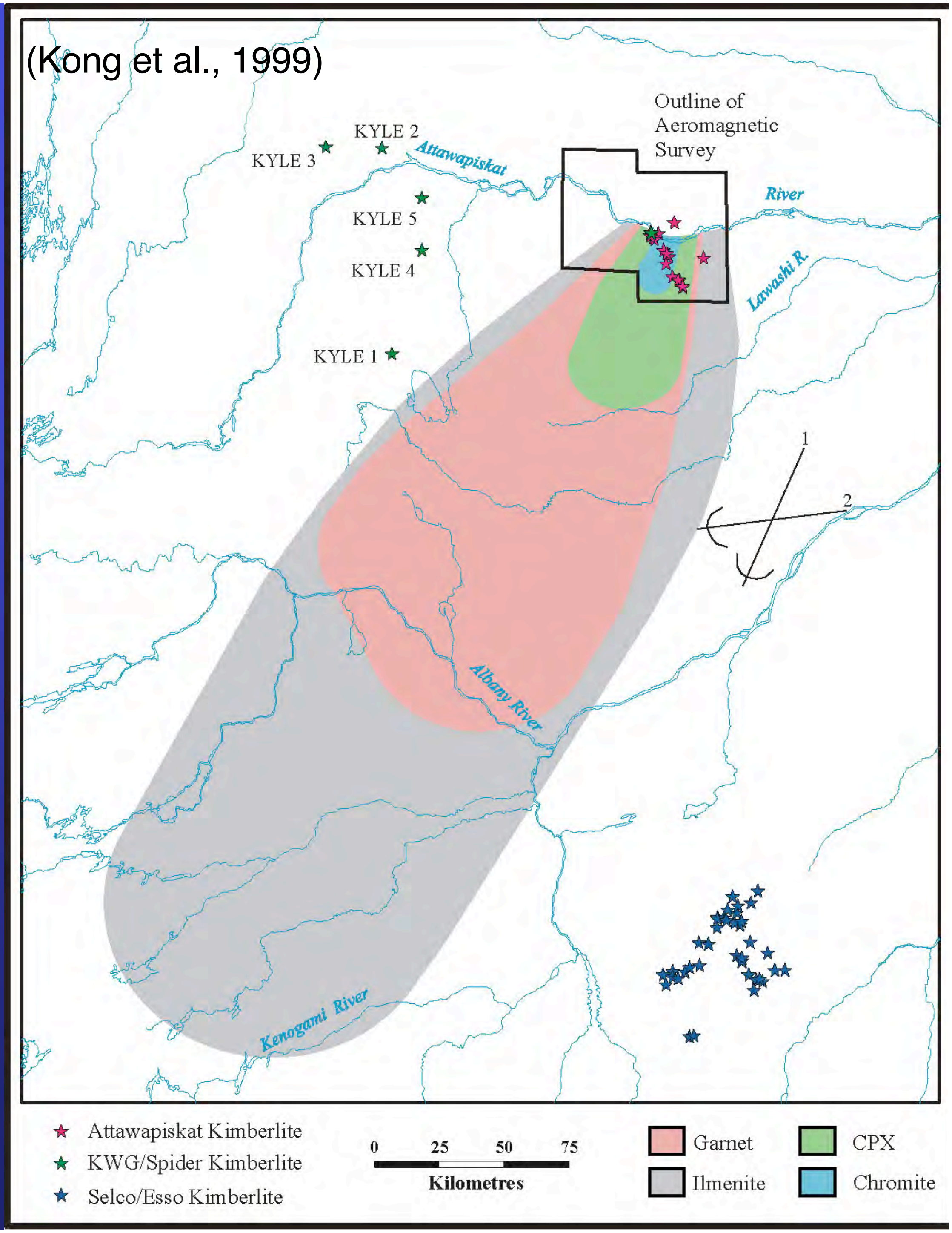

N
Ontario
Québec
COCHRANE LIMIT
20 km
Timmins
Kirkland Lake
Rouyn-Noranda
Harricana Moraine
Val d'Or
Ice flow phases
VII
VI
V
IV
III
II
I oldest
Abitibi Greenstone Belt
other Precambrian rock
COCHRANE LIMIT
southern limit of Cochrane Till



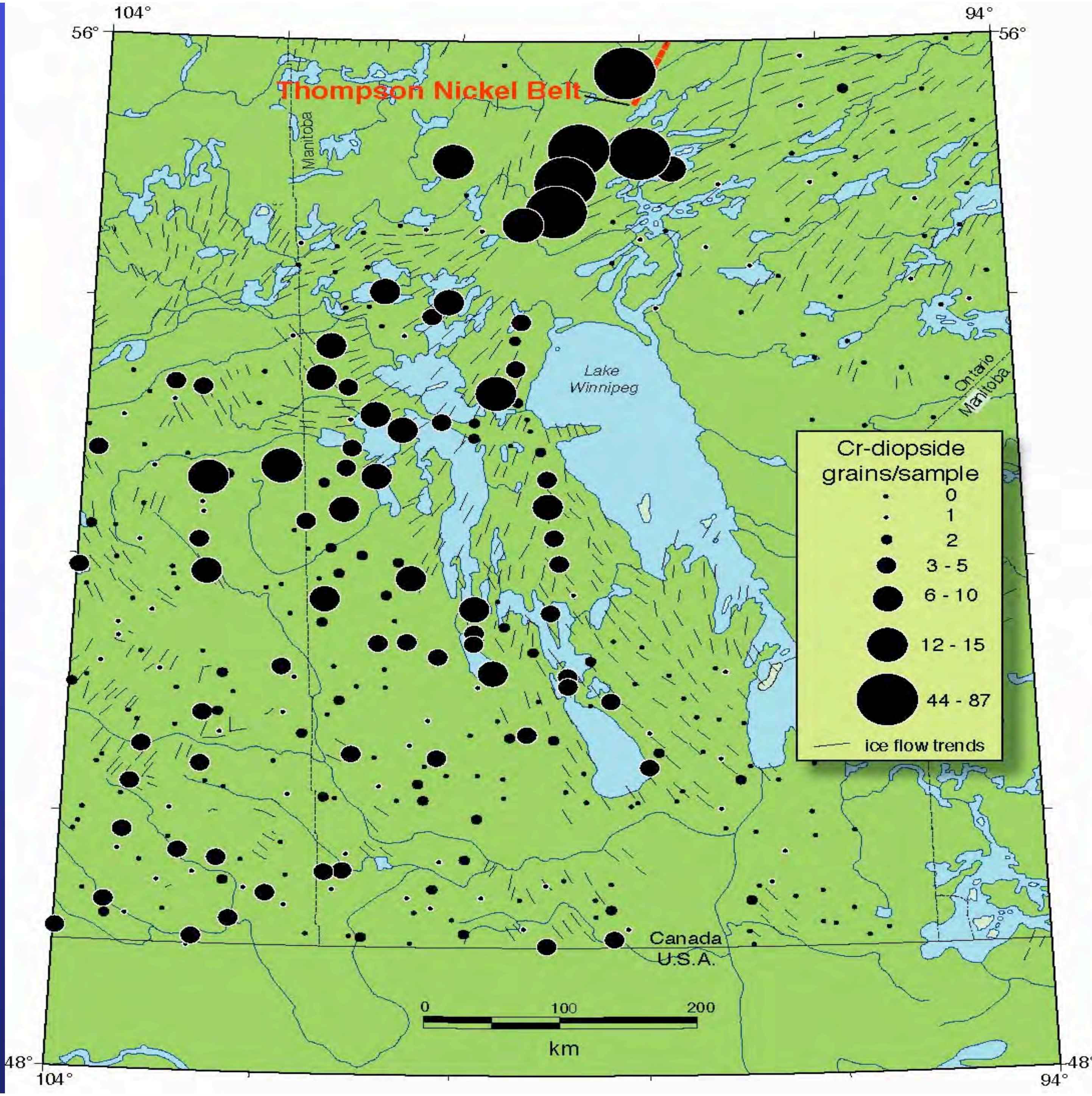
(J. Armstrong, 2003)

James Bay Lowland

Stream sediments derived from till



DE BEERS



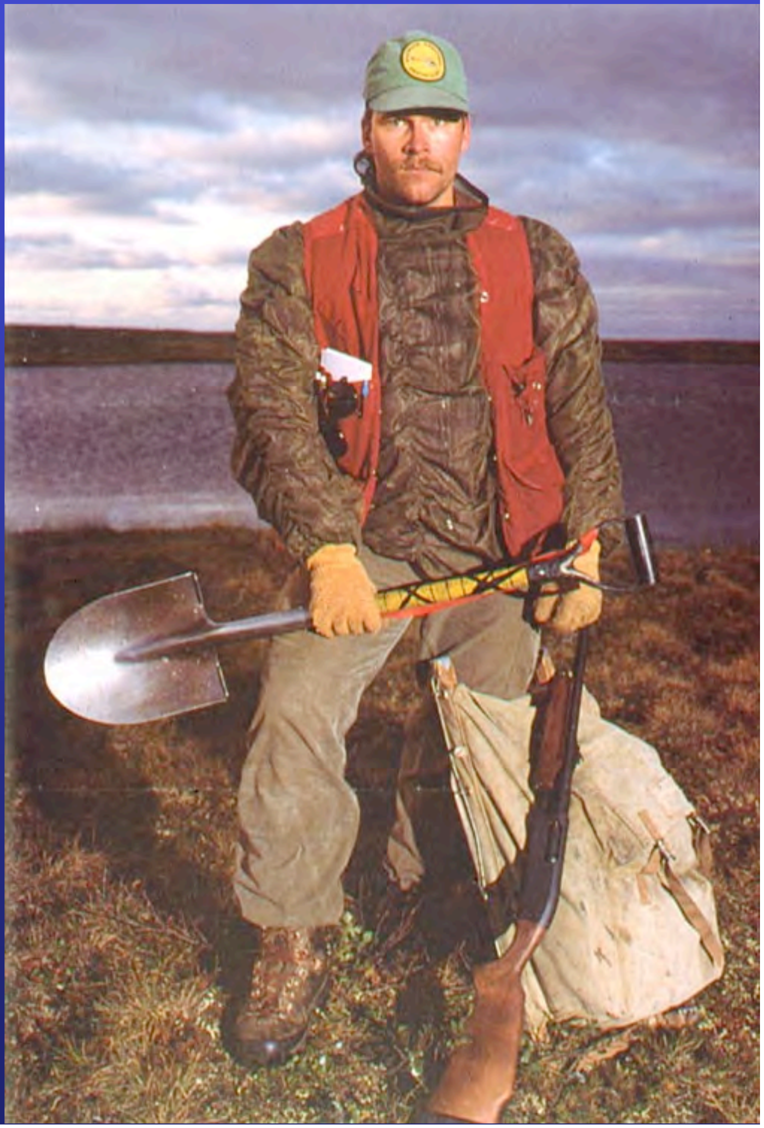
104°
94°
56°
56°
Thompson Nickel Belt
Manitoba
Lake Winnipeg
Ontario
Manitoba
Cr-diopside grains/sample
0
1
2
3 - 5
6 - 10
12 - 15
44 - 87
ice flow trends
Canada
U.S.A.
0
100
200
km
48°
48°
104°
94°

Size

- Samples on the order of 10 litres
  - Expected frequency ~ 1 indicator mineral per litre of sand
  - May require 5 to 50 litres of sand
  - % sand varies

Collection

- Road access, aircraft
- Exposures, shovel, excavator
- Large volume & weight
- Field concentration e.g. panning
- Field screening e.g. remove gravel




C-GEAP

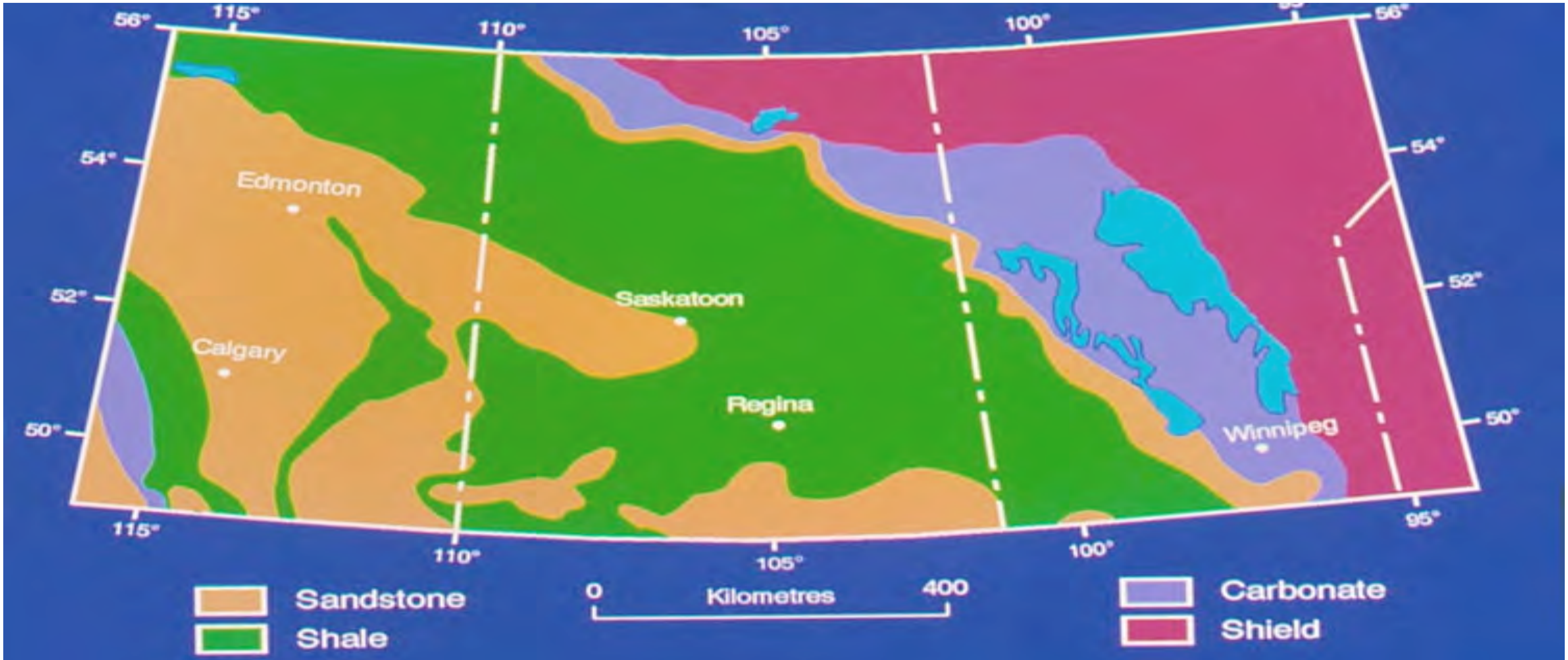


Field observations

- Boulders
- Striations

Processing

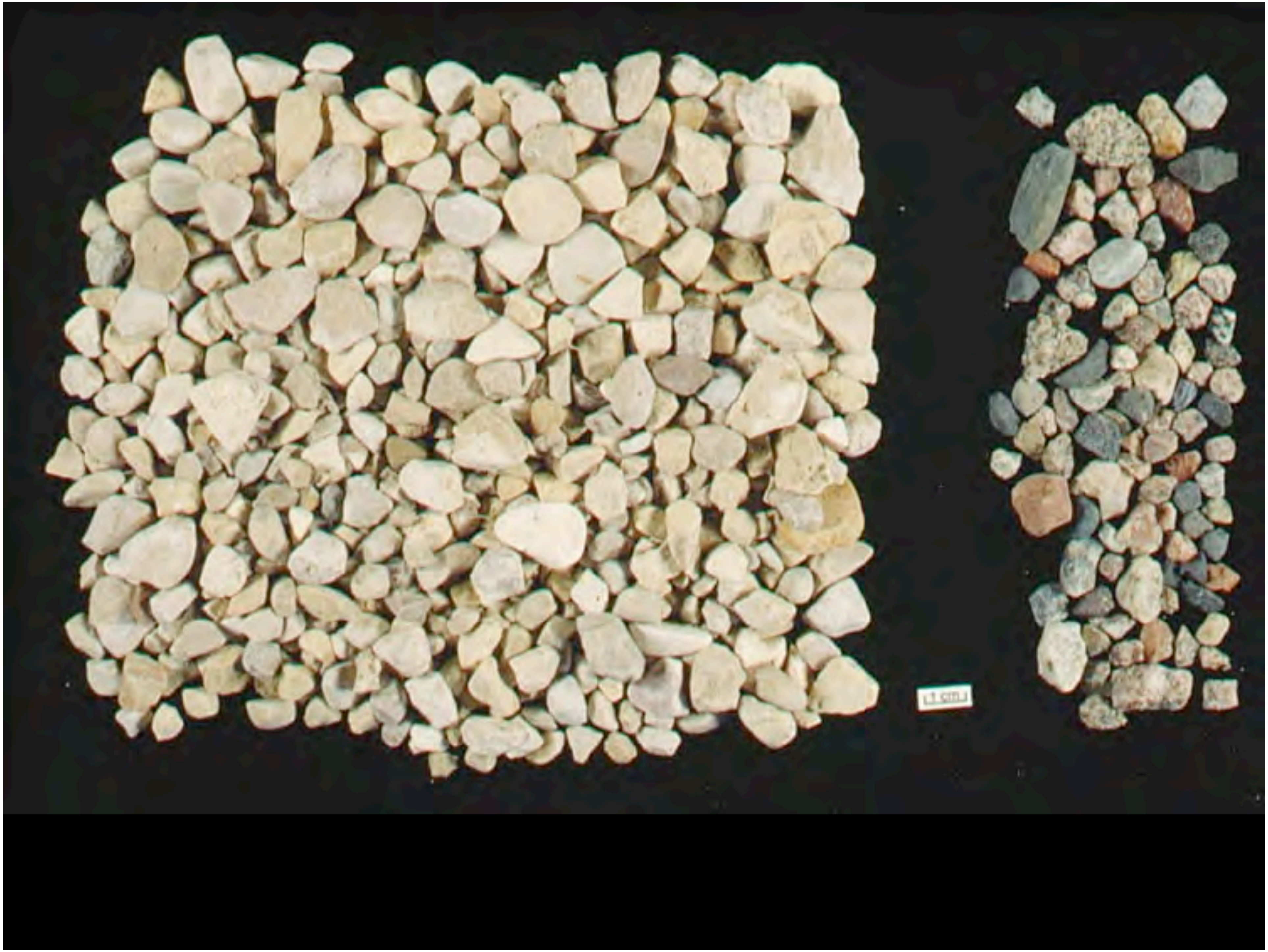
- Disaggregate
- Screen gravel
  - >2 mm (10 mesh)
  - >1 mm (20 mesh)
  - >4 mm (5 mesh)
- Retain gravel for lithology



