24th IAG Symposium
Fredericton, Canada
Workshop B: Indicator Mineral Exploration Technology

# Viable indicators in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu

Presented by Stu Averill
OVERBURDEN DRILLING MANAGEMENT LIMITED
May 31, 2009

# Selected Properties of Indicator Minerals

1. Heavy (due to low abundance)
2. Coarse-grained (>0.25 mm; unless ultra-heavy – e.g. gold and PGMs)
3. Resistant to weathering (eliminates most sulphide minerals; increases dependence on alteration minerals)

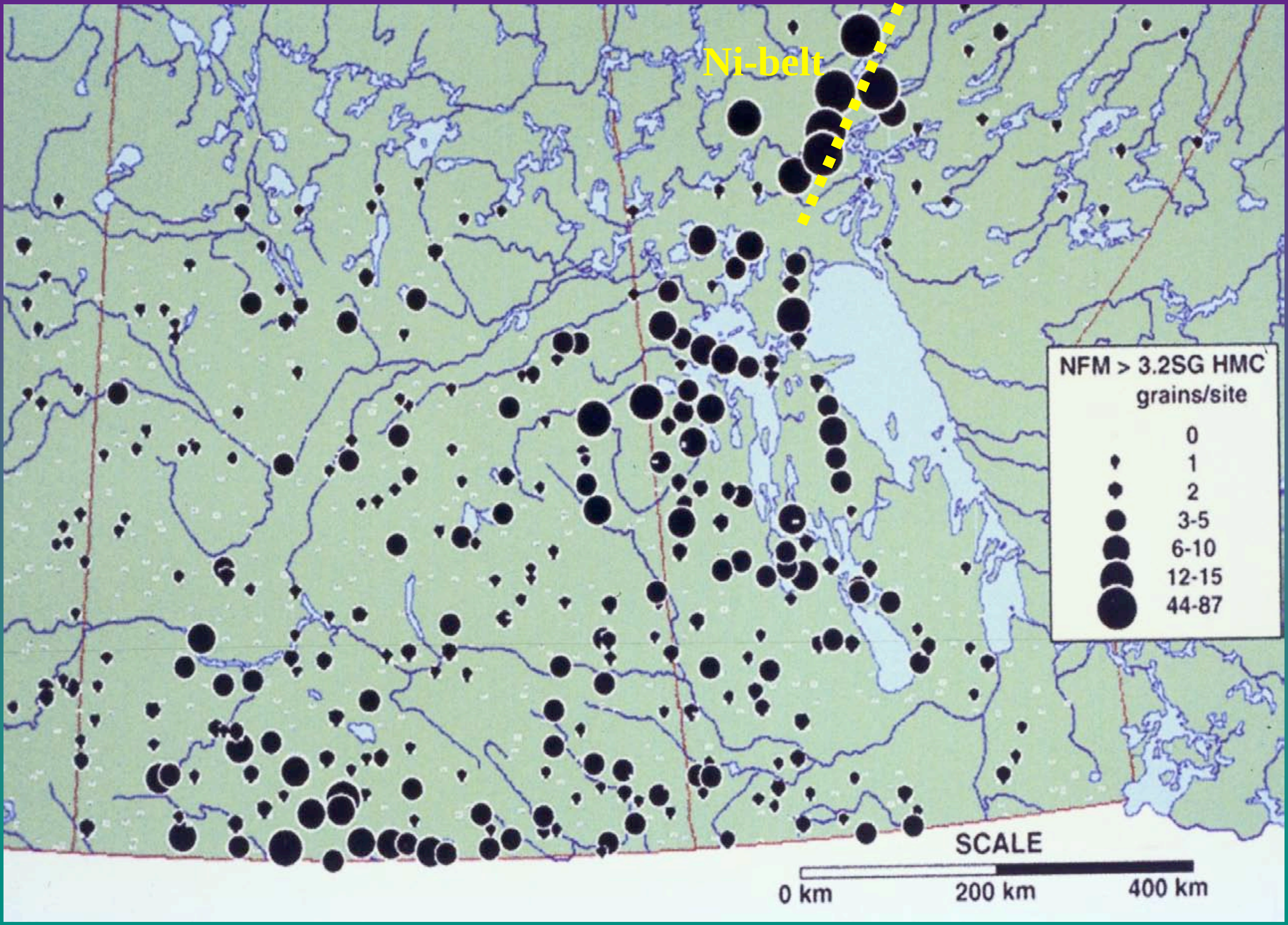
High pressures and temperatures increase mineral density and grain size

24th IAG Symposium
Fredericton, Canada
Workshop B: Indicator Mineral Exploration Technology

# Viable indicators in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu

Presented by Stu Averill
OVERBURDEN DRILLING MANAGEMENT LIMITED
May 31, 2009

# Dispersal of Cr-diopside from Thompson Ni-Belt




Courtesy: Harvey Thorliefson

# There are different indicator mineral suites and subsuites for:

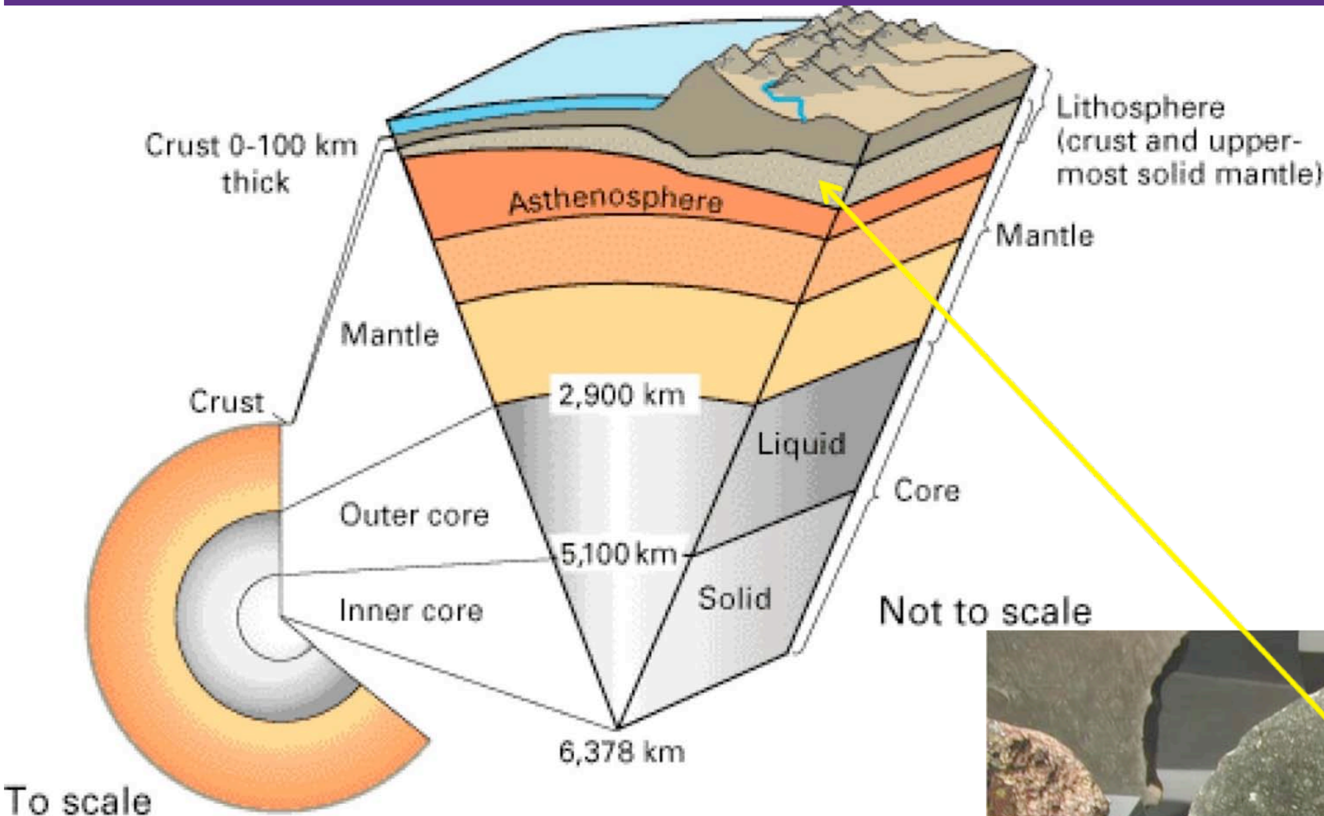
- Ni-Cu-PGE and porphyry Cu deposits
- the successive mineralizing events or processes that form these deposits
- each hydrothermal alteration zone

# Outline 1 – Ni-Cu-PGE Indicator Minerals

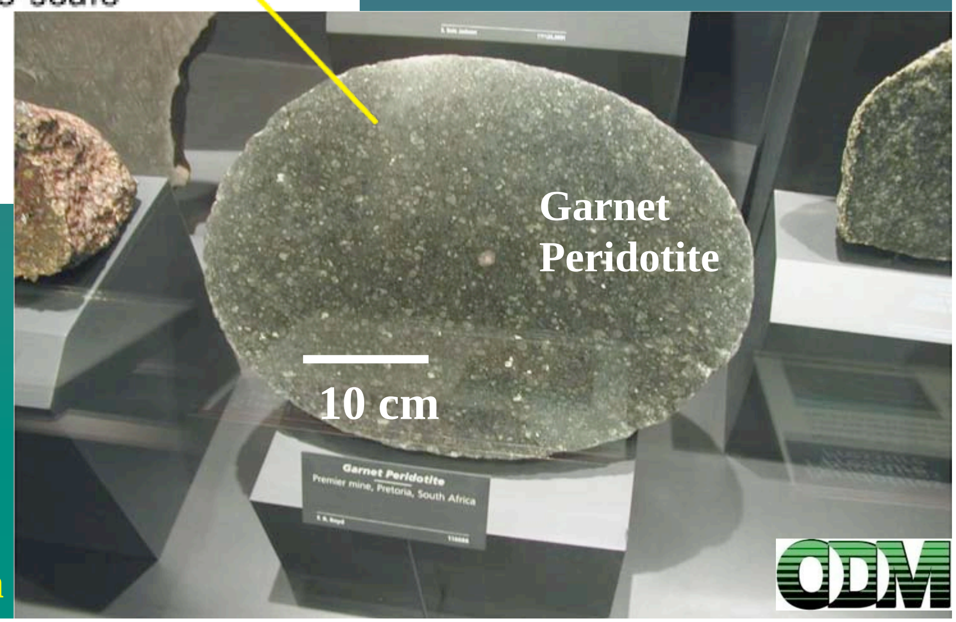
Four mineral subsuites indicating:

1. a fertile melt
2. rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization

