EARTH 471
Mineral Deposits

Skarn and IOCG deposits

Skarn deposits

Skarn

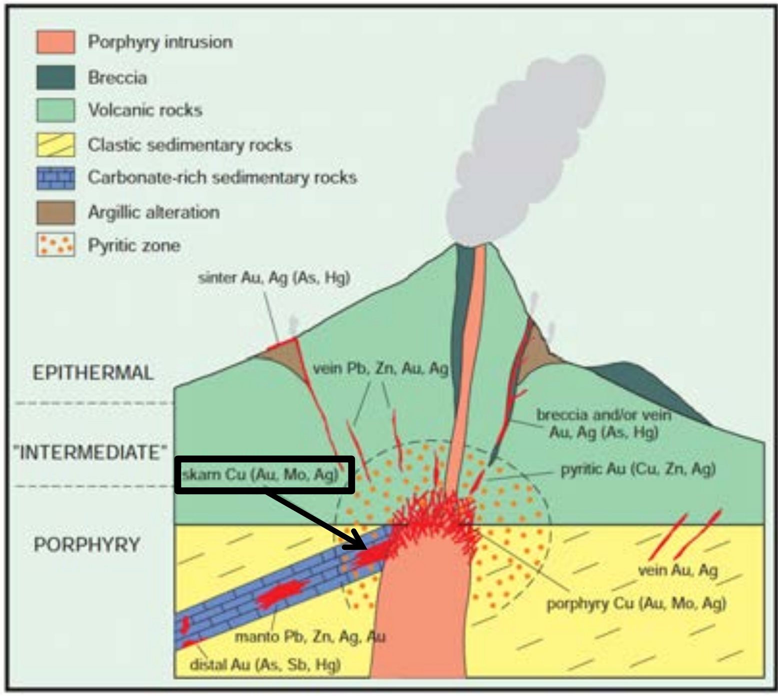
Historical Swedish mining term used for the assemblages of Fe-bearing calc-silicate gangue minerals (e.g. garnet, diopside, wollastonite)

Metamorphic petrologists use it to describe metasomatic rocks with calc-silicate minerals

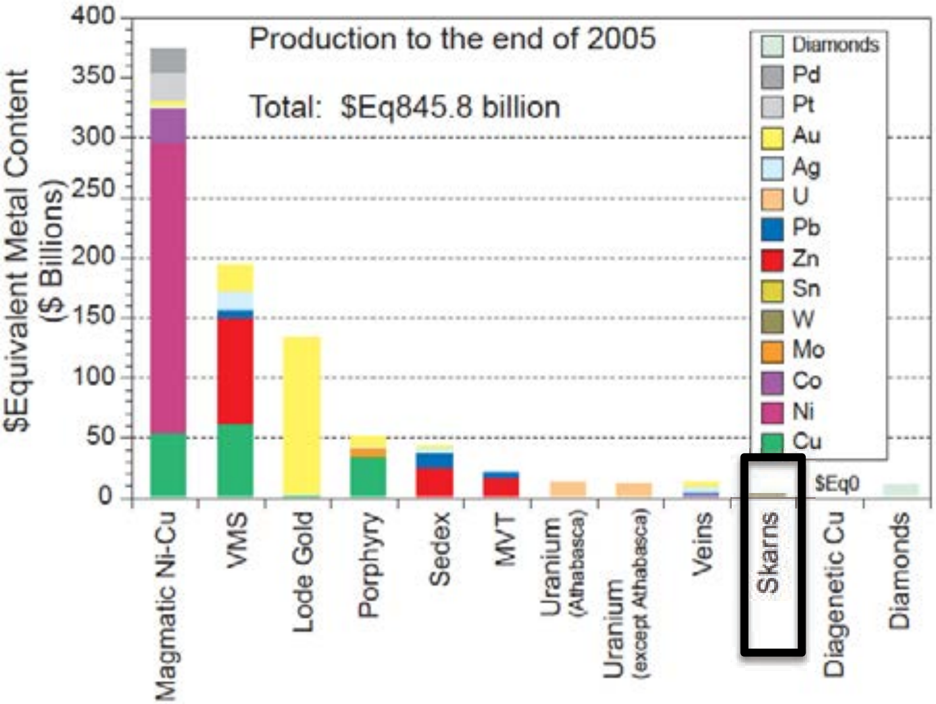
Fe-enriched pervasive alteration of carbonate-rich rocks by magmatic–hydrothermal fluids at the margins of felsic plutons

Usually associated with porphyry deposits but not always

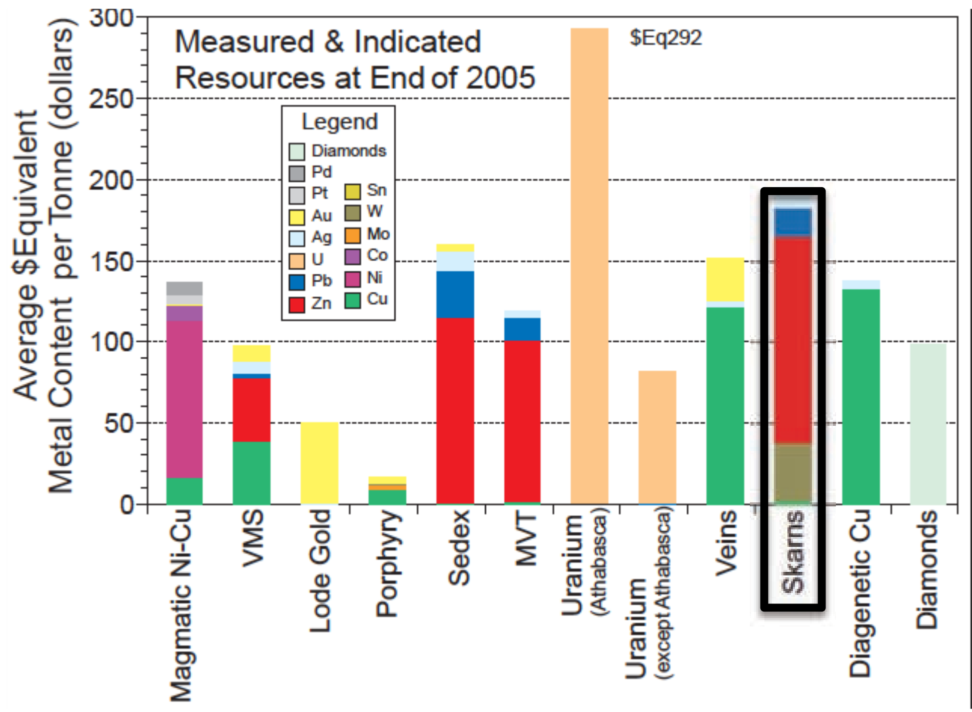
Cu, Au, **W**, Sn are the main commodities

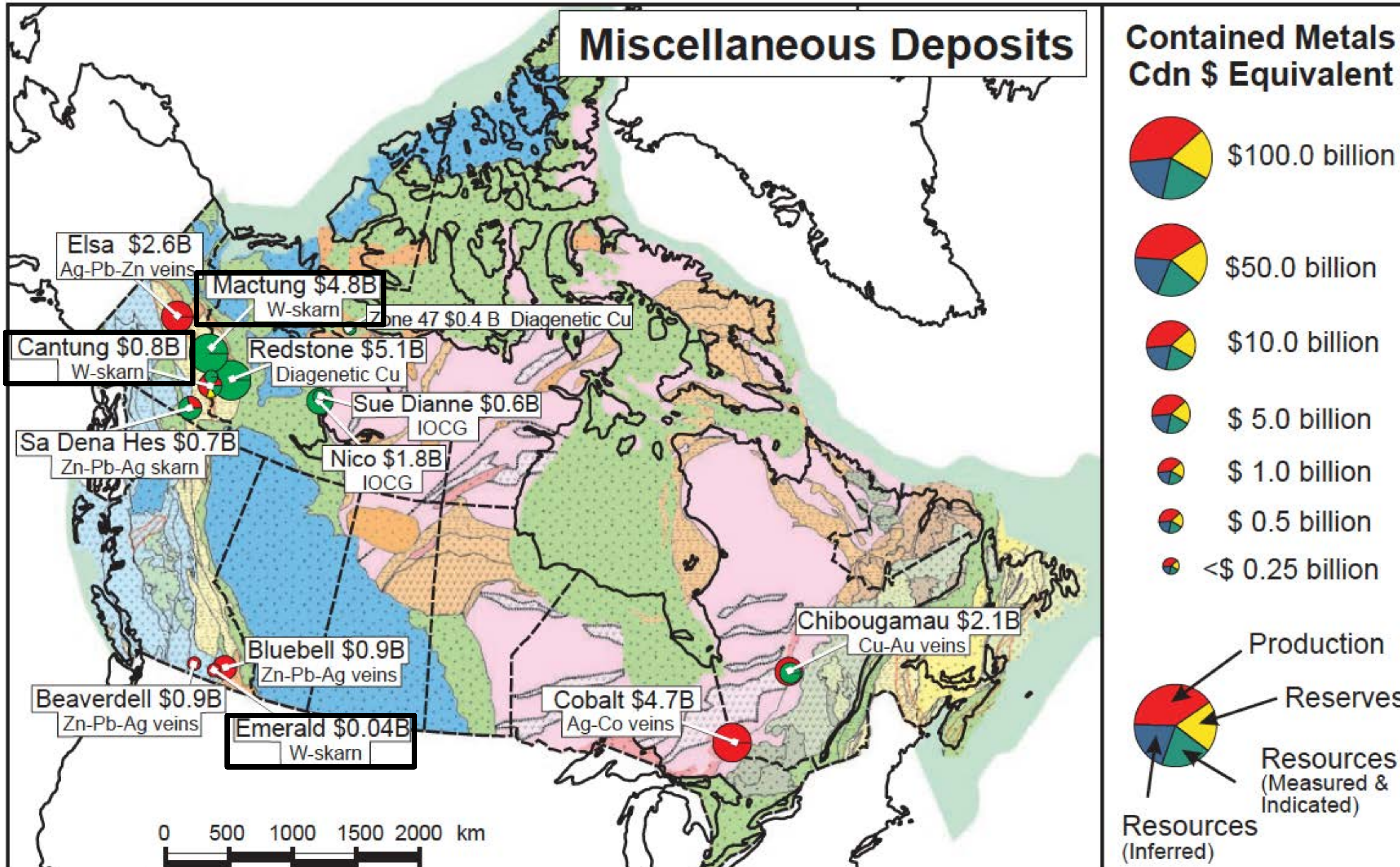


Currently, skarn deposits are not very important in Canada



But, they can be quite rich in metals





Dollar equivalent of metal contained in ores (Cdn $ billions)

Production: 11.11 **Reserves:** 0.09 **Resources: (Measured and Indicated)** 14.27 **Resources: (Inferred)** 0.0 **TOTAL:** 25.18

Tungsten

- Skarn deposits are the world's leading source of tungsten
- Middle ages: byproduct of tin smelting (tore apart tin metal 'like a wolf tearing apart sheep')
- Discovered by Carl Wilhelm Scheele in 1781
- *W* = wolfram (think wolframite)
- Tung-sten: Nordic for 'heavy stone'