56°
115°
110°
105°
100°
54°
52°
50°
95°
Edmonton
Saskatoon
Calgary
Regina
Winnipeg
Sandstone
Shale
0
Kilometres
400
Carbonate
Shield

[redacted]


1 cm


1 cm

Pre-concentration

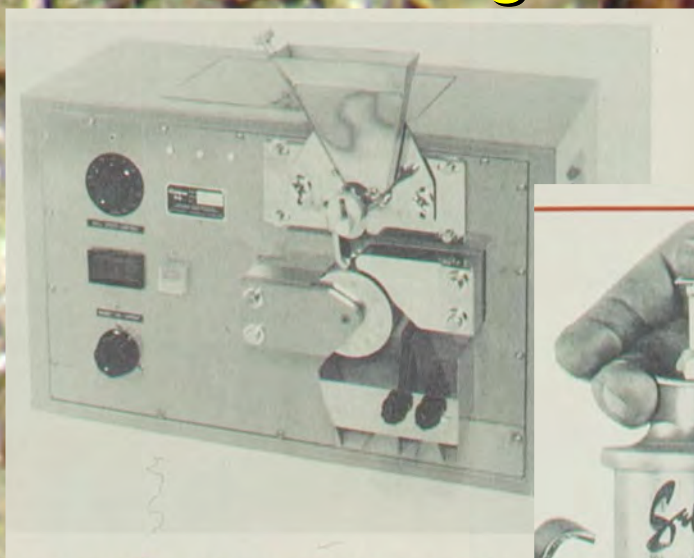
- Density
  - Jig, table, pan, spiral, wheel
  - Heavy liquid
- Size
  - medium to very coarse sand
- Magnetism
  - Reject non-paramagnetic

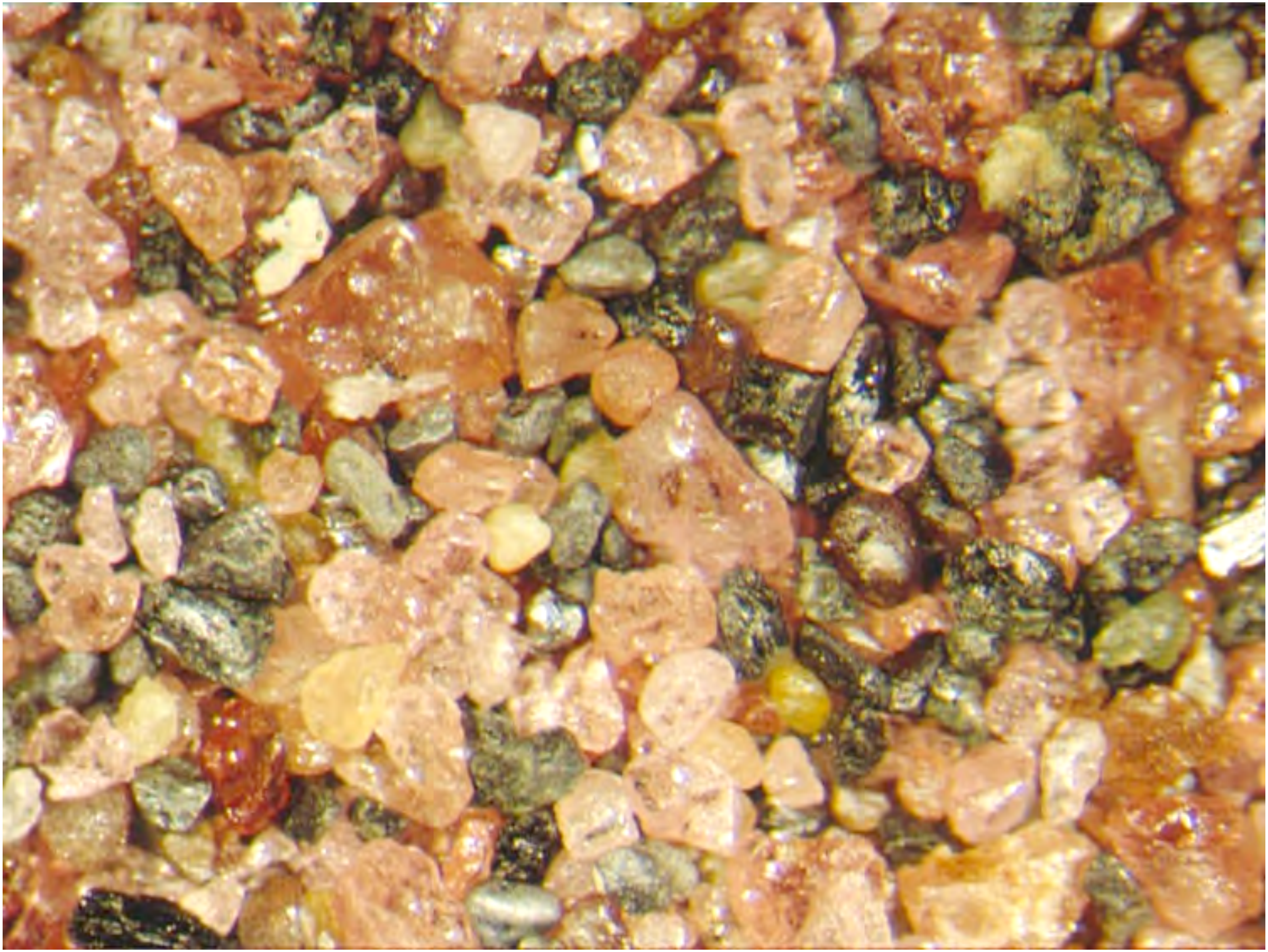
Concentration

- Heavy liquids
  - Methylene iodide (MI, 3.3)
  - Diluted MI (e.g. 3.2)
  - Tetrabromoethane (TBE, 2.96)
  - NaPolyW (variable)
- Superpanner
- DMS
- Magstream

Ferromagnetics

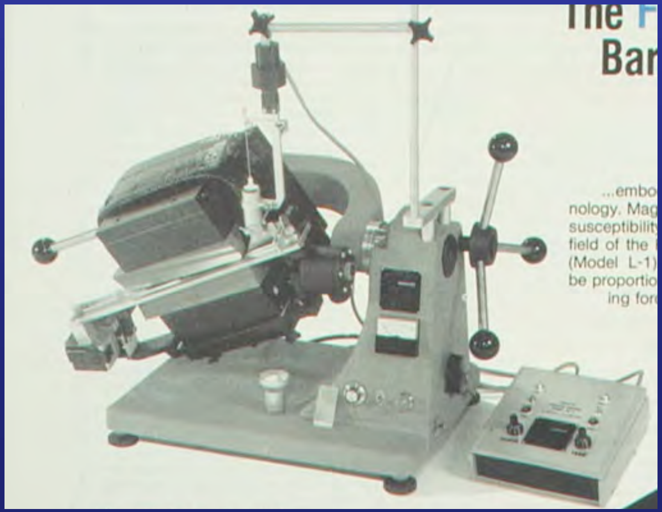
- Separator
- Hand magnet

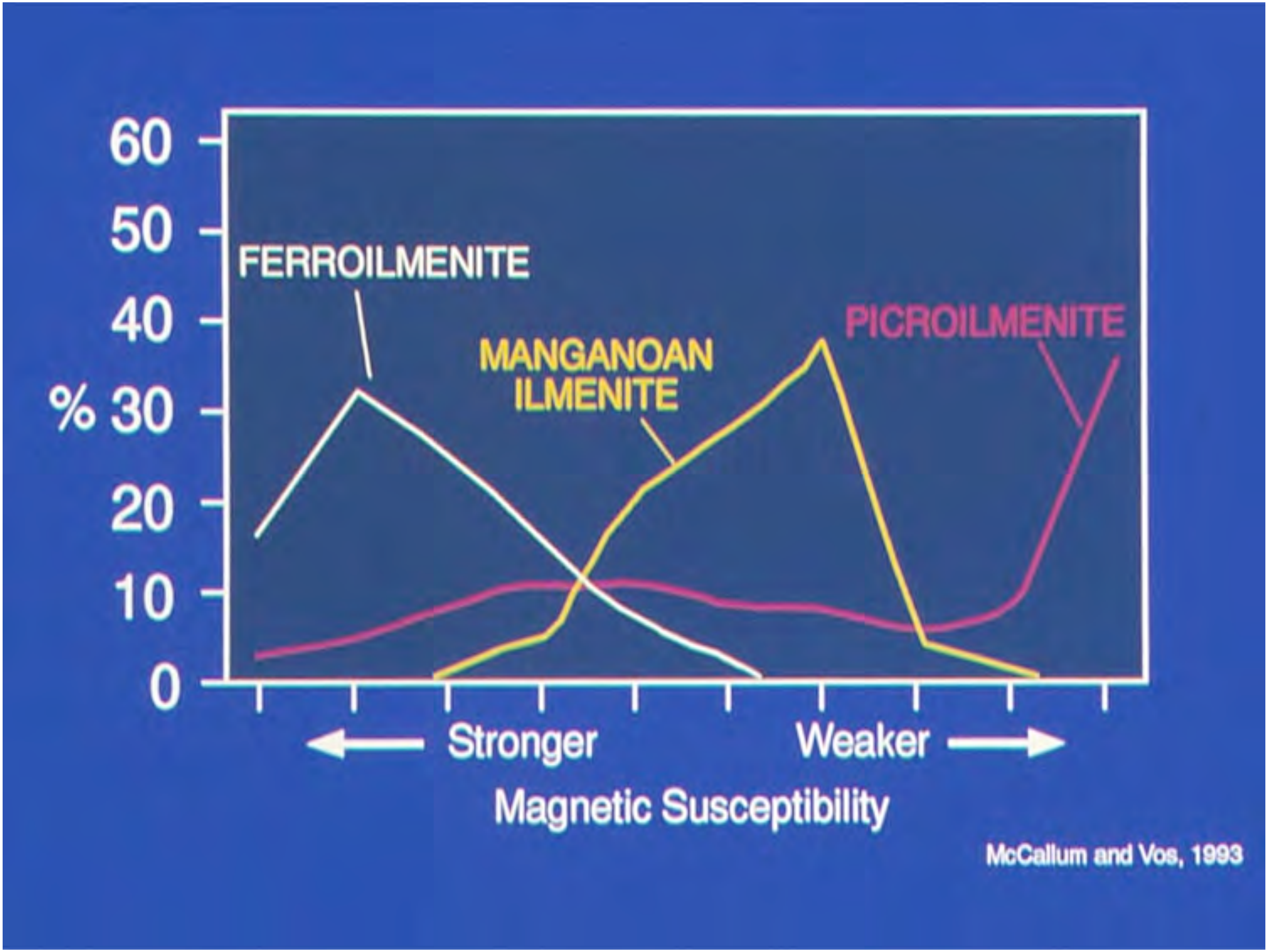




Classification

- Processing of nonferromagnetics
  - Reduce picking time
  - Add information
  - Sizing
    - E.g. 0.25-0.5 mm; 0.5-2.0 mm
  - Magnetic susceptibility
  - Magstream

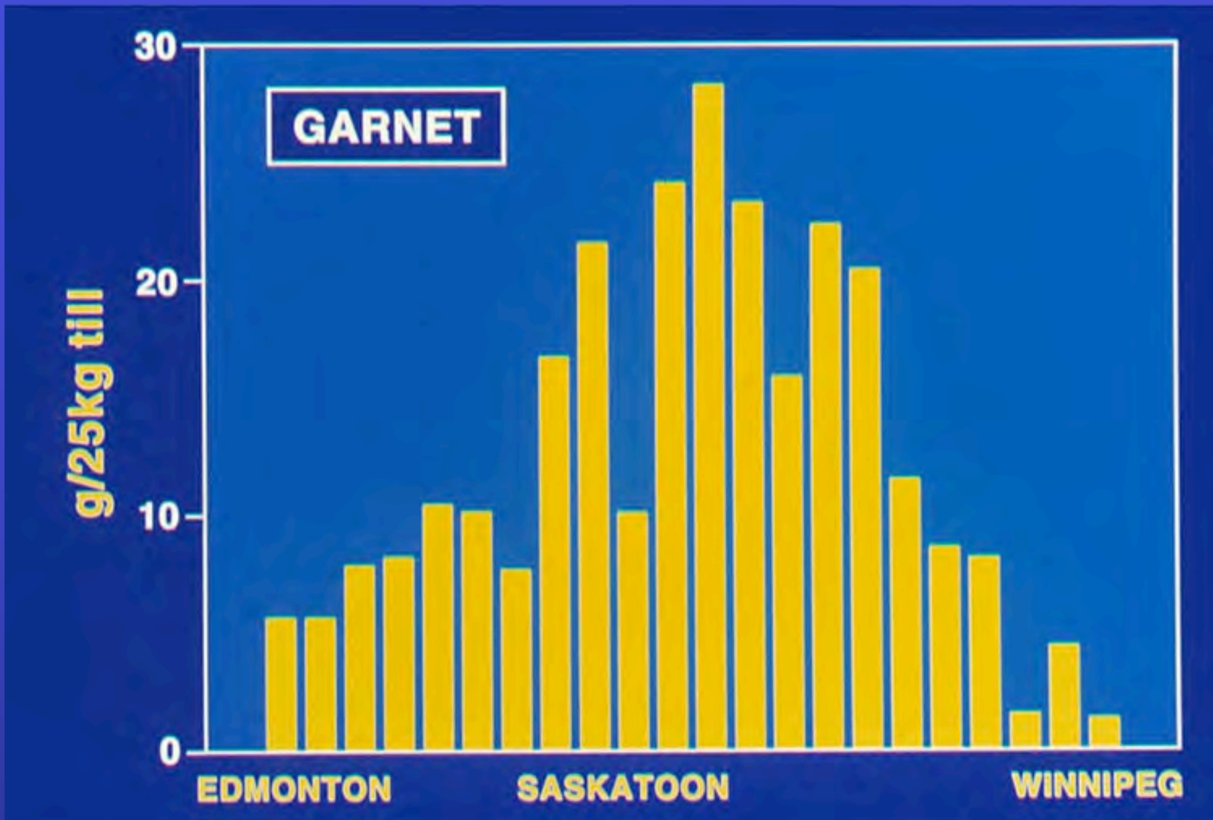


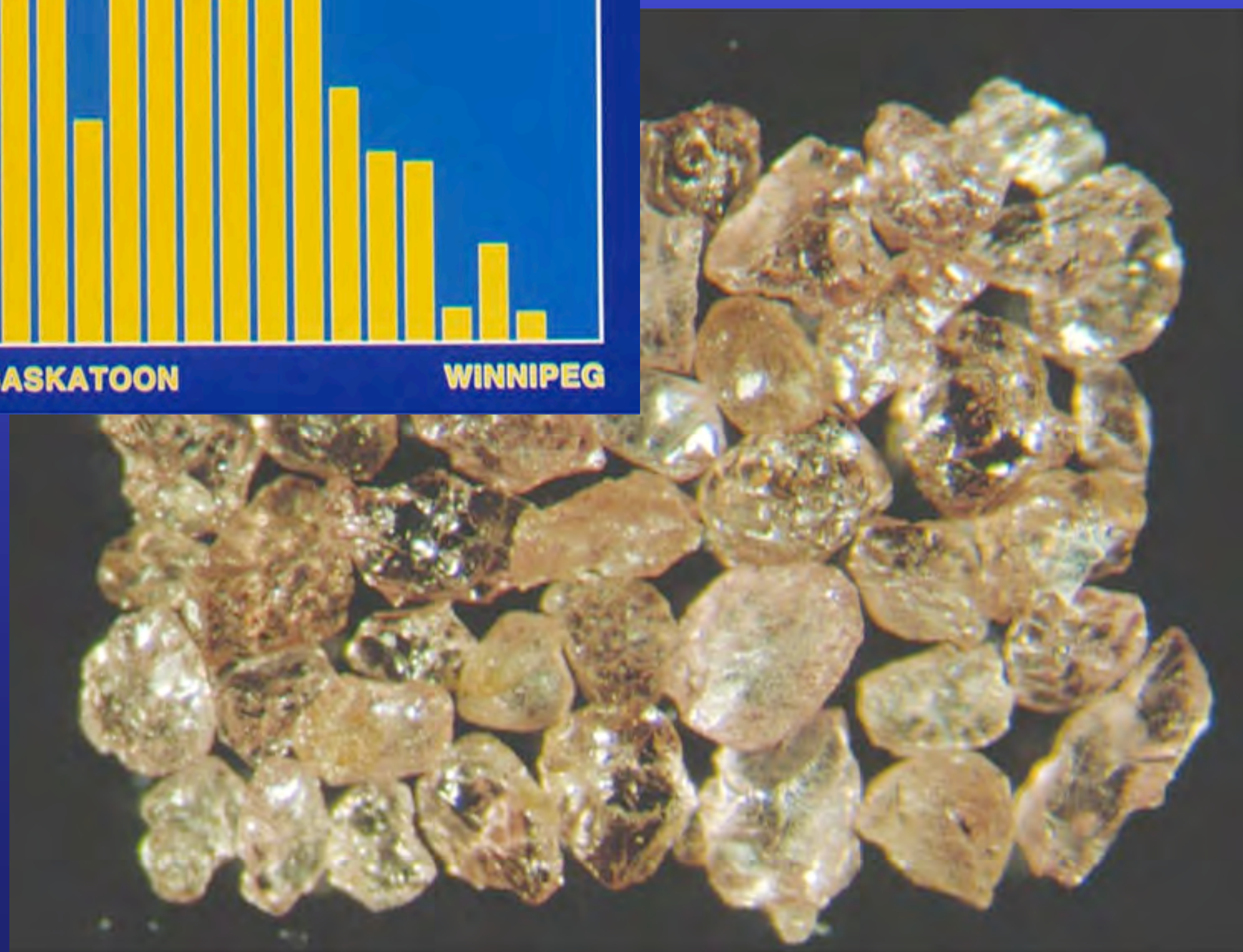


60
50
40
% 30
20
10
0
FERROILMENITE
MANGANOAN
ILMENITE
PICROILMENITE
Stronger
Weaker
Magnetic Susceptibility
McCallum and Vos, 1993

