WHEN DOES MY IOCG BECOME A SKARN?

…..and does it matter?

Dr Richard Lilly, University of Adelaide
Dr. Roger Taylor, Legend
Introduction

- Acknowledgements to Roger Taylor and Peter Pollard, who have completed work on this topic for over 40 years

- Like many geologists I left university with the notion that ‘skarns only form in carbonate rocks and that they are very high temperature’

  Note: Skarns are not covered at undergrad level in many Uni’s

- After working around Cloncurry for several years (and over many enjoyable discussions with Roger) the same patterns (specifically the paragenesis) are present at many ore bodies whether they are classed as ‘IOCG’ or ‘SKARN’

 NOTE: This talk focusses on Australian Proterozoic Cu-Au mineral systems and not the full suite of W-Sn exoskarns.
DEFINITIONS: SKARN (Meinert, 2005)

“Skarn is a relatively simple rock type defined by a mineralogy usually dominated by calc-silicate minerals such as garnet and pyroxene.”

“Although the majority of skarns are found in lithologies containing at least some limestone, they can form in almost all rock types during regional or contact metamorphism and from a variety of metasomatic processes involving fluids of magmatic, metamorphic, meteoric and marine origin.”

“Although they are found adjacent to plutons they can occur along faults and major shear zones, in shallow geothermal systems, on the sea floor, and at lower crustal depths in deeply buried metamorphic terrains. Thus neither a pluton nor limestone is necessarily required to form skarn.”
Although the majority of skarn styles involve carbonate rocks very similar mineral associations can occur in almost any rock type. Including: shale, sandstone, meta-arenites granite, basalt and meta-basalts (‘Mafic skarns’).
Early work (rather oddly) treated skarn evolution as a broad-brush two stage operation with an early (anhydrous) division followed by a later (hydrous stage).

Every skarn system is typical of hydrothermal mineralisation in general, in that it is composed of multiple stages of fluid introduction associated with multiple rock fracturing.

**Early fluids tend to be hot and saline (500-700°C) and there is a general trend for successive fluids to decrease in both salinity and temperature.**

Thus high temperature products such as garnets and pyroxenes appear at the beginning of the sequence whereas lower temperature species such as epidotes and clays tend towards the later stages.

There are always minor variations as each skarn is functioning as a dynamic individual, with its own history of fracturing and fluid flow.
In short; there is a well established general theme with variations of detail.

The realisation that each skarn will contain some 5-20 overprinting stages is extremely important as the economic components may only appear with one stage.

Successive stages tend to overprint each other and alter previous materials (giving rise to another odd term peculiar to skarn workers ‘retrograde alteration’)
SKARN PARAGENESIS (Taylor, 2015)

- **Early Garnet-pyroxene** (± wollastonite, vesuvianite carbonate)
  - There may be more than one stage of this nature.

- **Magnetite-Amphibole**
  - Often difficult to separate and appear together

- **‘Economic assemblage’**
  - Variable combinations of chlorite, Fe, pyrite, pyrrhotite, Au/Ag ± Cu, Pb, Zn, Bi (sulphides, sulphosalts tellurides) ± carbonate, quartz
  - Can be multiple stages
  - Note - Tin and tungsten are higher temp minerals, so tend to crop up at all stages

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Paragenesis-Coroccohuyaco copper gold skarn, Tintaya district, Peru-(Maher 2005)
Iron oxide copper-gold (IOCG) deposits are a diverse family of mineral deposits characterised by the following features:

1. Cu with or without Au, as economic metals,
2. Hydrothermal ore styles, strong structural controls, breccias common
3. Abundant magnetite and/or hematite,
4. Fe oxides with Fe/Ti greater than those in most igneous rocks, and
5. No clear spatial associations with igneous intrusions as, for example, displayed by *porphyry and skarn ore deposits* (Williams et al., 2005).
In addition;

6. Most IOCG deposits display a broad space-time association with batholithic granitoids,

7. Occur in crustal settings with very extensive and commonly pervasive alkali metasomatism

8. Many are enriched in a distinctive, geochemically diverse suite of minor elements including various combinations of U, REE, F, P, Mo, Ag, Ba, Co, Ni and As (Williams et al., 2005).