# The Garnet Peridotite Connection for Ni-Cu-PGE and Kimberlite Indicators




Courtesy: Bruce Kjarsgaard, GSC




Courtesy: Smithsonian Institution

# Outline 1 – Ni-Cu-PGE Indicator Minerals

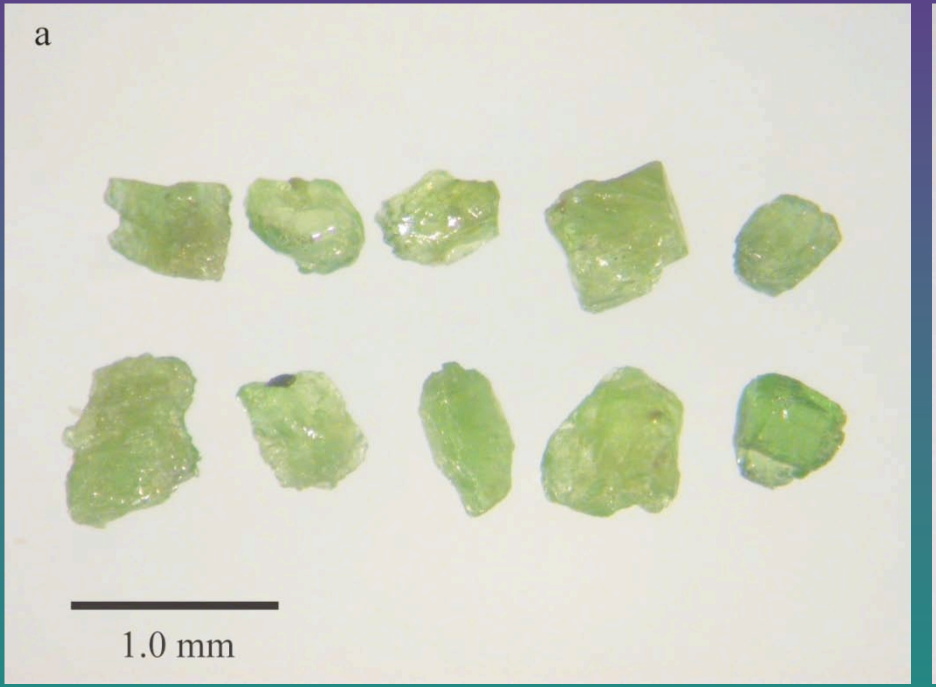
Four subsuites indicating:

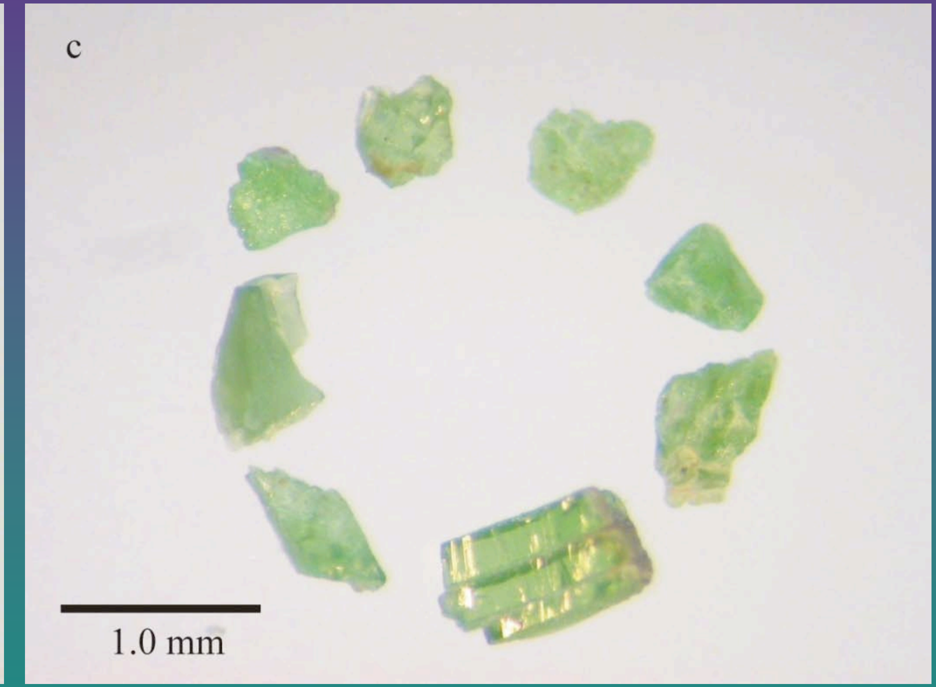
1. a fertile melt
2. rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization

# Indicators of a Fertile Melt

- orthopyroxene (enstatite – $Mg_2Si_2O_6$)
- olivine (forsterite – $MgSiO_4$)
- Cr-diopside – $Ca(Mg,Cr)Si_2O_6$
- chromite – $(Fe,Mg)(Cr,Al)O_4$

