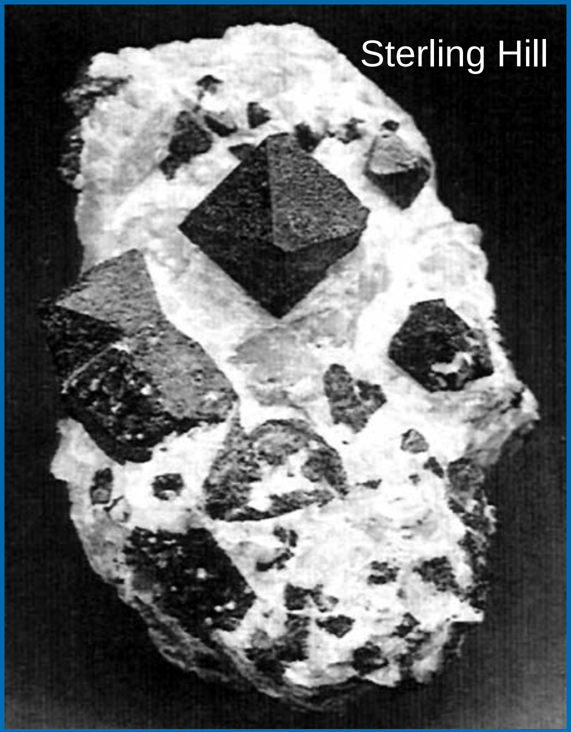
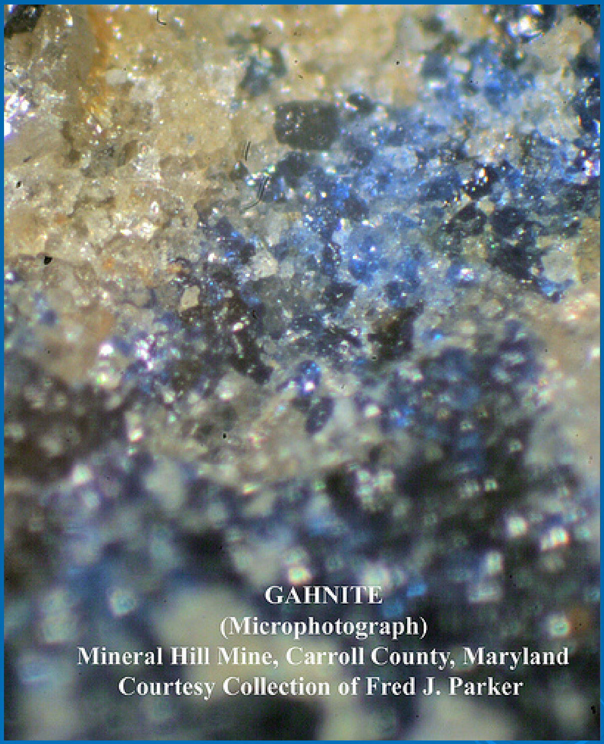
Gahnite Composition as a Guide in the Search for Metamorphosed Massive Sulphide Deposits



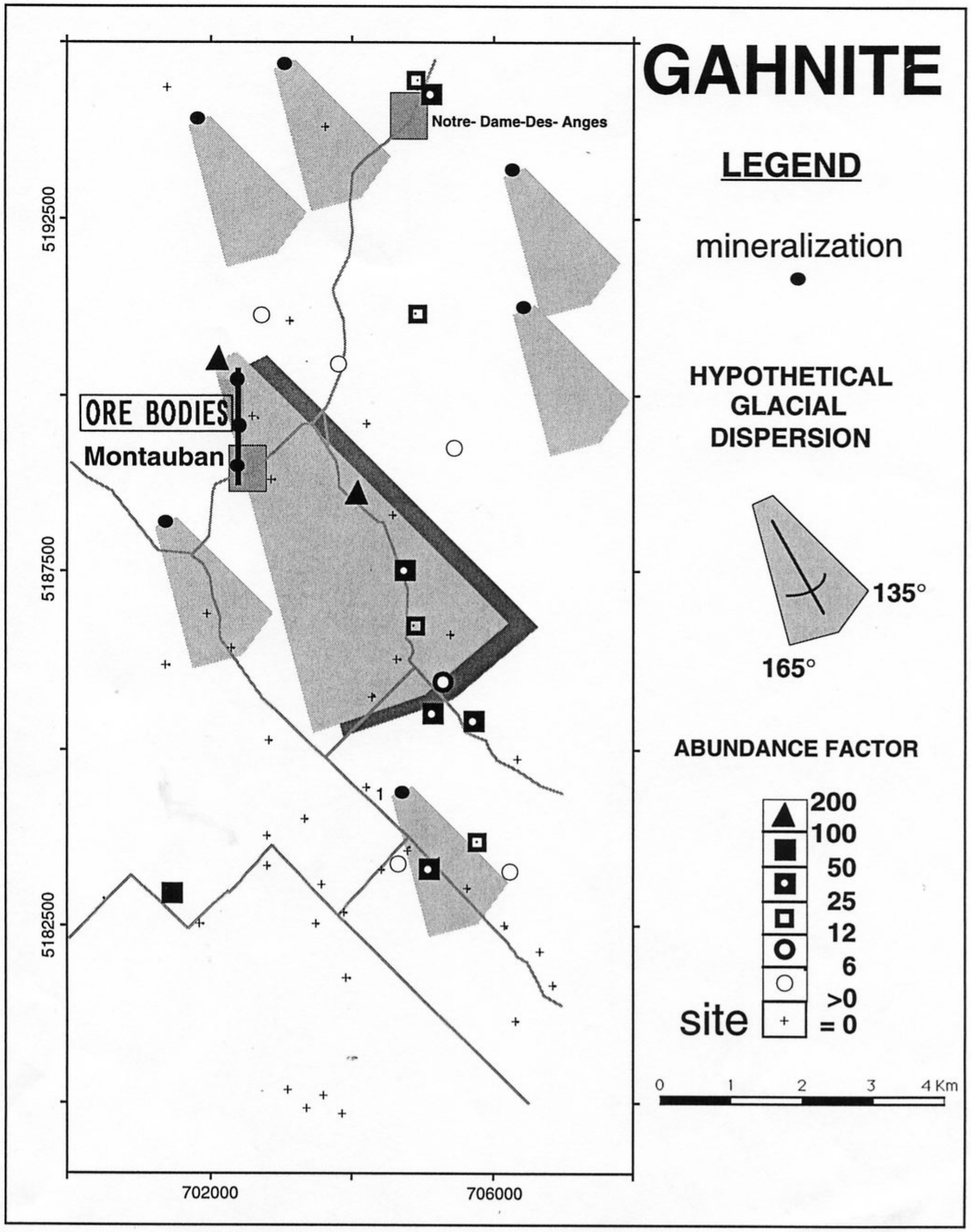


Paul. G. Spry[1], Graham S. Teale[2]

[1] *Geological & Atmospheric Sciences, Iowa State University, U.S.A.*
[2] *Teale & Associates, North Adelaide, South Australia, Australia*

Indicator Minerals

- Used in the exploration for base metal sulfides, porphyry Cu, magmatic (Ni-Cu-PGE), gold, tungsten, tin, and diamond deposits
- The so-called metamorphosed or magmatic sulphide indicator minerals (MMSIMs®) of Overburden Drilling Management Ltd (Stu Averill) include for metamorphosed deposits: gahnite, spessartine, sphalerite, chalcopyrite, apatite, tourmaline, staurolite, rutile, anthophyllite



Bernier et al. (1994) Gahnite in basal till: Montauban, Québec.

Background and Aims

- **"Gahnite, a zinc-bearing spinel, is a resistate mineral that may be used as an indicator mineral of polymetallic minerals in high-grade metamorphic terrains (Morris et al., 1997)"**
- The composition of spinels, garnet, and staurolite has been used in the exploration for metamorphosed massive sulfide (MMS) deposits
- These minerals can form in a variety of geological settings and so the identification of these minerals is not sufficient for them to be used as guides to ore
- The composition of these minerals is dependent on geological environment
- Gahnite is stable from upper greenschist to granulite facies in regionally metamorphosed terrains but it must also be stable at higher temperatures since it is found in granite
- The composition of zincian spinels is evaluated here with the view of being able to use them as exploration guides to MMS deposits. Discussion will centre on why spinels that are likely to be found in and adjacent to metamorphosed massive sulfide deposits have compositions that can be distinguished from those in non-prospective environments

Spinel-Group End Members

- $ZnAl_2O_4$ – gahnite; $FeAl_2O_4$ – hercynite
- $MgAl_2O_4$ – spinel; $MnAl_2O_4$ – galaxite
- Fe_2FeO_4 – magnetite; $ZnFe_2O_4$ – franklinite
- $MgFe_2O_4$ – magnesioferrite; Fe_2O_3 – γ-maghemite
- $FeTi_2O_4$ – ulvospinel; $MnFe_2O_4$ – jacobsite
- $NiFe_2O_4$ – trevorite; $FeCr_2O_4$ – chromite
- $MgCr_2O_4$ – magnesiochromite

Coarse-grained gahnite (15.8% Zn) from the Two Mile Ridge prospect (BHT deposit, South Australia)

An aside: Grade of Zn so high….can it be mined?