In summary: All IOCG’s are different!

PS-Many IOCG’s contain garnet and pyroxene
CLONCURRY IOCGs

‘Some of the most metasomatised rocks on the planet’
(M. Rubenach pers comm)

- ‘Classic’ IOCG terrain with well established ore deposit models and yet every year somebody discovers something different.

- Strong mineral endowment in a variety of commodities
  \((Cu, Au, Pb, Zn, Ag, Co, REE)\)
• Discovered 1992 (Mag-TEM)

• Cu-Au ore hosted by brecciated and altered intermediate volcanic rocks (1750Ma)

• Pipe-like breccia body dipping SSE at 30-50°

• 2017 UG Resource 87.1 million tonnes at 1.18% Cu with 0.6 g/t Au

• LOM to 2027
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ERNEST HENRY Cu-Au

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- LOM to 2027
Ernest Henry Paragenesis

- **Stage 1:** Regional Na-Ca
  - Albite/Scapolite (+ apatite 1580Ma)
- **Stage 2:** ‘Dark Rock’
  - Biotite-magnetite (K-spar)
  - Garnet (interlens)
- **Stage 3:** Mineralisation
  - K-spar-magnetite
  - Chalcopyrite-pyrite-calcite-quartz
- **Post-min carb/qtz** (marble matrix breccia) ± fluorite/barite
K-spar altered intermediate volcanics (red) magnetite±biotite (dark), chalcopyrite±pyrite, calcite±quartz (white)
Ernest Henry Cu-Au, NW Queensland.
Ernest Henry: Garnet

Cave et al., 2018

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<th>Alteration Stage</th>
<th>Ab</th>
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Cave et al., 2018
Monakoff: Geology

- 21km south of Ernest Henry
- Narrow, mineralised shear (<15m)
- Hosted by Soldiers Cap Group at contact of Mt. Norna Quartzite (‘predominantly altered volcanics’) and Toole Creek meta-volcanics.
- Ore is hosted in magnetite altered metasediments
- 4Mt at 1.3% Cu and 0.4g/t Au
- Mined briefly (Xstrata) 2011-2012
Monakoff: Geology

Monakoff

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Mount Norna Quartzite (Basalts + garnet)

~10mm

Ore horizon ‘Banded ironstone’ (Magnetite) chalcopyrite-fluorite and barite

~10mm
Artemis

- Discovered by Minotaur, 2014 (EM)
- Cu-Au-Zn-Pb-Ag
- Variably described as ‘ISCG’ (pyrrhotite-dominant), IOCG, skarn with BHT characteristics
- Blind deposit, limited alteration halo, steep, tabular
- No significant magnetics or gravity

All correct?
ARTEMIS: PARAGENESIS

- ‘Dirty marble’ carbonate associated with ore

I. Early garnet
   (plus minor amphibole)
• ‘Dirty marble’ carbonate associated with ore

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II. Amphibole-magnetite-biotite-quartz

Paragenesis after A. Stephens, 2018
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Paragenesis after A. Stephens, 2018
Mount Elliot

- Discovered 1899 by John Elliot
- 280Mt at 0.5%Cu and 0.4g/t Au (2008)
- Mined in 1906 (and briefly in 1994)
- ‘IOCG family with skarn gangue mineralogy’
- Hosted within carbonaceous phyllite and amphibolite rocks in dilational setting
Geochemistry and origin of Proterozoic skarns at the Mount Elliott Cu–Au–(Co–Ni) deposit, Cloncurry district, NW Queensland, Australia