Background

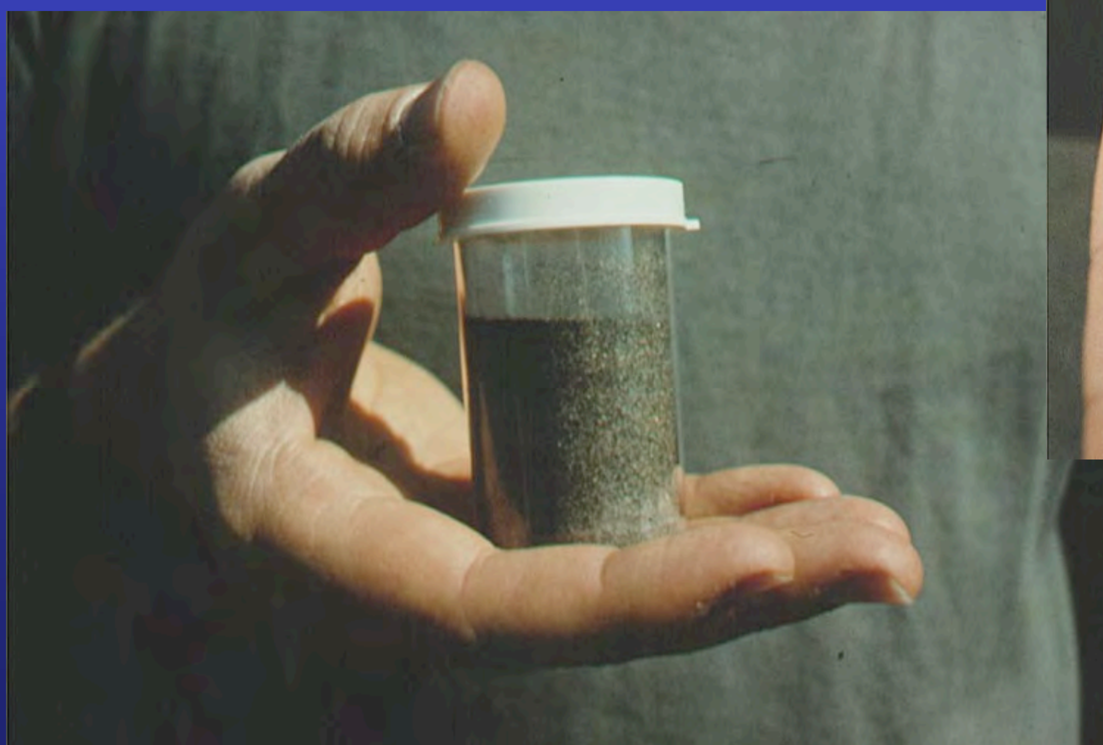
- Many aspects of processing are governed by regional heavy mineral background


GARNET
g/25kg till
30
20
10
0
EDMONTON
SASKATOON
WINNIPEG



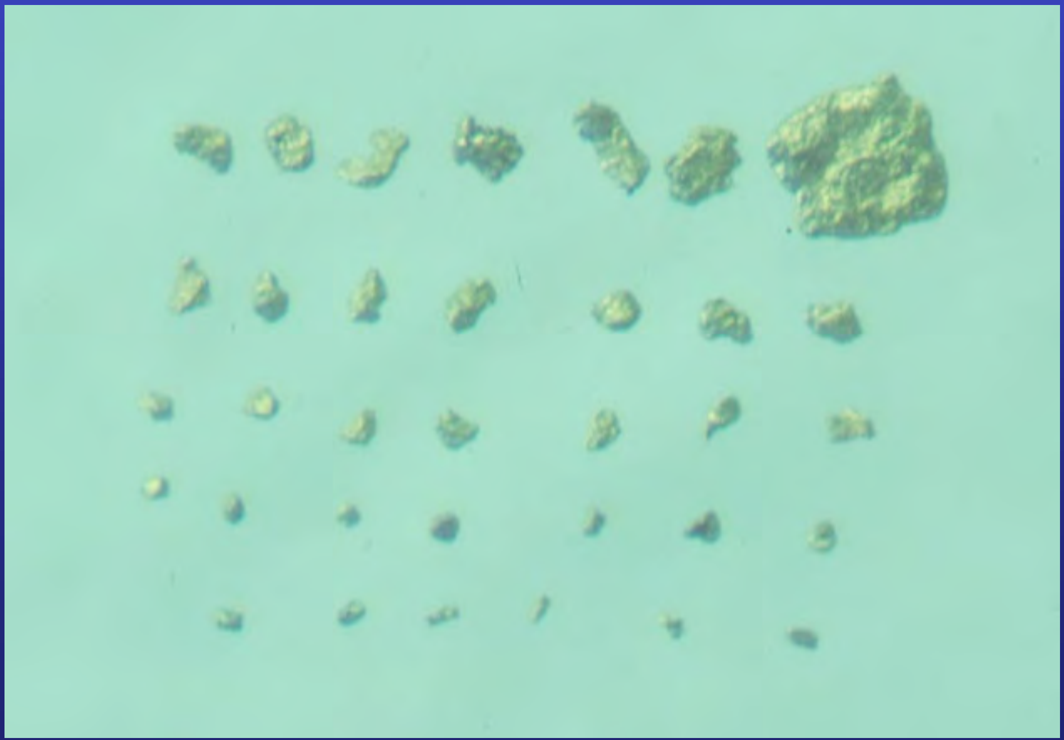
Picking/panning

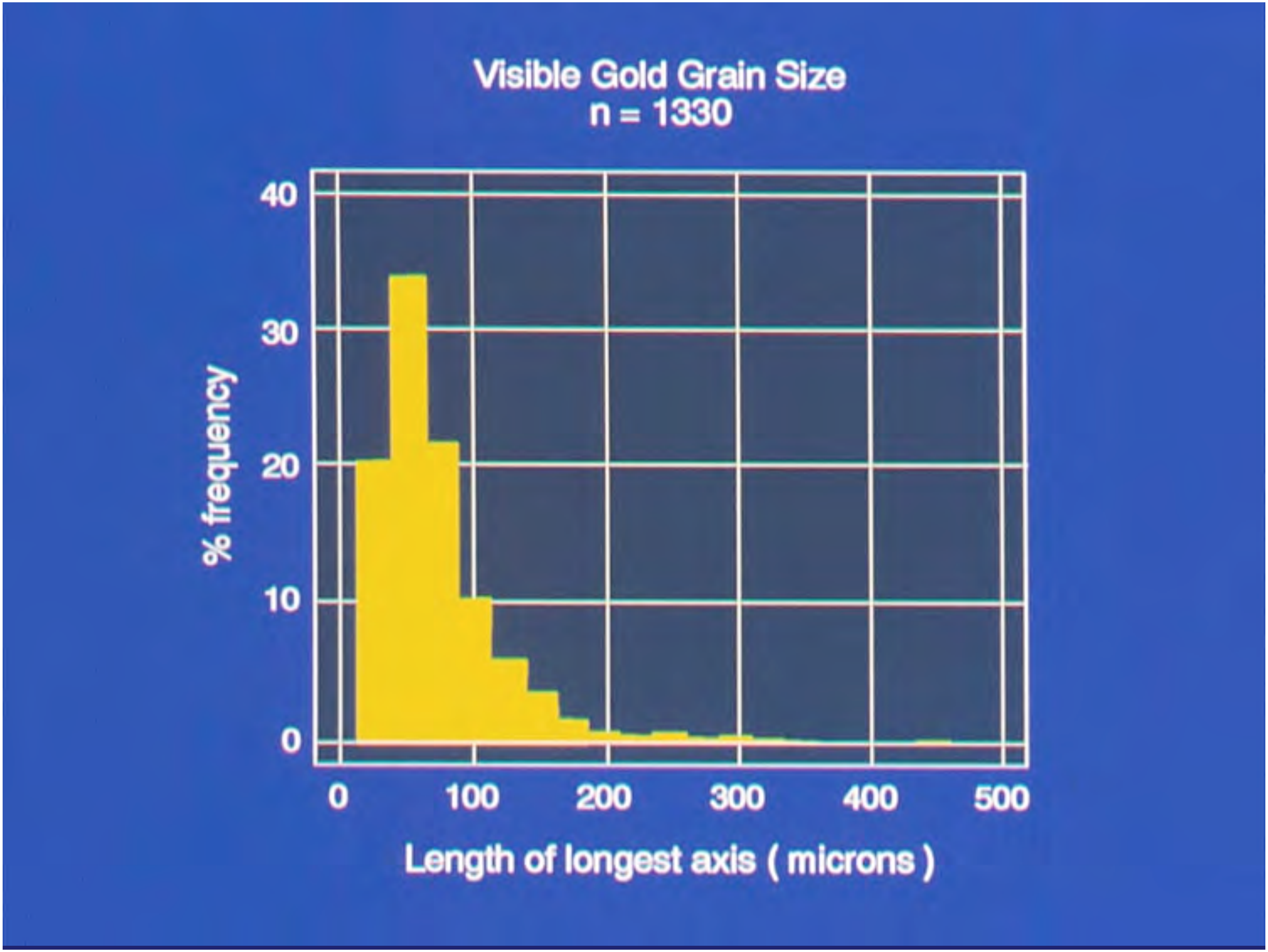
- Identification of possible & probable indicator minerals
- Recovery
- Morphology
- Spikes
- Re-picks