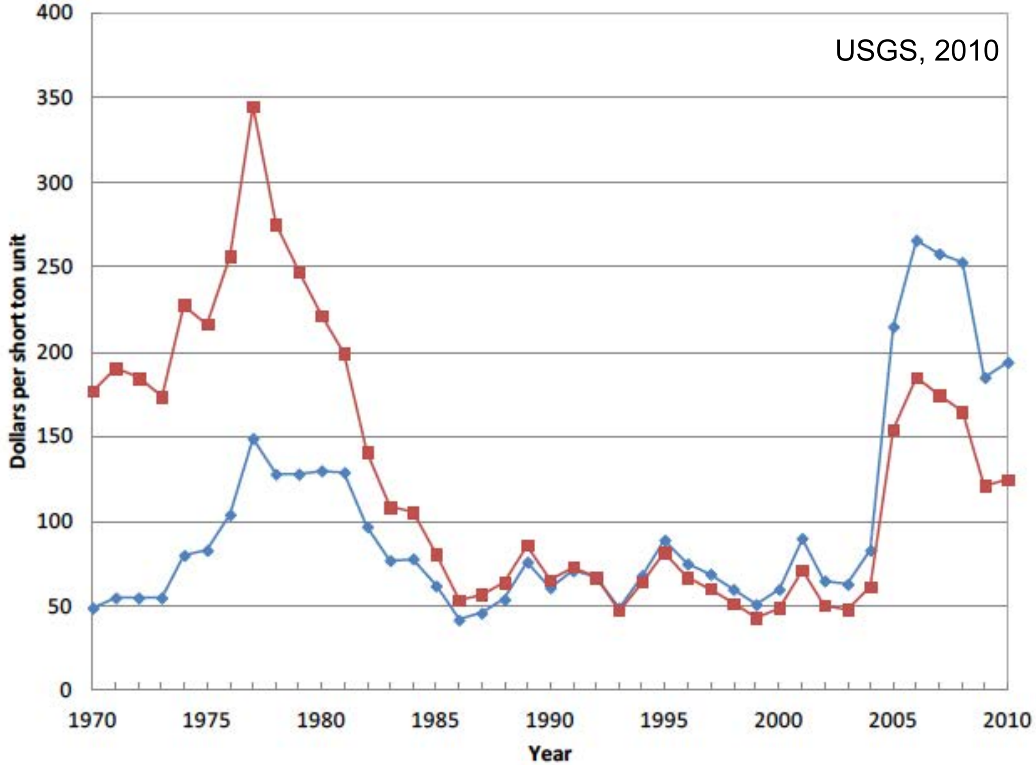
Economics

1970–74: Strong demand during improved economic conditions

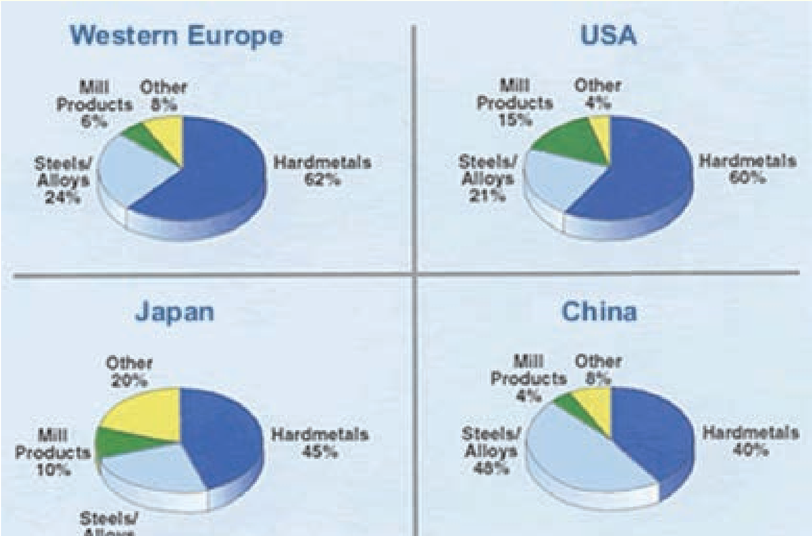
1979–2000: China becomes main supplier (cheaper to produce)

2006: China slows down annual exports – also an increase in global demand

2008: Global financial crisis decreased tungsten consumption



Tungsten – uses



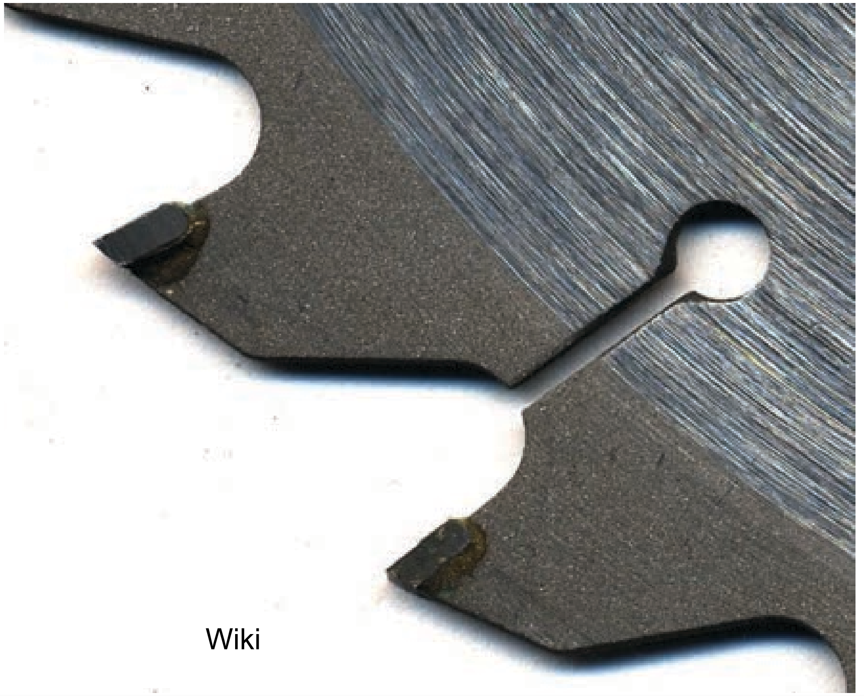
USGS, 2007

Properties

- Very hard and dense
- Unreactive
- Second highest melting temperature of all elements (first is carbon – graphite)

Uses

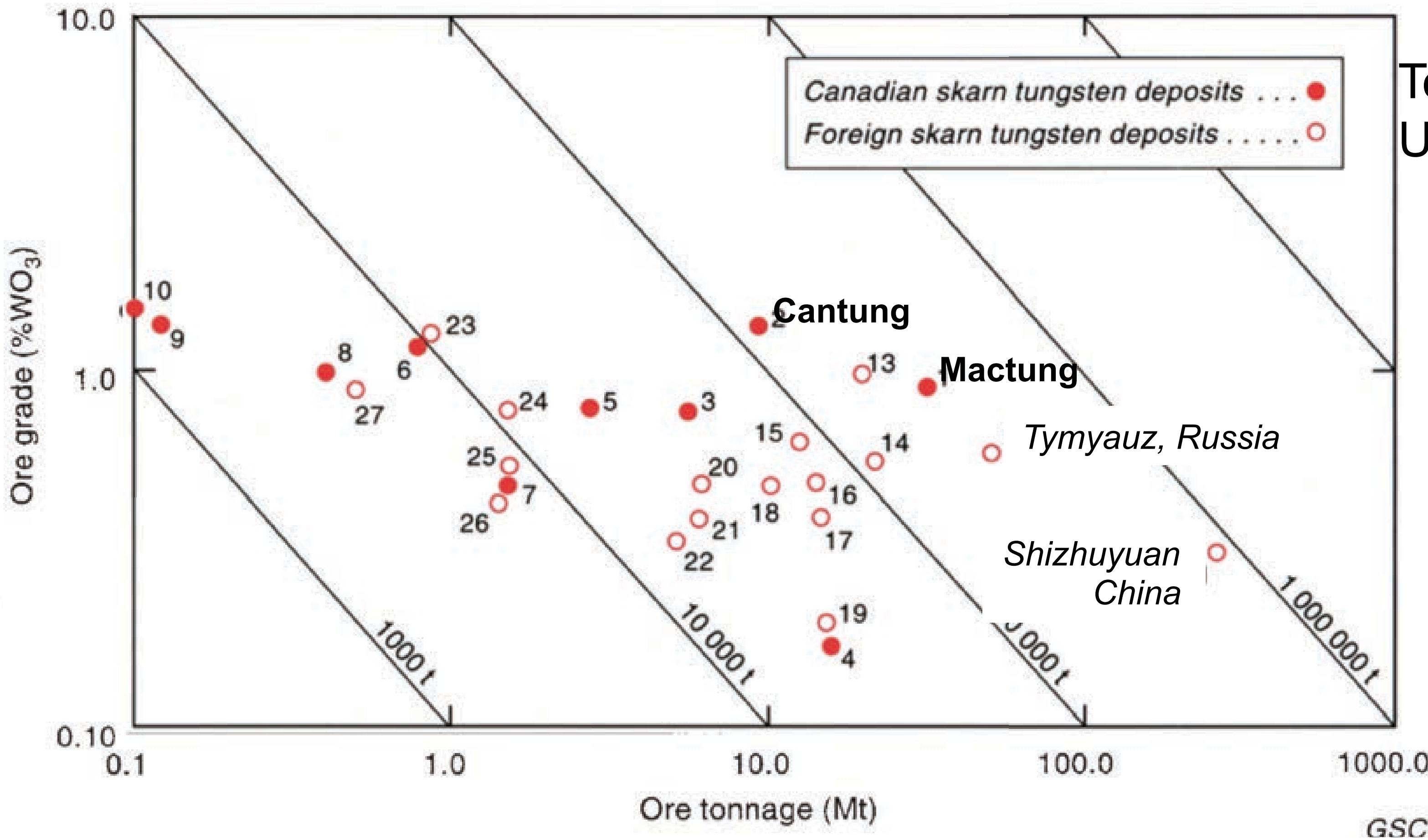
- Adds hardness and strength to steel alloys
- Tungsten carbide is the second hardest compound


Wiki

W skarn deposits

Grade:
0.2–1.4% WO_3

Tonnage:
Up to 170 Mt



Tungsten in Canada

W mining in Canada part of the war effort:
1914–1918: Burnt Hill, NS
1939–1945: Indian Path, NS; Outpost Island, NWT; Emerald, BC

Cantung skarn deposit (NWT)
- Discovered in 1954, production started in 1962
- $0.8 Billion, $111.6/ton resource (operating)

Mactung skarn deposit (Yukon)
- Discovered in 1962
- $4.8 billion, $60.2/ton resource (has not been mined)
- Feasibility study conducted in 2009

Until 1986, Canada produced 8% of world's W; low-priced W exports from China forced closure of Canadian W mines

*1984 start of W production of Mount Pleasant (porphyry) in New Brunswick

W Skarn ores

- Relatively high grade but low tonnage
- Scheelite ($CaWO_4$): main W ore mineral
- Gangue: diopside, garnet, wollastonite, calcite (calc-silicate minerals)
- Stratiform, less commonly vein-like

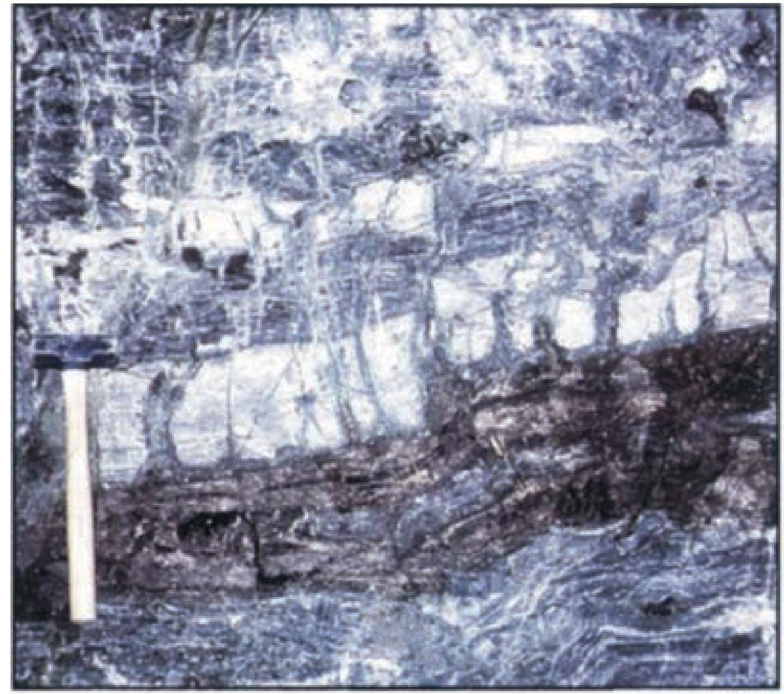


Plate 38. ***Deposit subtype 20.5,*** Skarn tungsten. Pyrrhotite (bronze-brown) with scheelite (not visible) in fractured limestone. E-zone orebody, Cantung mine, Northwest Territories. GSC 1995-220A

Plate 39. ***Deposit subtype 20.5,*** Skarn tungsten. High-grade tungsten ore; scheelite crystals (white) in biotite-diopside-pyrrhotite skarn. E-zone orebody, Cantung mine, Northwest Territories. GSC 1995-220B