# Cr-diopside

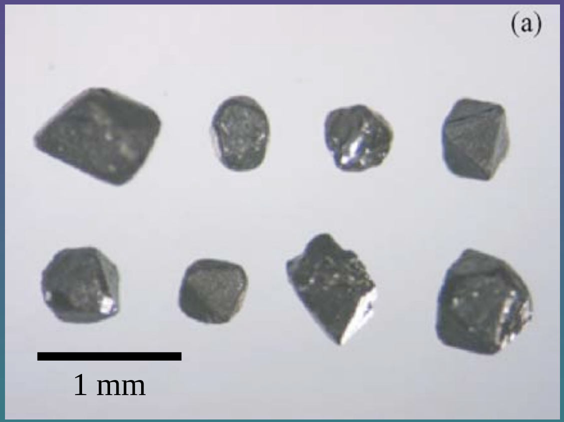


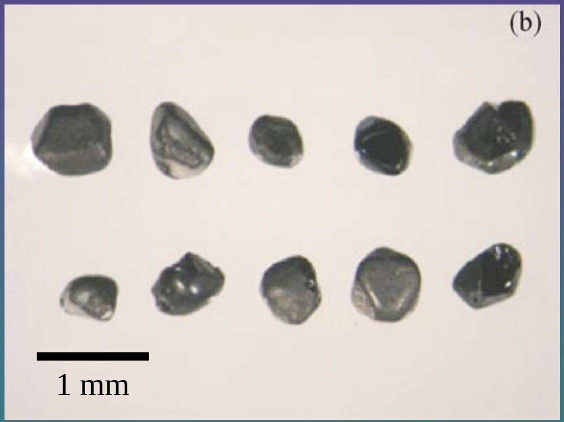

Non-kimberlitic
$<1.25\%\ Cr_2O_3$

Kimberlitic
$>1.25\%\ Cr_2O_3$

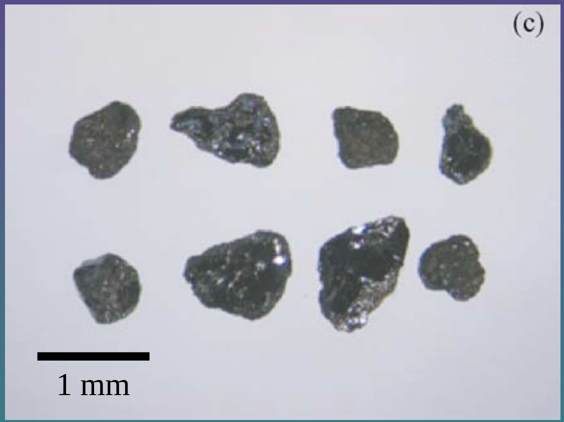
# Chromite




Non-kimberlitic

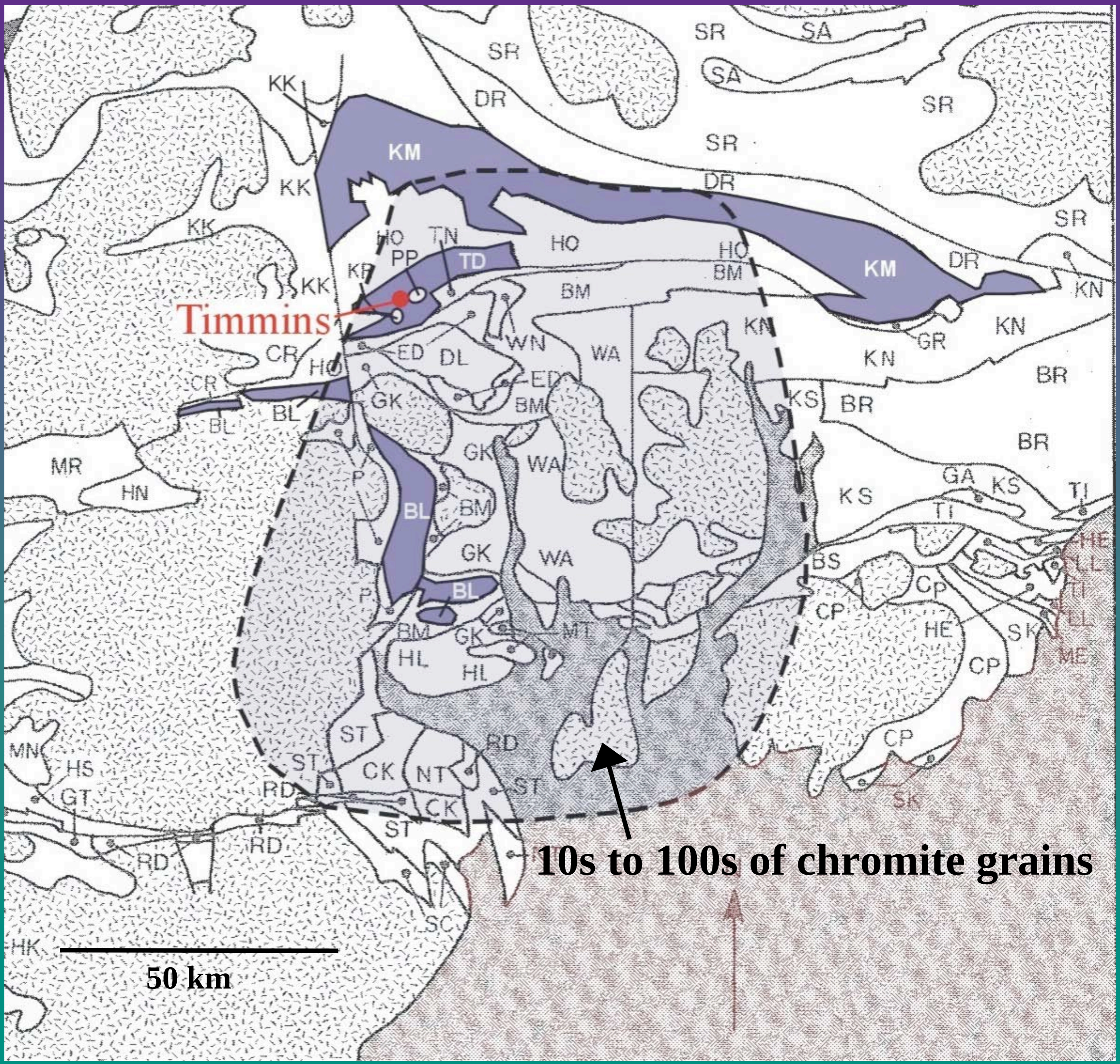



Kimberlitic

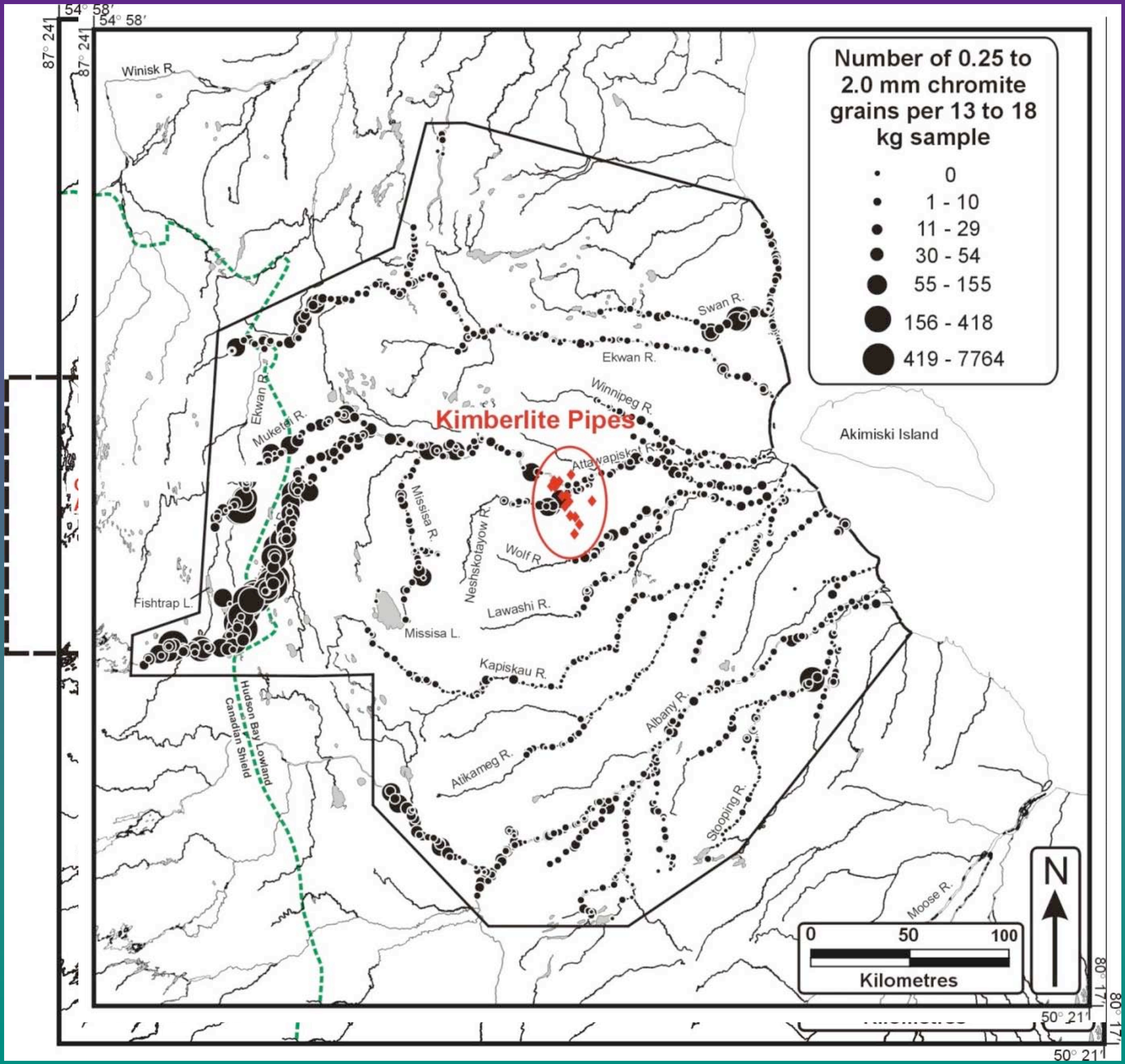



Lateriti
c

# Dispersal of chromite from fertile Timmins komatiites

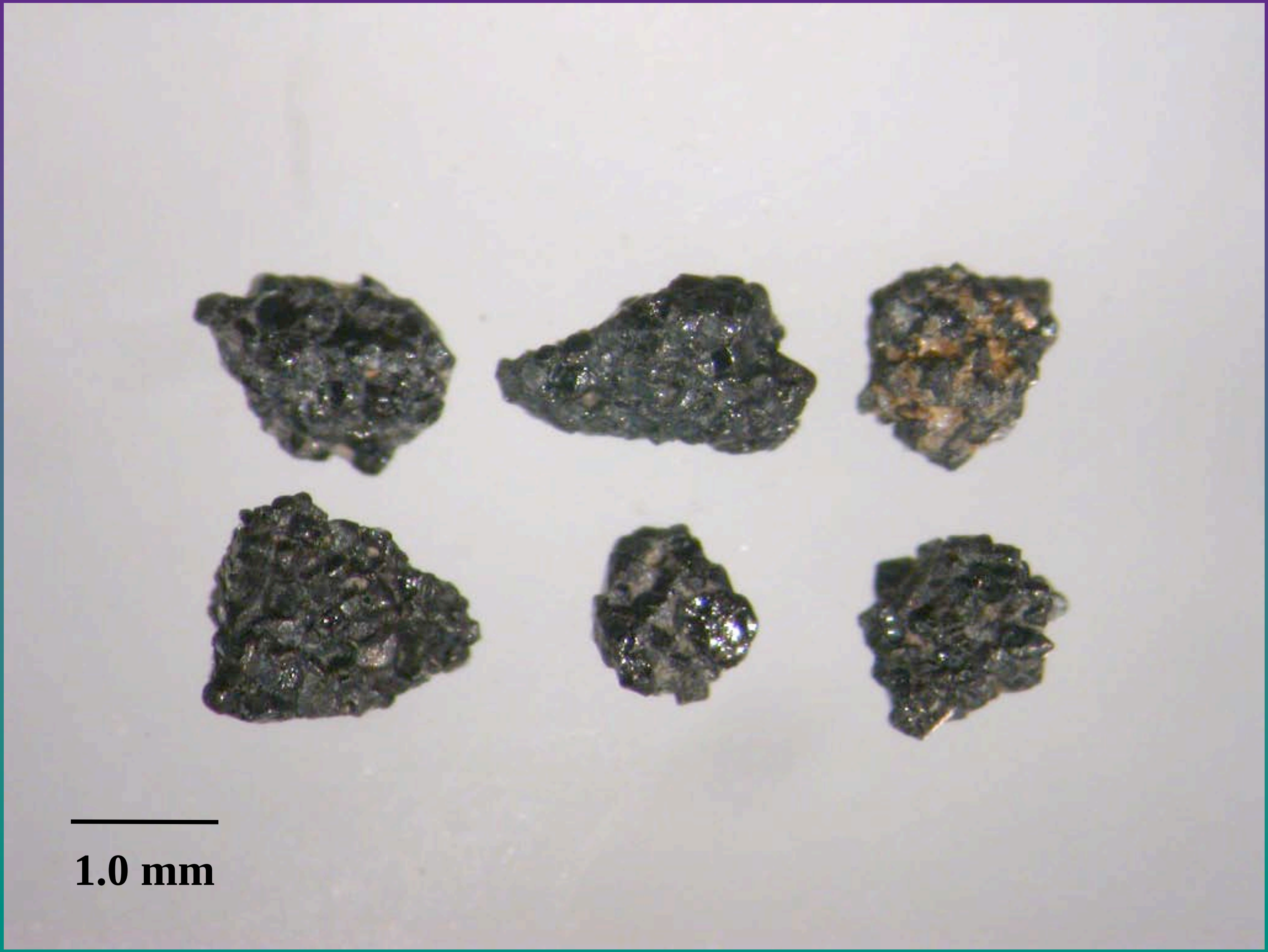


# Chromite Dispersal in the Attawapiskat River

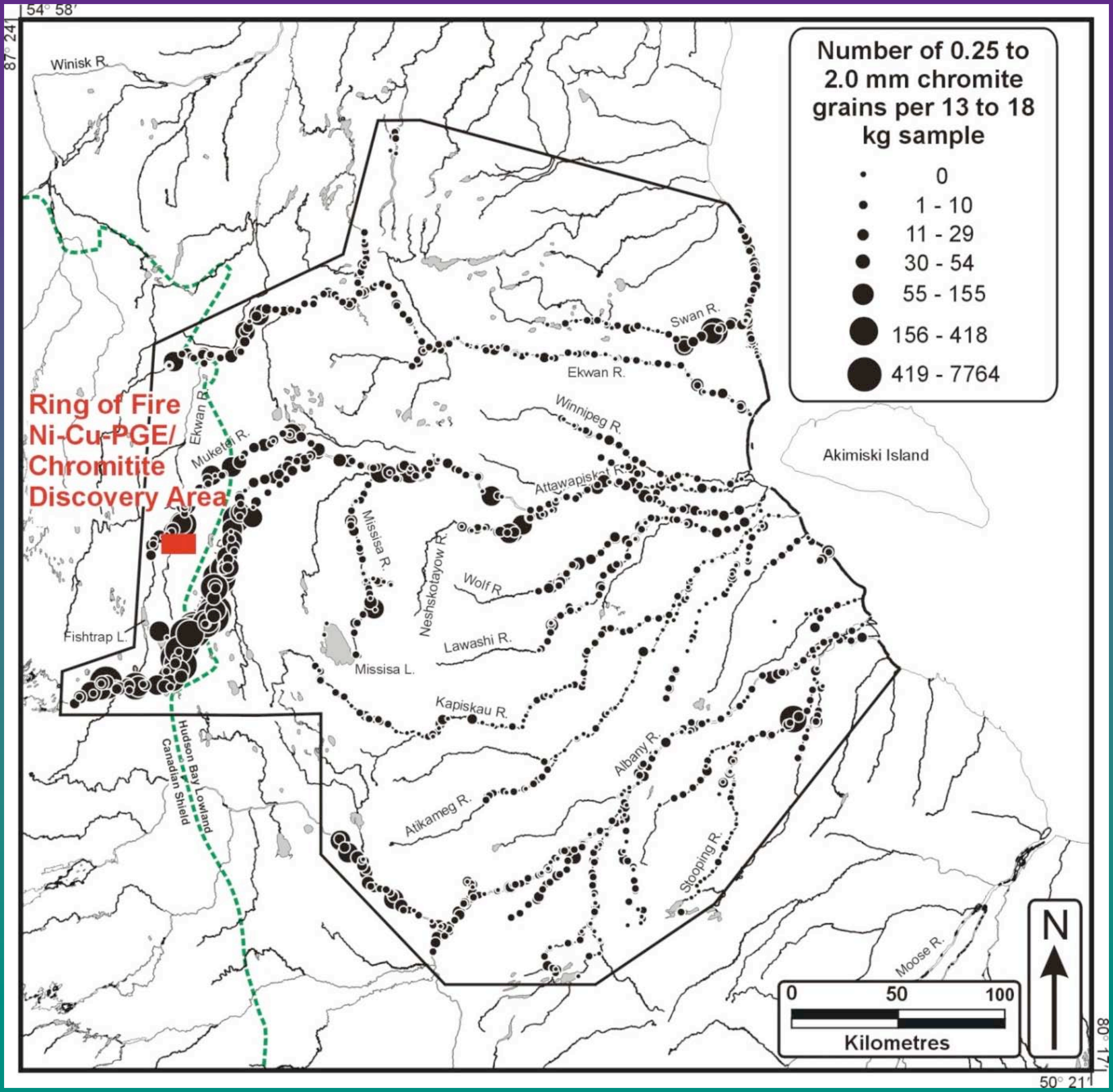



Modified from: Ontario Geological Survey

# Chromitite Grains, Attawapiskat River



# "Ring of Fire" Chromitite Discoveries




**Modified from: Ontario Geological Survey**

# 70 m of Massive Chromitite

Courtesy: Noront Resources Ltd.