Shiqi Wang · Patrick J. Williams

Received: 1 September 1999 / Accepted: 28 September 2000

Abstract Diopside-rich, skarn-hosted, copper-gold ore derived primarily from carbonaceous metapelites at Mount Elliott forms a distinctive member of the spectrum of Cu–Au–(Fe oxide) deposit styles in the Cloncurry district of the Palaeoproterozoic to Mesoproterozoic Mount Isa Inlier. The mine sequence is a package of carbonaceous metapelites and metabreccias containing amphibolites derived from tholeiitic basic rocks. A $^{40}Ar^*/^{39}Ar^*$ age spectrum with an extensive plateau-like segment at 1,510 ± 3 Ma from an actinolite associated with sulfides is taken to represent the age of mineralization and is identical within error to the ages of most of the nearby bathonial granitoids. The mine sequence is locally intruded by 1- to 10-m-thick late to post-tectonic trachydendrite dikes, which were emplaced during the hydrothermal activity that created the orebodies and have affinities with the regional high potassium “Farralka” supraschist granitoids. Stable isotope data are consistent with dominantly magmatic fluids during mineralization and the regionally distinctive skarn (Ca–Mg) and Cu–Au–Ni–Co–Te–Se–(low Fe–Zn–Ag–Sb) chalcopyrite element associations may reflect a primitive magmatic fluid source and/or leaching of these elements from country rocks. Mount Elliott is an unusual skarn deposit characterized by pronounced early albitization (R–Fe–Mg depletion) of the host rocks succeeded by predominantly open-space deposition of sodic diopside + actinolite + seapolite + andradite + magnetite + sulfides + apatite + alkali + tremolite + calcite. The Ca–Fe–Mg–Na-rich (mangano)pyroxene chemistry was imposed from the fluid phase.

Introduction

Skarn is defined in terms of a calcio-silicate mineralogy that reflects the physical and chemical stability of the constituent minerals rather than implying any particular geological setting or protolith composition (e.g. Meinert 1992). However, it is clear that most known mineralized skarns formed by replacement of carbonate and/or mafic to intermediate igneous rocks whose calcium and/or magnesium-rich character significantly influenced the alteration mineralogy. In this paper we present geochemical evidence that diopside-rich skarn at the Mount Elliott Cu–Au–(Co–Ni) deposit formed mainly by direct precipitation from hydrothermal fluids in predominantly

Image T. Evans

Diopside
(Mg-rich pyroxene)

Wang and Williams, 2001

Skarn-type mineralogy well documented at Mt. Elliot
Mt. ELLIOT (and SWAN): PARAGENESIS

Wang and Williams, 2001

3 Main stages:

I. Albitisation
   fracture- and fabric-controlled

II. Early skarn
   diop-scap-act

III. Main skarn –
   main brecciation and mineralisation cpy-py-
   mag-po-cal-gt-ap-tour-act

Note: Ore minerals clearly post-date magnetite/garnet/amphibole....
Scope to review paragenesis?
Mt. ELLIOT (and SWAN): PARAGENESIS

Wang and Williams, 2001

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Cannington:

• Discovered by BHP in 1990 (mag)
• 44Mt at 538g/t Ag, 11.6% Pb, 4.4% Zn (1998)
• Hosted in Soldiers Cap Group, ‘stratabound’, strongly deformed biotite, sillimanite and garnet-bearing gneiss and associated ‘core’ amphibolite.
• Distinct chemical zonation, strain partitioning and ‘remobilisation’.
• Genesis classed as ‘Broken Hill Type’ or Skarn, depending if you ask JCU or CODES

From Huisman, 2016
The Cannington deposit is hosted by a combination of sillimanite bearing metasediments gneiss, pegmatites and major amphibolite.

Subject of gross confusion with a debate in the literature concerning its origin and paragenesis.

Essentially post-discovery studies concluded a skarn-type origin (JCU) or a BHT-type origin (CODES).

Upon review BHP went with the BHT-type classification.