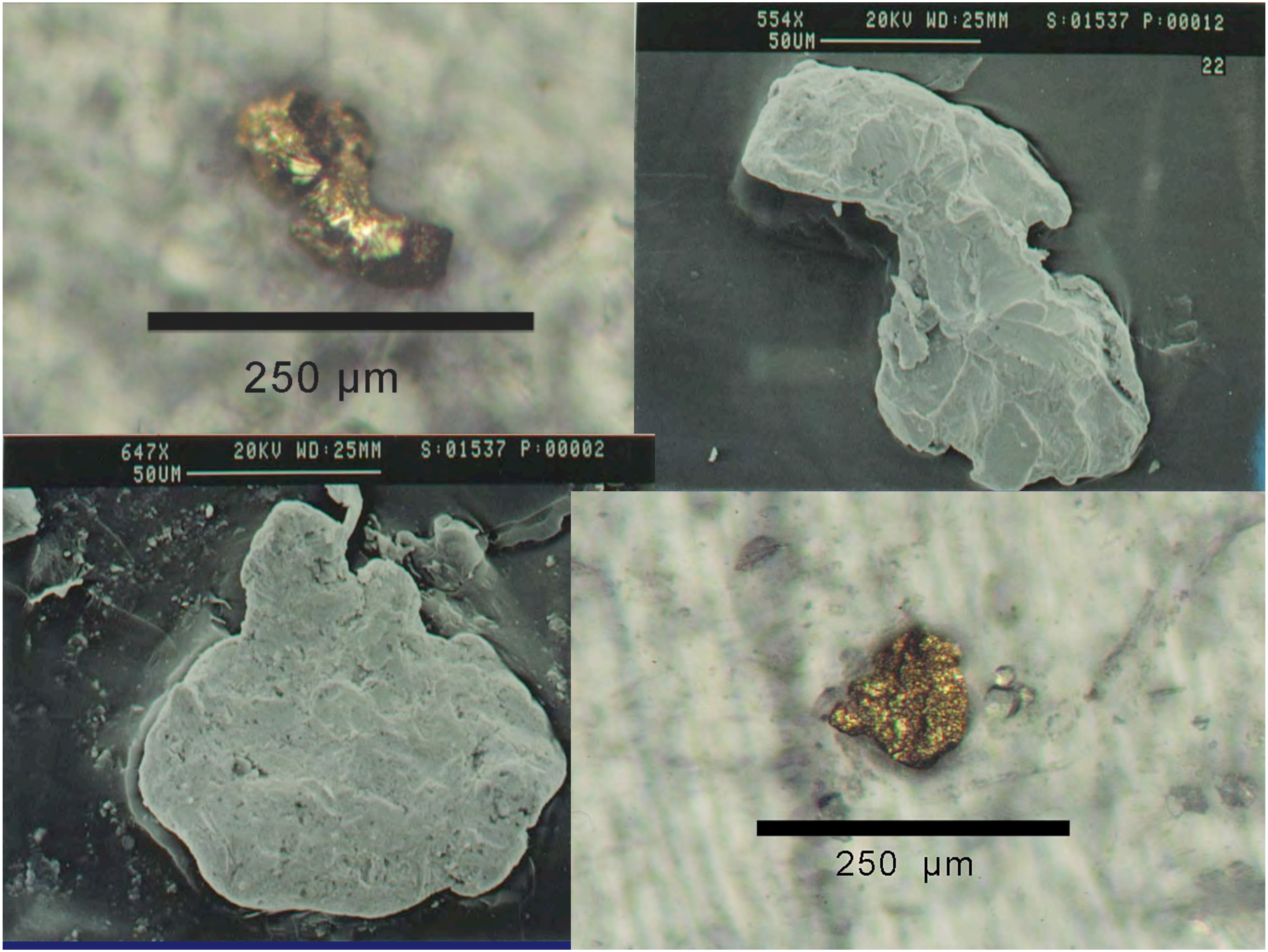


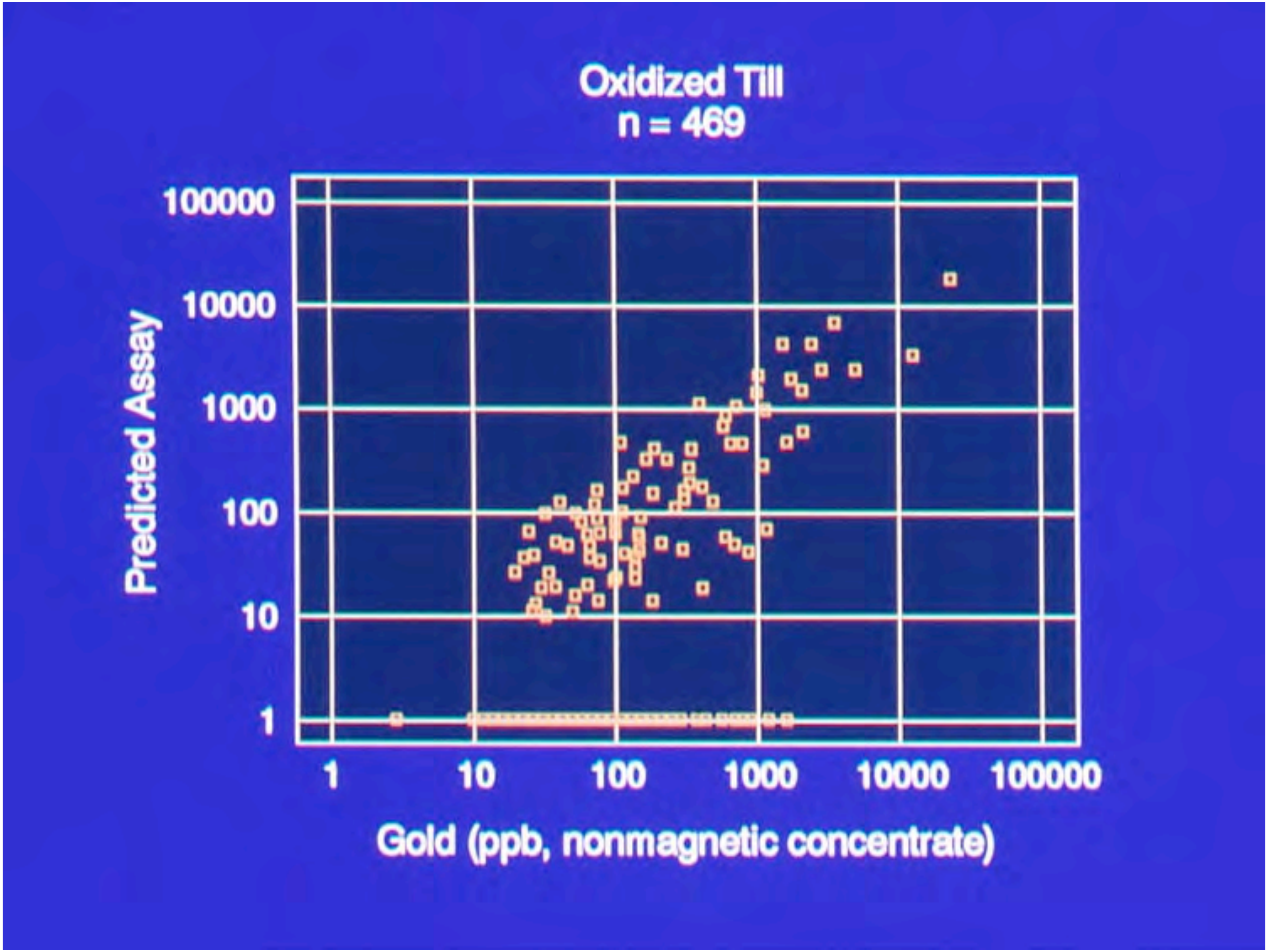
Gold grains

- Number
- Morphology
- Mass
- Composition

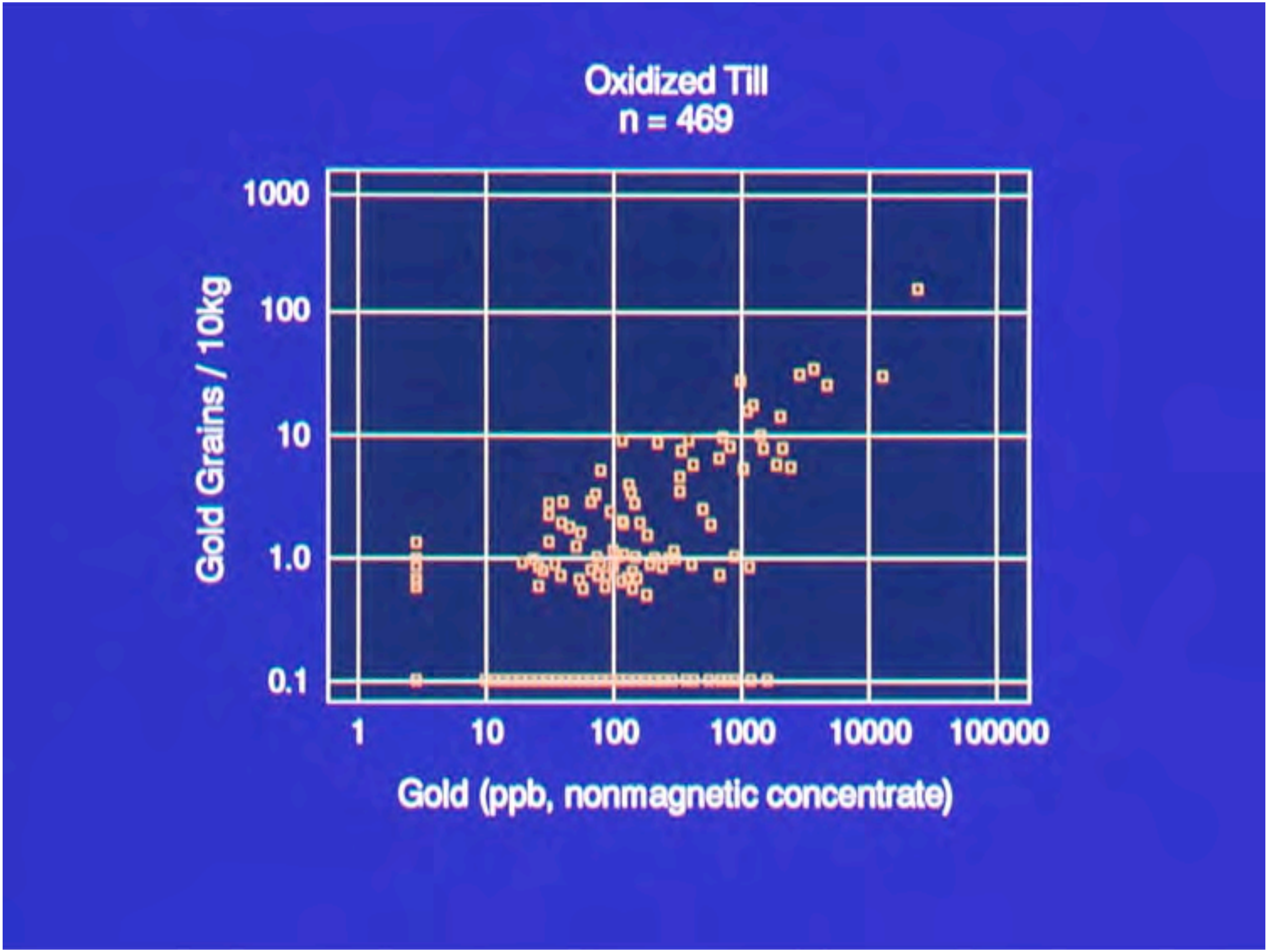


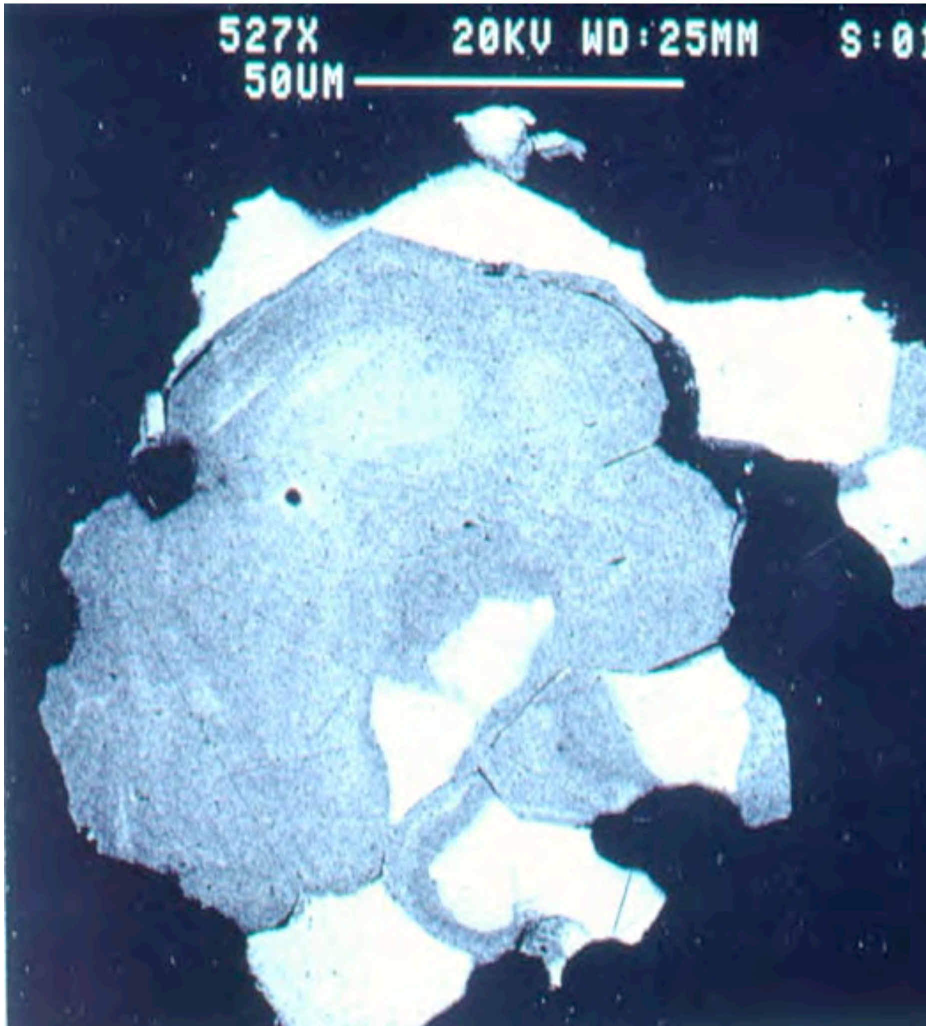

Visible Gold Grain Size
n = 1330
% frequency
40
30
20
10
0
0
100
200
300
400
500
Length of longest axis (microns)


250 µm
554X 20KV WD:25MM S:01537 P:00012
50UM
22
647X 20KV WD:25MM S:01537 P:00002
50UM
250 µm



Oxidized Till
n = 469
Predicted Assay
100000
10000
1000
100
10
1
1
10
100
1000
10000
100000
Gold (ppb, nonmagnetic concentrate)

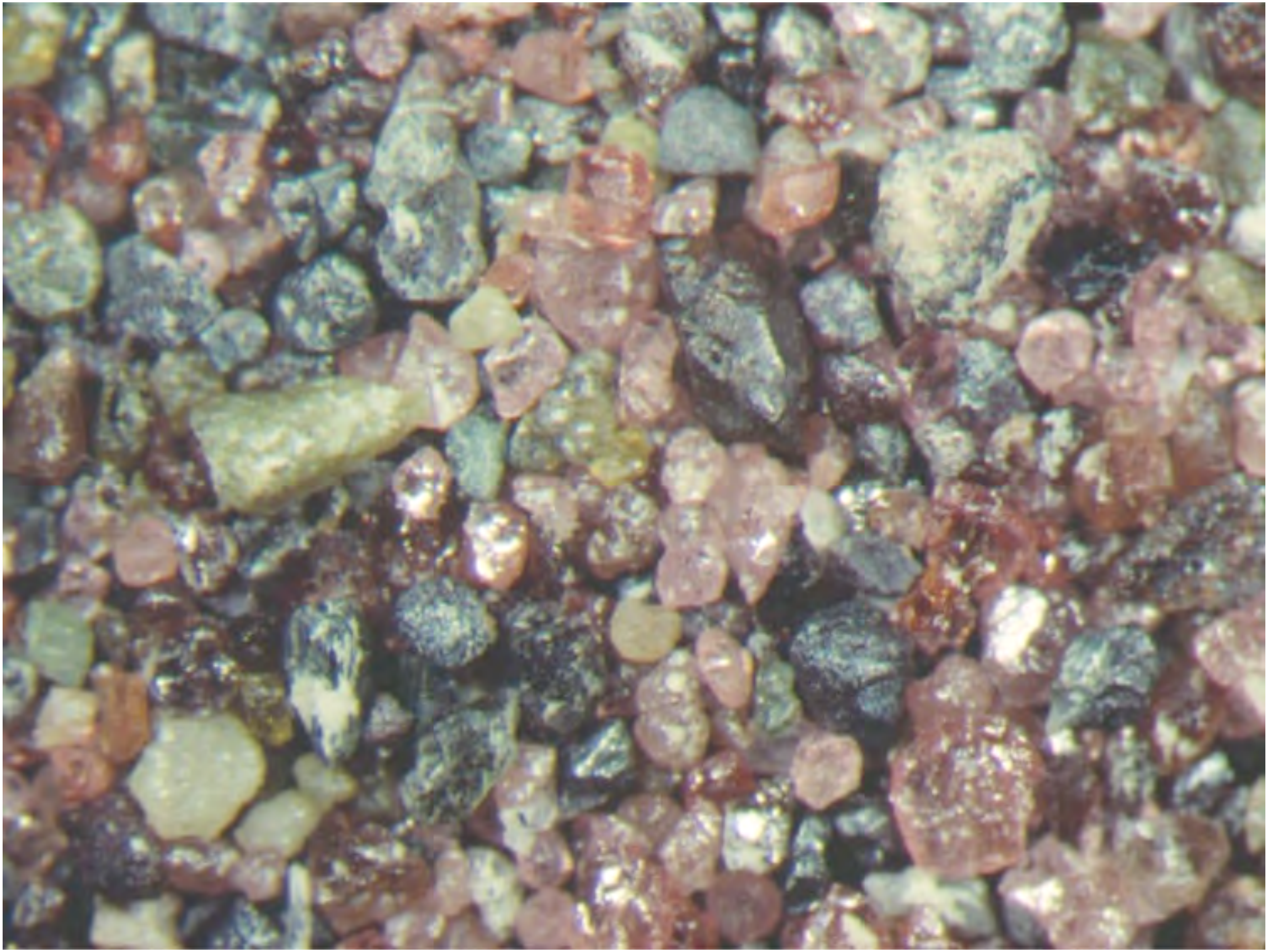

Oxidized Till
n = 469
Gold Grains / 10kg
1000
100
10
1.0
0.1
1
10
100
1000
10000
100000
Gold (ppb, nonmagnetic concentrate)