# Role of Sulphide Saturation

- Causes sulphide liquid to separate from silicate melt
- Sulphide liquid collects Ni-Cu-PGE from silicate melt
- Heavy sulphide liquid settles in pools or layers, further concentrating metals

# Outline 1 – Ni-Cu-PGE Indicator Minerals

Four subsuites indicating:

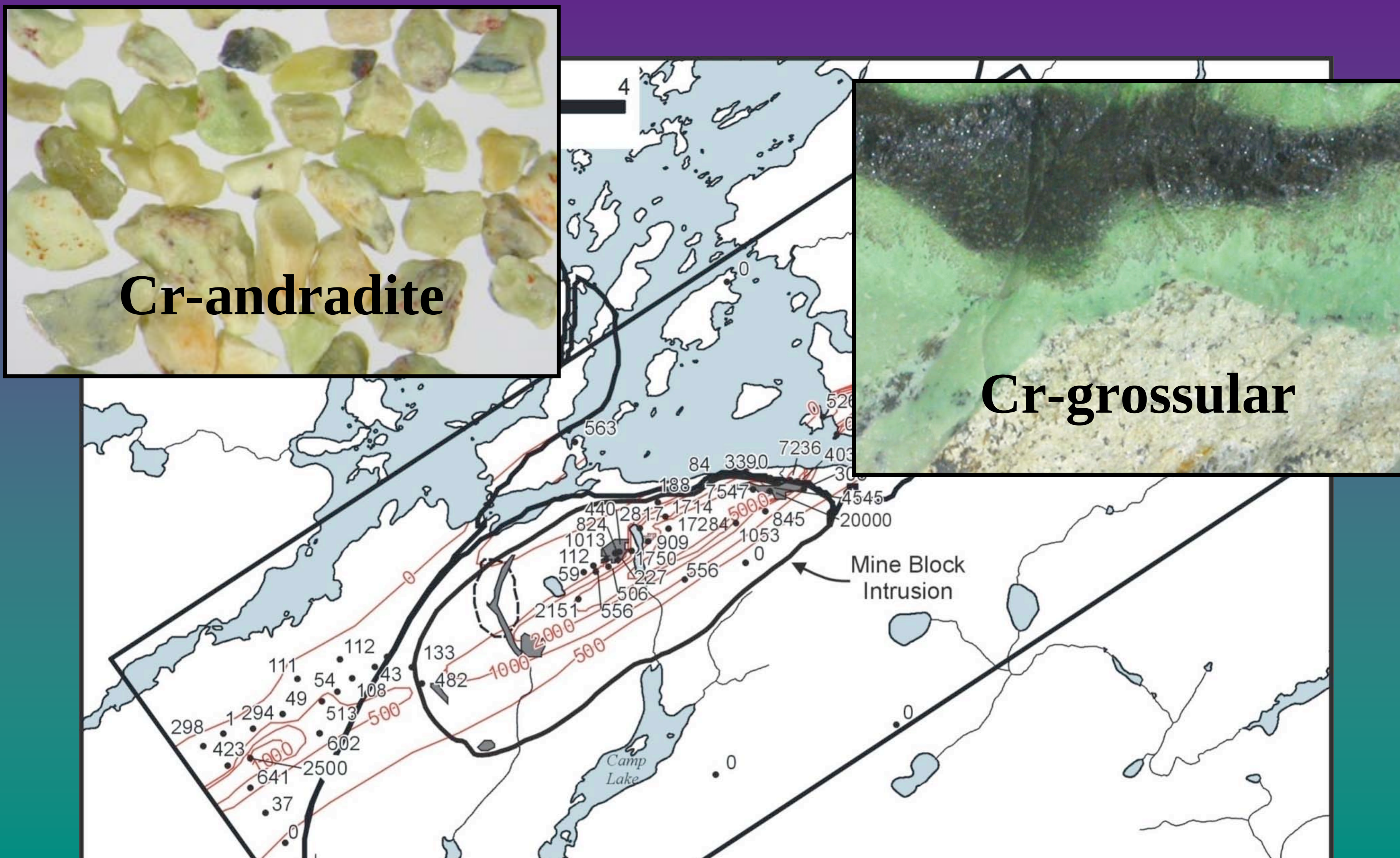
1. a fertile melt
2. rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization

# Indicators of Concentrated Cumulus Segregation

- orthopyroxene (enstatite – $Mg_2Si_2O_6$)
- olivine (forsterite – $MgSiO_4$)
- Cr-diopside – $Ca(Mg,Cr)Si_2O_6$
- chromite – $(Fe,Mg)(Cr,Al)O_4$

# Ruby Corundum $(Al,Cr)_2O_3$

# Dispersal of Cr-andradite from Lac des Iles Intrusive Complex




Courtesy: Peter Barnett

# Outline 1 – Ni-Cu-PGE Indicator Minerals

Four subsuites indicating:

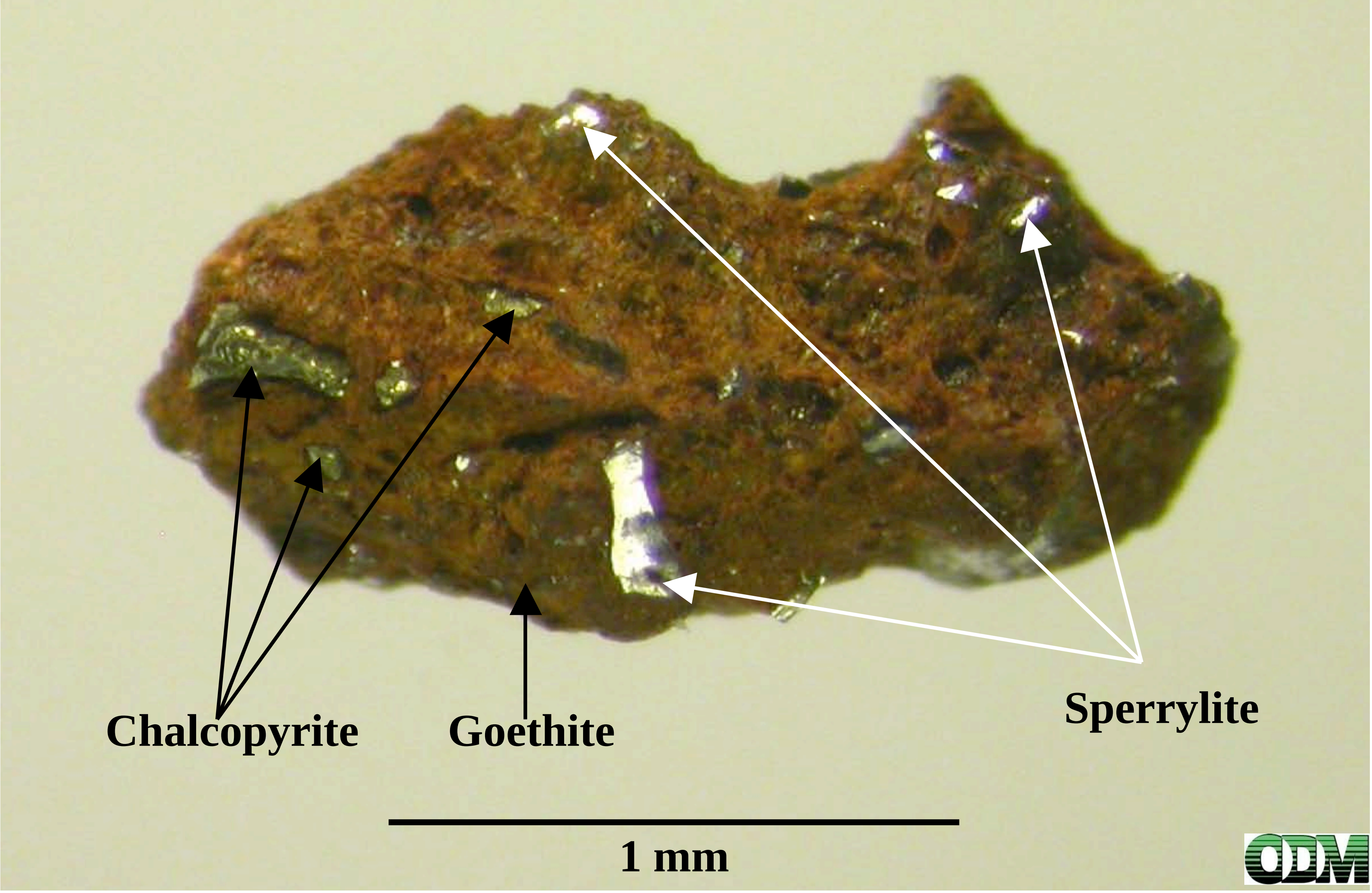
1. a fertile melt
2. rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization

ODM

# Relative stabilities of Fe-sulphides and Ni-Cu-PGE ore minerals

| Mineral | Stability |
|---|---|
| Ni-sulphides | unstable |
| PGE-sulphides | unstable |
| PGE-tellurides | unstable |
| pyrrhotite | unstable |
| pyrite | unstable |
| chalcopyrite | significantly stable |
| FeNi and PGE-arsenides | stable (but silt-sized) |
| PGE-antimonides | stable (but silt-sized) |
| native Au and PGE | very stable (but silt-sized) |