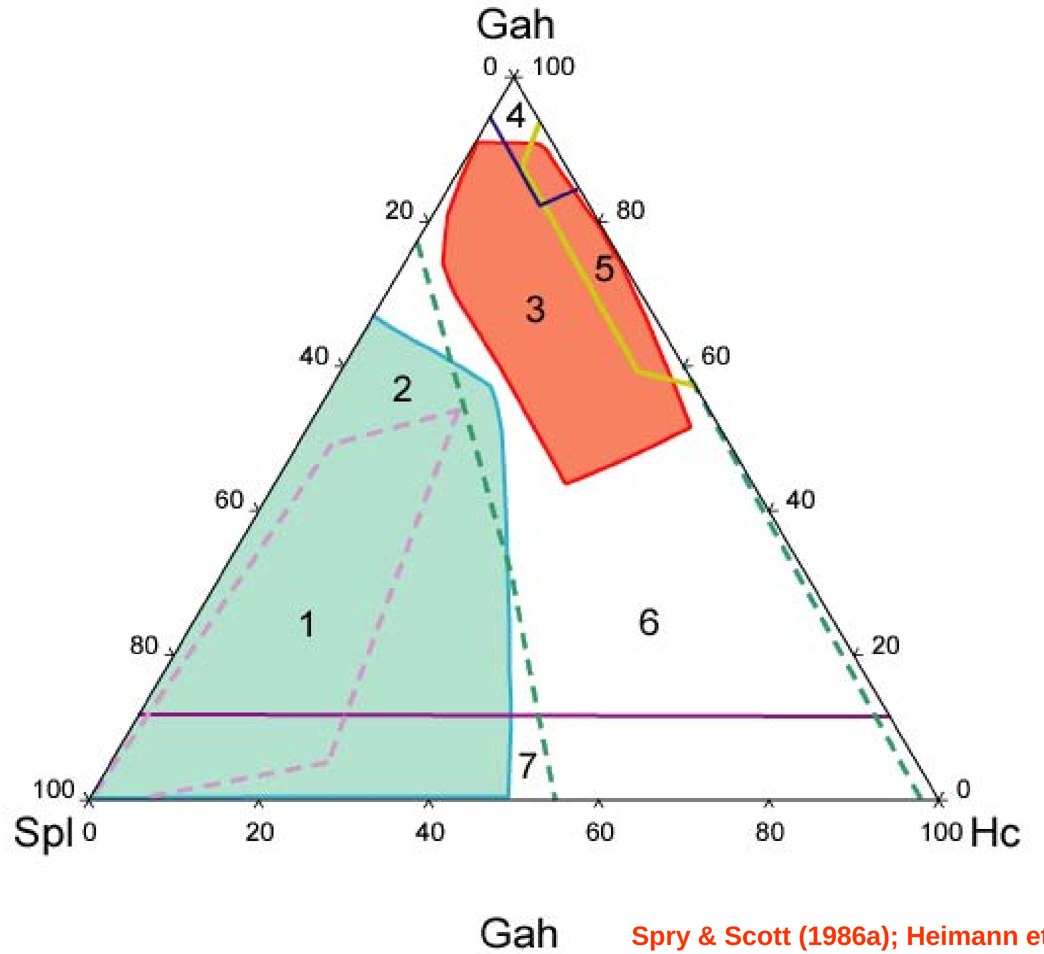
Selected Examples of Geological Settings of Gahnite

Setting/ Deposit Type	Location/Deposit	Reference
Broken Hill-type deposit	Broken Hill, South Africa	Spry (1987)
Volcanogenic massive sulfide deposit	Palmeiropoulos, Brazil	Araujo *et al.* (1995)
Sedimentary exhalative deposit	Wheal Ellen, Australia	Spry *et al.* (1988)
Non-sulfide zinc deposits	Franklin, New Jersey	Johnson & Skinner (2003)
Gold deposit	Mount Gibson, Australia	Yeats & Groves (1998)
Tin-tungsten skarn	Dusky Sound, New Zealand	Challis (1986)
Contact metamorphic aureole	Ardara pluton, Ireland	Atkin (1978)
Diamonds	Ivancauti, Romania	Gardu (2004)
Marble	Bohemian Massif, Czech Rep.	Novak *et al.* (1997)
Iron formation	West Greenland	Appel (1986)
Quartz veins	Broken Hill area, Australia	Wall (1977)
Al-rich metasedimentary rocks	New Hampshire, U.S.A.	Schumacher & Robinson (1987)
Aluminous granulite	Araku, India	Sengupta *et al.* (1991)
Metabauxite	Menderes massif, Turkey	Yalçin *et al.* (1993)
Pegmatite	California	Kleck & Foord (1999)
Granite	Buryat, Russia	Lisitsyn & Yurkina (1974)
Glacial sediments	Kallala Lake, Ontario	Morris *et al.* (2000)
Beach sands	Martha's Vineyard, U.S.A.	Kaye & Mrose (1965)
Soil	Unspecified location	Nachtegaal *et al.* (2005)
Stream sediments	Kallala Lake, Ontario	Morris *et al.* (2000)

Types of Plots of Gahnite Compositions

- Ternary plot in terms of $ZnAl_2O_4$-$FeAl_2O_4$-$MgAl_2O_4$ (Spry & Scott, 1982; 1986). Used to distinguish among insitu MMS, aluminous metasediments, marble, pegmatite.
- Ternary plot (Zn-Fe-Mg) and bivariate plot [(Zn+Mn/Al) vs (Fe+Mg)/Al] (Batchelor & Kinnaird (1984). Used to distinguish igneous from metamorphic rocks.
- Ternary plot (ZnO-FeO-MgO) (Morris et al., 1997). Used base metal and rare element exploration
- Walters et al. (2001) discussed the role that gahnite had in the exploration for MMS (particularly BHT deposits) for Broken Hill Proprietary in the early 1980s. BHP used canonical bivariate plots involving, for example, Zn-Fe-Mg-Mn. Gahnite composition was key in the discovery of the Cannington Ag-Pb-Zn deposit (Frank Bunting pers. com., 2009).
- Heimann (2005) incorporated data from the Spry et al. (1986), new data in the literature from 1986 to 2005, and new data from several locations worldwide, including the southern Curnamona province (Broken Hill area; Spry et al., 2003) and the Proterozoic Colorado Cu-Zn sulfide district. These two locations show more exposures of gahnite-bearing rocks than any other locations. The plot used by Heimann et al. (2005) is the same as that used by Spry et al. (1986) but it allows for the discrimination of gahnite compositions for rocks from a much larger variety of geological settings.

Composition of Gahnite in Natural Geological Settings

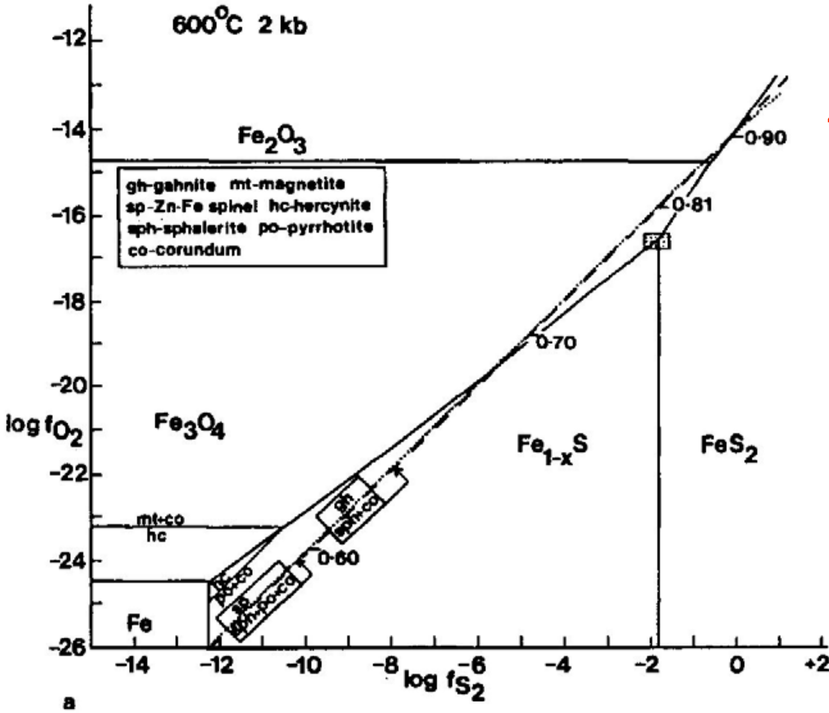


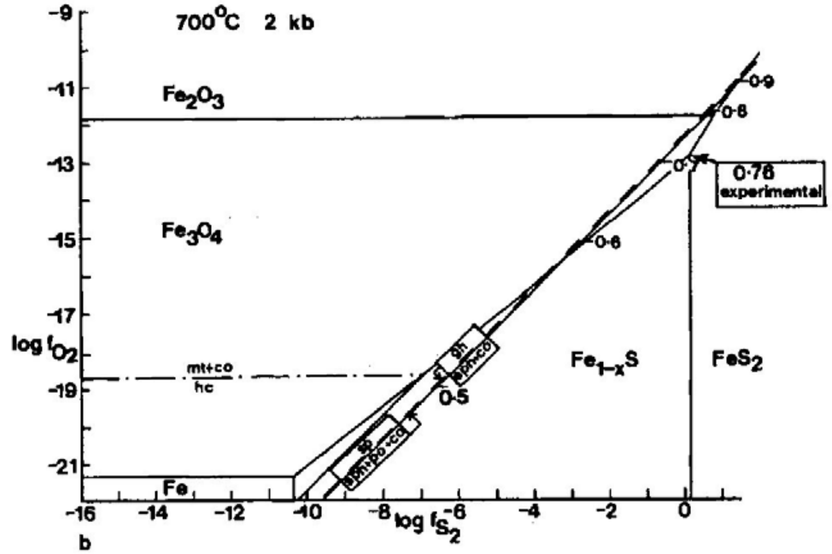
Spry & Scott (1986a); Heimann et al. (2005)

1 Marbles; 2 Metamorphosed massive sulfide deposits and S-poor rocks in Mg-Ca Al alteration zones; 3 Metamorphosed massive sulfide deposits in Fe-Al metasedimentary and metavolcanic rocks; 4 Metabauxites; 5 Pegmatites; 6 Unaltered and hydrothermally altered Fe-Al-rich metasedimentary and metavolcanic rocks; and (7) Al-rich granulites