Two skarn classification schemes

1. Calcic: if the host rocks are limestones
2. Magnesian: if the host rocks are dolostones

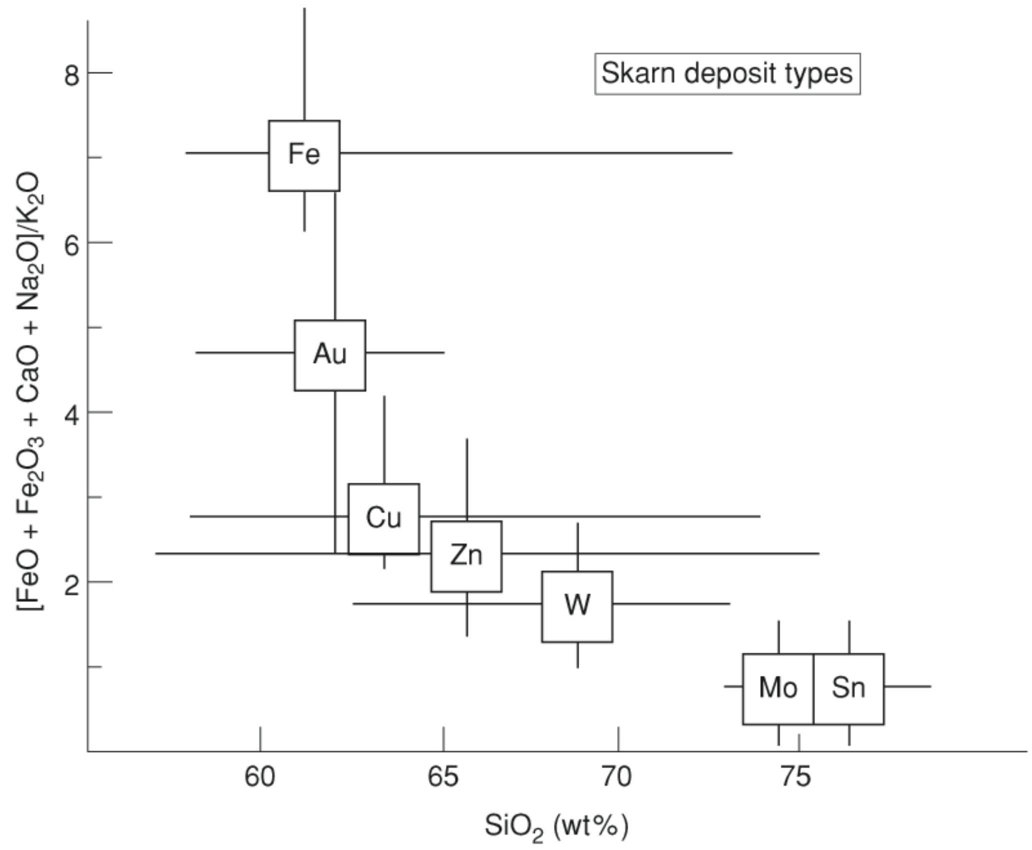
OR

1. Endoskarn: if the metasomatic assemblages are internal to the intruding pluton
2. Exoskarn: if the metasomatic assemblages are external to the intruding pluton

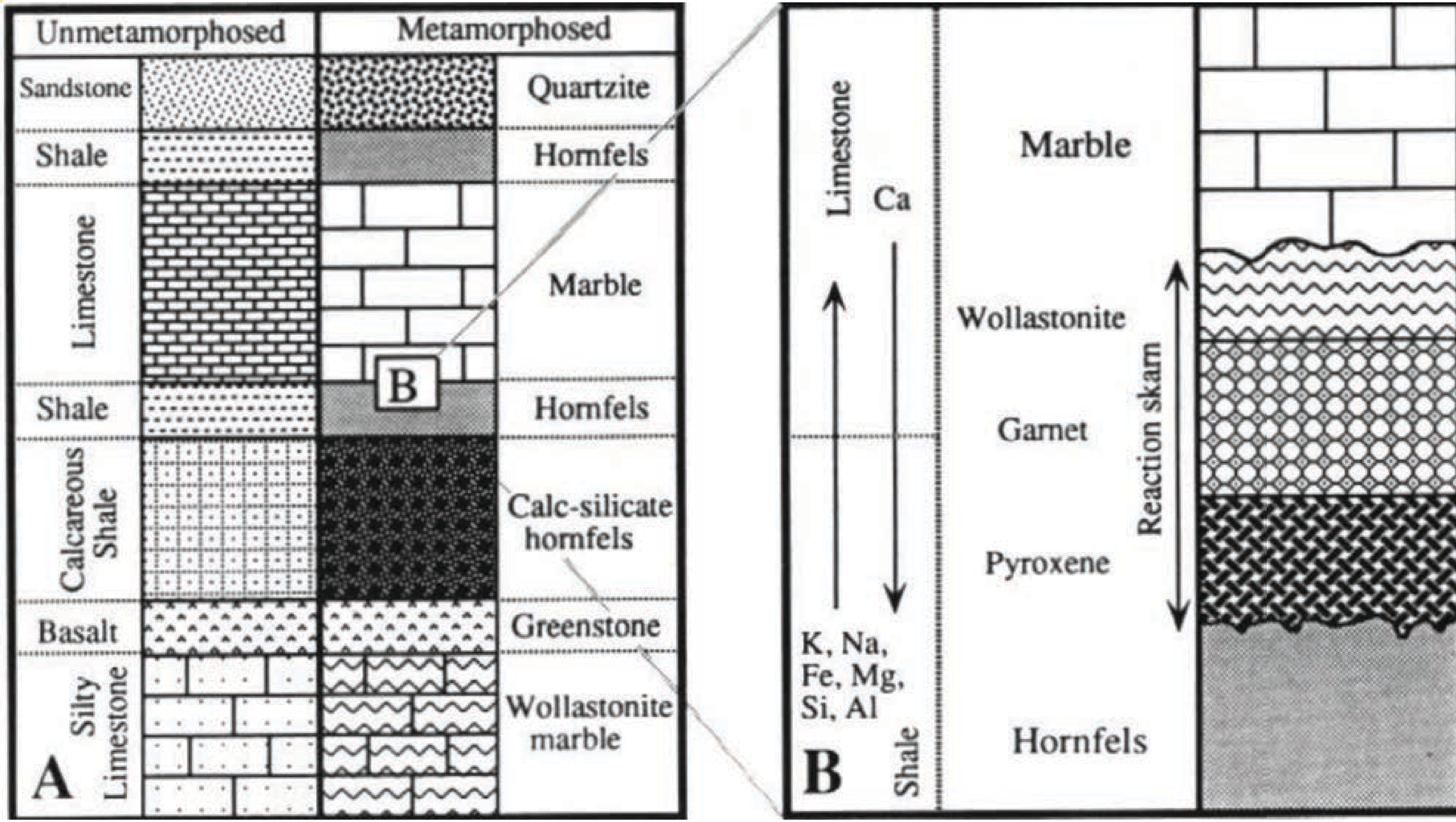
Most of the large economic skarn deposits are of calcic exoskarn types.

Skarn metals

- Variability of metals in skarn deposits is the product of different compositions, oxidation states and metallogenic affinities of igneous intrusions
- Fe, Au skarns associated with mafic–intermediate intrusions
- Cu, Zn and W associated with granites (I-type, magnetite, oxidizing)
- Mo, Sn associated with quite evolved granites (S-type, ilmenite, reducing)



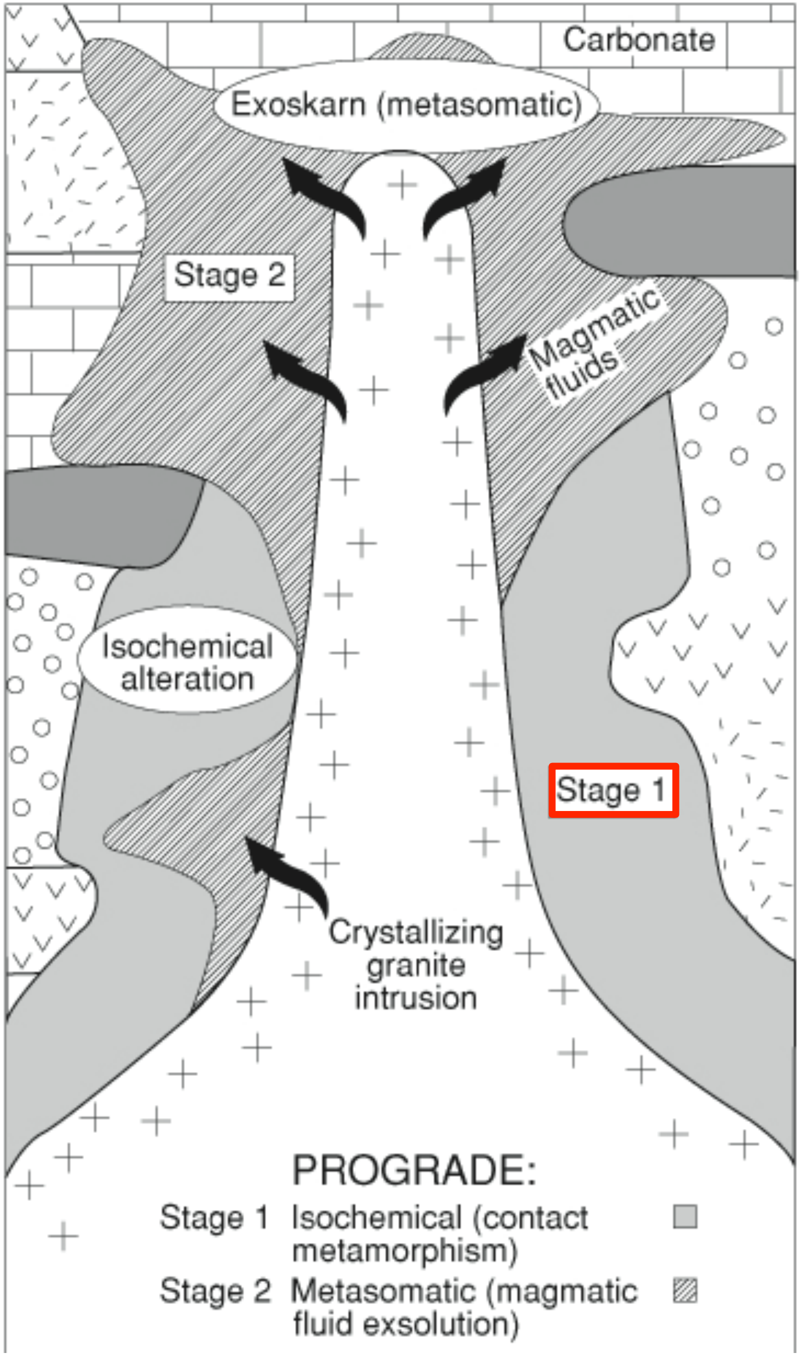
Skarn zoning



Skarn genetic model

Stage 1 (isochemical metamorphism)

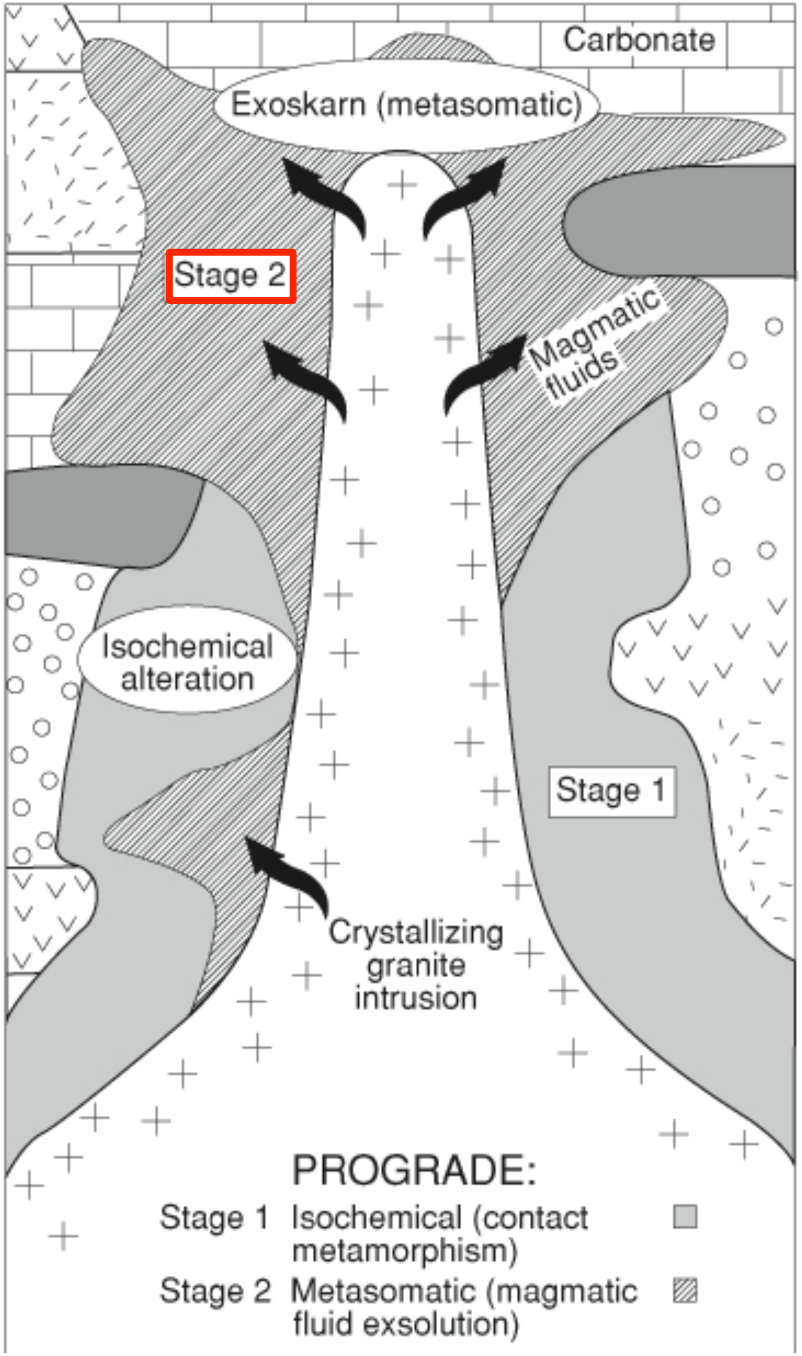
- Granite pluton intrudes country rock inducing contact metamorphism and producing hornfels textures
- Mineral assemblages reflect bulk composition of the protolith
- Some H_2O and CO_2 released
- Dolostone: Grt–>Cpx–>Trem–>Talc
- Limestone: Grt+Ves –> Wol+marble
- No mineralization during this stage