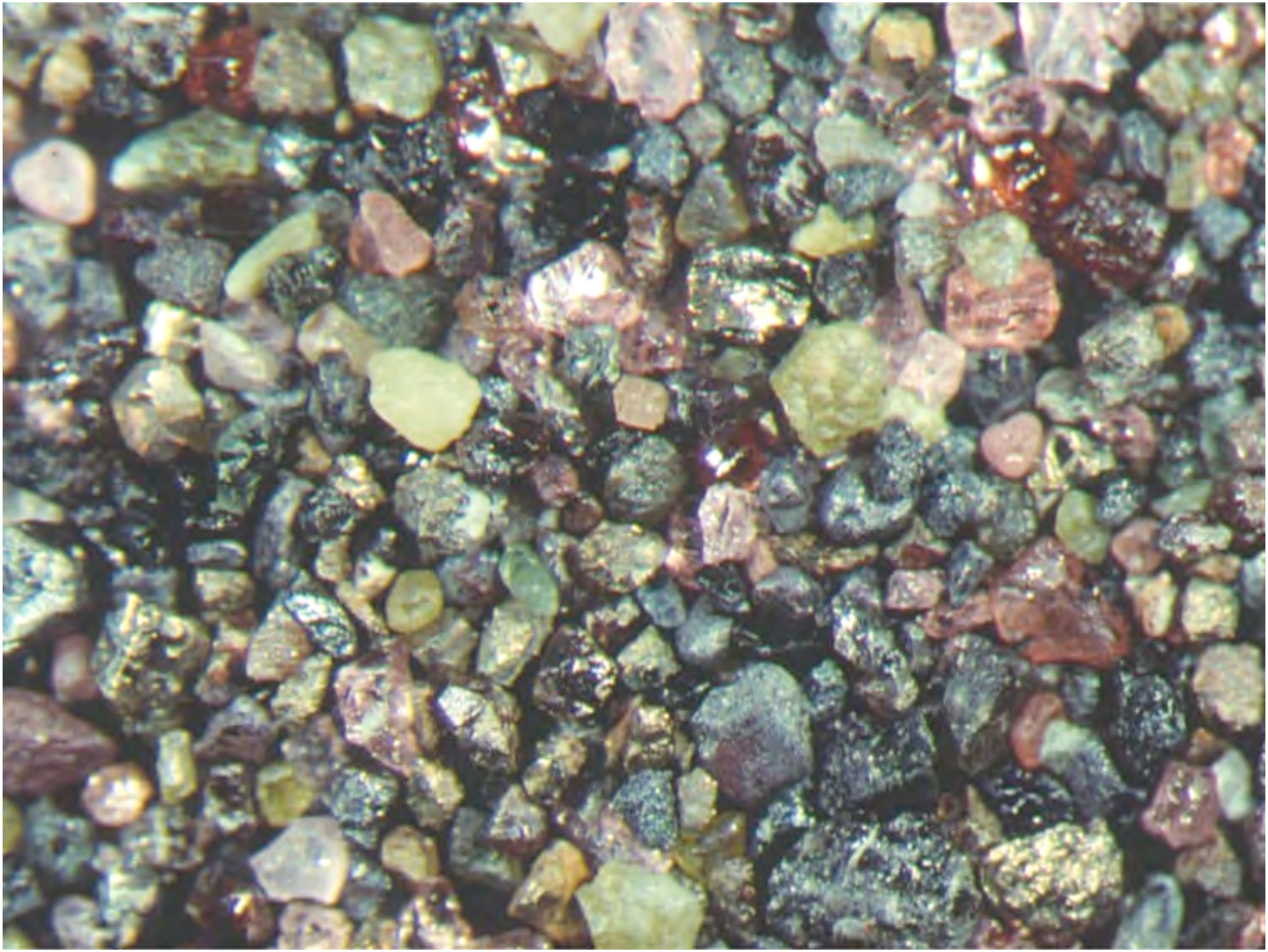

527X 20KV WD:25MM S:01
50UM

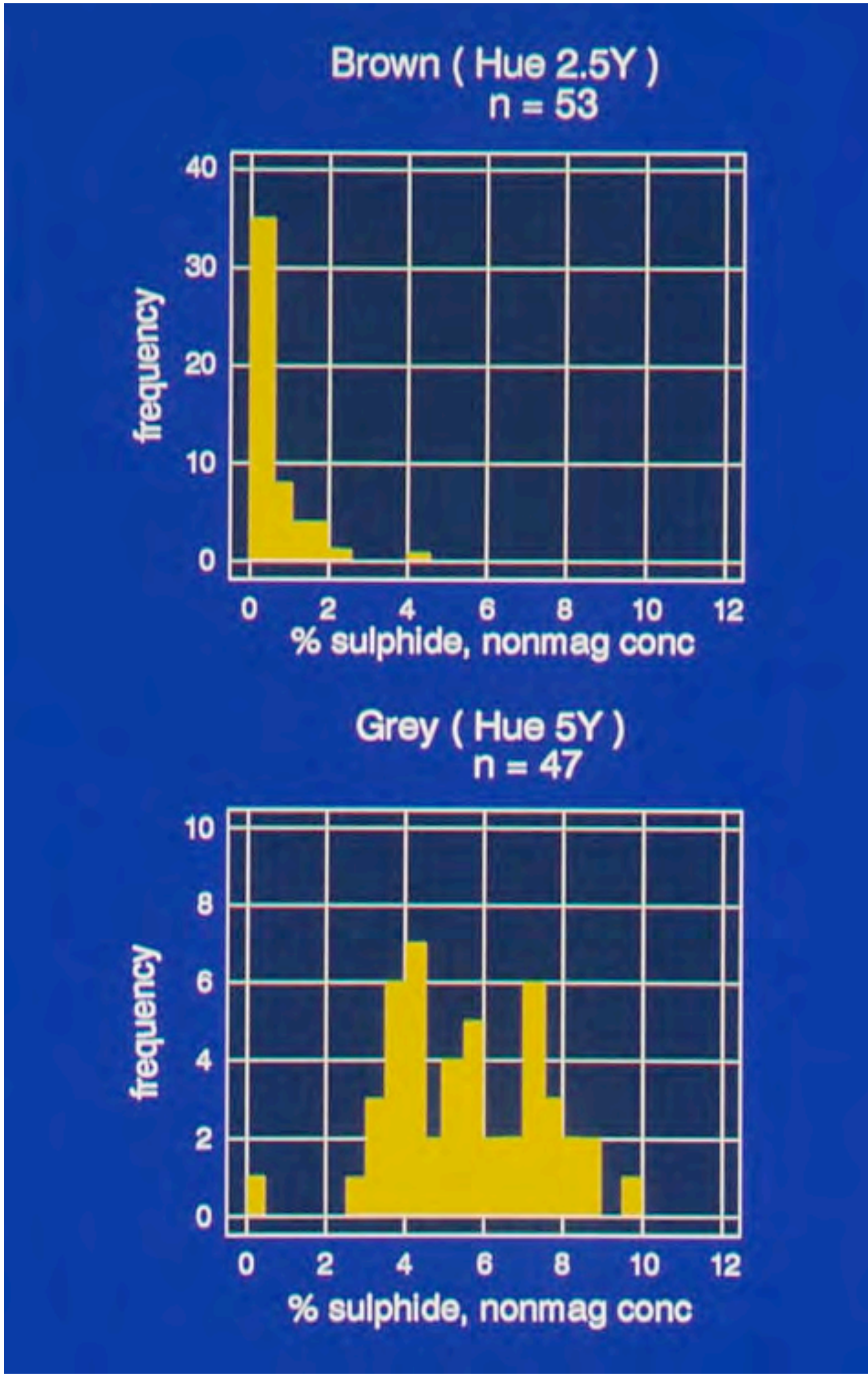

Visible Gold Grains
n = 55
frequency
weight % Au
Visible Gold in Bedrock
n = 8
frequency
weight % Au

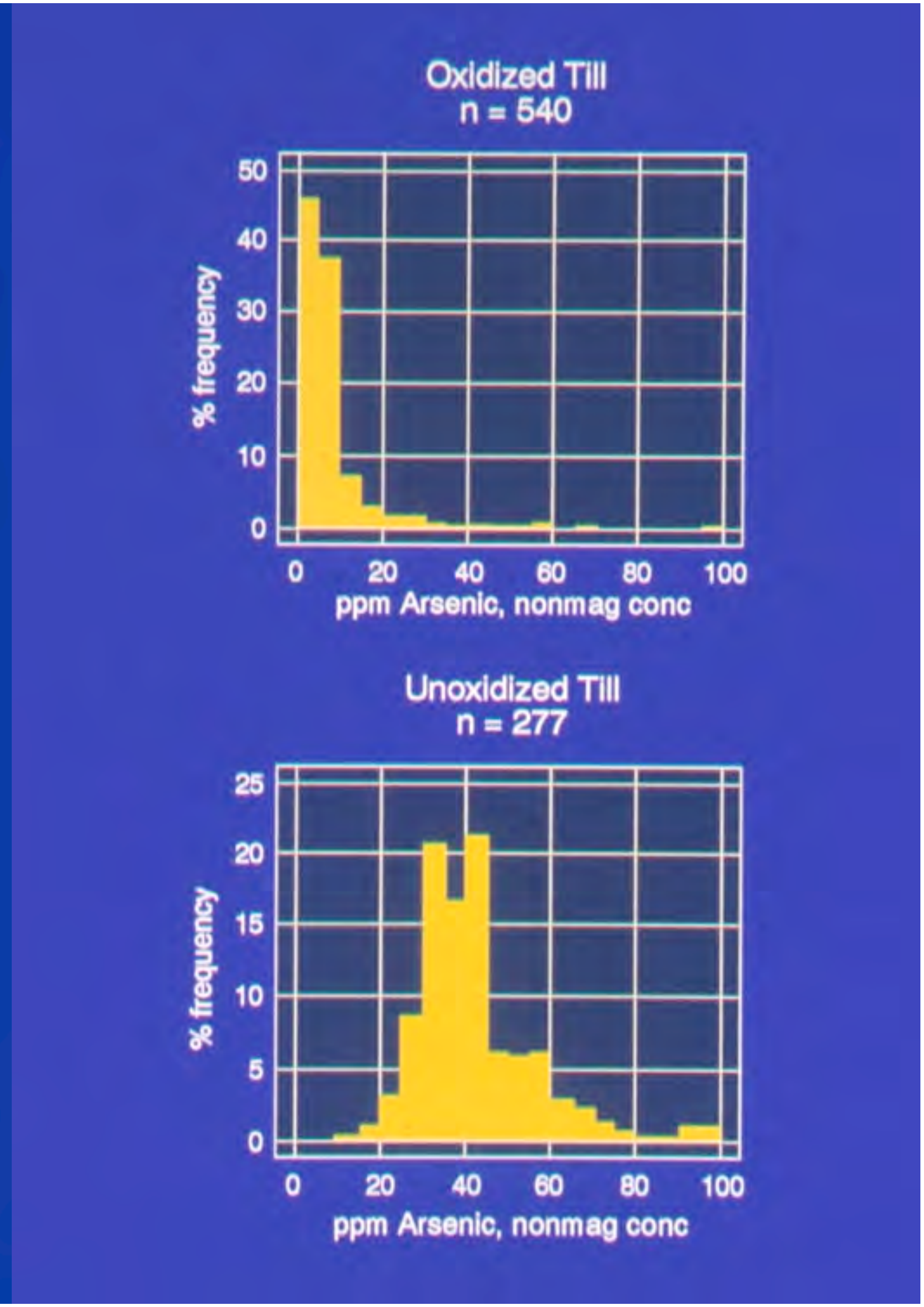
Sulphides

- Rare coated grains in aerated sediments
- Fresh sulphides in sediments obtained by drilling



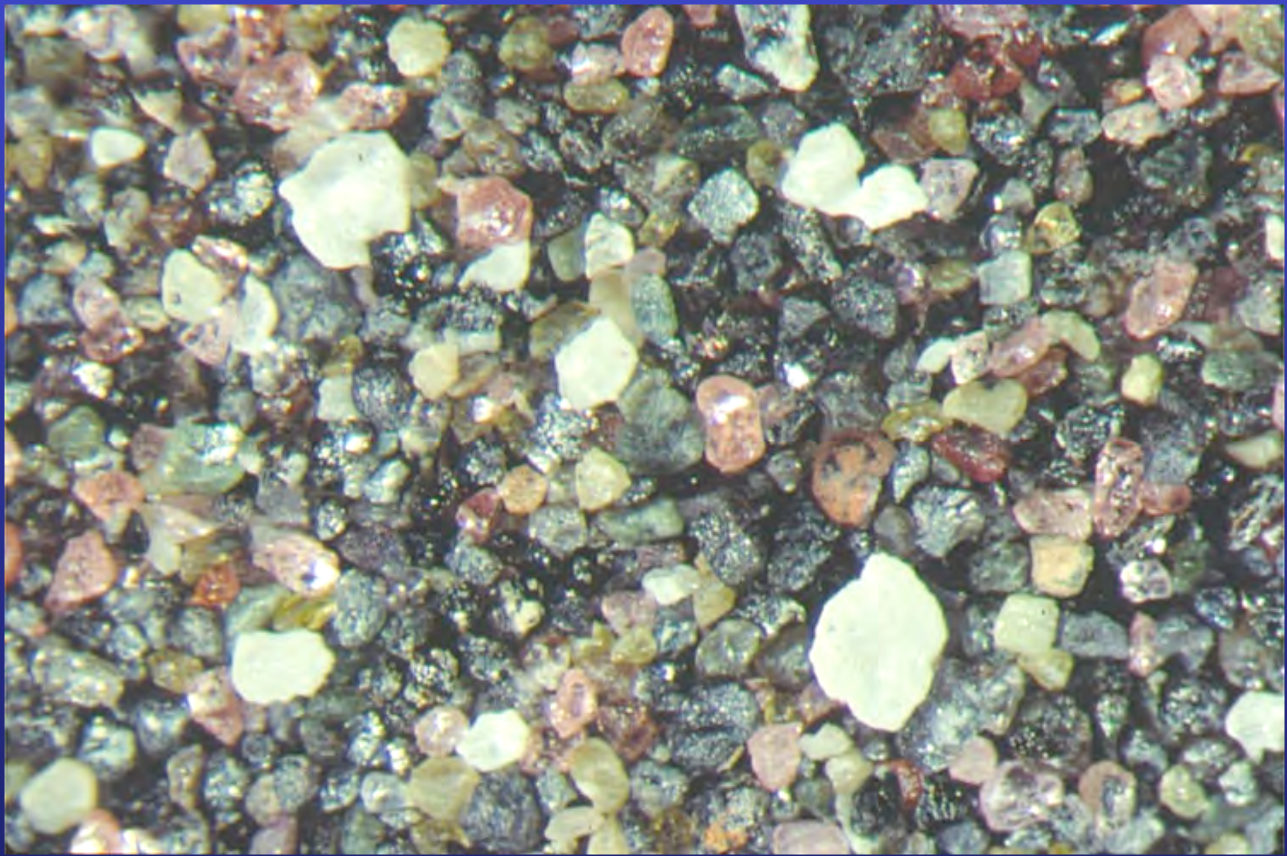



Brown (Hue 2.5Y)
n = 53
frequency
40
30
20
10
0
0
2
4
6
8
10
12
% sulphide, nonmag conc
Grey (Hue 5Y)
n = 47
frequency
10
8
6
4
2
0
0
2
4
6
8
10
12
% sulphide, nonmag conc


Oxidized Till
n = 540
% frequency
50
40
30
20
10
0
0
20
40
60
80
100
ppm Arsenic, nonmag conc
Unoxidized Till
n = 277
% frequency
25
20
15
10
5
0
0
20
40
60
80
100
ppm Arsenic, nonmag conc