# Broken Hammer Gossan

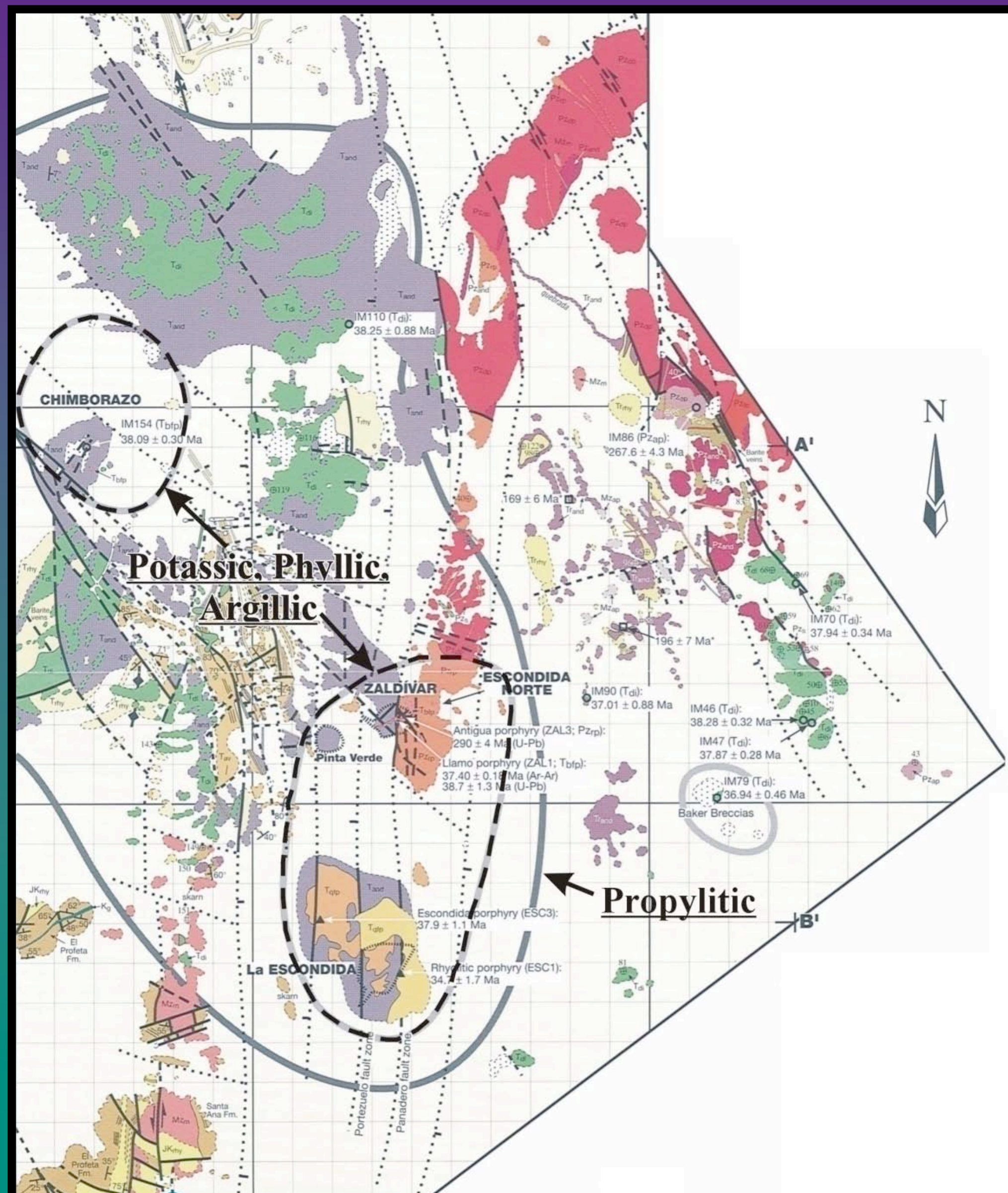


# Outline 2 – Porphyry Cu Indicator Minerals (PCIMs®)

**PCIM®** anomalies, like Ni-Cu-PGE anomalies are:

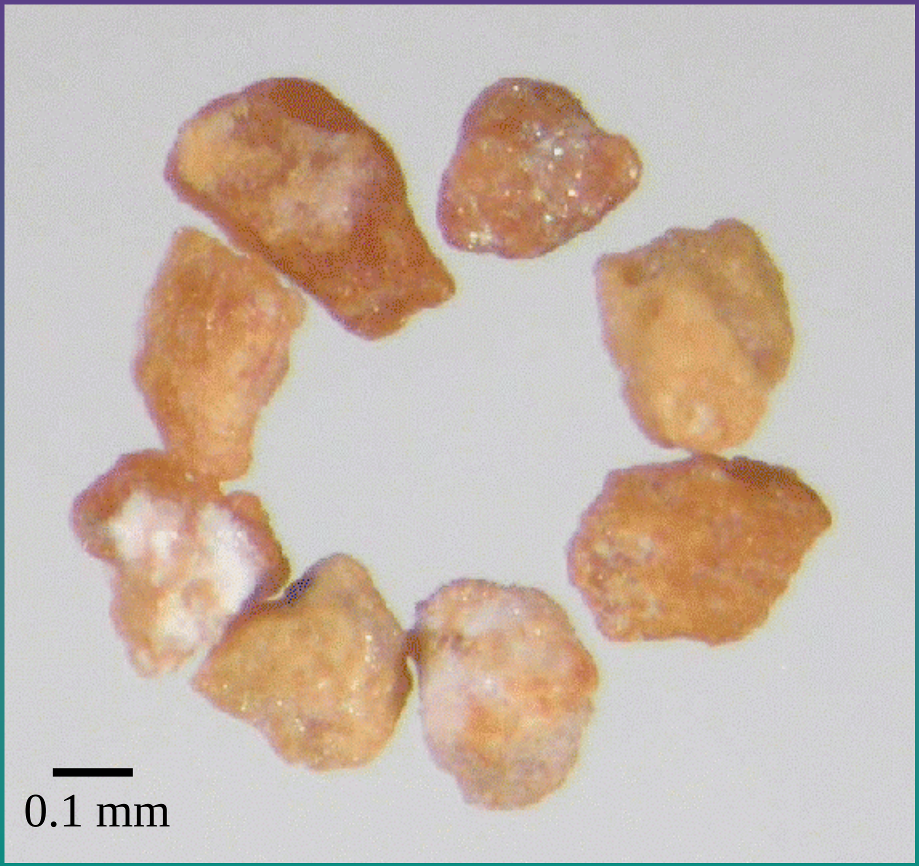
1. Big
2. Strong
3. Zoned

# Alteration zones, Escondida, Chile

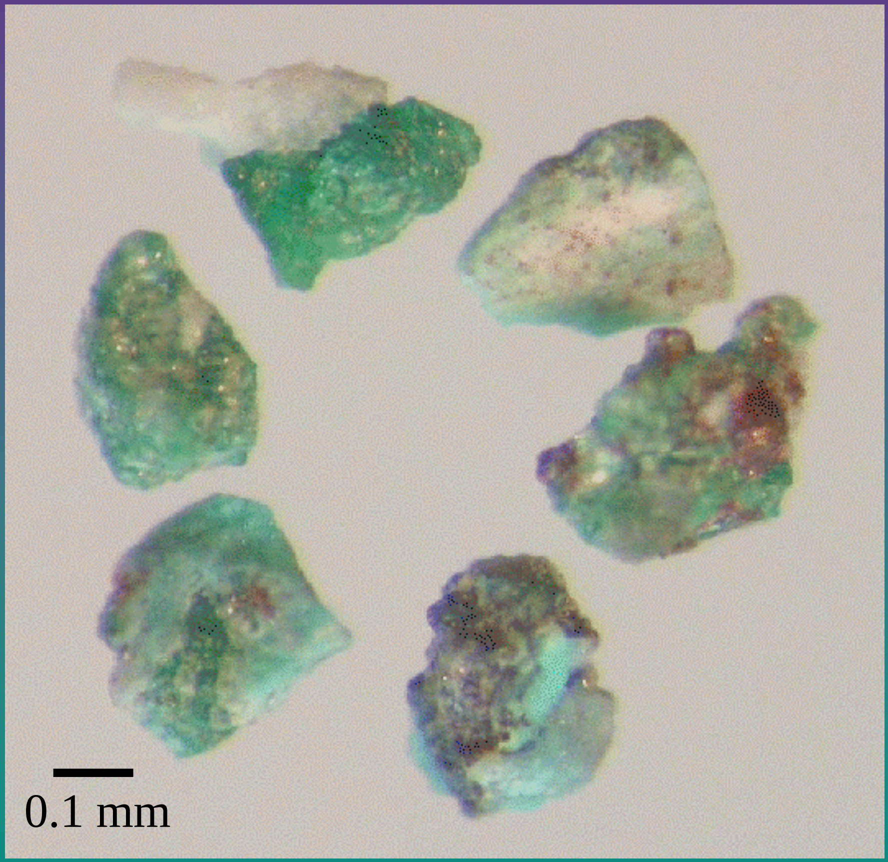


# Arid landscape, Atacama Desert, Chile

# Jarosite



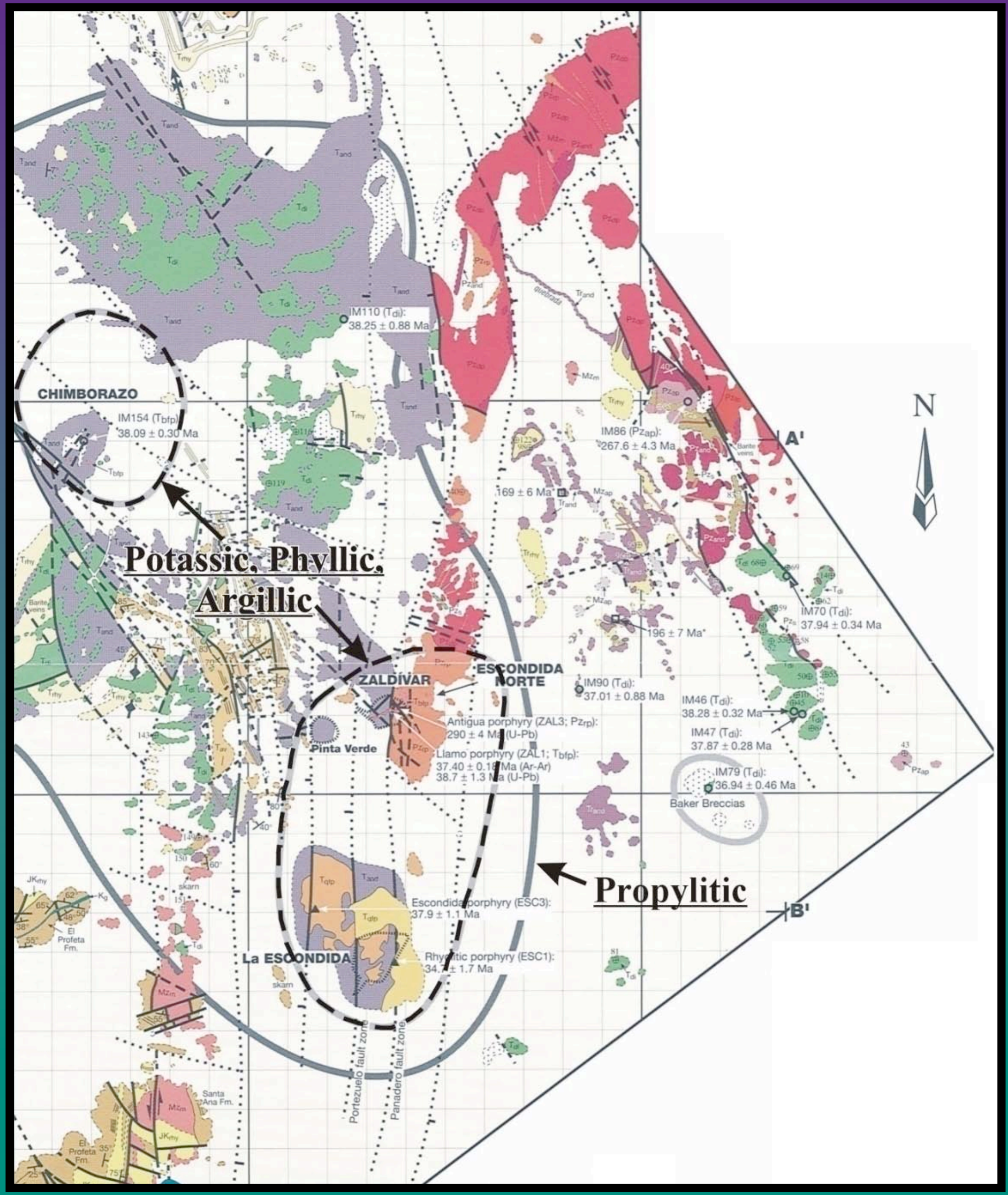

# Atacamite



| Mineral | Density | Composition | Principal provenance (alteration zone): Potassic | Argillic | Phyllic | Propylitic | Epithermal Au |
|---|---|---|---|---|---|---|---|
| **Hypogene suite:** | | | | | | | |
| Diaspore | 3.4 | $AlO(OH)$ | | X | | | |
| Alunite | 2.9 | $(K,Na)Al_3(SO_4)_2(OH)_6$ | X | X | | | |
| Dravite | 3.0 | $NaMg_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$ | | X | | | |
| Andradite | 3.9 | $Ca_3Fe_2(SiO_4)_3$ | | | | X | |
| Barite | 4.5 | $BaSO_4$ | | | | | X |
| **Supergene suite:** | | | | | | | |
| Alunite | 2.8 | $(K,Na)Al_3(SO_4)_2(OH)_6$ | X | X | | | |
| Jarosite | 3.1 | $(K,Na)Fe_3(SO_4)_2(OH)_6$ | X | X | | | |
| Atacamite | 3.8 | $Cu_2Cl(OH)_3$ | X | X | X | | |
| Turquoise | 2.8 | $CuAl_6(PO_4)_4(OH)_{8.5}H_2O$ | | X | | | |
| Malachite | 4.0 | $Cu_2CO_3(OH)_2$ | | | X | X | |