Skarn genetic model

Stage 2 (metasomatism)

- Magma reaches saturation (through first and/or second boiling)
- Exsolved fluids released into the surrounding contact metamorphic halo
- Shallow crustal levels: pervasive fluid infiltration and/or hydrofracture
- Deep crustal levels: fluid intrusion along structural/bedding conduits
- Metasomatic mineral assemblages will be similar to Stage 1 but coarser grained and include Si, Al and Fe bearing minerals (derived from magmatic fluid)
- No sulfide mineralization, but magnetite and scheelite (W) may form at this stage



Skarn genetic model

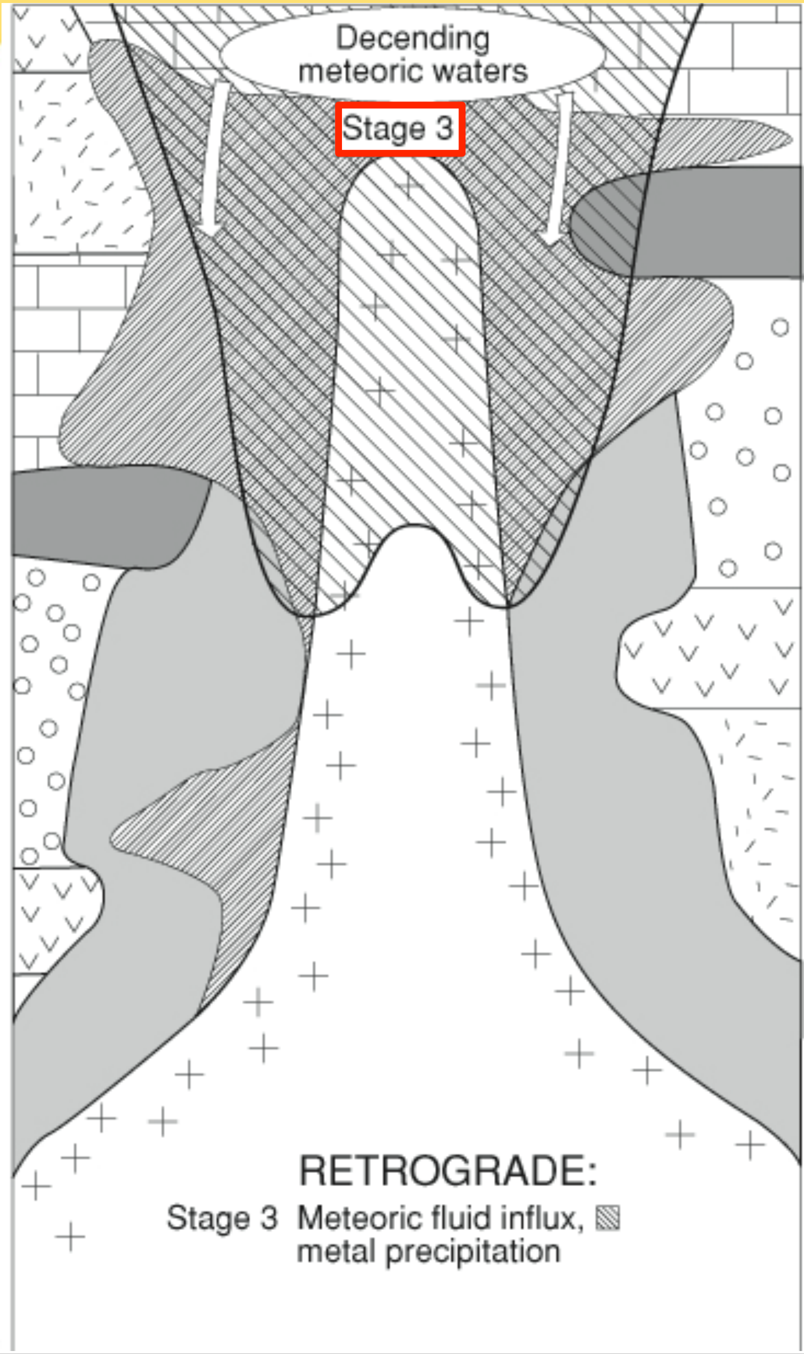
Stage 3 (retrograde)

- Magma continues to cool and meteoric waters descend to the level of intrusion
- Overprint prograde with retrograde (lower temperature) metamorphic assemblages
- Retrograde reactions

  Grt –> Epidote±Biotite±Chlorite±Quartz

  Pyroxene –> Talc ± Tremolite–Actinolite

  Olivine –> Serpentite
- Sulfide mineral precipitation: Pyrite, chalcopyrite, magnetite (proximal close to intrusion); sphalerite–galena (distal)
- Mineralization due to fluid mixing, reaction with carbonate, decreasing T



Skarn reactions

$$pH = -\log_{10}(a_{H^+})$$

$HCl_{(aq)}$ –> $H^+_{(aq)}$ + $Cl^-_{(aq)}$ (disassociation of HCl during cooling)

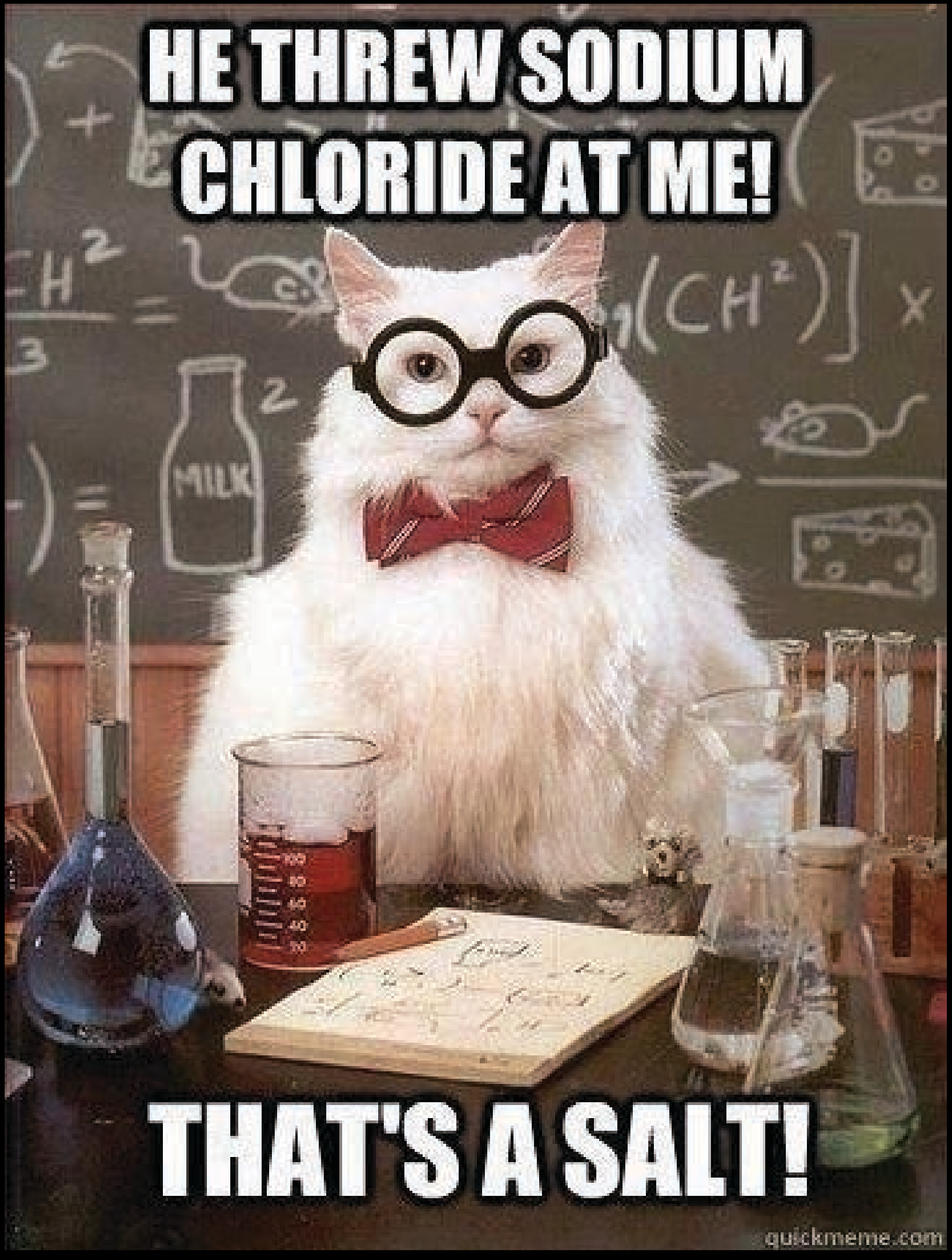
Decreases pH, but buffered by carbonate dissolution:

$CaCO_3 + 2H^+ \leftrightarrow Ca^{2+} + H_2CO_3$

$ZnCl_4^{2-} + H_2S_{aq} \leftrightarrow ZnS_{solid} + 2H^+ + Cl^-$

Ore mineral precipitation may occur through:

1. Acidic fluid neutralized by reaction with carbonate
2. Acidic fluid neutralized by mixing with meteoric water


HE THREW SODIUM CHLORIDE AT ME!
THAT'S A SALT!
quickmeme.com

Skarn metals in different tectonic settings

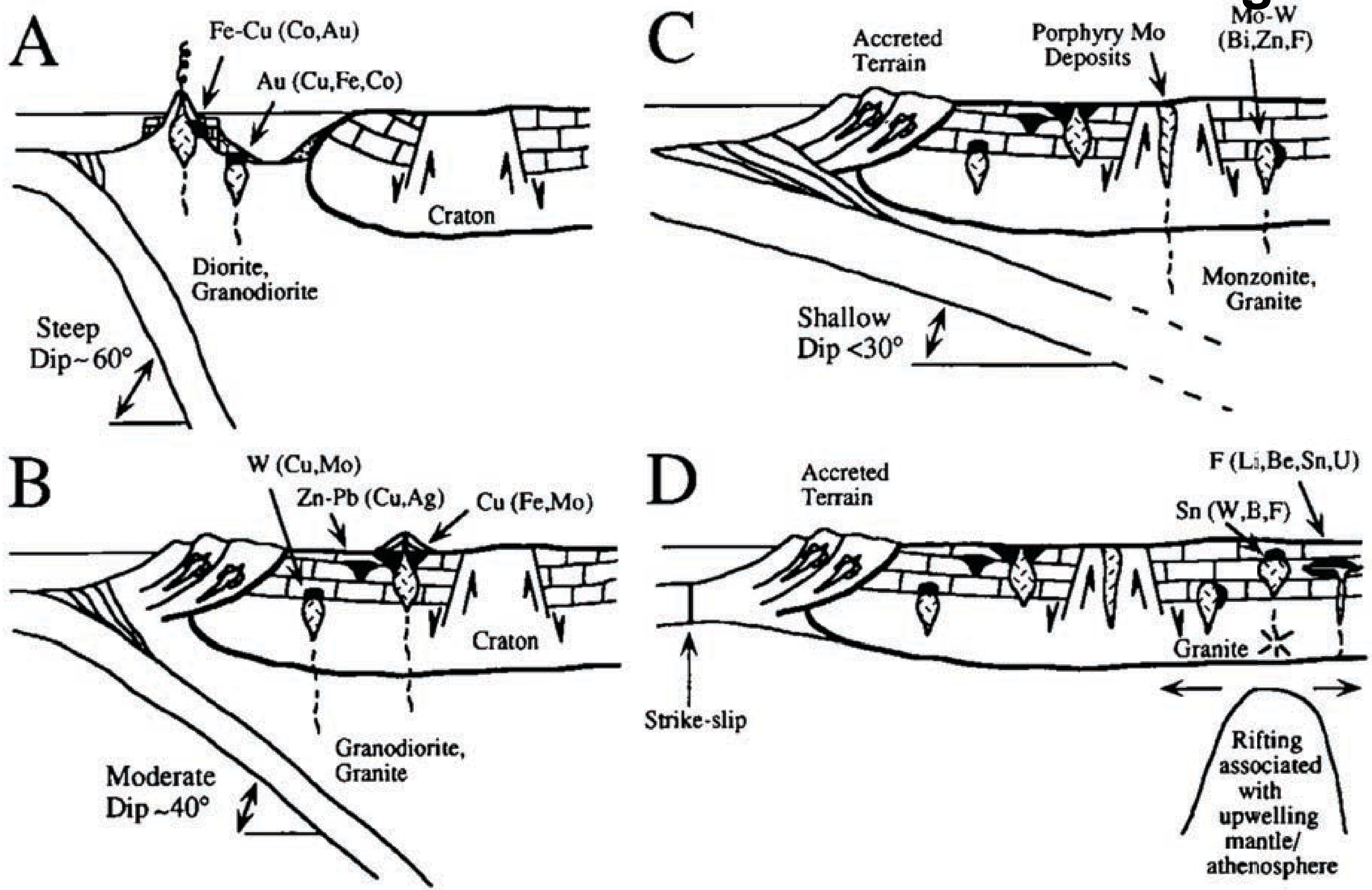
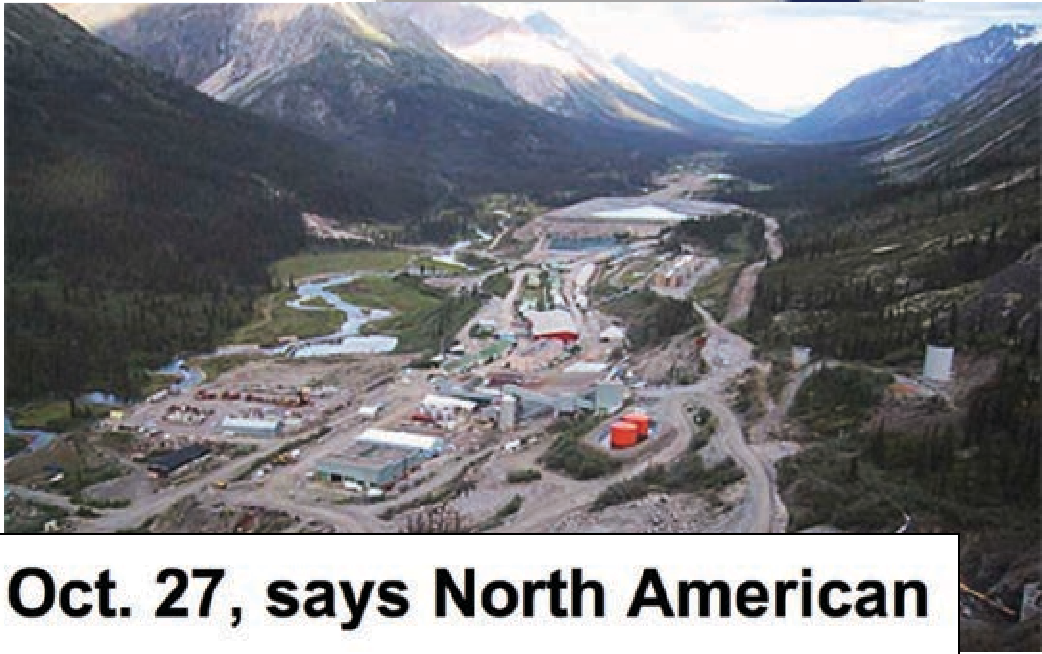