System Zn-Fe-Al-S-O

$ZnS + Al_2O_3 + 0.5O_2 = ZnAl_2O_4 + 0.5S_2$

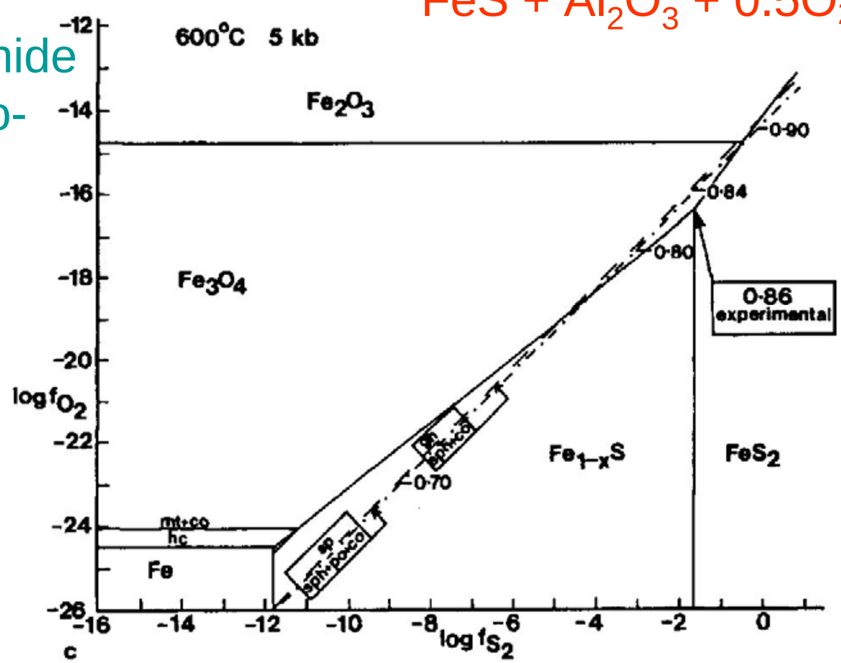




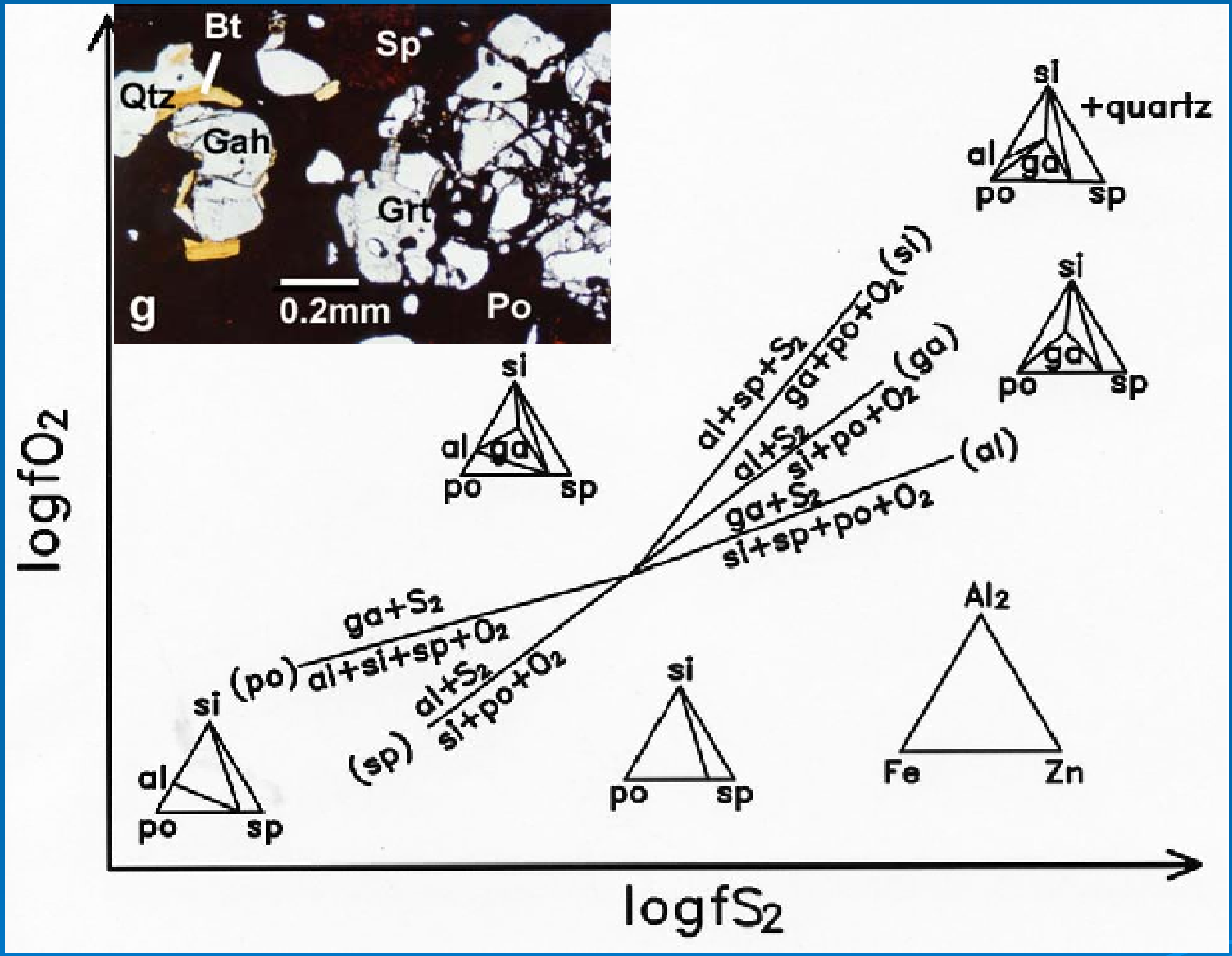
$FeS + Al_2O_3 + 0.5O_2 = FeAl_2O_4 + 0.5S_2$

Most massive sulphide deposits contain Po-Py or both

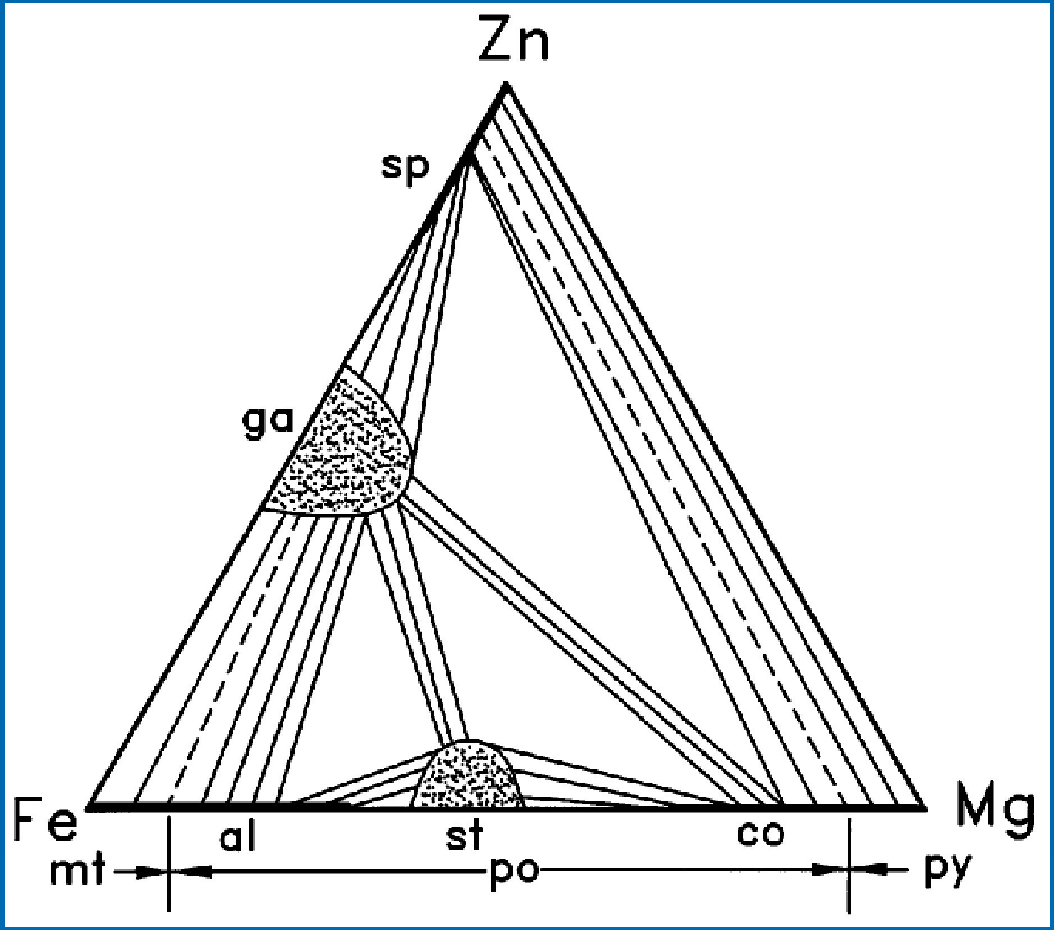
Means that gahnite must have a high Zn/Fe ratio if in equilibrium with Py or Py-Po



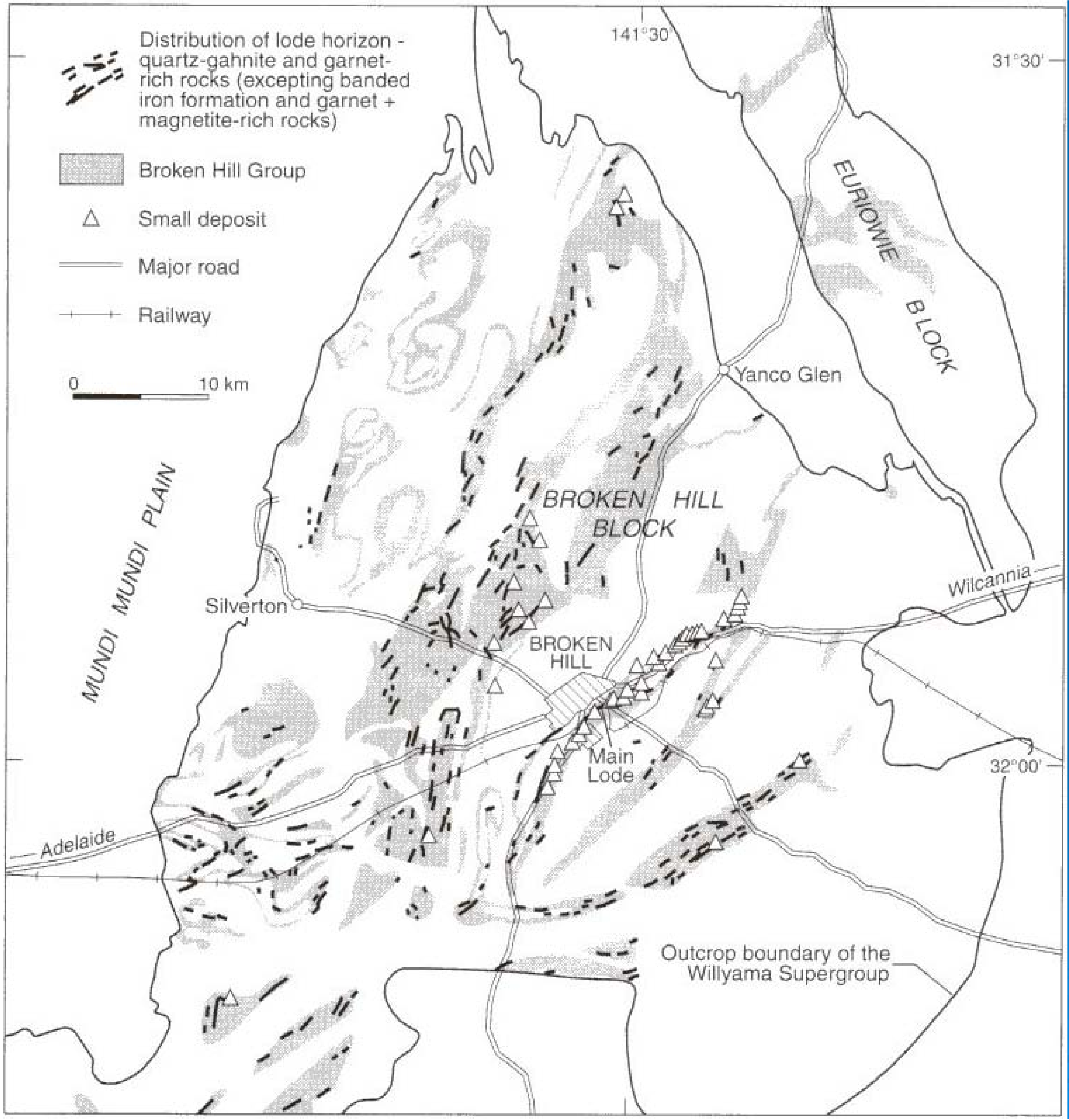
Spry et al. (1986)