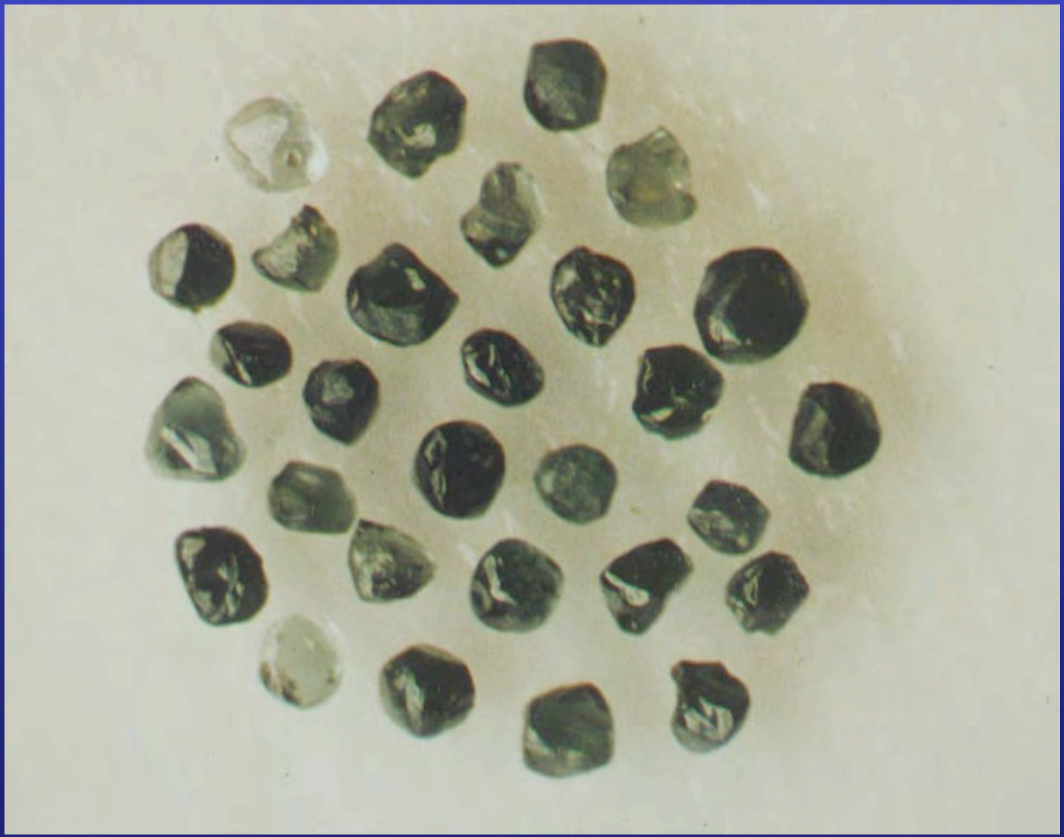
Scheelite

- Lamping under short-wave ultraviolet



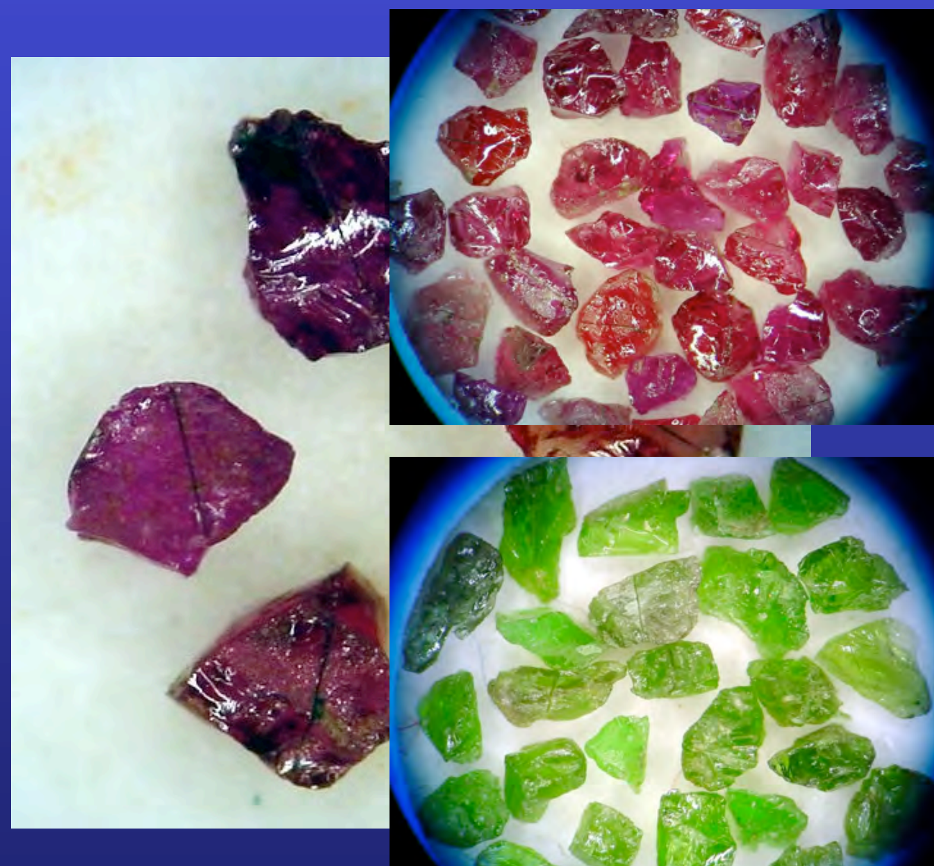
Base metal indicators

- e.g. resistates such as gahnite

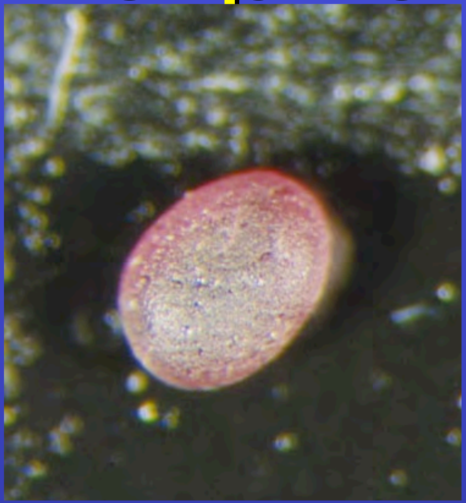


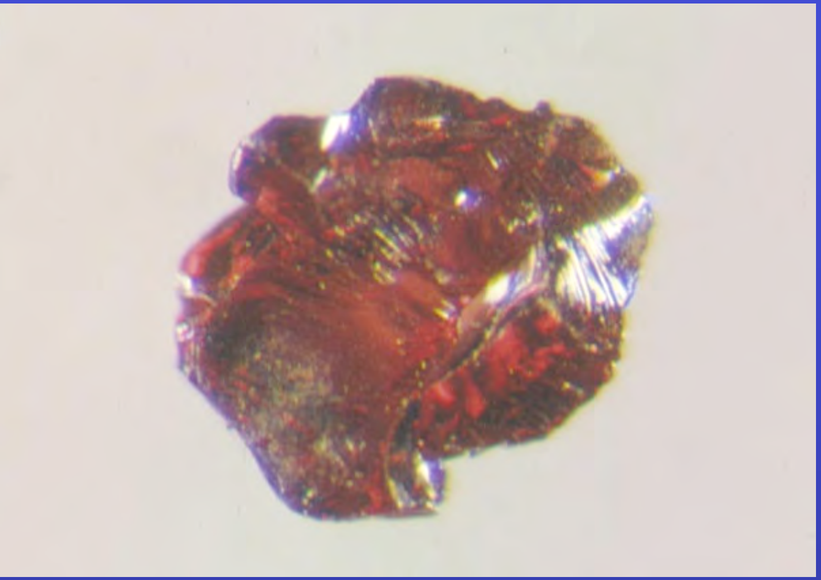
Kimberlite indicator minerals

- Cr-pyrope
- Mg-ilmenite
- Cr-spinel
- E-garnet
- Cr-diopside
- Olivine
- Diamond



Morphology



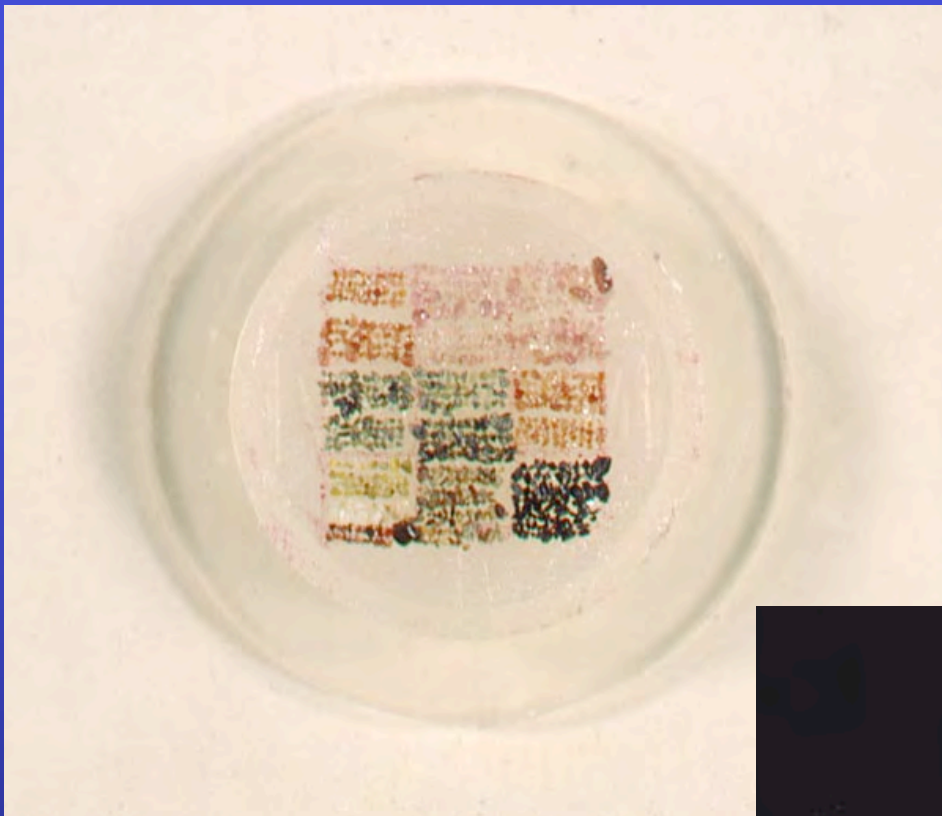



77,0X 20KV WD:58MM S:00000 P:00008
500UM

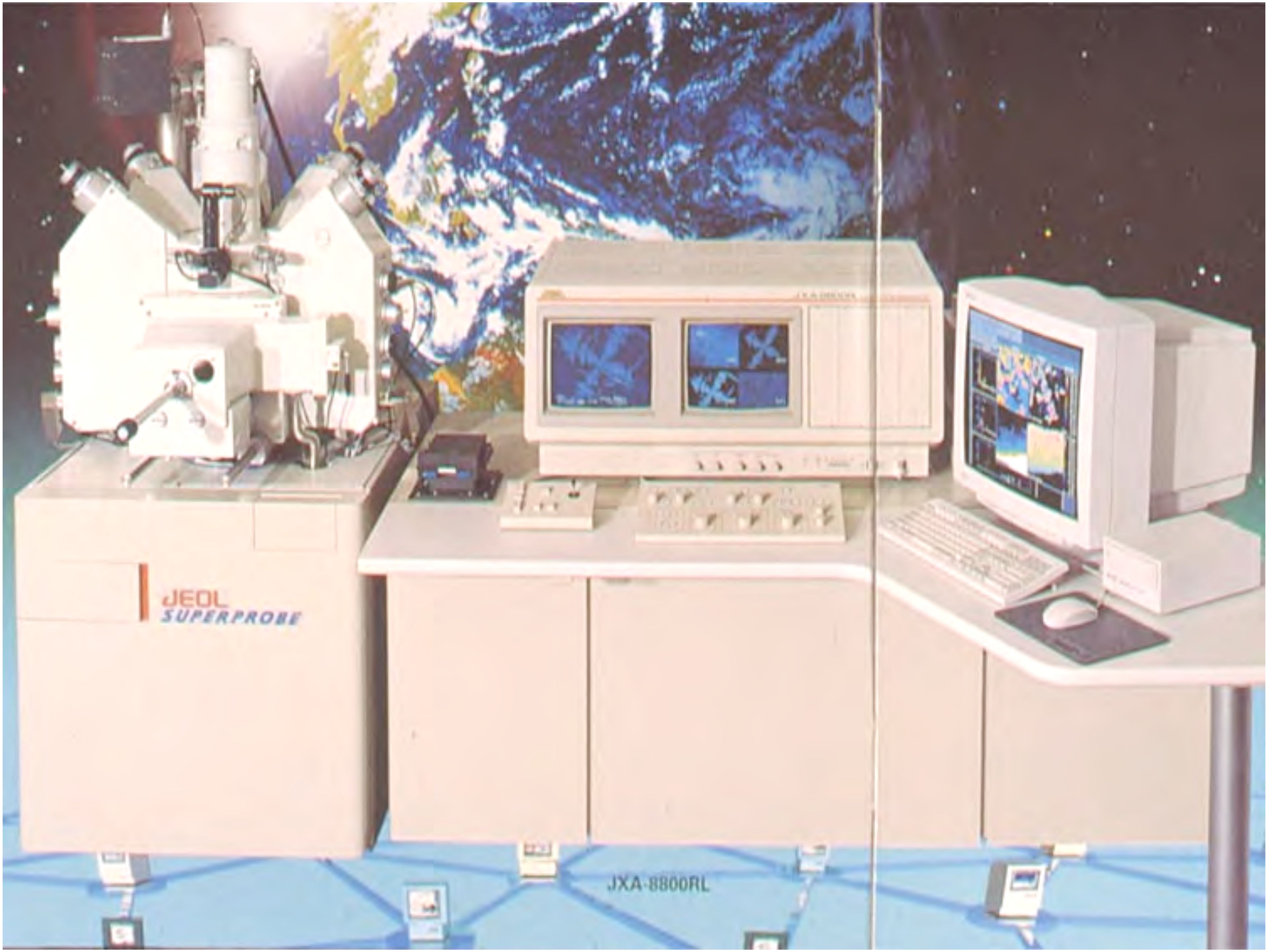

90,3X 20KV WD:58MM S:00000 P:00030
500UM

Mineral chemistry

- Mount & polish grains
- Semi-quantitative analysis
- Quantitative major element analysis
- Mineral classification
- Trace element analysis