Figure 6 *Idealized tectonic models for skarn formation:* **(A)** *oceanic subduction and back arc basin environment;* **(B)** *continental subduction environment with accreted oceanic terrane;* **(C)** *transitional low-angle subduction environment, and* **(D)** *post-subduction or continental rifting environment (modified from Meinert, 1983).*

Cantung deposit

- In operation by North American Tungsten Corp Ltd (acquired in 1997)
- Open pit: seasonal
- Underground: year round
- Mine life estimated to at least 2017
- Sporadic operation (closures, fires, bankruptcy, …)



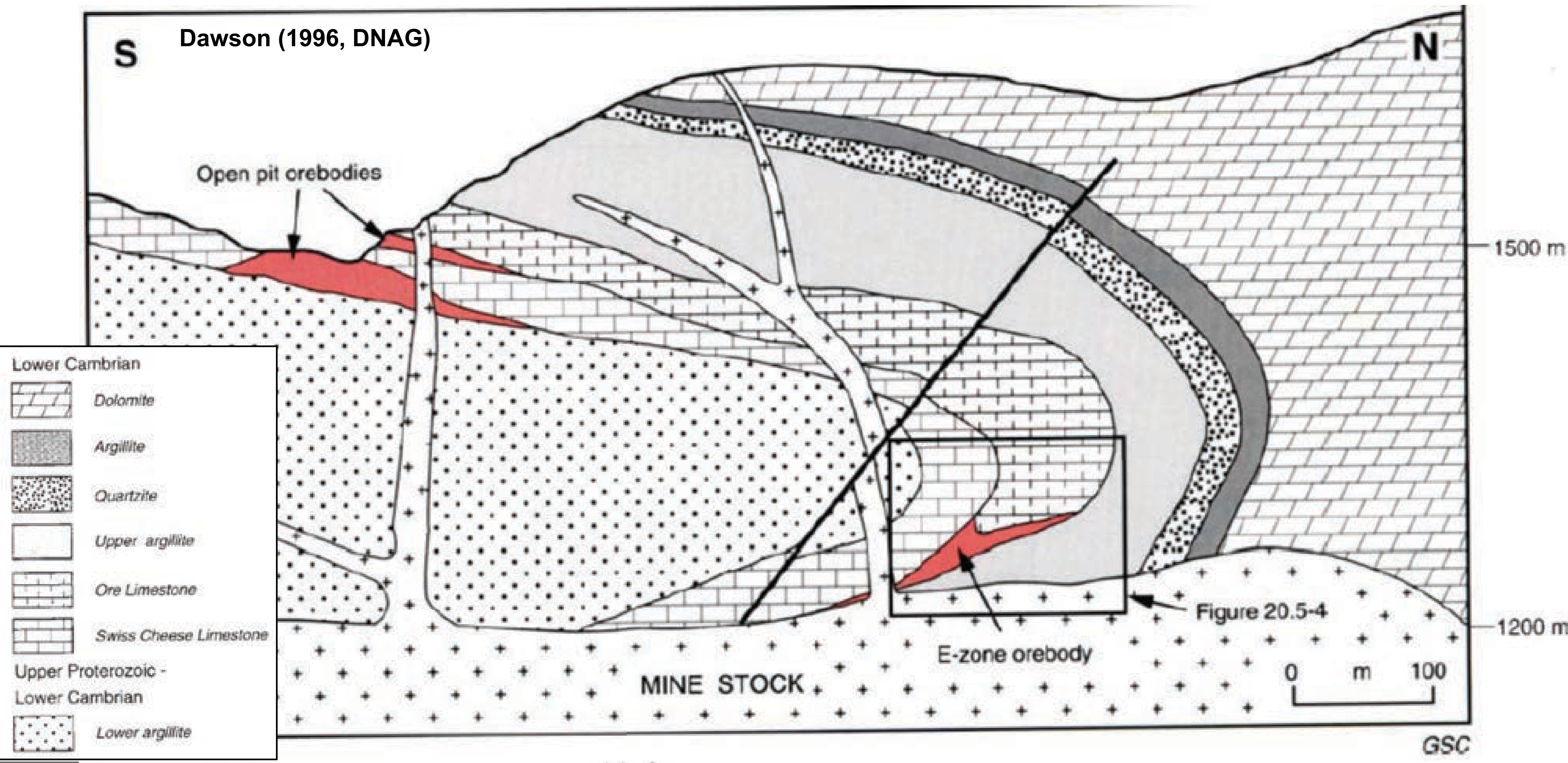
Cantung mine to close Oct. 27, says North American Tungsten

Company says it hopes to resume operations in summer 2016

CBC News Posted: Sep 18, 2015 5:00 AM CT | Last Updated: Sep 18, 2015 8:23 AM CT

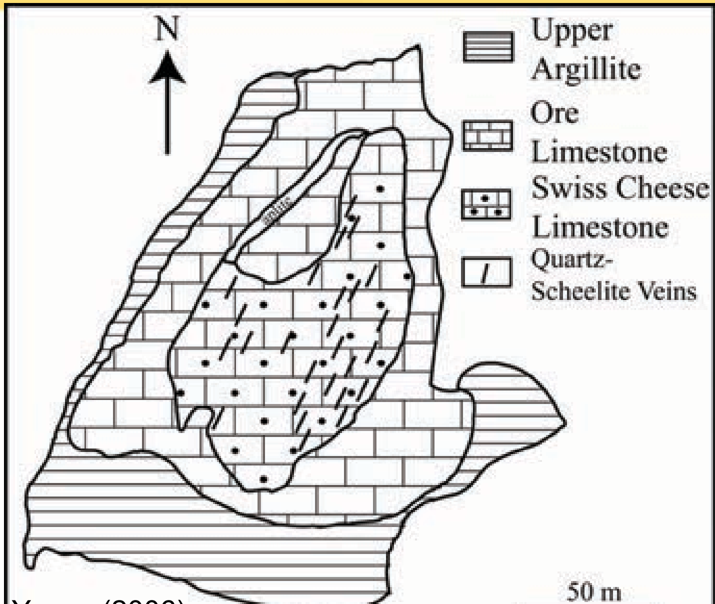
Cantung deposit geology

- Upper Proterozoic to Devonian sedimentary strata
- ~92 Ma biotite monzogranite stock intrusion
- Mineralization hosted in limestone

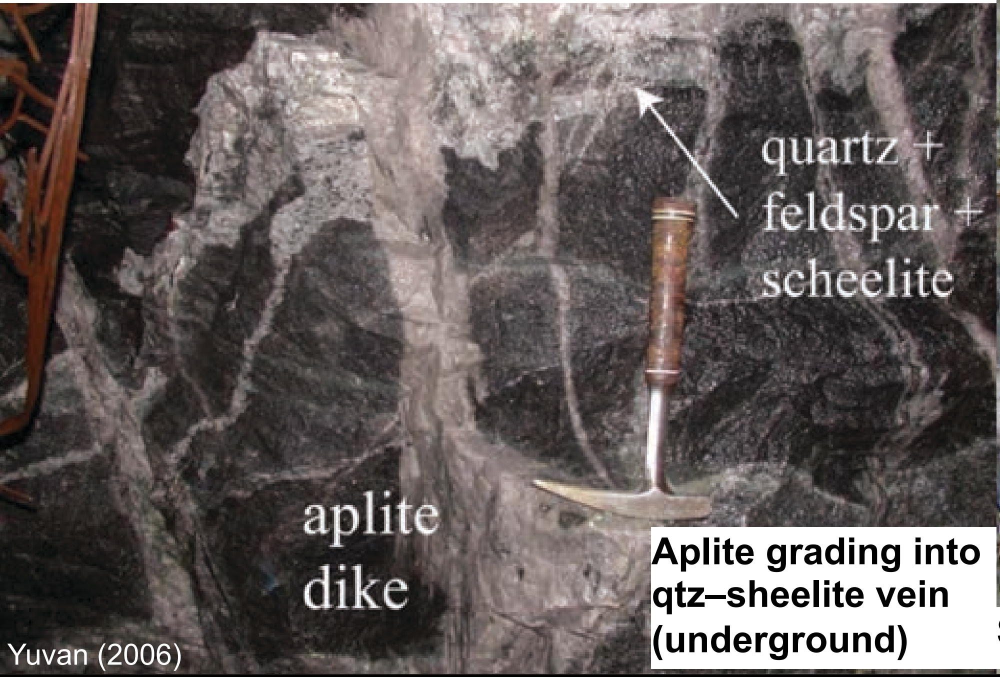


Cantung ore

- *En echelon* Quartz-scheelite veins (10 cm to 1 m wide)
- Skarns replace lower Cambrian limestone (marble)
- Veins contain up to 3.7 wt% WO_3
- Note that scheelite fluoresces under UV light ! – good for exploration!