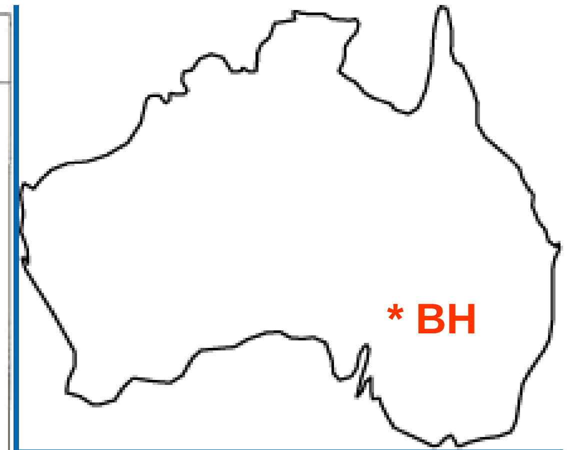


Schreinemakers' analysis of the system Zn-Fe-Al-Si-S-O in logfO_2-logfS_2 space (after Spry & Scott 1986a).



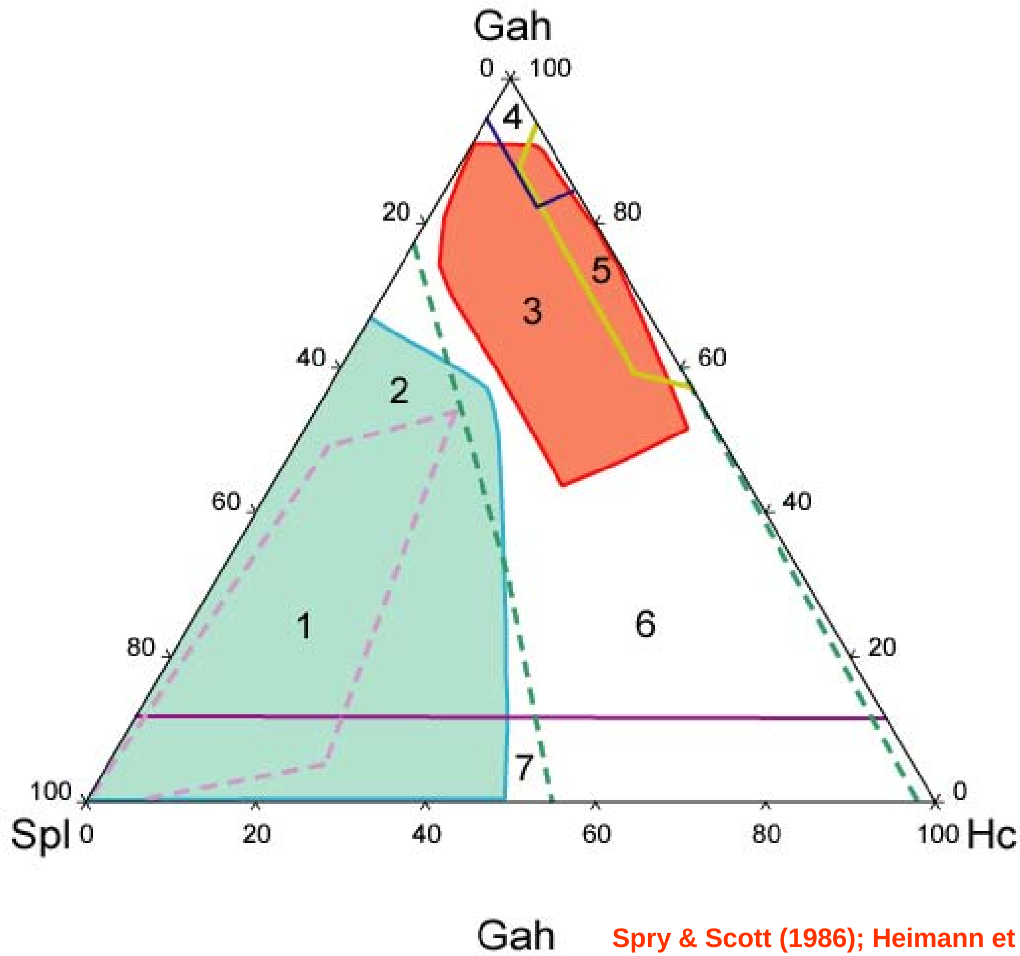
Phase relations among gahnite, staurolite and aluminous silicates shown in an Fe-Zn-Mg ternary diagram for the system Zn-Fe-Mg-Al-Si-S-O-H in the alteration zone of VMS deposit metamorphosed to the upper amphibolite facies (after Spry 2000).





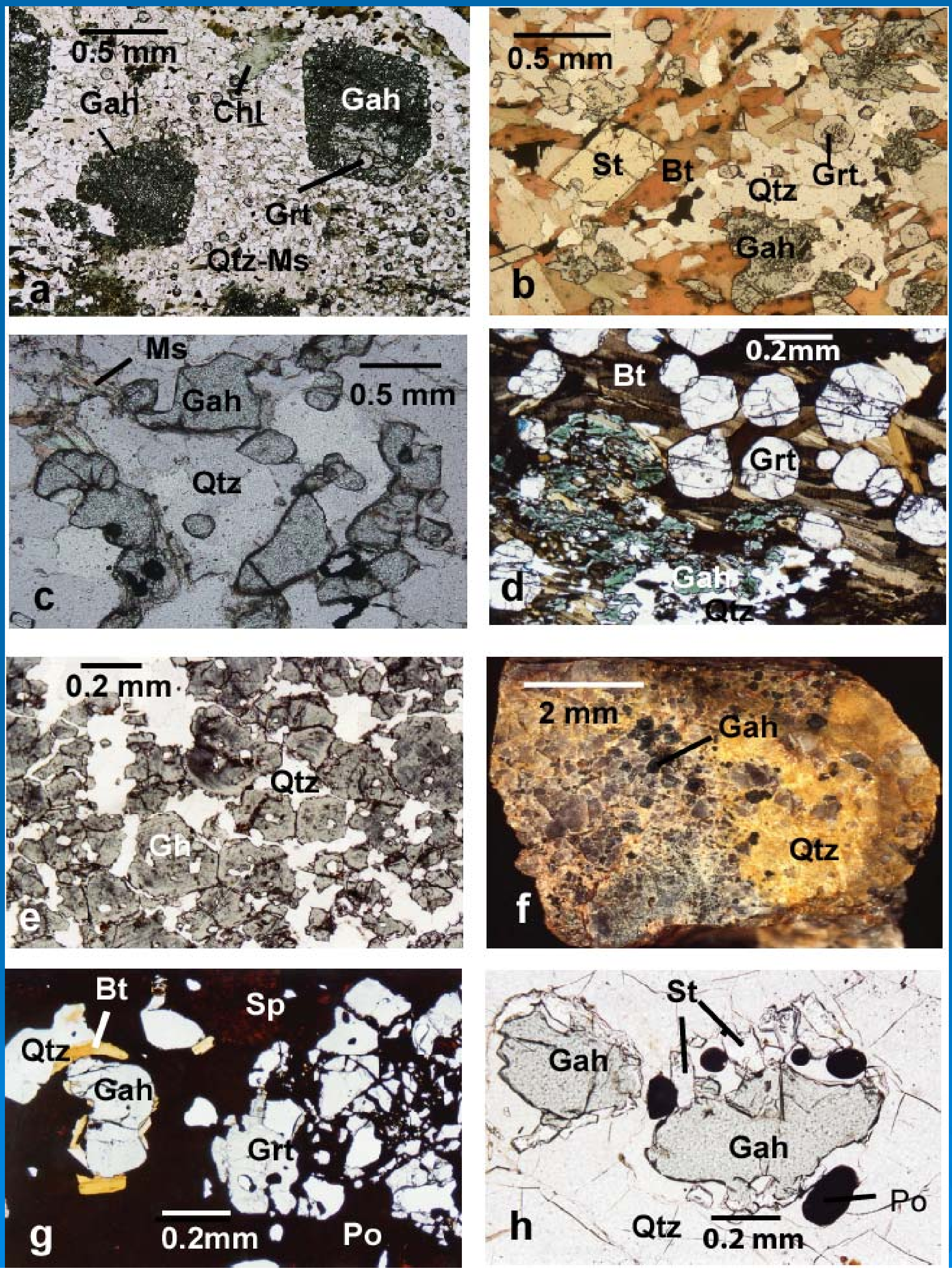
Distribution of Gahnite-Rich Rocks in the Broken Hill area, New South Wales, Australia

Composition of Gahnite in Natural Geological Settings



Spry & Scott (1986); Heimann et al. (2005)

1 Marbles; 2 Metamorphosed massive sulfide deposits and S-poor rocks in Mg-Ca Al alteration zones; 3 Metamorphosed massive sulfide deposits in Fe-Al metasedimentary and metavolcanic rocks; 4 Metabauxites; 5 Pegmatites; 6 Unaltered and hydrothermally altered Fe-Al-rich metasedimentary and metavolcanic rocks; and (7) Al-rich granulites