# Proven porphyry Cu indicator minerals (PCIMs®)

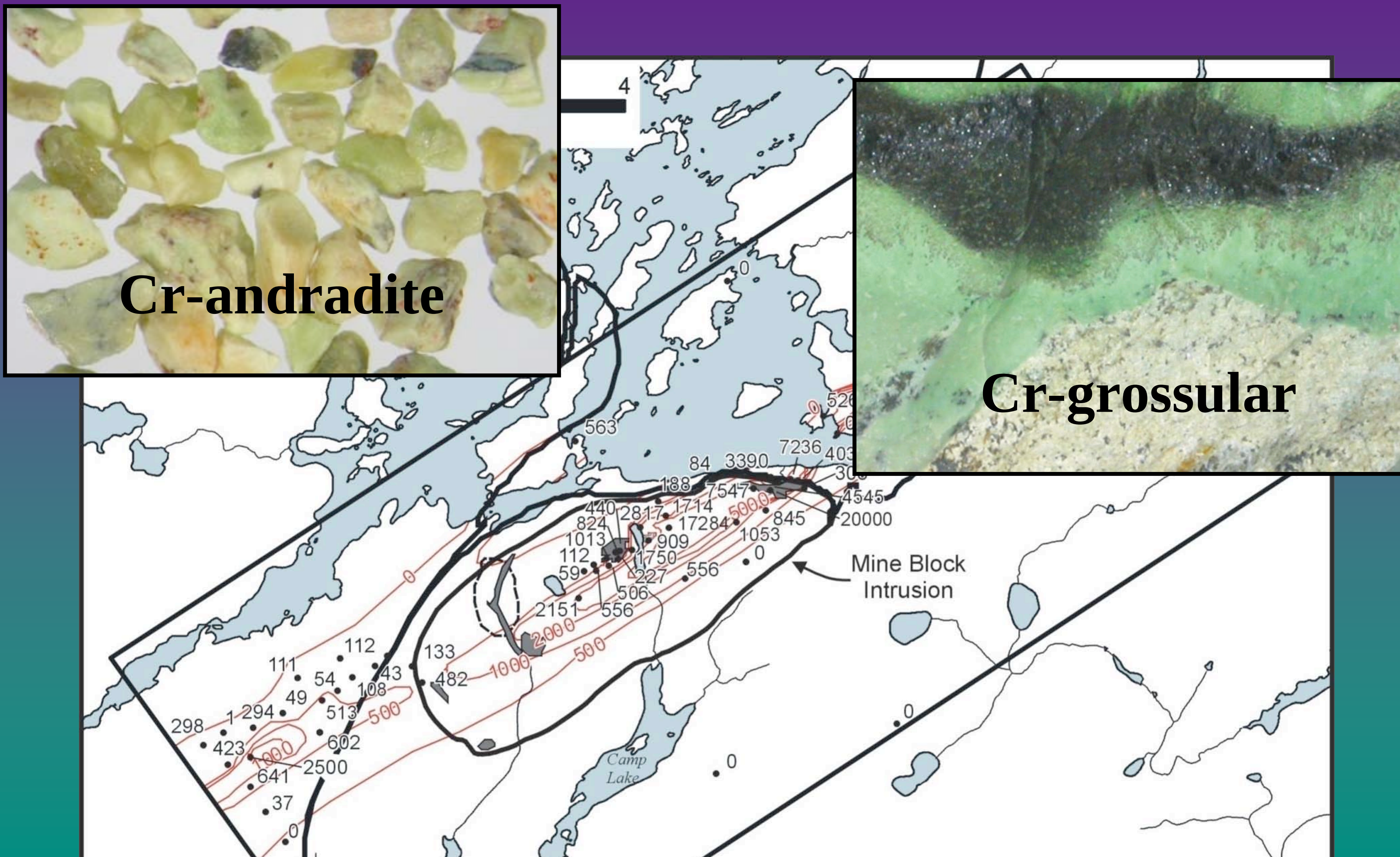
# Alteration zones, Escondida, Chile



| Mineral | Density | Composition | Principal provenance (alteration zone): Potassic | Argillic | Phyllic | Propylitic | Epithermal Au |
|---|---|---|---|---|---|---|---|
| **Hypogene suite:** | | | | | | | |
| Diaspore | 3.4 | $AlO(OH)$ | | — | | | |
| Alunite | 2.9 | $(K,Na)Al_3(SO_4)_2(OH)_6$ | — | — | | | |
| Dravite | 3.0 | $NaMg_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$ | | — | | | |
| Andradite | 3.9 | $Ca_3Fe_2(SiO_4)_3$ | | | | — | |
| Barite | 4.5 | $BaSO_4$ | | | | | — |
| **Supergene suite:** | | | | | | | |
| Alunite | 2.8 | $(K,Na)Al_3(SO_4)_2(OH)_6$ | — | — | | | |
| Jarosite | 3.1 | $(K,Na)Fe_3(SO_4)_2(OH)_6$ | — | — | | | |
| Atacamite | 3.8 | $Cu_2Cl(OH)_3$ | — | — | — | | |
| Turquoise | 2.8 | $CuAl_6(PO_4)_4(OH)_{8.5}H_2O$ | | — | | | |
| Malachite | 4.0 | $Cu_2CO_3(OH)_2$ | | | — | — | |

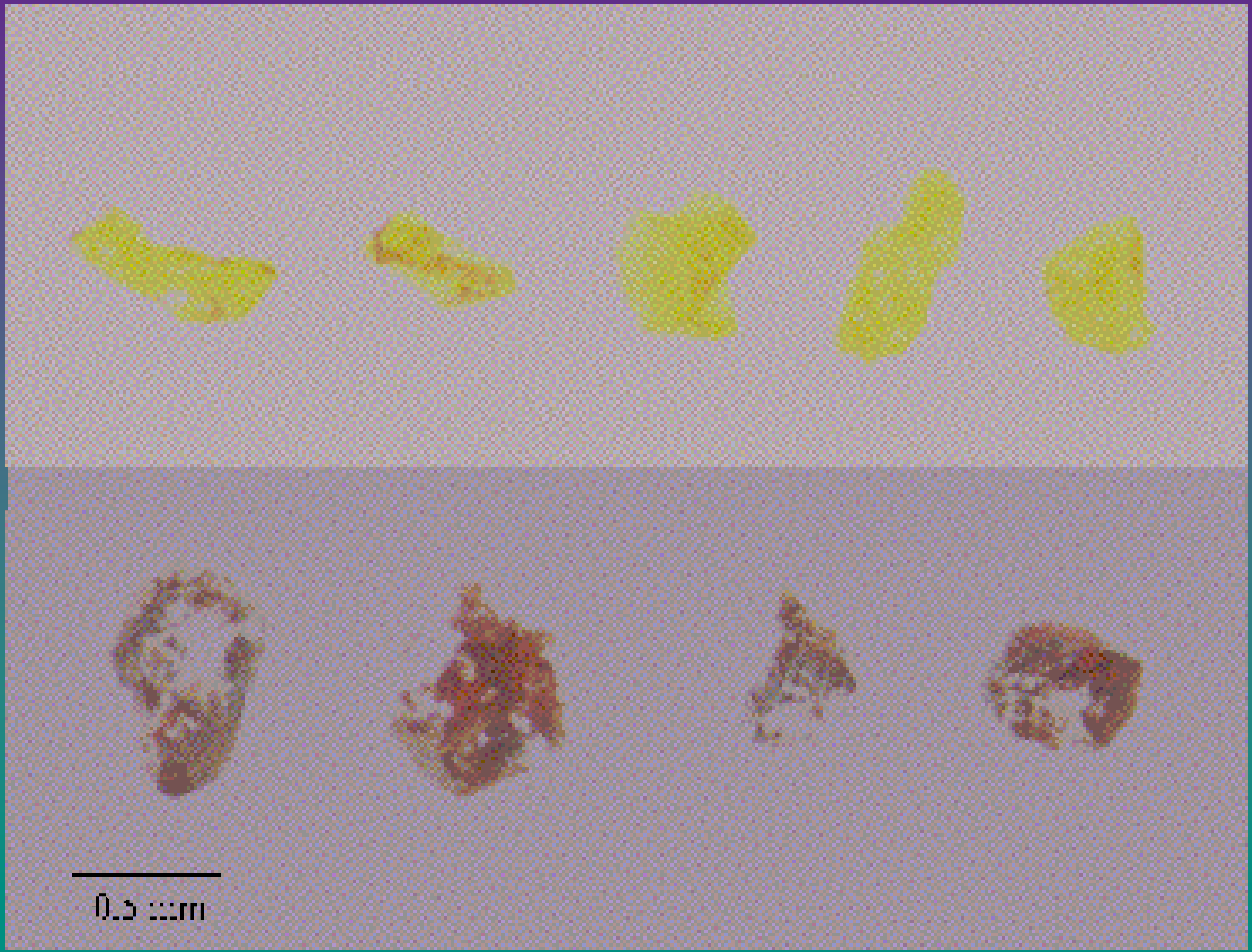
# Proven porphyry Cu indicator minerals (PCIMs®)