Main difference concerns interpretation of sulphide blebs occurring within some of the early skarn minerals (Bowden, 1998, and Chapman and Williams, 1998).
Cannington: Paragenesis

- Peak-Metamorphism-Sil-Kspar-Tour-Bio-Graphite

- Post-metamorphism:
  I. Garnet - pyroxene
  II. Amphibole-Magnetite-Mn silicates
  III. Sulphides-Sph-Gal-Cpy-Au
  IV. post-ore

- Entire sequence is very Mn enriched

  “besides their Zn-Pb-Ag metal content Zn skarns can be distinguished from other skarn types by their distinctive Mn- and Fe- rich mineralogy.

  Almost all skarn minerals in these deposits can be enriched in Mn, including garnet, pyroxene, olivine, Ilvaite, pyroxinoid, amphibole, chlorite and serpentine”

  (Meinert , 2005)
CANNINGTON: PARAGENESIS

I. Garnet - pyroxene
II. Amphibole-Magnetite-Mn
III. Sulphides-Sph-Gal-Cpy-Au
CANNINGTON: PARAGENESIS

I. Garnet - pyroxene
II. Amphibole-Magnetite-Mn
III. Sulphides-Sph-Gal-Cpy-Au

Is Cannington a ‘skarn’?
Are our classifications holding us back?

...But the status-quo (and investor market) requires a ‘model’...
‘TYPICAL’ IOCG ALTERATION and INFILL
Magpie Prospect, Cloncurry, NQ Qld

Host Dolerite

Carbonate/Quartz

Late pink ‘zeolite’

Albite

Sulphides (py>cpy)

Magnetite

Amphibole (Actinolite)

‘The best place to fracture a rock is where is has already been fractured’
Hillside

- Discovered 2008 (mag-grav)
- 337Mt @ 0.6% copper and 0.14g/t Au
- ‘IOCG-Skarn’
- Hosted in strongly altered and metasomatised volcanics and metasediments in dilational setting
- Two skarn developments in host lithologies prior to mineralisation events (1570-1580Ma)
- 50+ minerals complex paragenesis
Hillside

3 Main stages

I. ‘Early Pink’:
   Albite-Scap-Kspar (Mag-Bio)
Hillside

3 Main stages

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Hillside
3 Main stages:

I. ‘Early Pink’
   Albite-Scap-Kspar (Mag-Bio)

II. Skarn Garnet-Pyrx

III. Mag-Bio-Amph

IV. Main Mineralisation
   cpy-born-py-carb-qtz (Epi?)
Hillside

3 Main stages:

I. ‘Early Pink’  
   Albite-Scap-Kspar (Mag-Bio)

II. Skarn  
    Garnet-Pyrx

III. Mag-Bio-Amph

IV. Main Mineralisation  
    cpy-born-py-carb-qtz (Epi?)

V. Post-mineralisation  
    retrograde assemblage  
    carb-clays-oxides-hem
Hillside

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Skarn or IOCG?

Depends which tray of core you look at…

Depends what your investor market demands?
Garnet–K-feldspar–chlorite–sulfide–hematite skarn within Wallaroo Group. GHDD1, 886 m

Fabris et al. 2018

Partly calcite–sulfide–hematite retrogressed, garnet–pyroxene–sulfide skarn. GHDD1, 854 m
Other SA examples: Mount Brady Region

Pyx

Phlog

Mag

Carb (x 2?)
A carbonate host rock is not essential to form a skarn mineral assemblage. Skarns can form in almost all rock types. Neither a pluton or a limestone is necessarily required to form a skarn.
TAKE AWAY POINTS

MOST ‘IOCG’S’ CONTAIN GARNET AND PYROXENE IN THEIR EARLY-STAGE PARAGENESIS

‘IOCG’ or ‘SKARN’ is just a question of mineral abundance: both are structurally controlled hydrothermal assemblages

Who are we helping when we force deposits into a classification?

Better to use ‘mineral systems thinking’?