Plane-polarized photomicrographs and hand-specimen photos of gahnite-bearing rocks in Fe-Al rocks

a. Mulyungarie antiform; South Australia; upper greenschist facies

b. Angas Pb-Zn-Ag SEDEX deposit, South Australia; middle amphibolite facies

c. George Zn-Pb SEDEX deposit, Saskatchewan; upper amphibolite facies

d. Thunderdome Zn-Pb BHT prospect, New South Wales; upper amphibolite facies

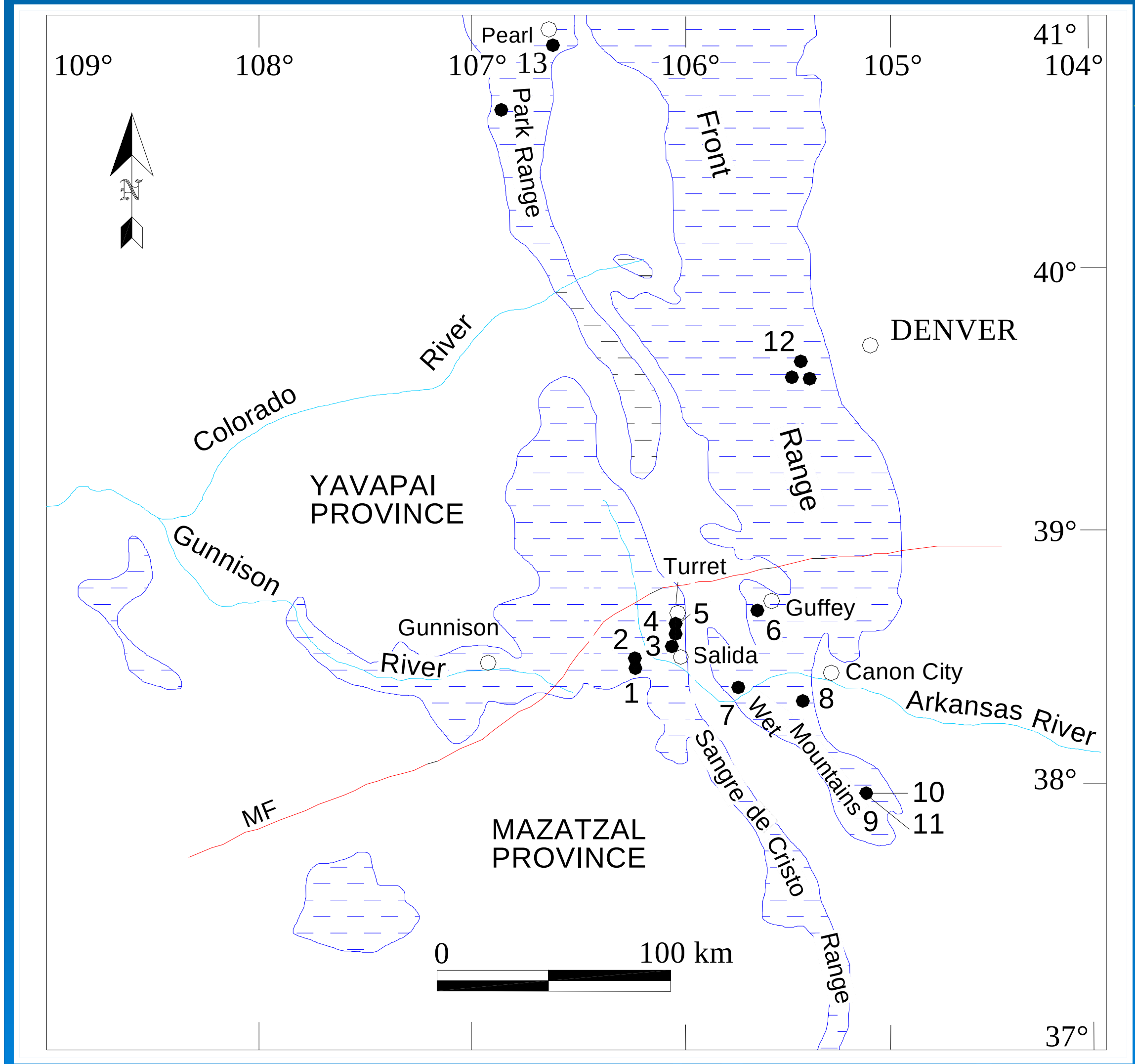
e. Emu Pb-Zn-Ag BHT prospect, South Australia; granulite facies

f. Centennial Pb-Zn-Ag prospect, New South Wales; granulite facies

g. C-lode, Broken Hill Pb-Zn-Ag deposit, New South Wales; granulite facies

h. Berta Tank Pb-Zn-Ag BHT prospect, South Australia; granulite facies

GEOGRAPHIC & GEOLOGICAL SETTING

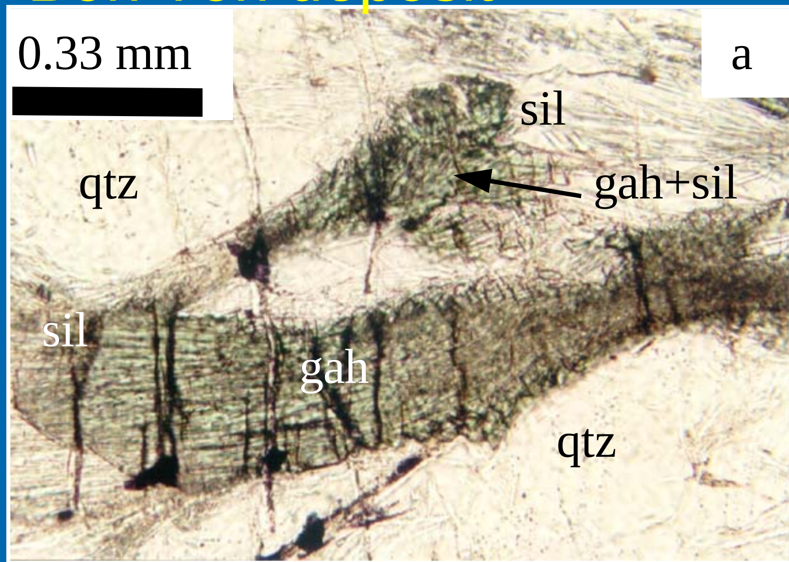


- **Proterozoic rocks**
  (Sheridan & Raymond 1984)
- **Lithotypes**
- **Age**
- **Terrane boundaries**
  MF: Mazatzal Deformation Front (Shaw & Karlstrom 1999)

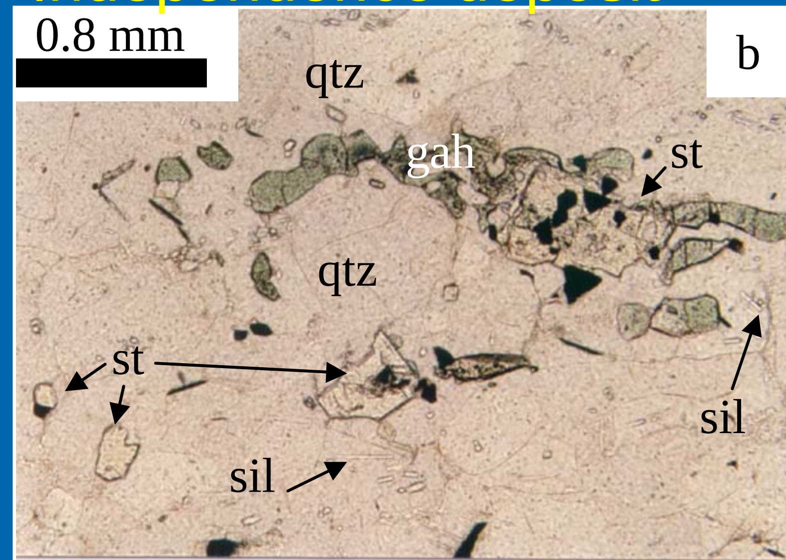
Fig. 1 Sites: 1. Bon Ton, 2. Cinderella, 3. Sedalia, 4. Ace High/Jackpot, 5. Independence, 6. Betty, 7. Green Mountain, 8. Cotopaxi, 9. Marion, 10. Amethyst, 11. Unnamed, 12. Evergreen, and 13. Caprock.