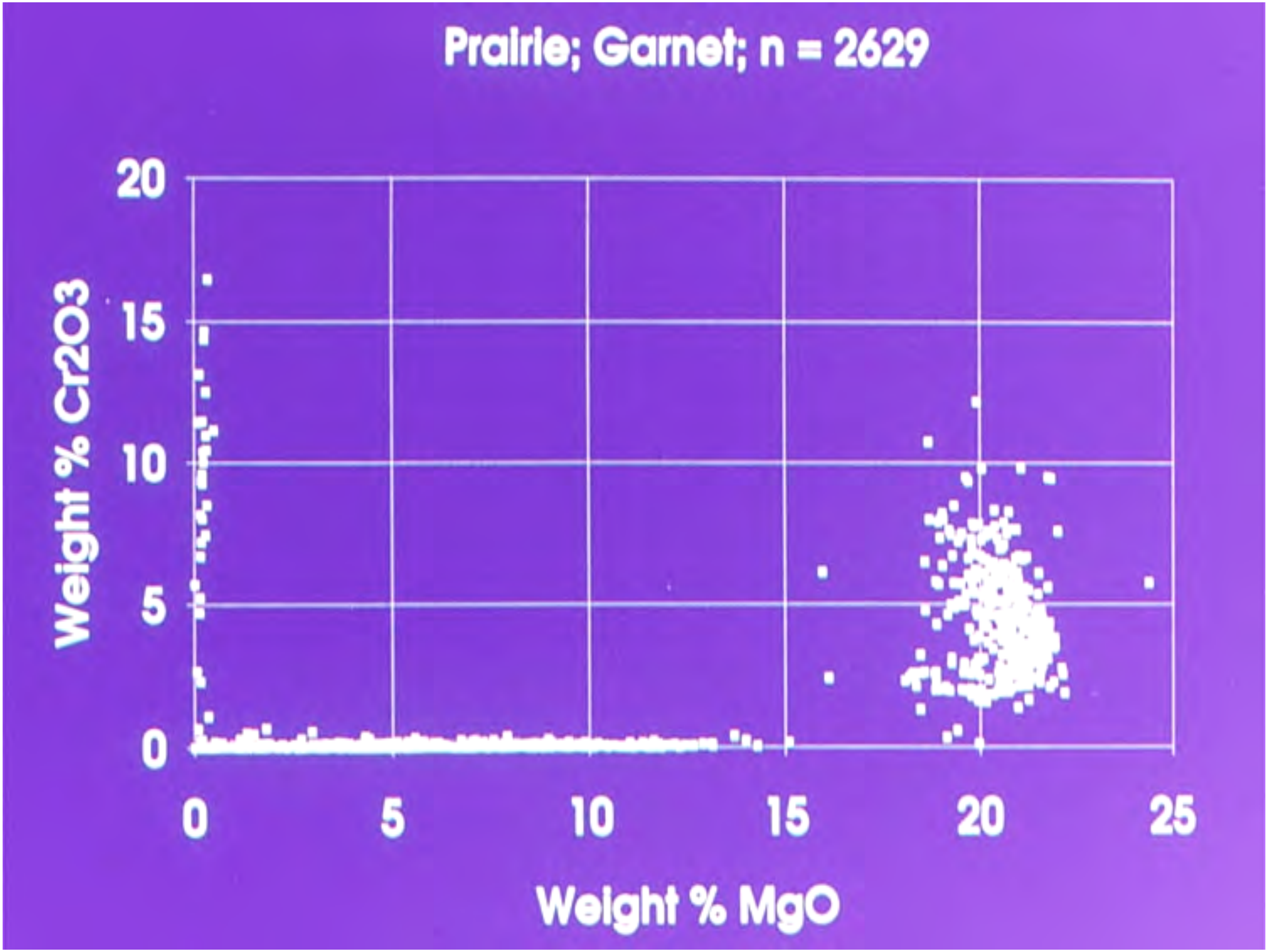


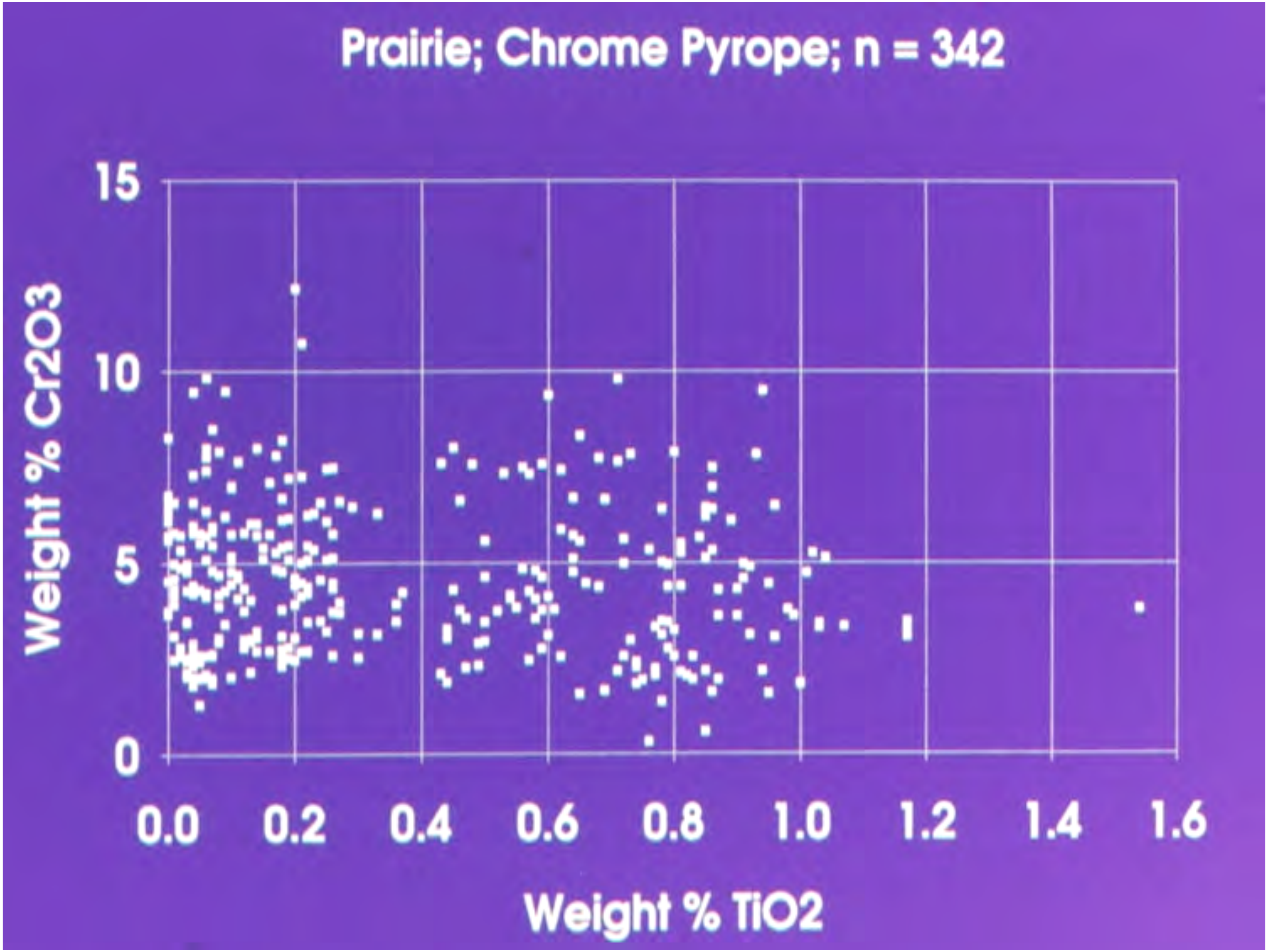

METASERV

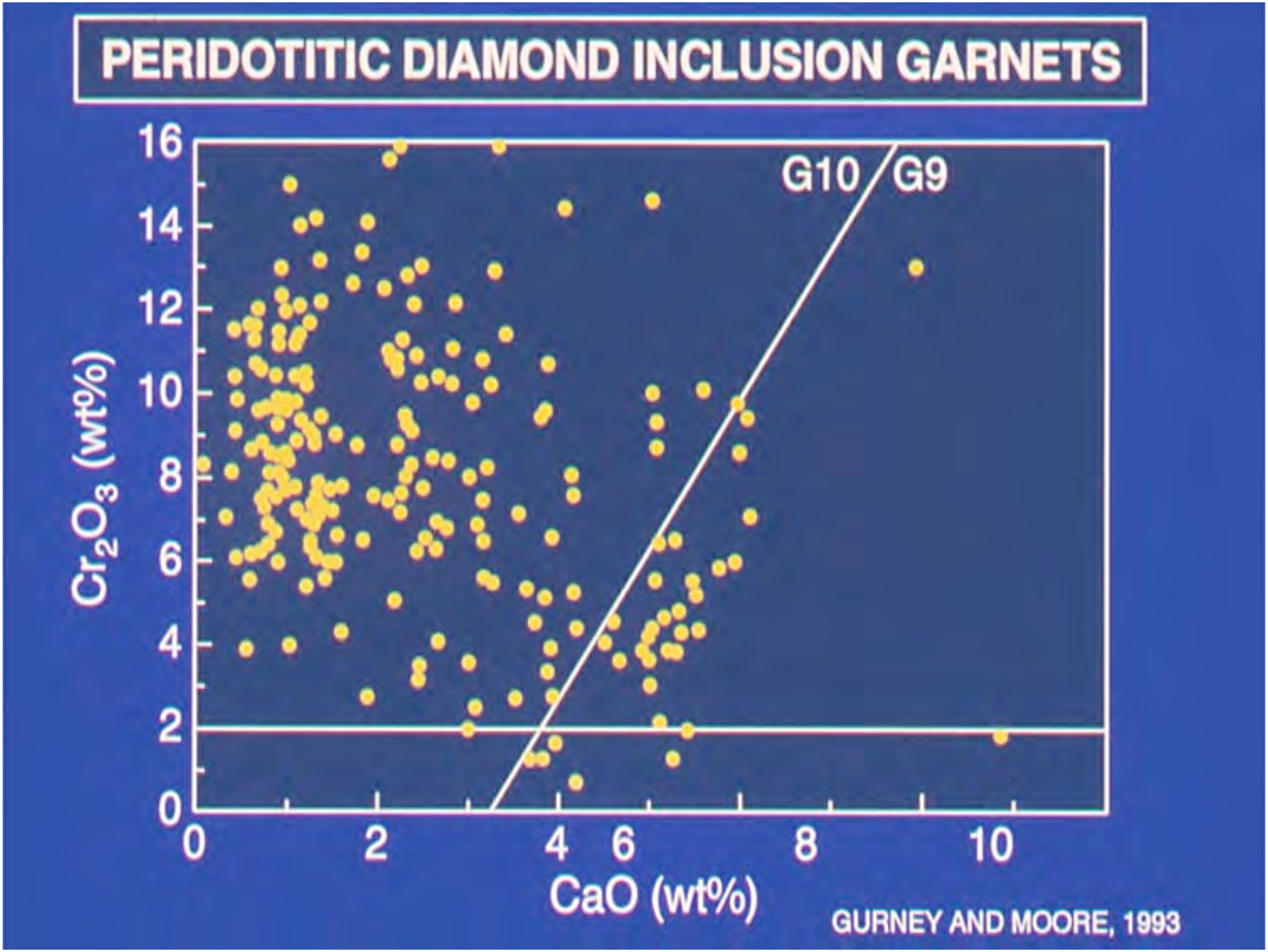

JEOL
SUPERPROBE
JXA-8800RL

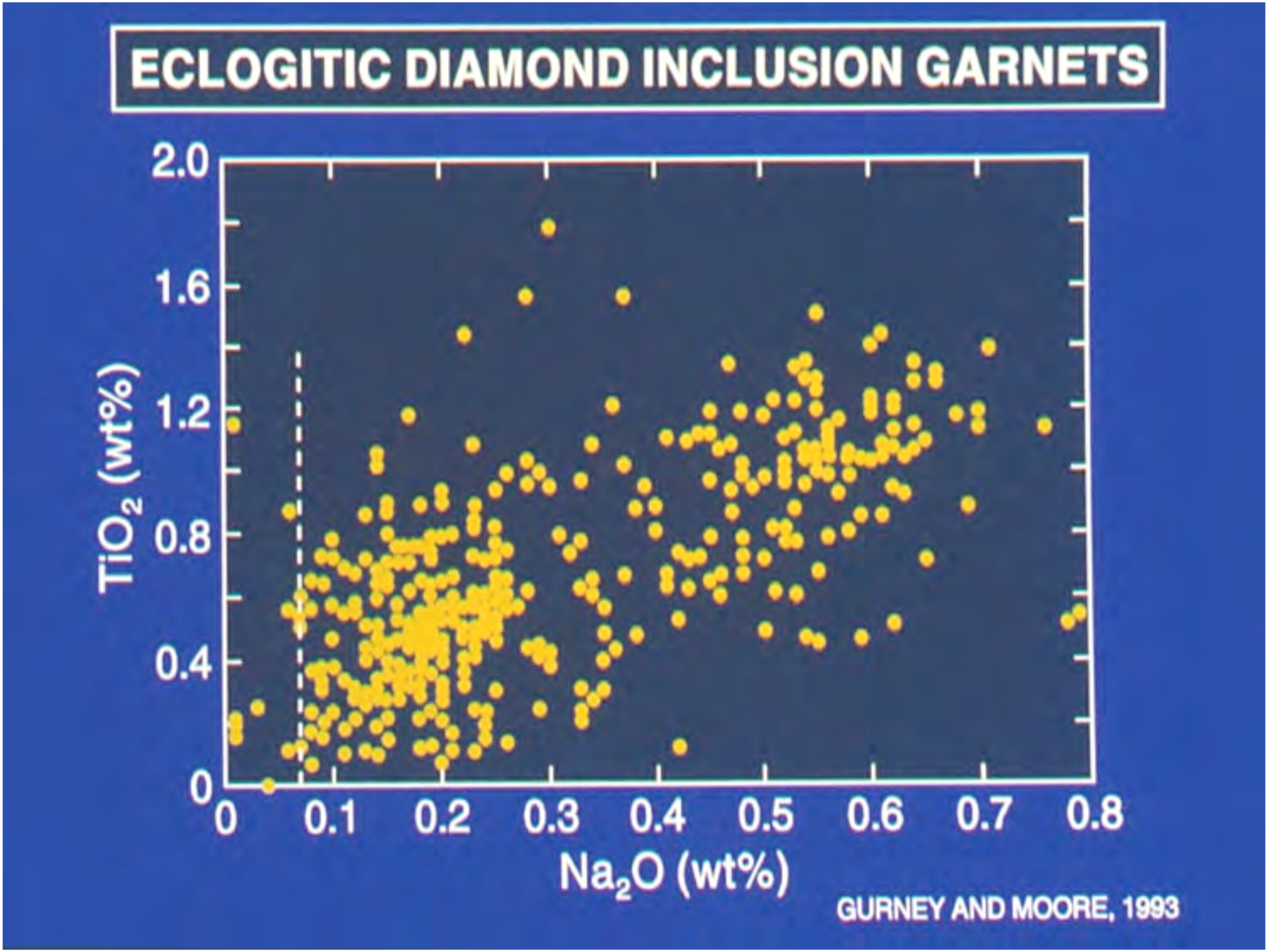
Dawson and Stephens
Kimberlitic Garnet Classification

Mean:	TiO_2	Cr_2O_3	FeO	MgO	CaO
G1	0.58	1.34	9.32	20.00	4.82
G2	1.09	0.91	9.84	20.30	4.52
G3	0.31	0.30	16.49	13.35	6.51
G4	0.90	0.08	17.88	9.87	9.41
G5	0.05	0.03	28.33	7.83	2.44
G6	0.24	0.27	10.77	10.38	14.87
G7	0.29	11.52	5.25	8.61	21.60
G8	0.25	0.04	6.91	4.69	24.77
G9	0.17	3.47	8.01	20.01	5.17
G10	0.04	7.73	6.11	23.16	2.13
G11	0.51	9.55	7.54	15.89	10.27
G12	0.18	15.94	7.47	15.40	9.51

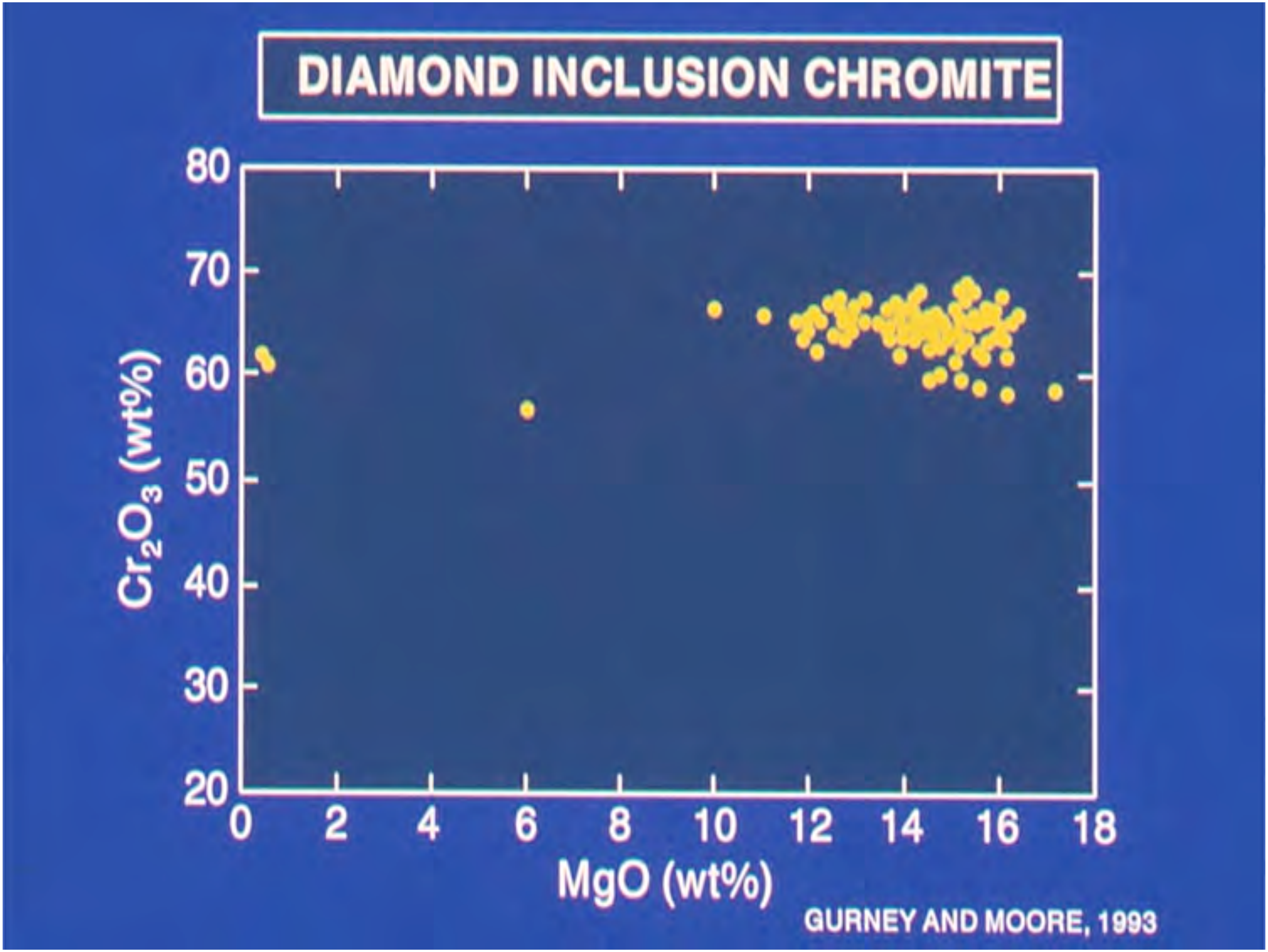

Prairie; Garnet; n = 2629
20
15
10
5
0
Weight % Cr2O3
0
5
10
15
20
25
Weight % MgO

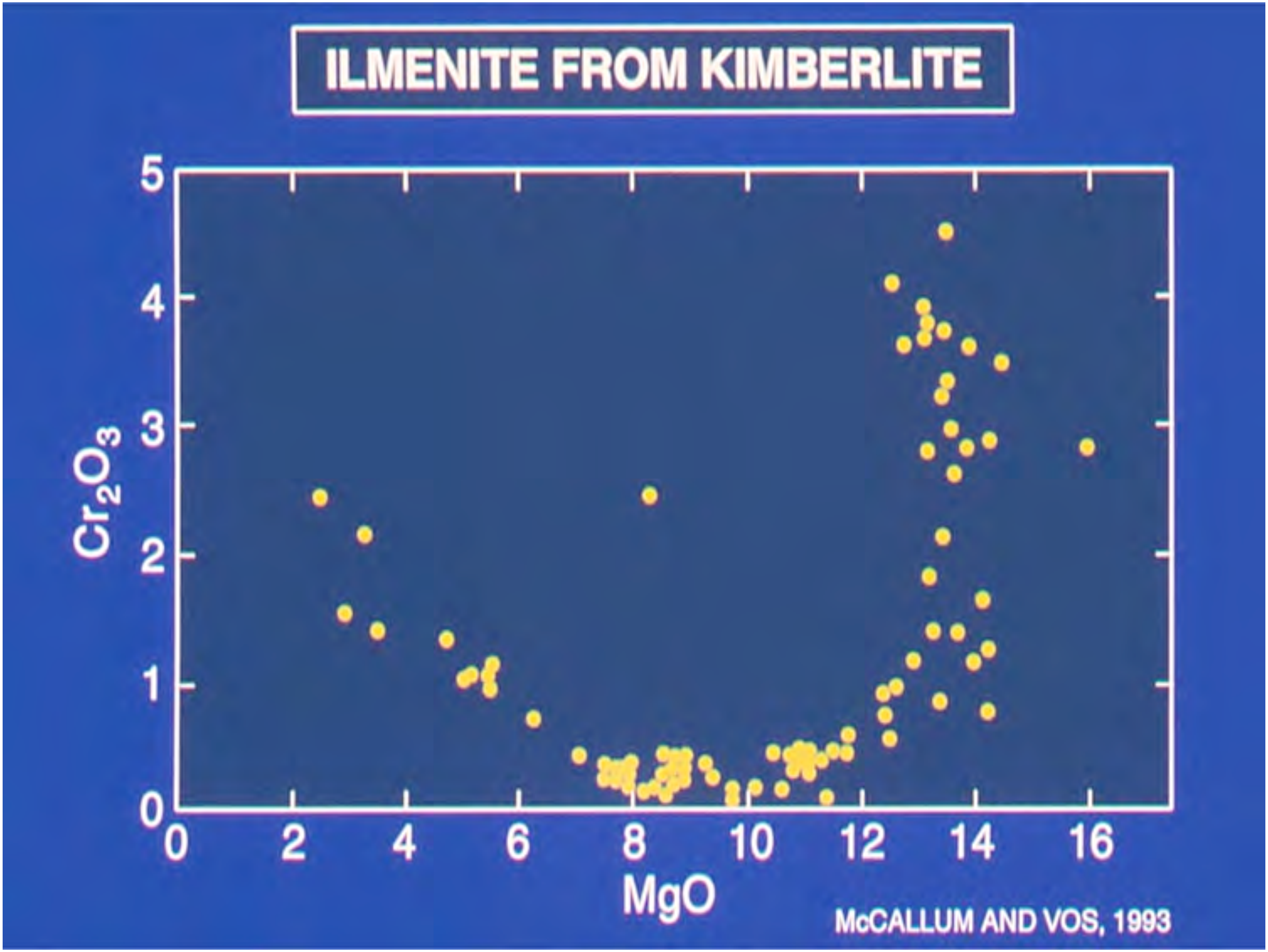

Prairie; Chrome Pyrope; n = 342
15
10
5
0
Weight % Cr2O3
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Weight % TiO2


PERIDOTITIC DIAMOND INCLUSION GARNETS
G10
G9
16
14
12
10
8
6
4
2
0
Cr_2O_3 (wt%)
0
2
4
6
8
10
CaO (wt%)
GURNEY AND MOORE, 1993