Yuvan (2006)



Aplite grading into qtz–sheelite vein (underground)

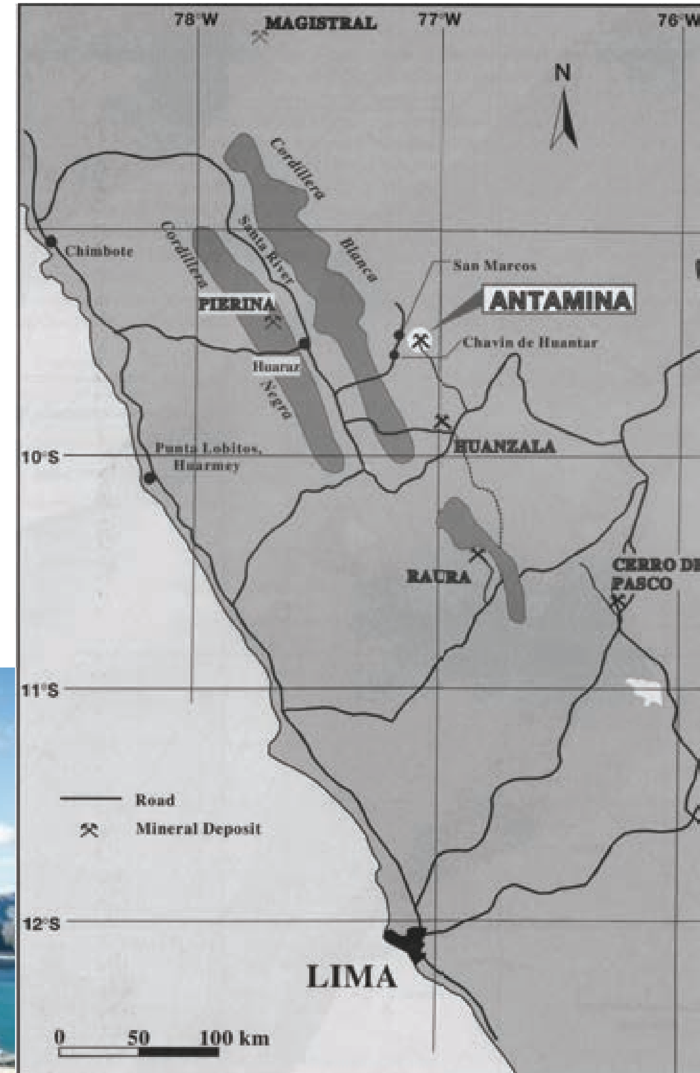
Yuvan (2006)

Yuvan (2006)

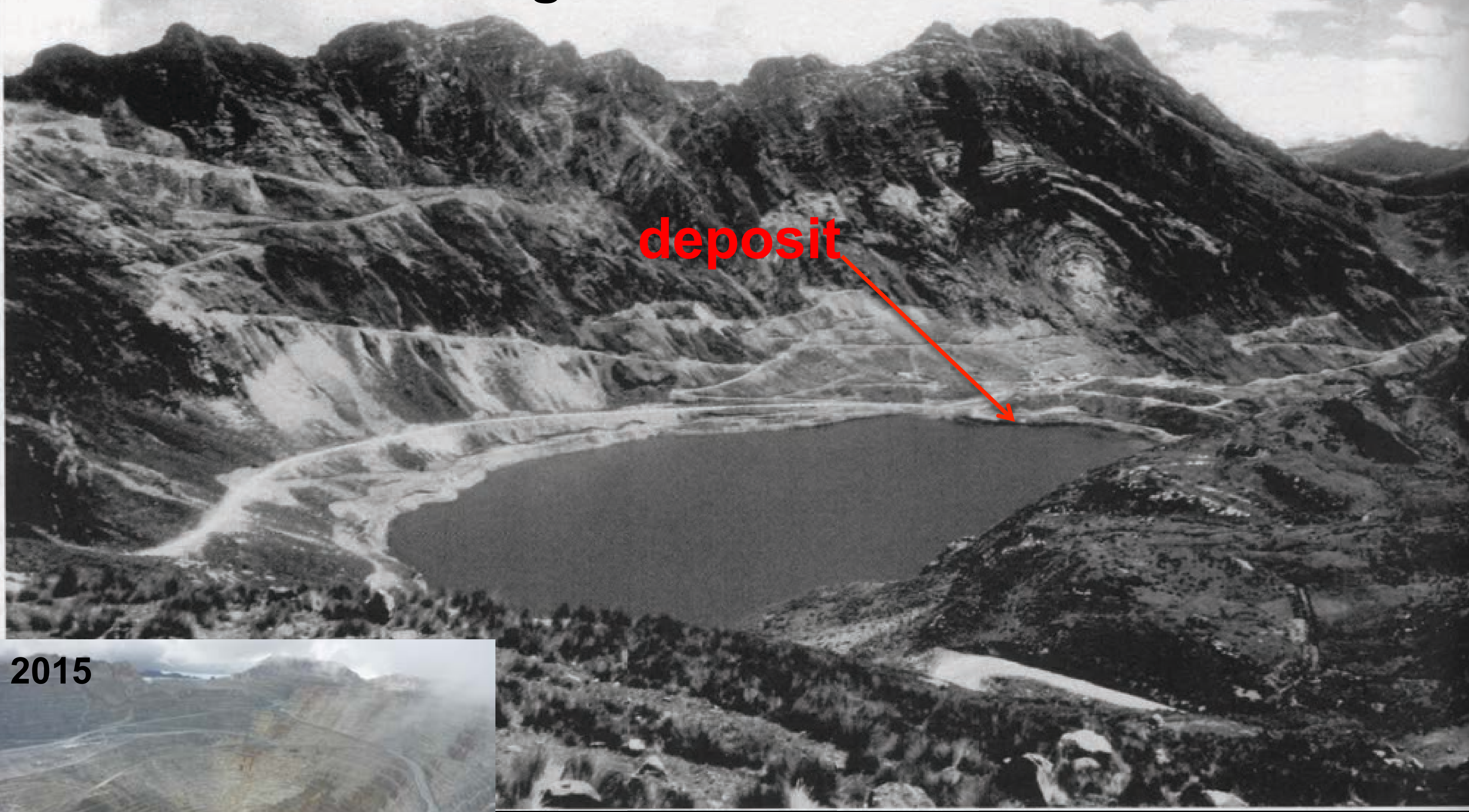
Scheelite–quartz vein in diopside skarn (open pit)

Anatamina Cu–Zn skarn

- “Anta” is copper in Quechua
- “Mina” is mine in Spanish
- Western Cordillera of northern Peru
- World’s largest Cu–Zn skarn deposit
- World class!
- Long exploration history
- Cu mined in 1873
- Large-scale production started in 2001

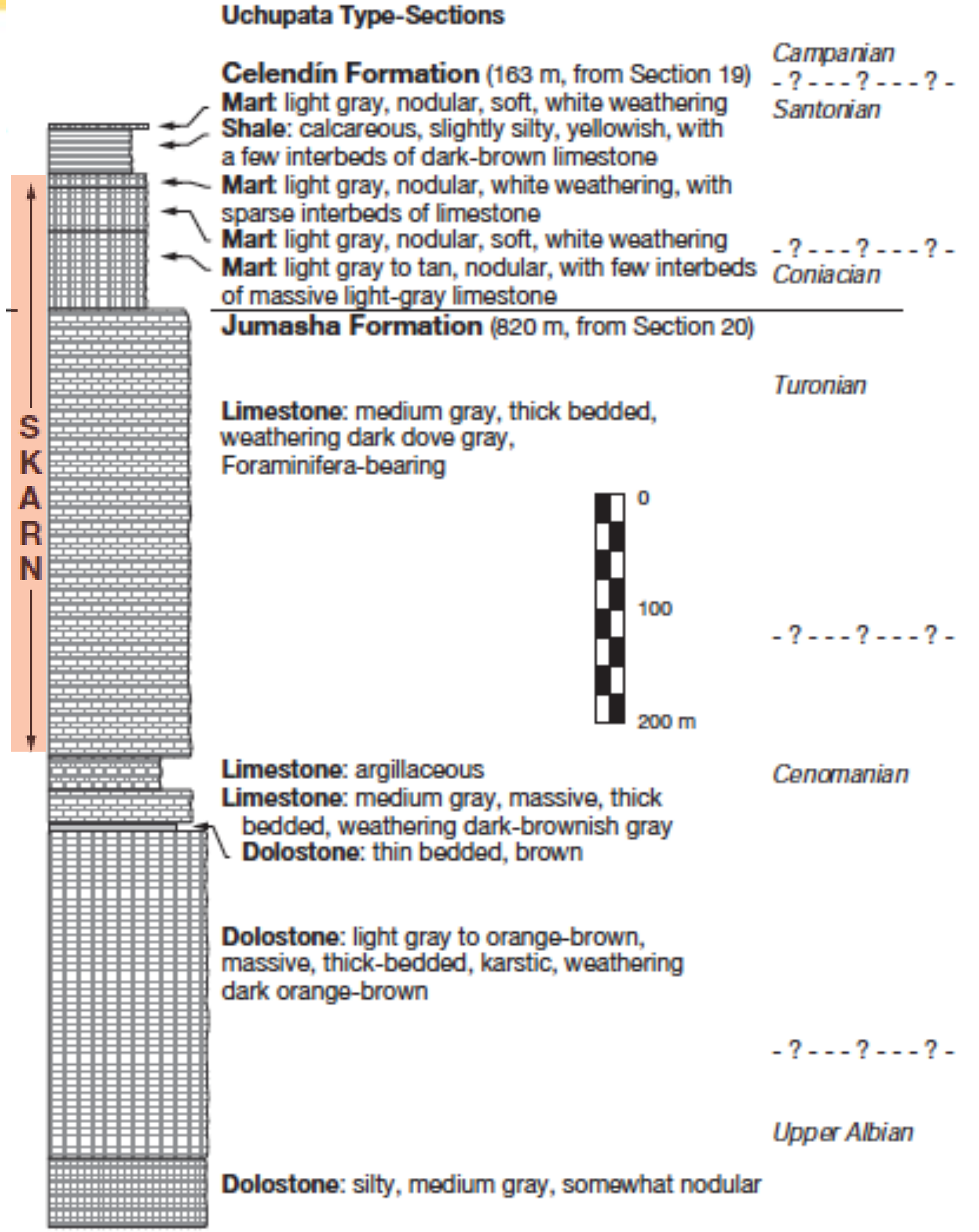


1998: before mining



Antamina geology

- Hosted by Cretaceous calcareous siltstone and argillaceous limestone
- Folded and thrust-faulted in late Eocene (Incaic orogen)
- 10 Ma intrusion of monzonite along fault jog
- Jumasha formation acted as chemical trap
- Celedin Formation provided an impermeable cap allowing fluid recirculation



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Complex structural history

a) Before intrusion there were offset thrust ramps
b) E–W shortening (N–S extensional veins)
c) E–W extension reactivated fault system (dilational jog)
d) Intrusion of monzogranitic magma and **skarn mineralization**
e) Renewed E–W compression formed post-mineralization veins