# Dispersal of Cr-andradite from Lac des Iles Intrusive Complex

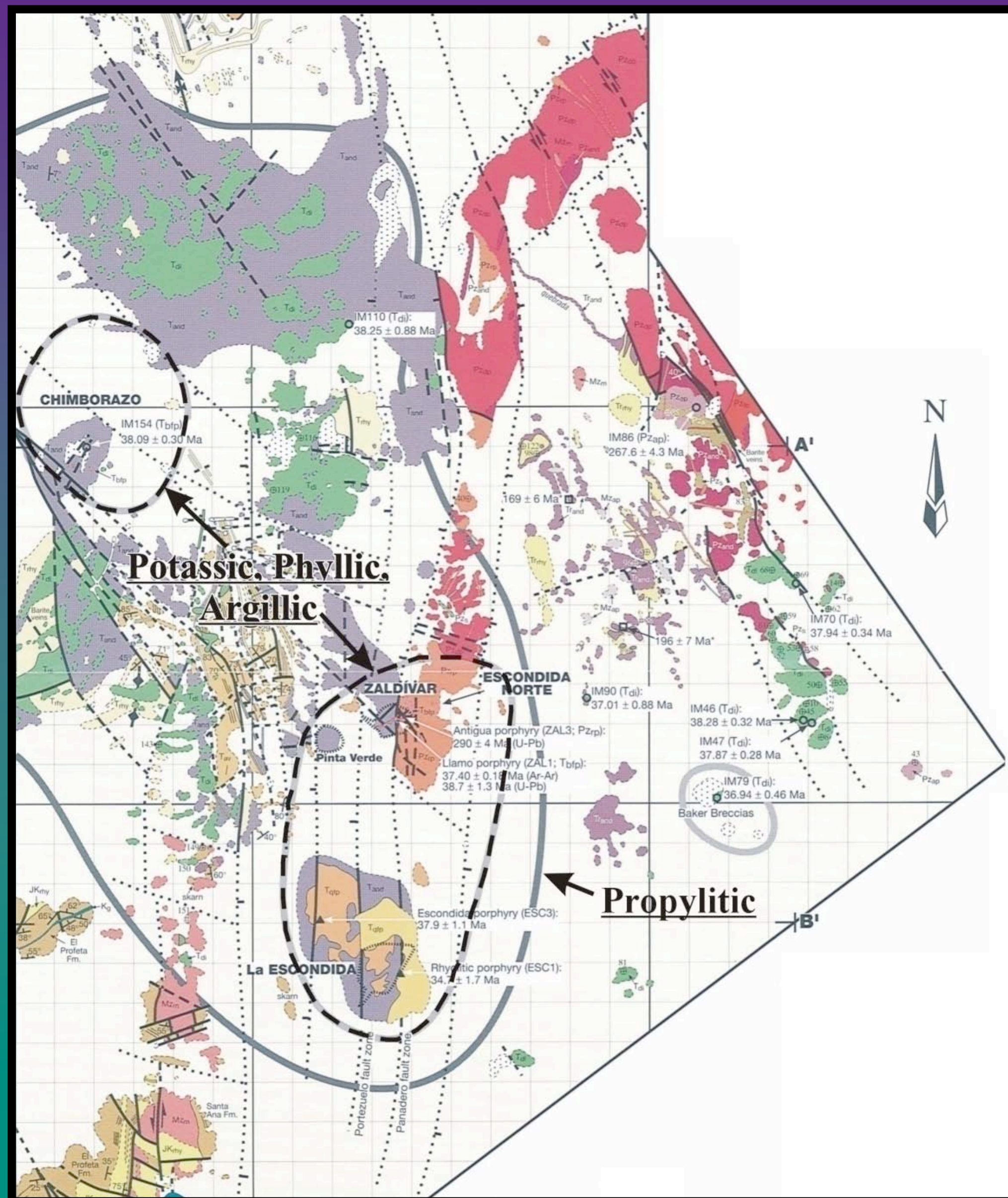



Courtesy: Peter Barnett

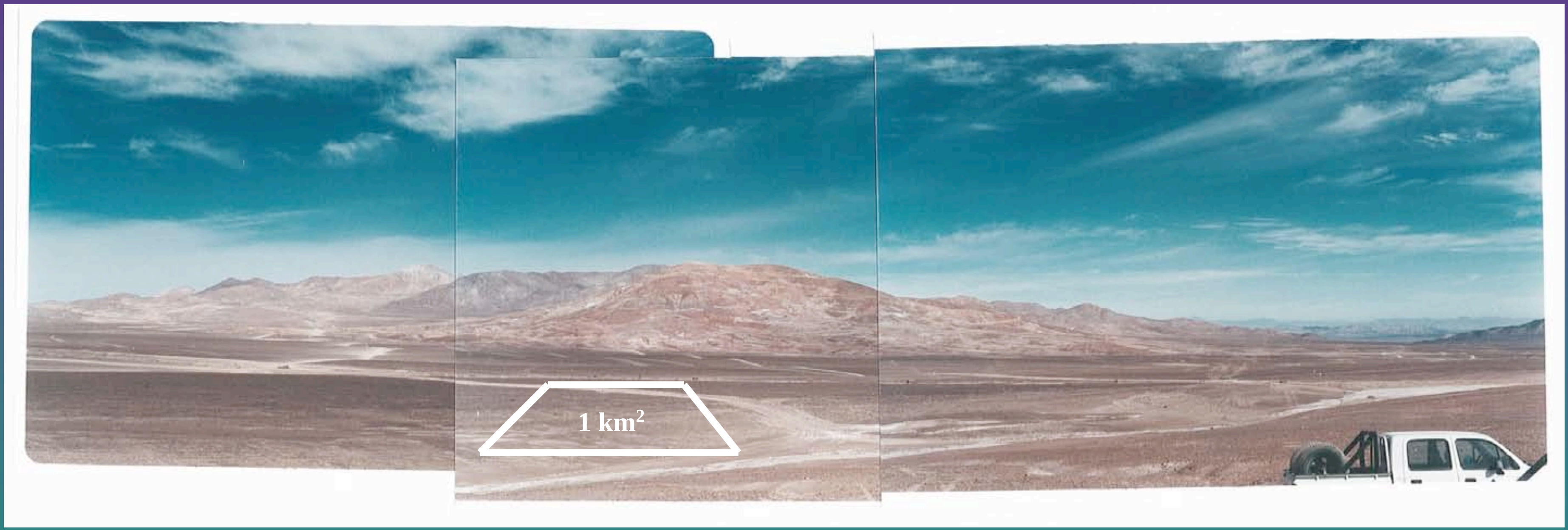
# Andradite garnet – $Ca_3Fe_2(SiO_4)_3$