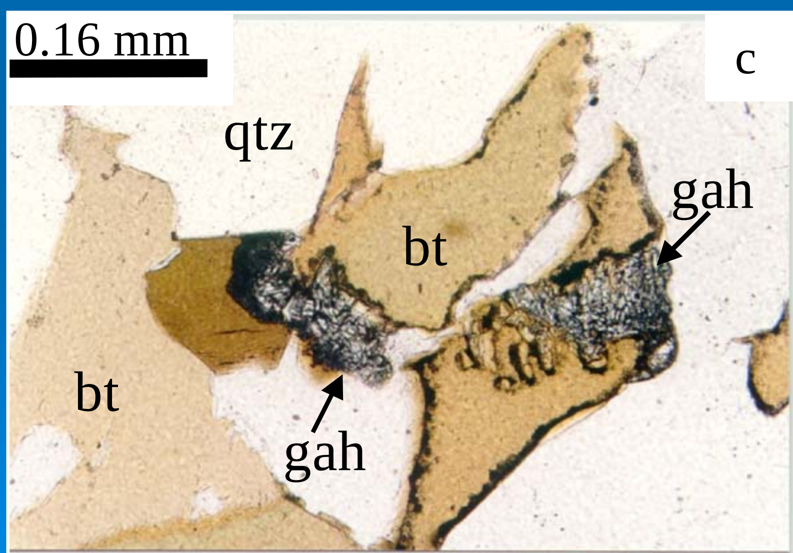
PETROGRAPHY

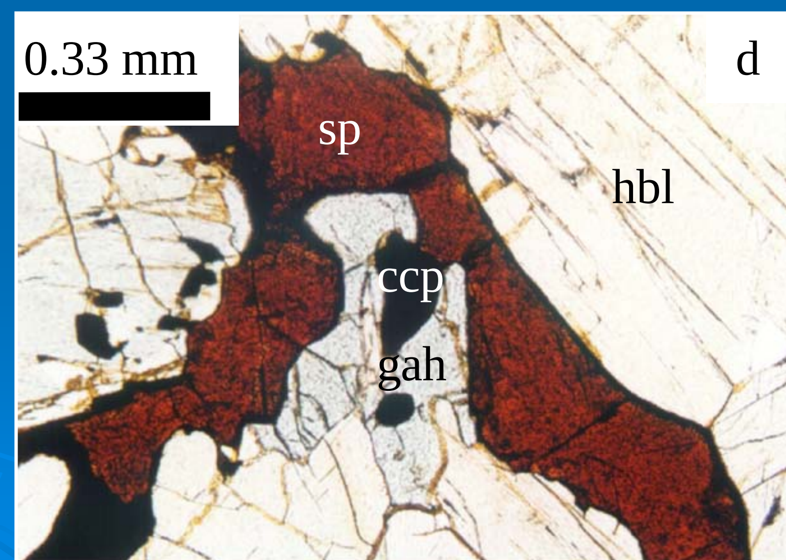
Bon Ton deposit



Independence deposit



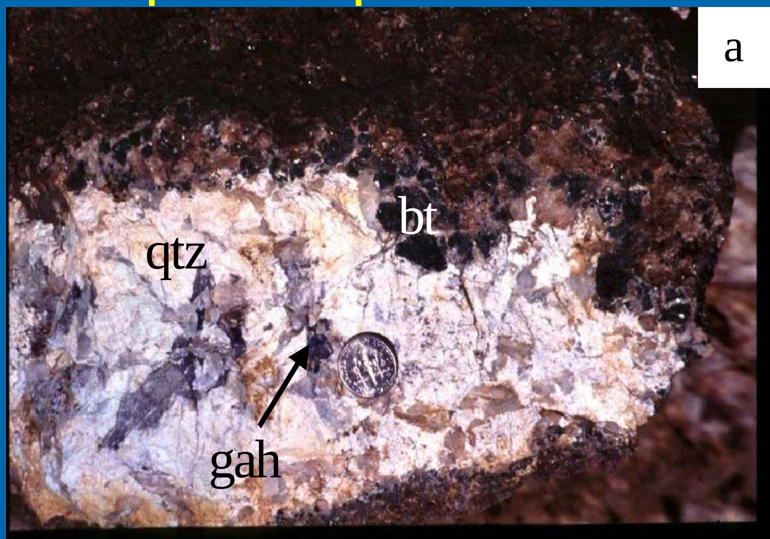




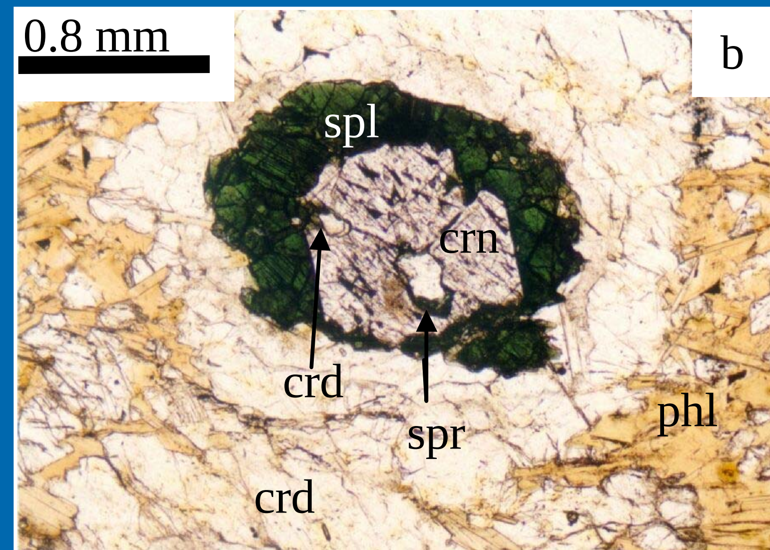
Green Mountain deposit

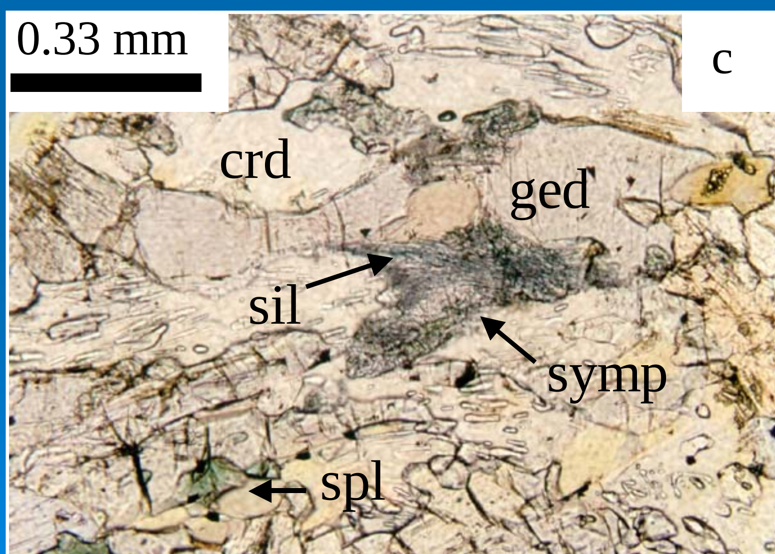
PETROGRAPHY

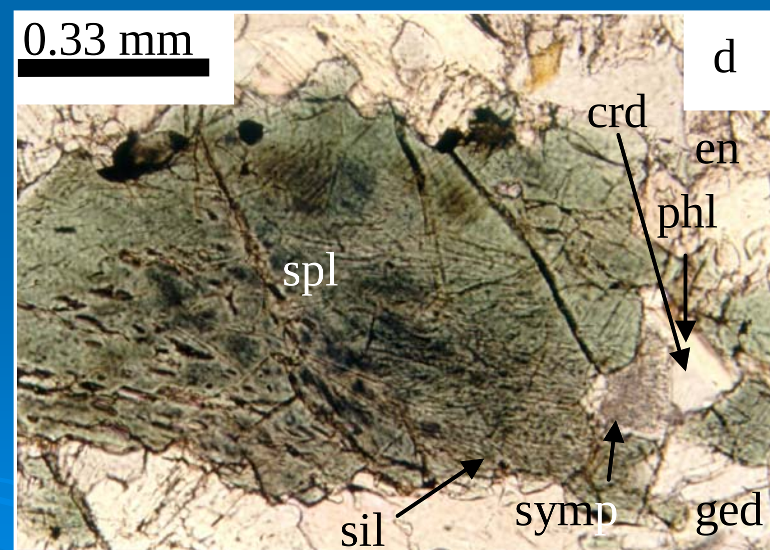
Cotopaxi deposit



Marion deposit







Unnamed prospect

ORIGIN OF Zn-SPINELS FROM COLORADO

- Desulfidation of sphalerite, for example via replacement of sillimanite (Bon Ton, Cotopaxi):

  sphalerite + sillimanite + ½ O_2= gahnite + quartz + ½ S_2

- Breakdown of zincian biotite (Green Mountain) or staurolite (Independence):

  Zn-staurolite + cordierite = Zn-hercynite + quartz

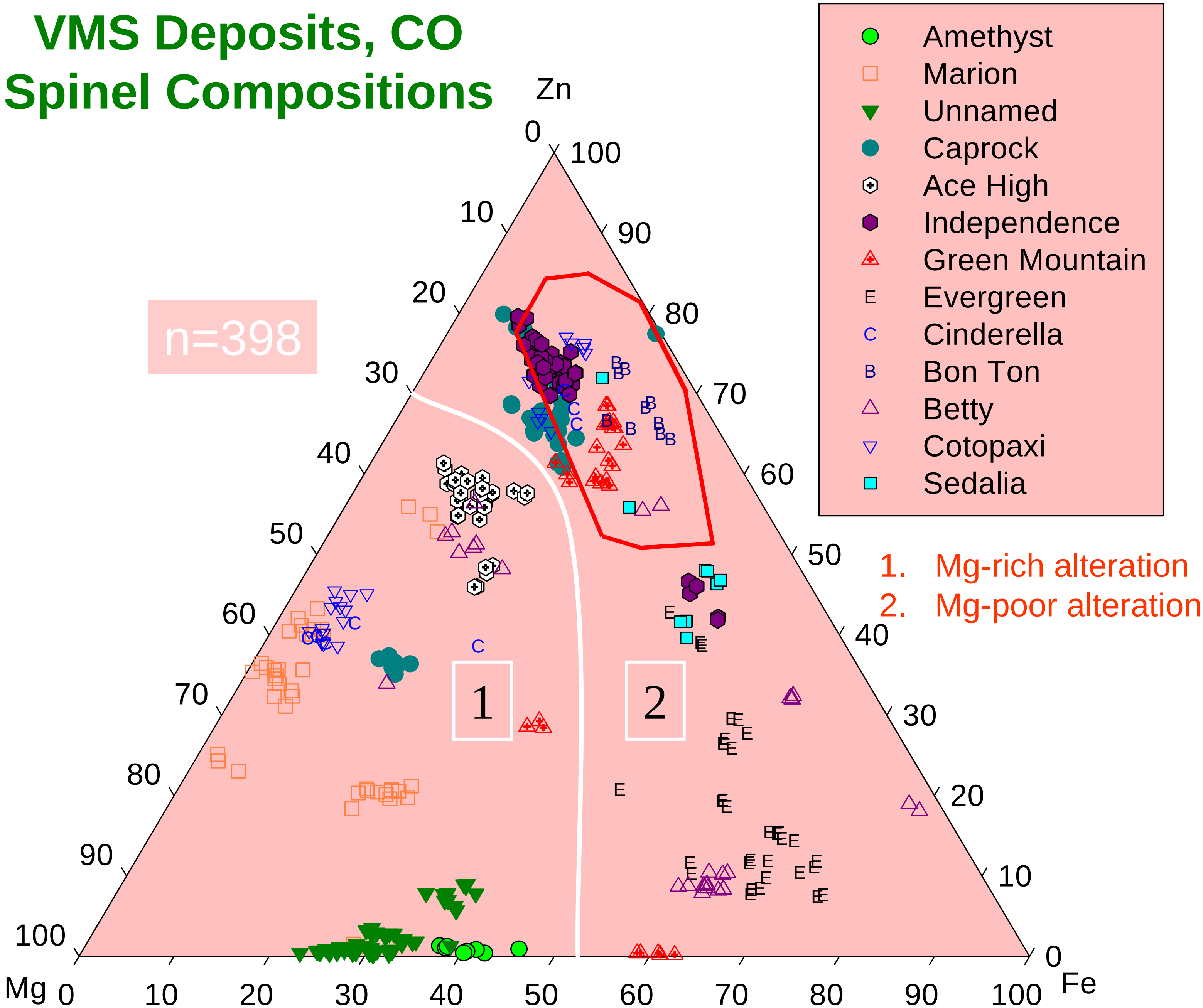
- Product of prograde metamorphism in Mg-rich rocks (e.g., Cotopaxi, Marion):

  sapphirine + corundum = spinel + cordierite;