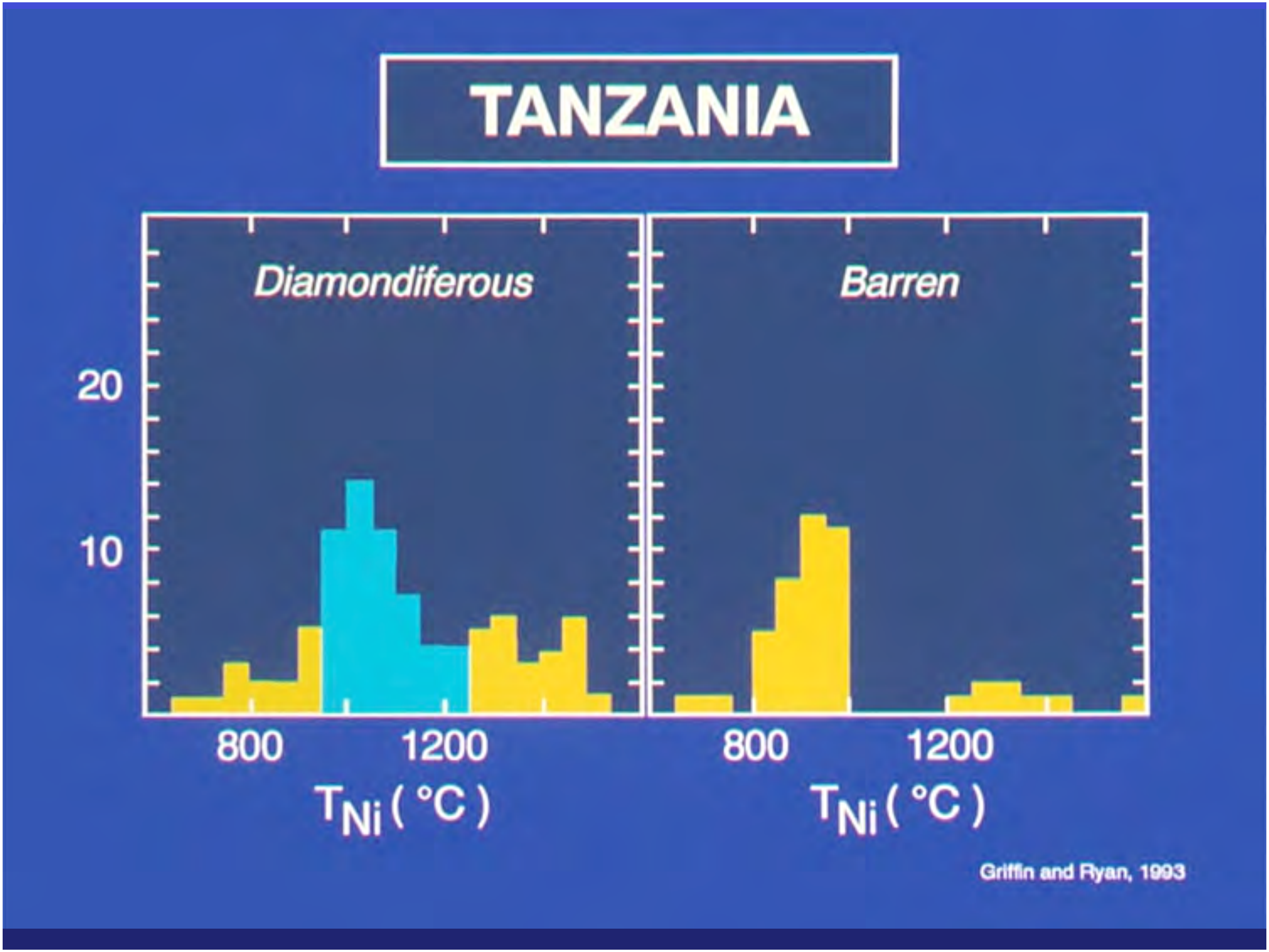


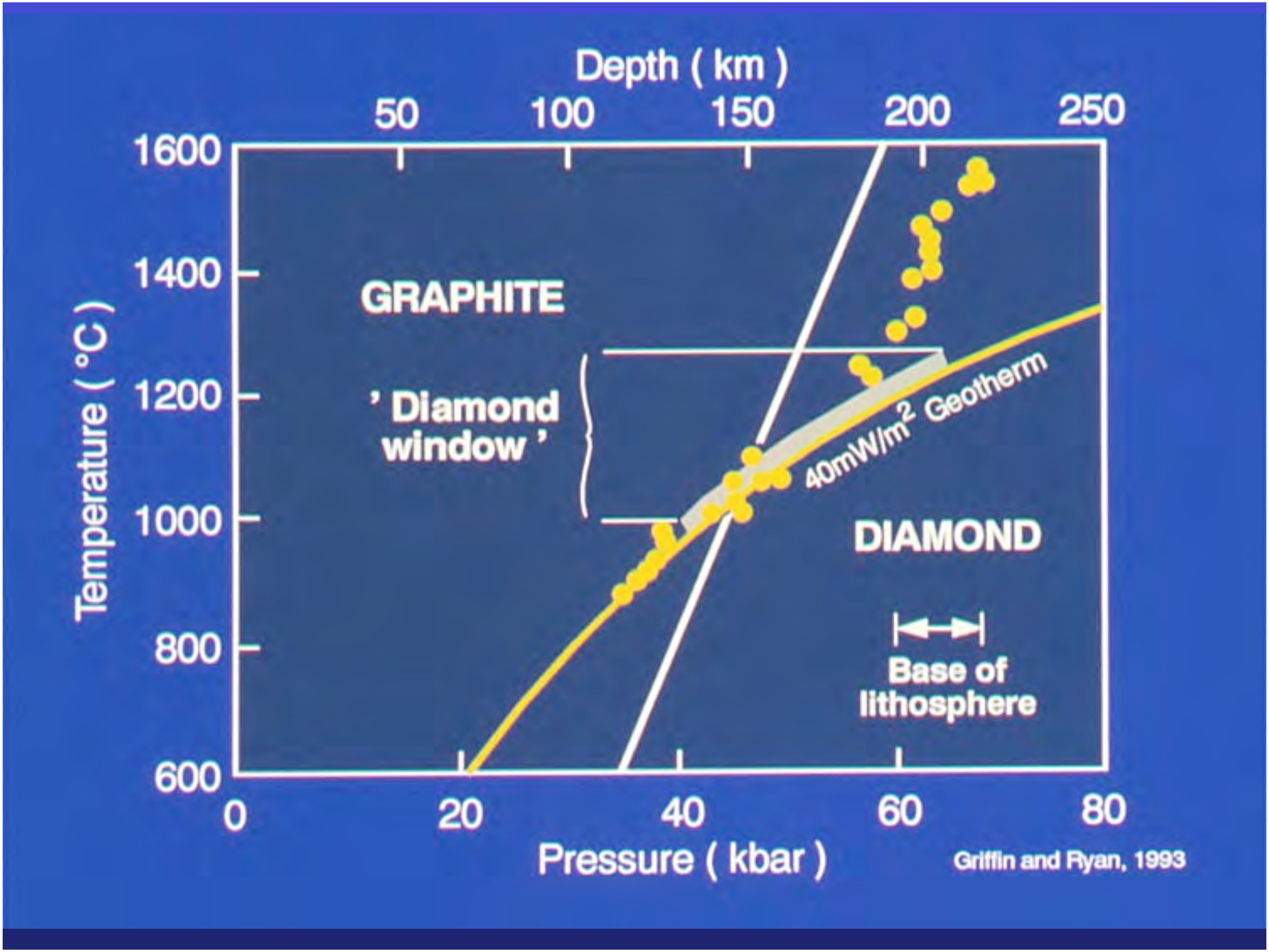
ECLOGITIC DIAMOND INCLUSION GARNETS
2.0
1.6
1.2
0.8
0.4
0
TiO2 (wt%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Na2O (wt%)
GURNEY AND MOORE, 1993


DIAMOND INCLUSION CHROMITE
80
70
60
50
40
30
20
0
2
4
6
8
10
12
14
16
18
Cr_2O_3 (wt%)
MgO (wt%)
GURNEY AND MOORE, 1993

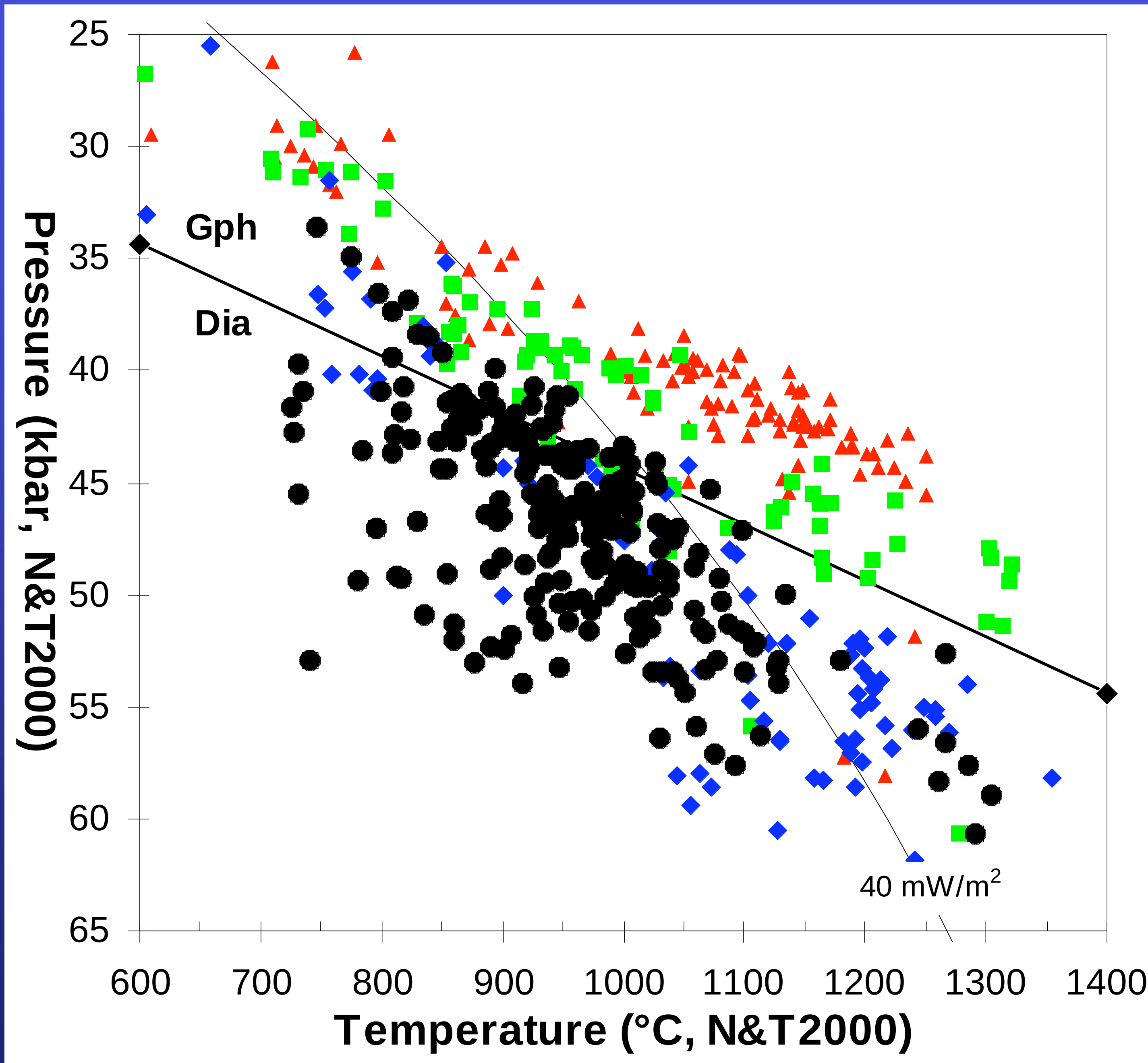


ILMENITE FROM KIMBERLITE
5
4
3
2
1
0
Cr_2O_3
0
2
4
6
8
10
12
14
16
MgO
McCALLUM AND VOS, 1993


TANZANIA
Diamondiferous
Barren
20
10
800
1200
800
1200
T_{Ni} (°C)
T_{Ni} (°C)
Griffin and Ryan, 1993

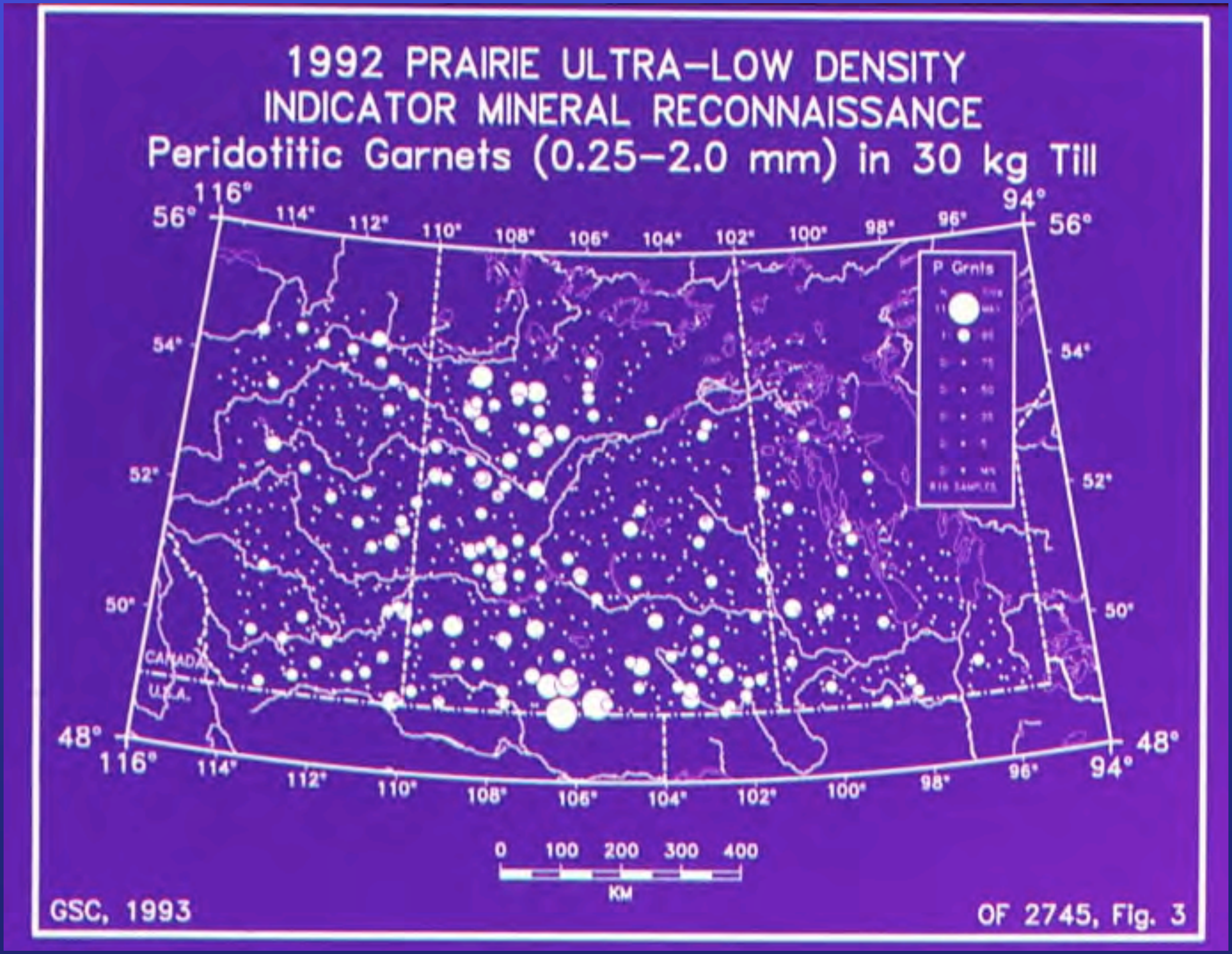


Depth (km)
50
100
150
200
250
1600
1400
1200
1000
800
600
Temperature (°C)
GRAPHITE
' Diamond window '
40mW/m^2 Geotherm
DIAMOND
Base of lithosphere
0
20
40
60
80
Pressure (kbar)
Griffin and Ryan, 1993



Mineral Services

Interpretation & follow-up



Indicator mineral surveys

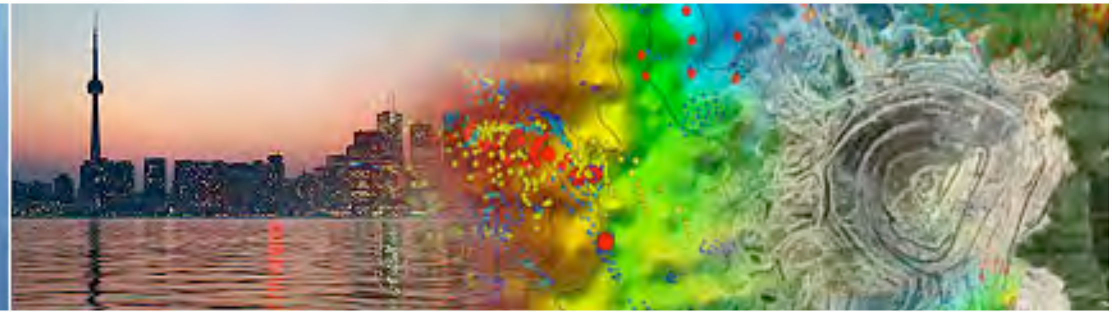
- Objective
- Media
- Spacing
- Size
- Collection
- Processing
- Pre-concentration
- Concentration
- Ferromagnetics
- Classification
- Picking
- Morphology
- Mineral chemistry
- Interpretation & follow-up

Exploration07

Indicator Mineral Methods in Mineral Exploration: Introduction

Harvey Thorleifson

Minnesota Geological Survey



Exploration07

Workshop 3

Indicator Mineral Methods in Mineral Exploration

Sunday, September 9, 2007

Association of Applied Geochemists (AAG)

Convenors:
Harvey Thorleifson, MGS & Beth McClenaghan, GSC