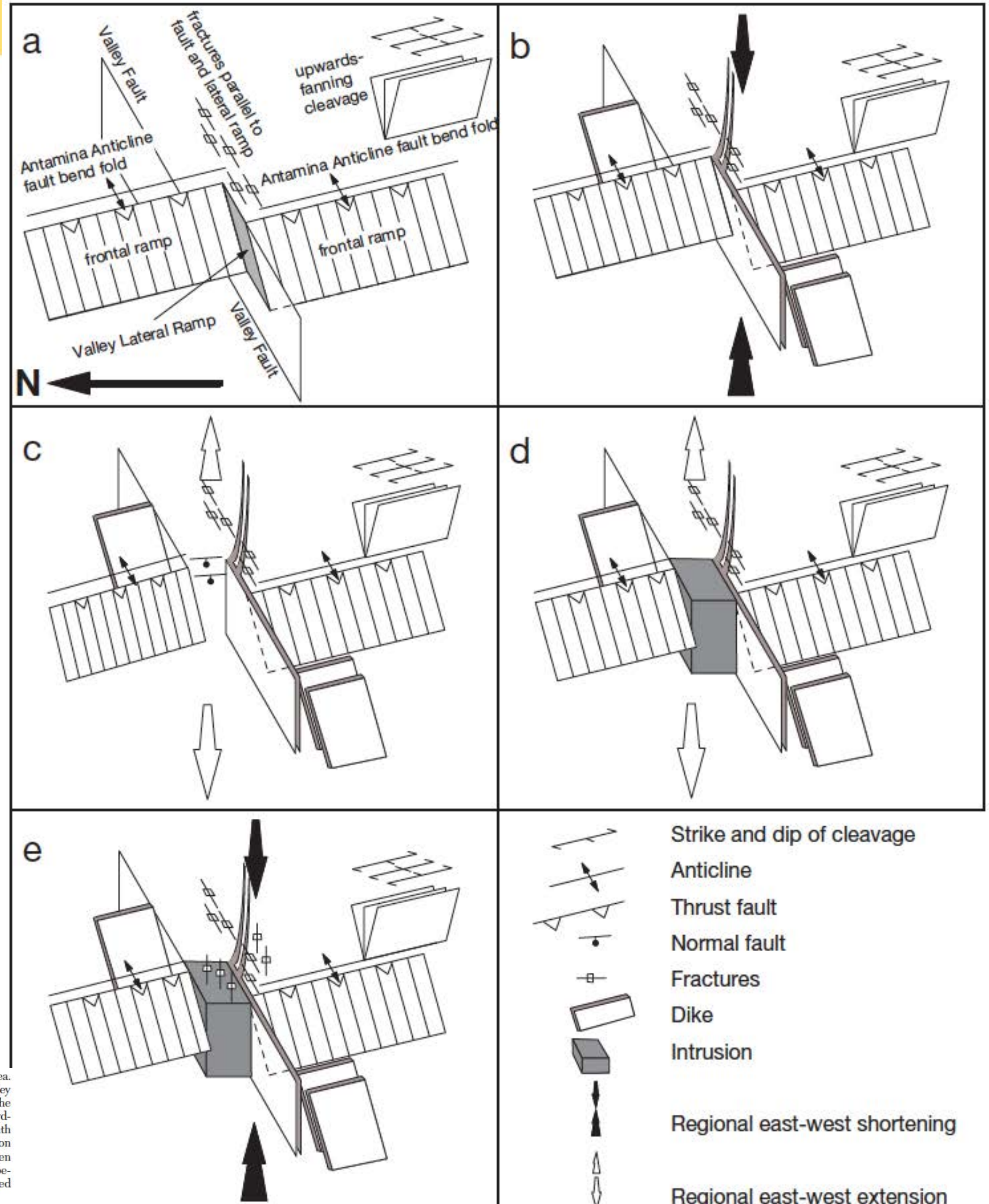
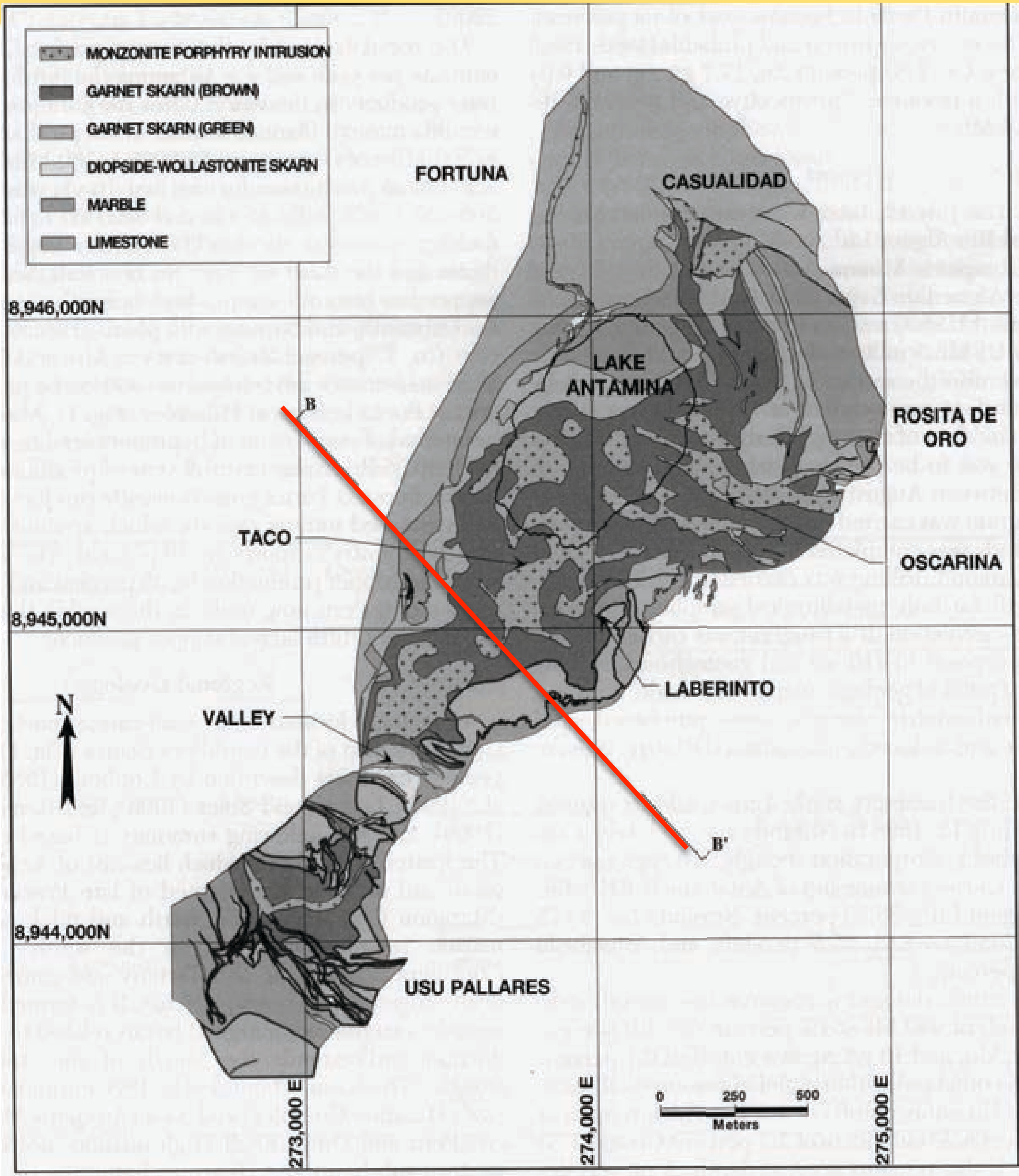


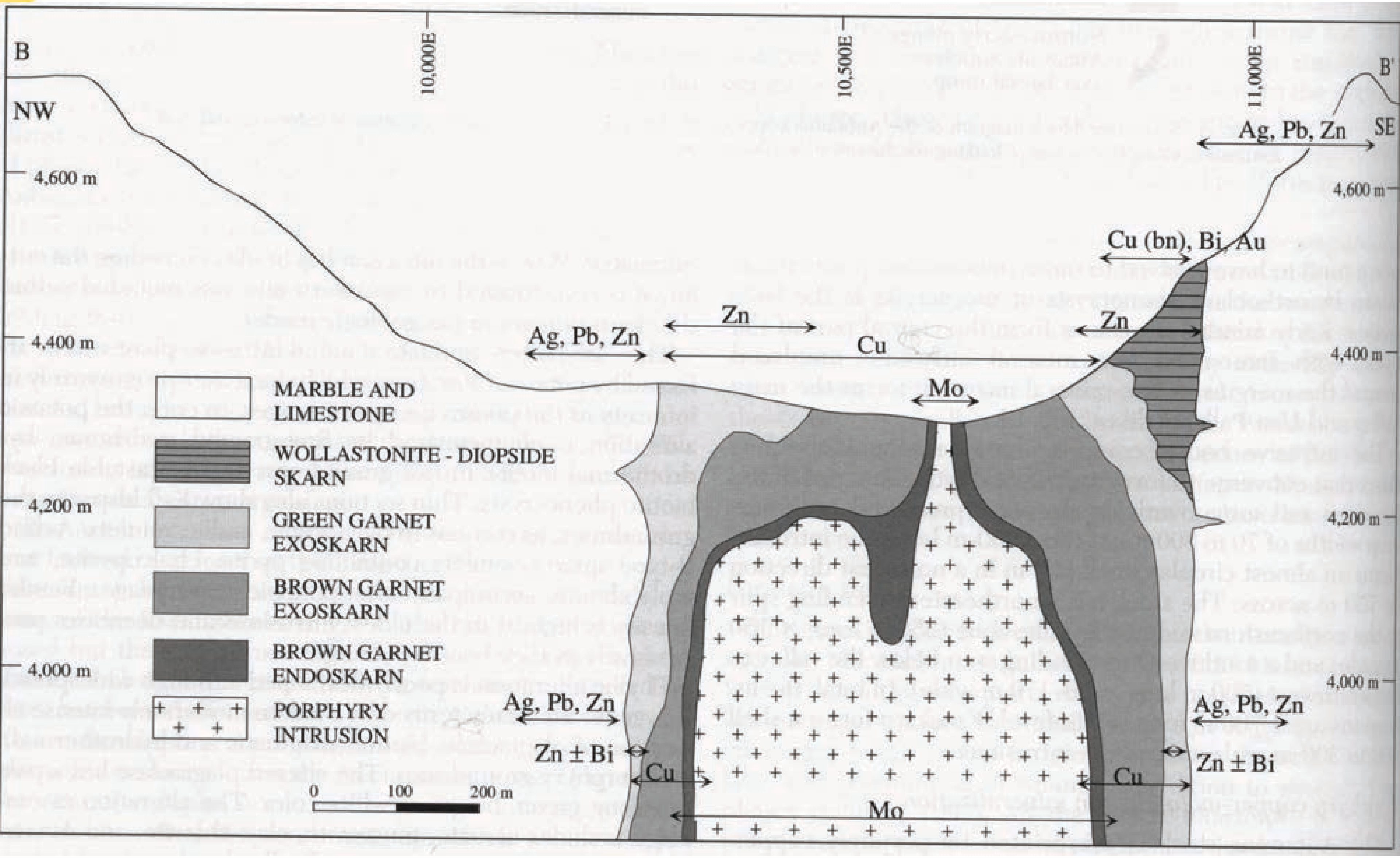
FIG. 18. Schematic diagrams, looking east, illustrating the proposed local-scale structural evolution of the Antamina area. (a) Structural elements in the Antamina area prior to intrusion and mineralization: frontal thrust ramps offset by the Valley lateral ramp, which was localized by a jog in the transcurrent Valley fault; fault-bend-fold anticlines overlying the tops of the offset frontal ramps; strongly developed northeast-striking fracturing parallel to and overlying the lateral ramp; and upward-fanning axial cleavage in the overlying anticlines. (b) East-west compression oblique to the Valley fault induced north-south extension and allowed intrusion of dikes in wing cracks localized at the end of one segment of the Valley fault. (c) Relaxation of east-west compression allowed east-west extension manifested as north-south–striking normal faulting in the jog between the two segments of the Valley fault. (d) Monzogranitic magma intruded the parallelogram-shaped extensional regime between the two segments of the Valley fault, and ultimately generated skarn ore. (e) Renewed east-west compression formed east-west–striking veins in skarn.

Antamina alteration

1. Brown garnet and chalcopyrite (endoskarn)
2. Brown garnet with chalcopyrite (exoskarn)
3. Green garnet with chalcopyrite and sphalerite (exoskarn)
4. Diopside–wollastonite with bornite and sphalerite (exoskarn)
5. Recrystallized limestone (marble) with veins of mantos of wollastonite–green garnet, with Zn, Pb and Ag



Antamina geology



Skarn summary

- Epigenetic
- Stratabound (carbonate rocks)
- Develop from hydrothermal contact metamorphism and metasomatism of carbonates adjacent to an igneous intrusion (exoskarn)
- Are often associated with large-scale mineralizing systems (e.g. porphyry deposits nearby)
- Can be polymetallic

Fluid: magmatic–hydrothermal (Cl^- ligands from magma)

Source of metals: magmas

Transport: faults/fractures (hydrofracturing)

Trap: fluid–rock interaction

IOCG deposits

Iron–oxide–copper–gold

IOCG deposits worldwide

IOCG deposits worldwide

TABLE 2. Resources of selected iron oxide copper-gold deposits.

Deposit	Country	Resources[1]	Grade	Key References
Olympic Dam	Australia	3810 Mt	1.1% Cu, 0.4 kg/t U_3O_8, 0.5 g/t Au	Western Mining press release, 2004
Phalaborwa	South Africa	850 Mt	0.5% Cu (+ Au, Ag, PGE, U, Zr, REE, Ni, Se, Te,	Leroy, 1992
Salobo	Brazil	789 Mt	0.96% Cu, 0.52 g/t Au	Souza and Vieira, 2000
Manto Verde	Chile	600 Mt	0.5% Cu, 0.1 g/t Ag	Sillitoe, 2003
Aitik	Sweden	380 Mt[2] 226 Mt[3]	0.4% Cu, 0.2 g/t Au, 4 g/t Ag[2] 0.37% Cu, 0.2 g/t Au, 3 g/t Ag[3]	Wanhainen et al., 2003
Cristalino	Brazil	500 Mt	1% Cu, 0.30 g/t Au	Tallarico et al., 2004
Candelaria	Chile	470 Mt	0.95% Cu, 0.22 g/t Au, 3.1 g/t Ag	Marschik et al., 2000
Sossego	Brazil	355 Mt	1.1% Cu, 0.28 g/t Au	Haynes, 2000
Igarapé Bahia	Brazil	170 Mt	1.5% Cu, 0.8 g/t Au	Ronze et al., 2000
Ernest Henry	Australia	167 Mt	1.1% Cu, 0.5 g/t Au	Williams and Skirrow, 2000
Prominent	Australia	101 Mt	1.5% Cu, 0.55 g/t Au (+21 Mt at 1.2 g/t Au)	Oxiana Limited, 2005
Bayan Obo	China	48-100 Mt	6% REE_2O_3 (+1 Mt at 0.13% Nb)	Smith and Chengyu, 2000
NICO	Canada	22 Mt[3]	1.08 g/t Au, 0.13% Co, 0.16% Bi	Fortune Minerals, 2007
Osborne	Australia	15.5 Mt	3.0% Cu, 1.05 g/t Au	Gauthier et al., 2001
Sue Dianne	Canada	17 Mt	0.72% Cu, 2.7 g/t Ag	Goad et al., 2000
Starra	Australia	7.4 Mt	1.9% Cu, 3.8 g/tAu	Rotherham et al., 1998
Eloise	Australia	3 Mt	5.5% Cu, 1.4 g/t Au (+Fe, Ni)	Williams and Skirrow, 2000
Peko	Australia	3 Mt	4% Cu, 3.5 g/t Au, 14 g/t Ag, 0.2% Bi	Skirrow and Walshe, 2002
Monakoff	Australia	1 Mt	1.5% Cu, 0.5 g/t Au (Pb, Zn, U)	Williams and Skirrow, 2000
Kiruna district	Sweden	3400 Mt	60% Fe (400 Mt produced)	Frietsch et al., 1979

1: million tonnes of ore calculated; 2: produced; 3: reserve.