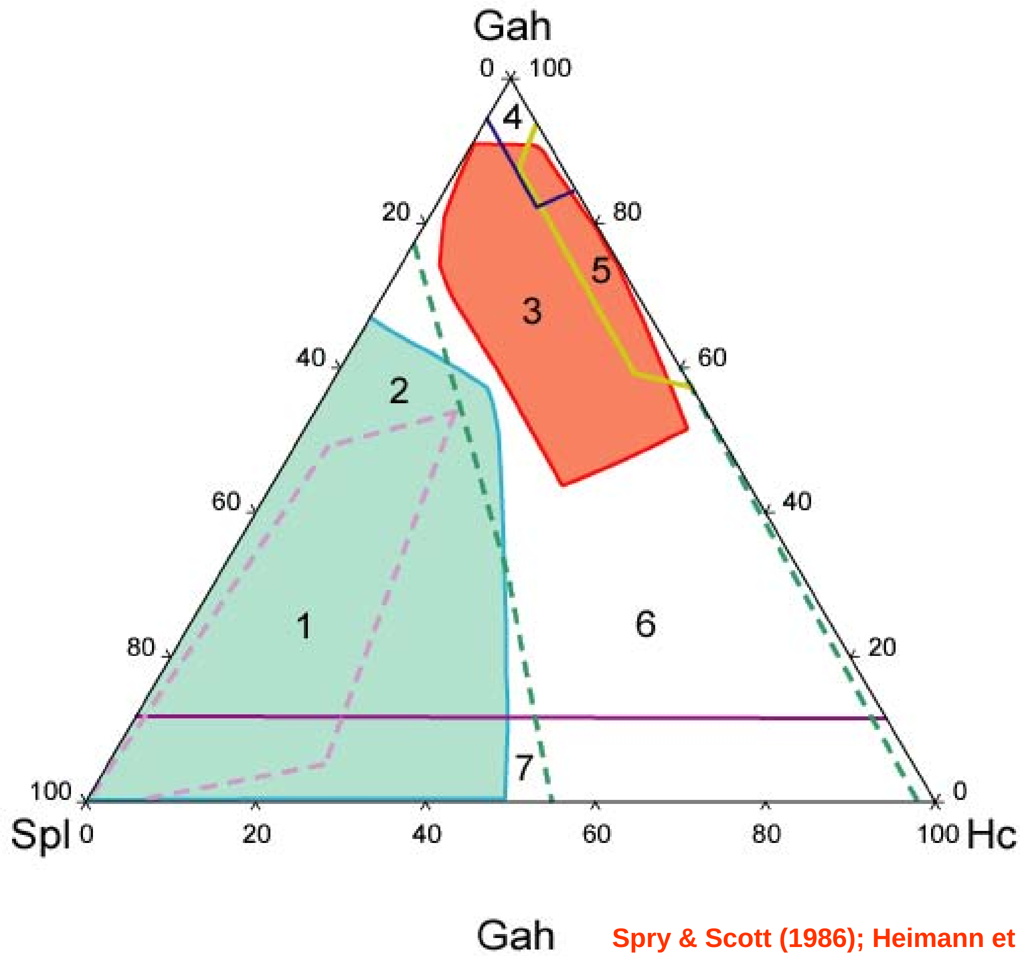
  cordierite = spinel + gedrite.

- Precipitation from a metamorphic hydrothermal solution in pegmatitic veins (Cotopaxi)

VMS Deposits, CO
Spinel Compositions



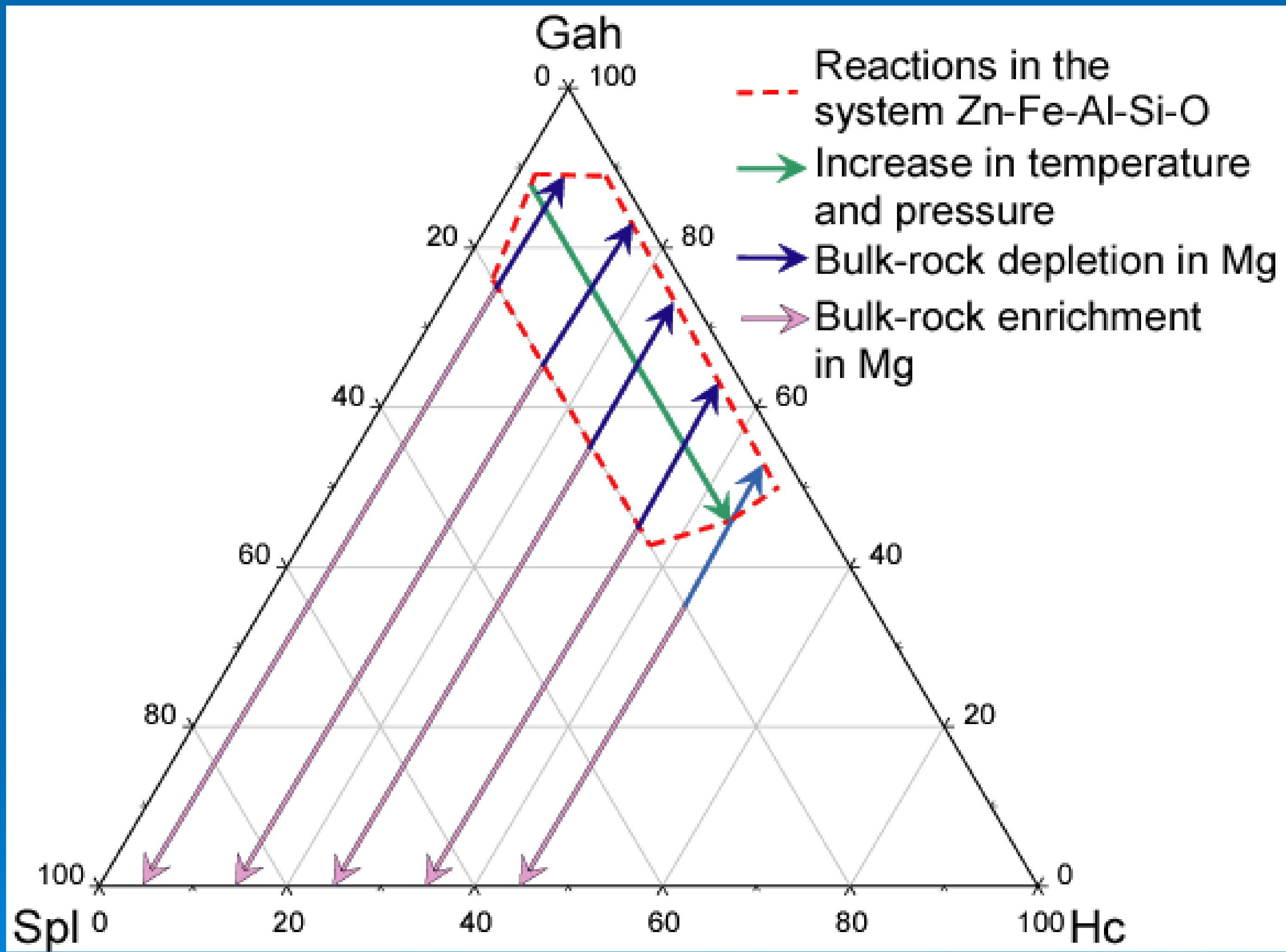
Composition of Gahnite in Natural Geological Settings



Spry & Scott (1986); Heimann et al. (2005)

1 Marbles; 2 Metamorphosed massive sulfide deposits and S-poor rocks in Mg-Ca Al alteration zones; 3 Metamorphosed massive sulfide deposits in Fe-Al metasedimentary and metavolcanic rocks; 4 Metabauxites; 5 Pegmatites; 6 Unaltered and hydrothermally altered Fe-Al-rich metasedimentary and metavolcanic rocks; and (7) Al-rich granulites

Schematic ternary plot showing the gahnite, hercynite, and spinel content of zincian spinels in metamorphosed massive sulfide deposits



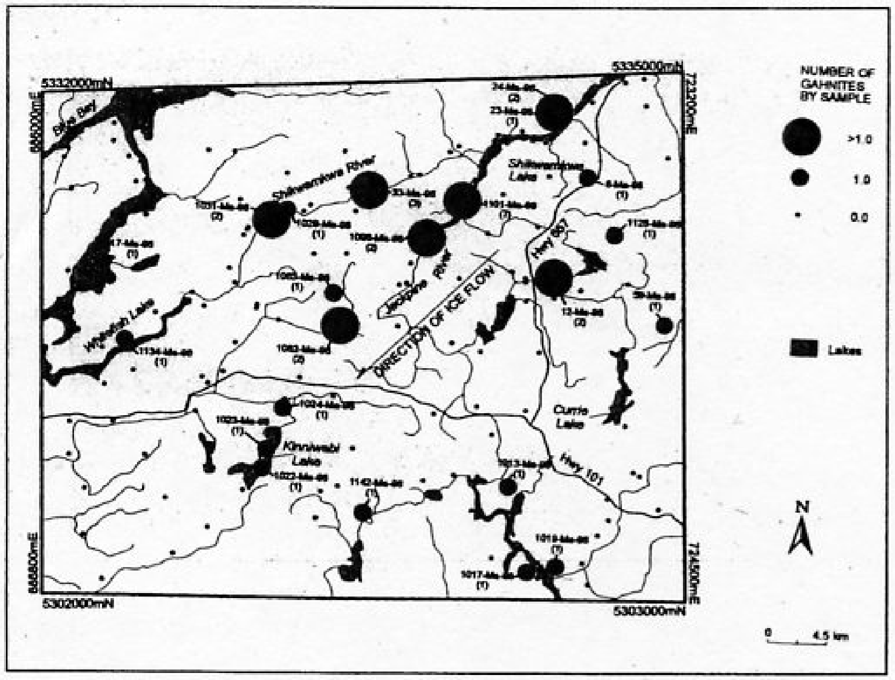


Fig. 6. Distribution of gahnite recovered from modern alluvium in the Kinniwabi Lake area, northeastern Ontario. Note the close association of the presence of gahnite to river valleys and lake basins whose orientation is controlled by faults.