# Alteration zones, Escondida, Chile

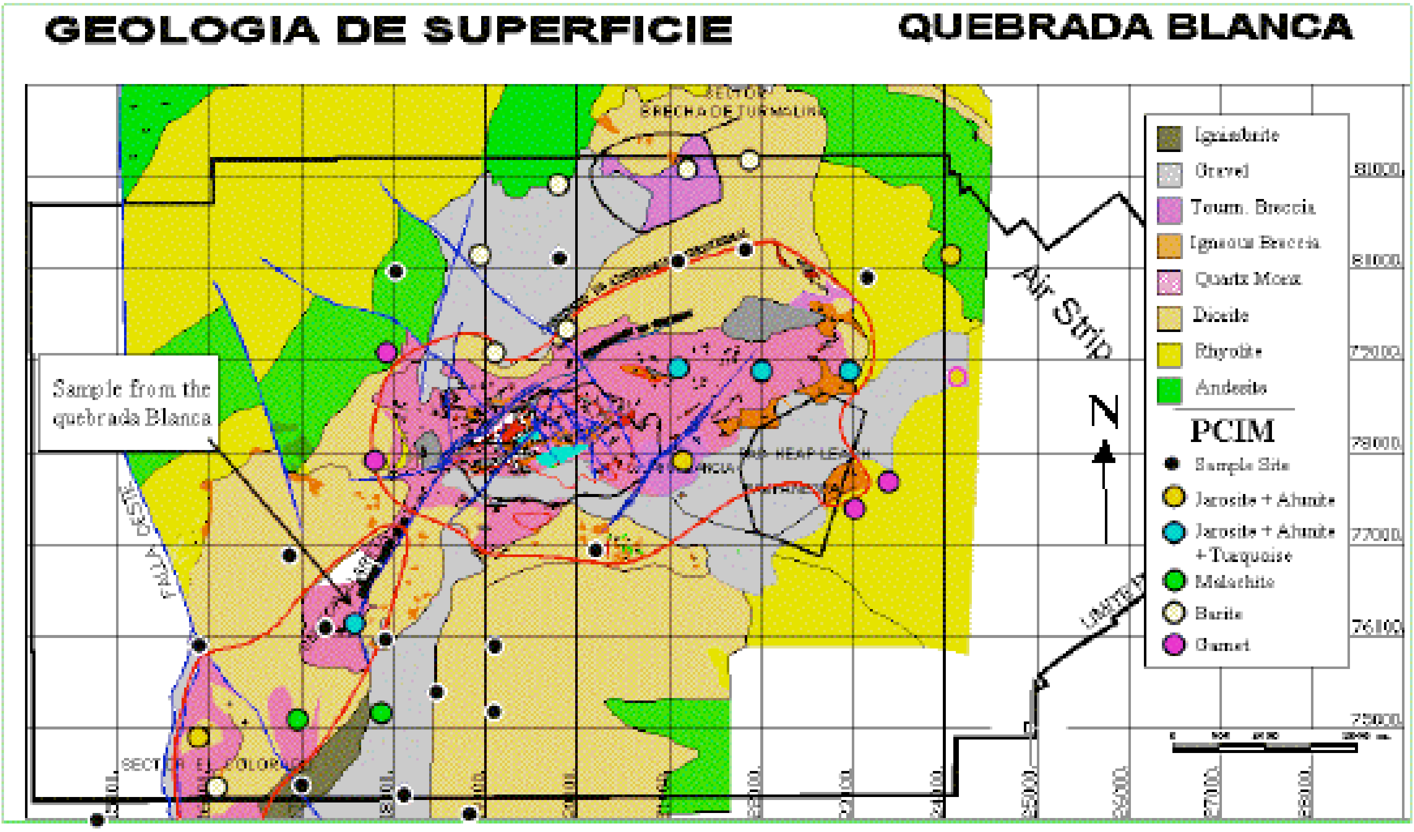


# Arid landscape, Atacama Desert, Chile



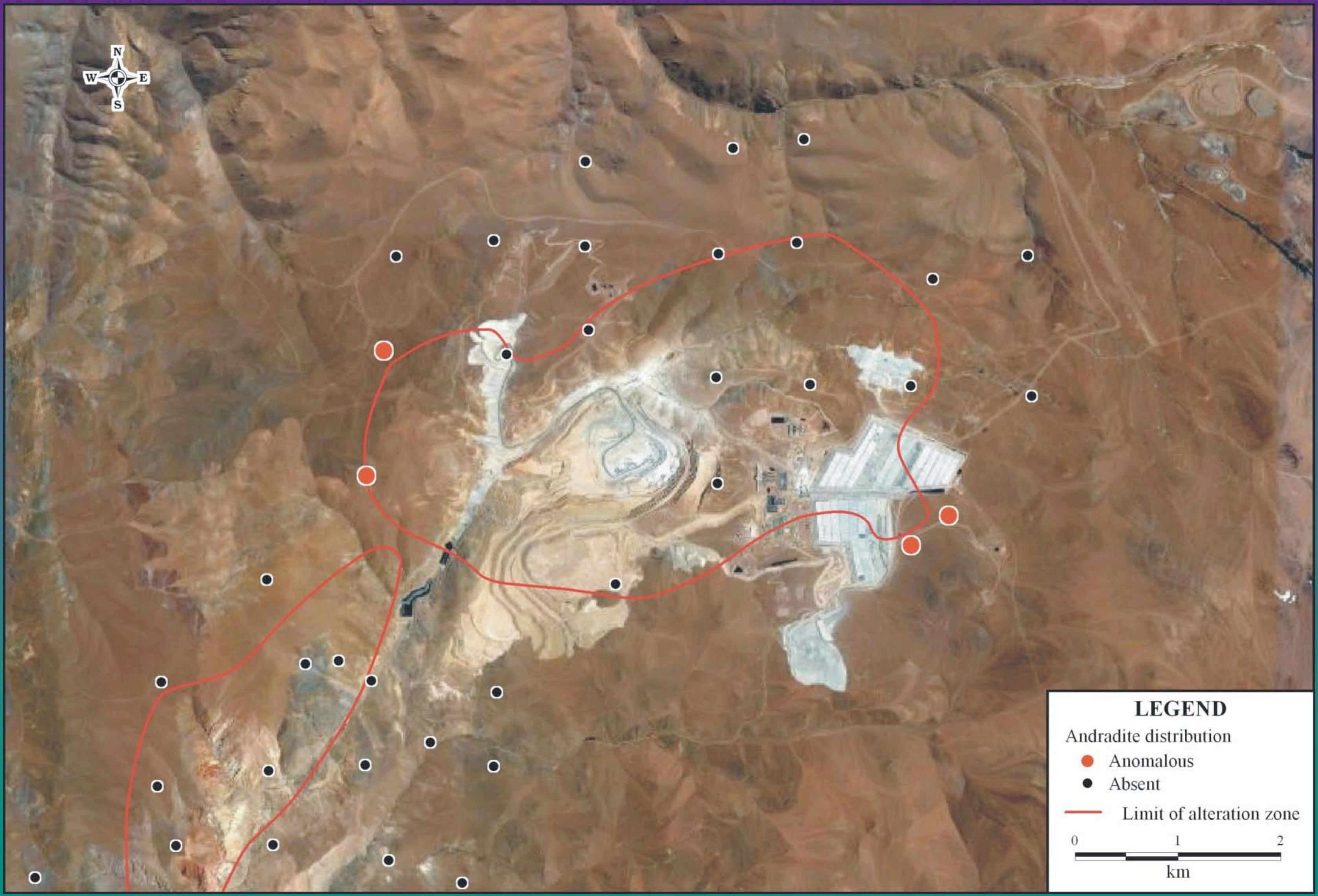
# Sample sites, Quebrada Blanca


Courtesy: Aur Resources



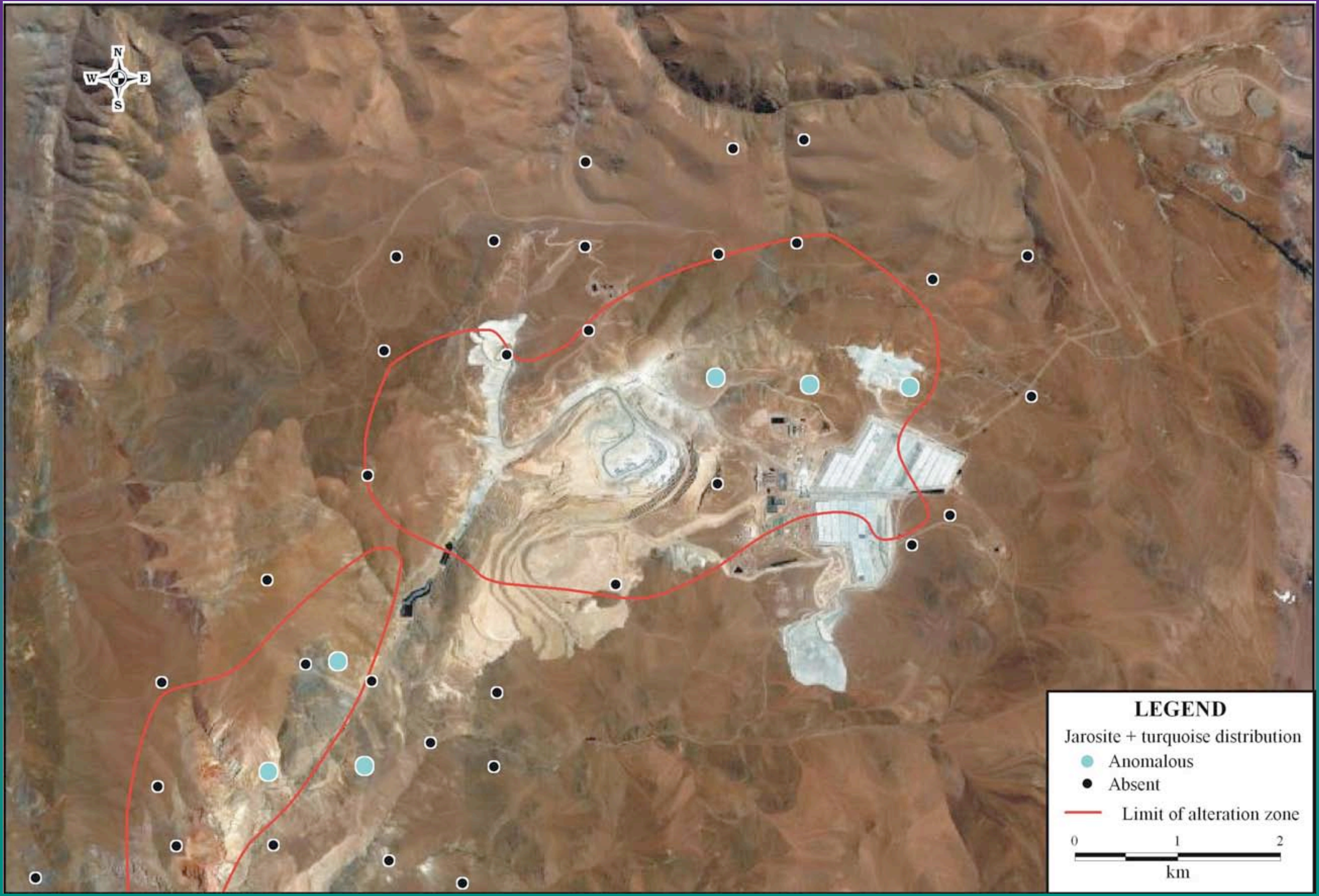

Courtesy: Aur Resources

# Andradite in alluvium, Quebrada Blanca



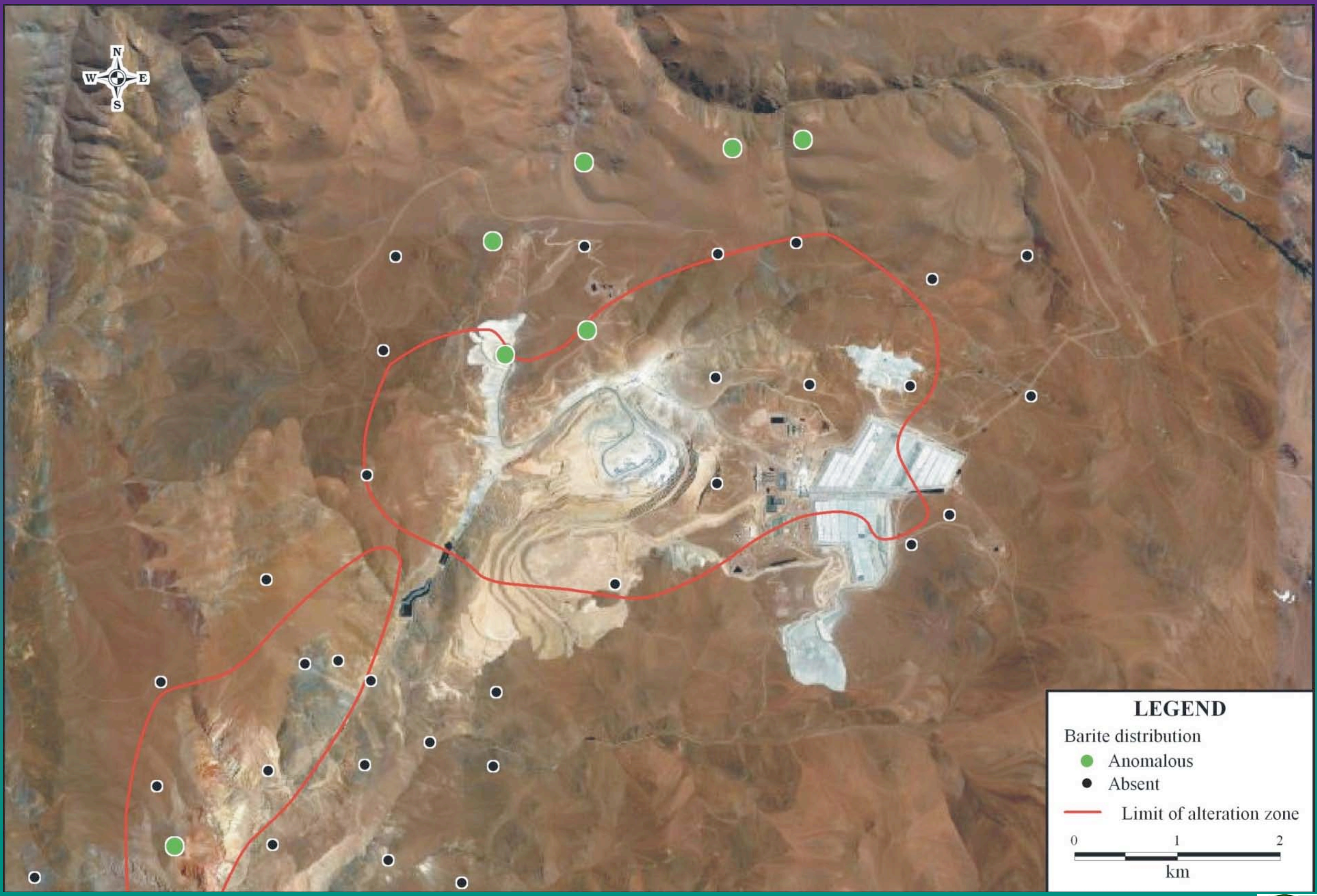

**Courtesy: Aur Resources**

# Jarosite + turquoise in alluvium, Quebrada Blanca




Courtesy: Aur Resources

# Barite in alluvium, Quebrada Blanca




**Courtesy: Aur Resources**

# Conclusions

Ni-Cu-PGE and porphyry Cu *systems* are very different but they share two key features that are reflected in their indicator mineral footprints:

- Both are *large*. Therefore both have *regional-scale* indicator mineral footprints that can be detected economically with a wide sample spacing (comparable to the footprint of an entire field of kimberlite pipes)
- Both systems are *zoned* in time and space. Each mineralizing event, process or alteration zone supplies a different subsuite of indicator minerals to the regional anomaly. If we *tighten* our sample spacing at the head of this anomaly, we can resolve this zoning and focus on the best targets (comparable to locating the most fertile pipes within a kimberlite field)

Together these features make indicator mineralogy a very effective exploration tool for both Ni-Cu-PGE and porphyry Cu deposits …. and possibly for other large-scale magmatic-hydrothermal systems such as IOCG.