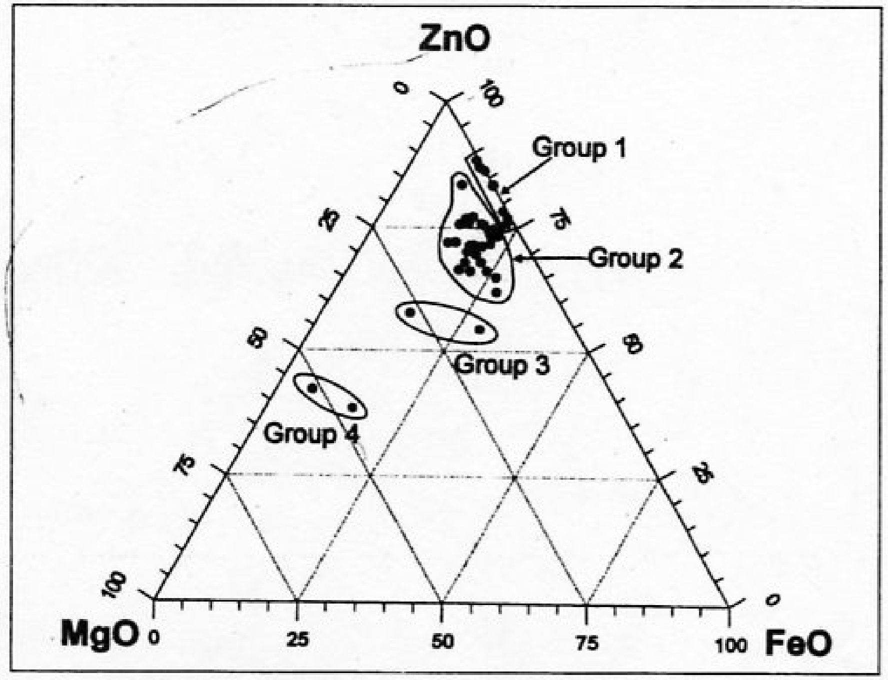
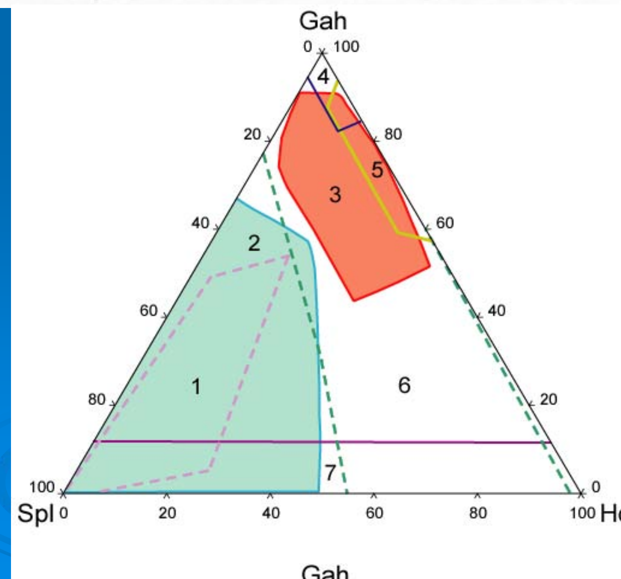


Fig. 7. Gahnite composition, Kinniwabi Lake. Gahnite recovered from modern alluvium samples. Note that gahnite composition plots into four distinct groups (see Table 4 for summary of composition).

Distribution of Composition of Alluvial Gahnite in Kinniwabi Lake, Ontario



Figures shamelessly stolen from Morris et al. (1997)

Gahnite in till from northwestern Ontario

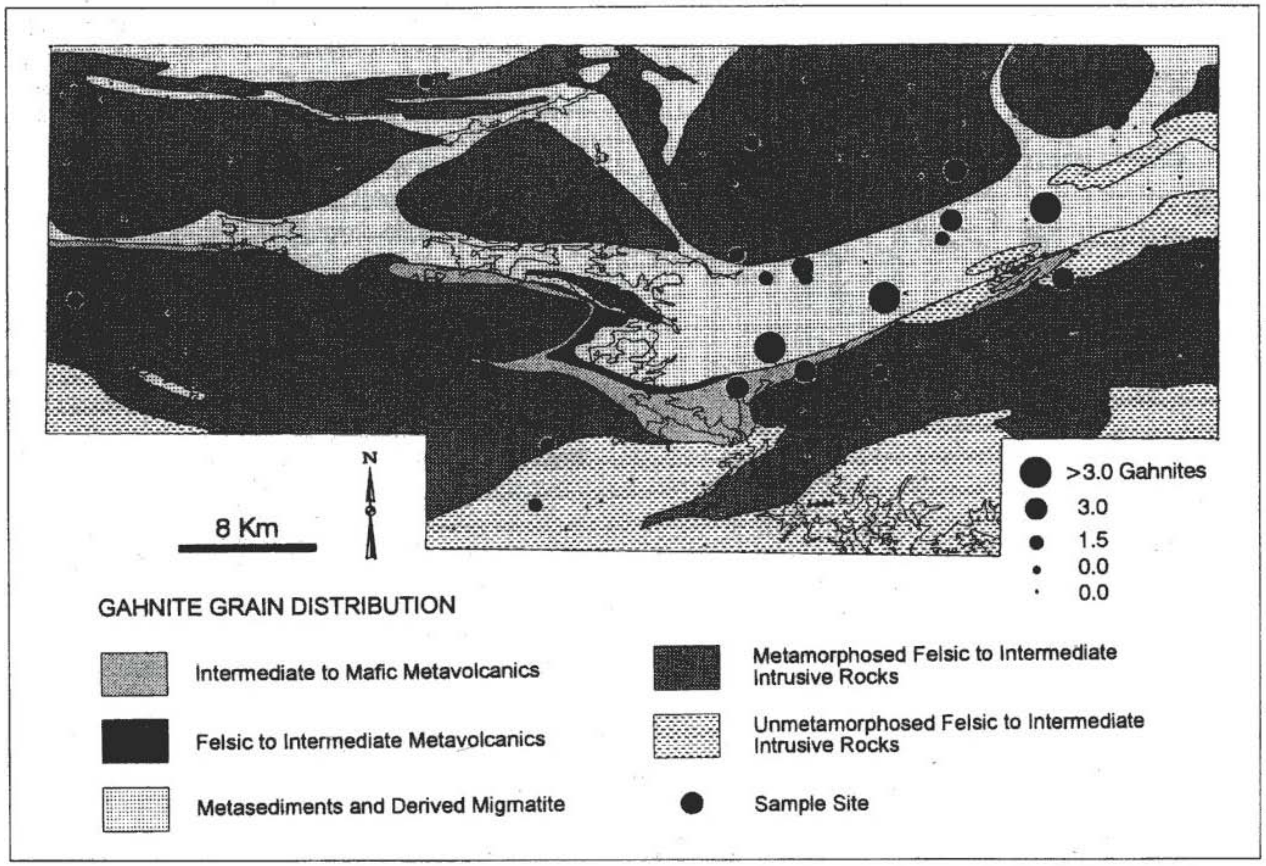


Fig. 4. Distribution of gahnite recovered from till in the Separation Lake area, northwestern Ontario. Note the distribution of gahnite associated with the southern margin of the eastern half of the migmatite belt. Group 1 gahnite, associated with rare-element pegmatite, were only recovered in the Selwyn Lake area. This area is located down-ice from an area of known pegmatite.

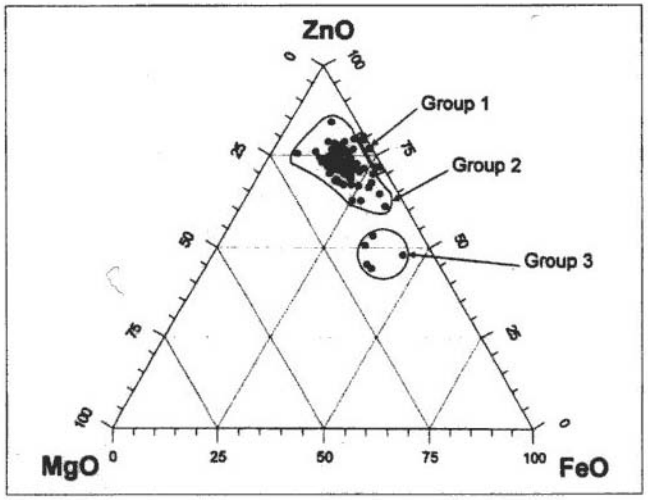
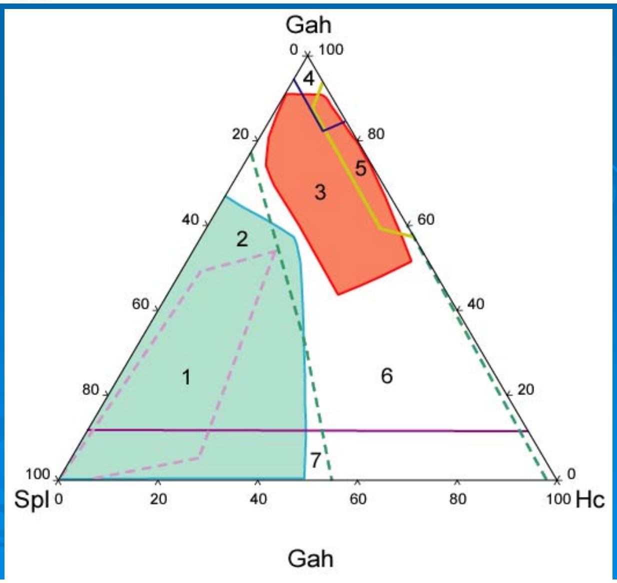


Fig. 5. Gahnite composition, Separation Lake. Gahnite recovered from C horizon till samples. Note that gahnite composition plots into three distinct groups (see Table 4 for summary of composition).



Morris et al. (1997)

Summary

- Gahnite occurs in a wide variety of geological settings both in situ and in unconsolidated sediments
- Although the discovery of gahnite in glacial sediments, beach sands, soils, and stream sediments is useful as an exploration guide to MMS deposits, it is most useful as a guide to ore when the composition of the zincian spinel is known.
- Where spatially related to MMS deposits, gahnite has a high Zn/Fe ratio (>1) that is dictated by the buffering capacity of members of the system Zn-Fe-S in equilibrium with the zincian spinel.
- The Mg content of the host rock dictates the Mg content of the zincian spinel (Mg-rich rocks produce compositions near the Mg apex, since the Mg component is not buffered by sulfides).
- One final thought, in addition to gahnite, zincian staurolite, zincian ilmenite-ecandrewsite ($ZnTiO_3$), zincohögbomite $[(Zn,Al,Fe)_6(Al_{14}Ti_2)_{\Sigma 16}O_{30}(OH)_2]$, and zincian tourmaline may also serve as resistate minerals in the search for MMS deposits