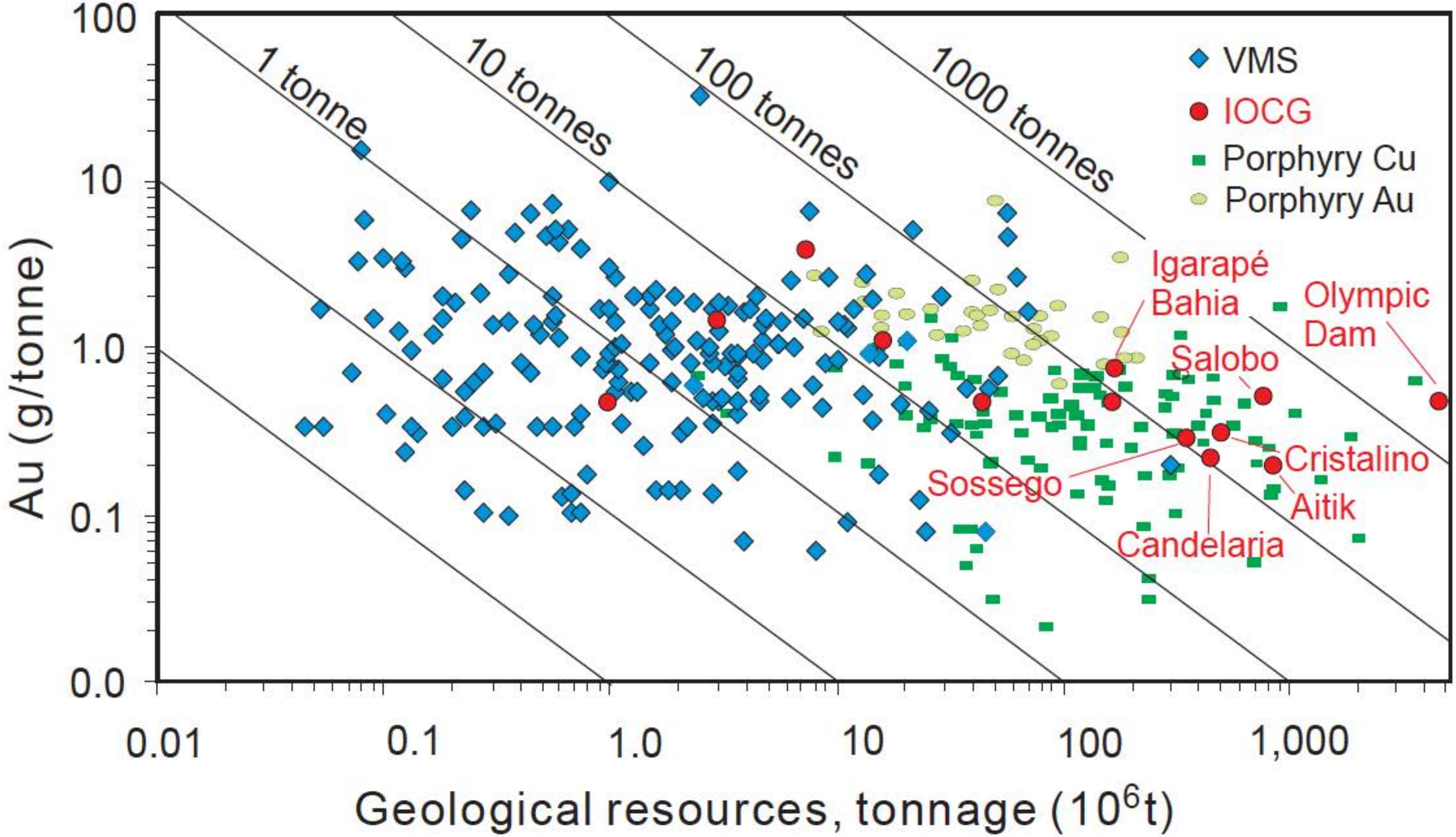


FIGURE 2. Au grade versus tonnage plot of iron oxide copper-gold (IOCG), volcanogenic massive sulphide (VMS), and porphyry Cu deposits from Kirkham and Sinclair (1996), Galley et al. (2007), and Table 2.

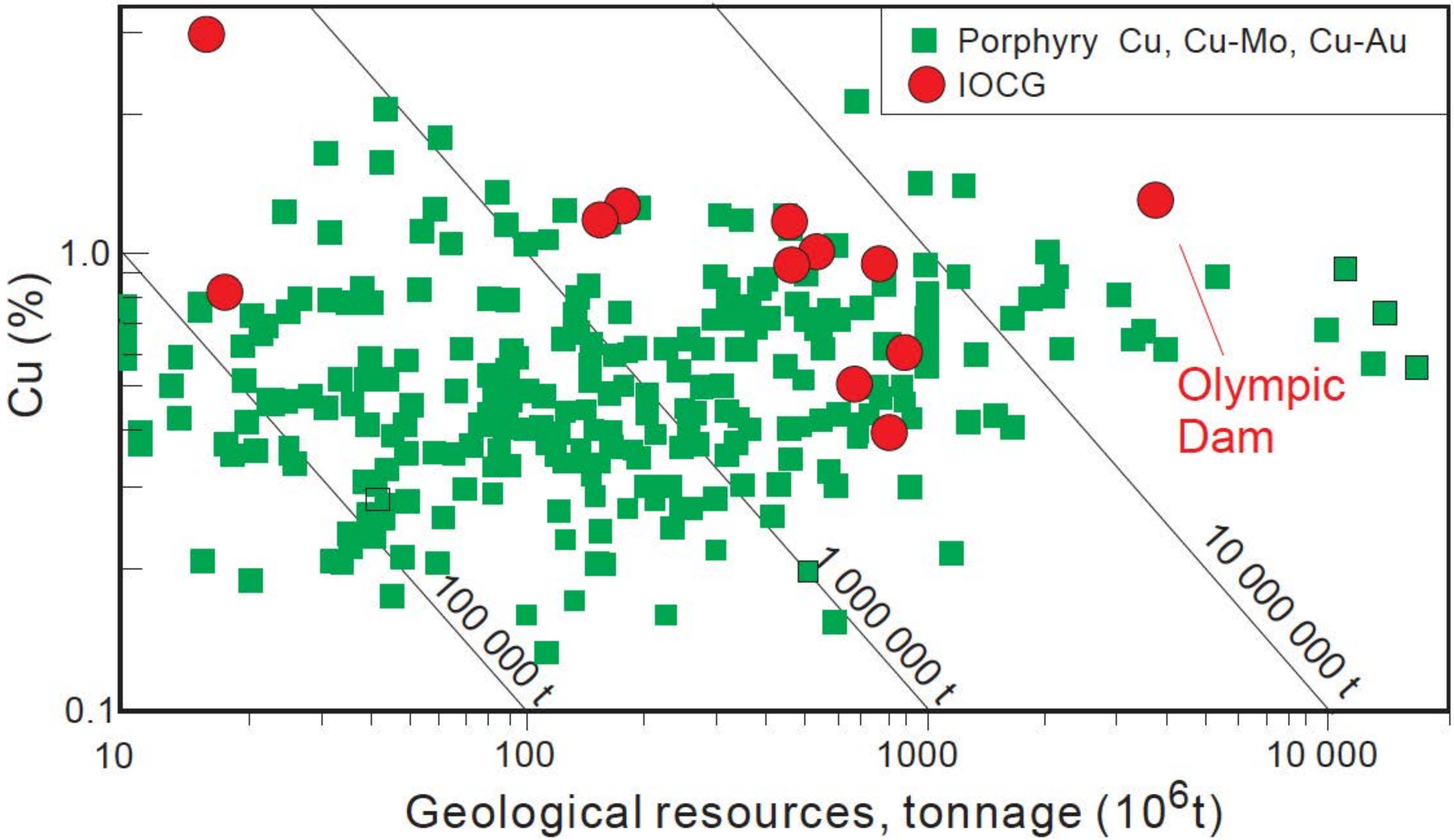


FIGURE 3. Cu grade versus tonnage plot of the geological resources of iron oxide copper-gold (IOCG) deposits and porphyry Cu based on Kirkham and Sinclair (1996).

IOCG: Iron–oxide–copper–gold – fun facts!

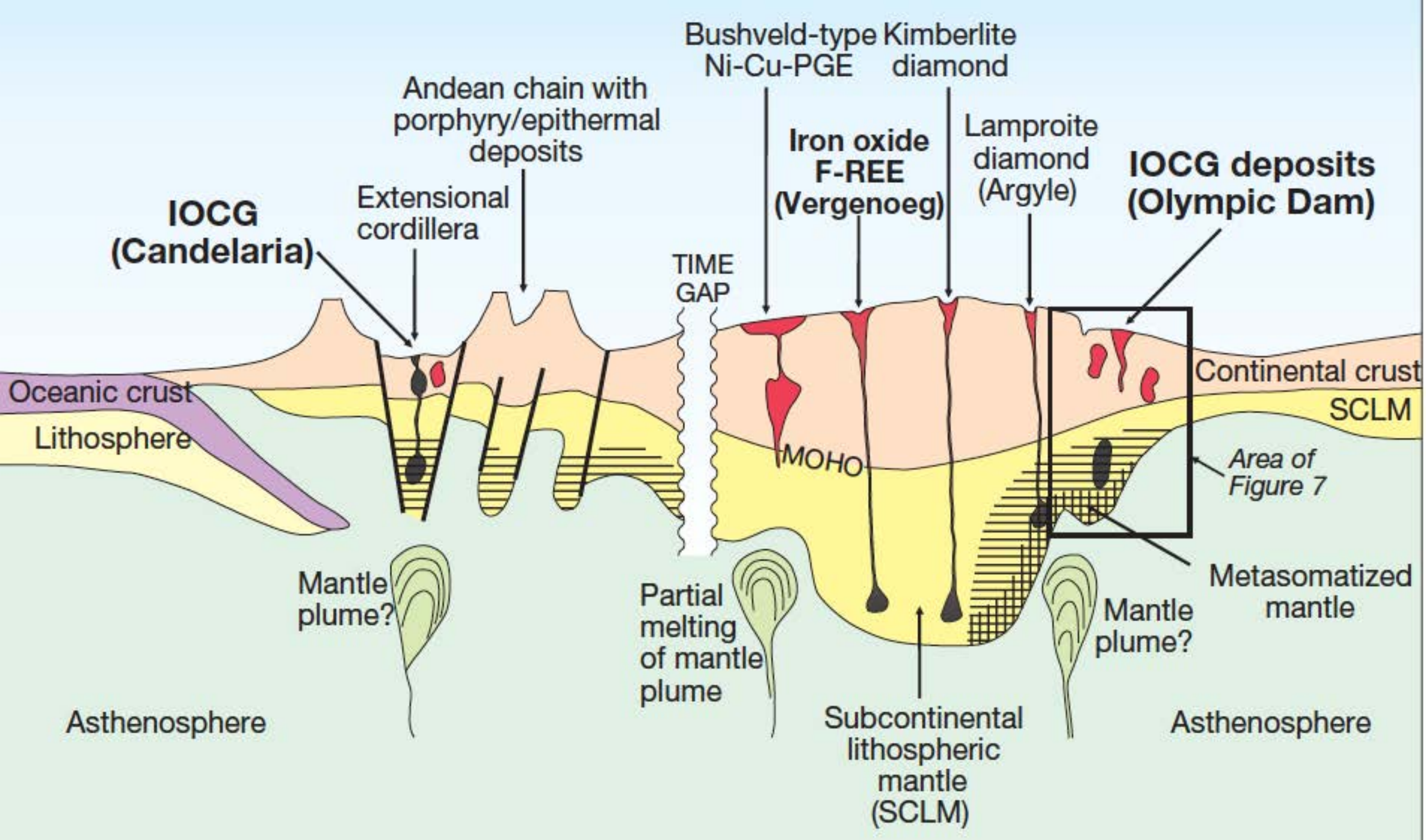
- Term encompasses a wide spectrum of sulfide-deficient magnetite/hematite ore bodies of hydrothermal origin
- Fe-oxides are the major minerals
- Lots of debate about what deposits are 'true' IOCGs or oxide-rich varieties of other types
- Biggest is Olympic Dam (Australia) discovered in 1970
- Canadian ones include NICO (discovered in 1995) and Sue Dianne (1970s) in the NWT
- Relatively recent 'type' of ore deposit

IOCG Geology

- Deposits are **highly variable** in form, geological settings and host rocks
- Breccia (most), vein, disseminated, massive
- Generally quartz poor
- Polymetallic (Cu, Au, Ag, U, REE, Bi, Co, Nb, P)
- >20% Fe-oxides
- Generally found in Precambrian shields and circum-Pacific regions
- Temporally and spatially associated with magmatic activity

General genetic models are still relatively undeveloped

IOCG tectonic settings



IOCG classification (well…one of them)

TABLE 1. Classification of magmatic-hydrothermal iron oxide deposits and related Cu-Au deposits (after Gandhi, 2004a).

Source → *Proximal* → *Distal*

Calc-alkaline magma

Iron Skarn-type	Kiruna-type	Olympic Dam-type	Cloncurry-type
Massive magnetite-garnet-pyroxene	Massive magnetite-apatite-actinolite	Breccia (one or more stages), magnetite-hematite matrix	Hydrothermal veins & disseminations in older 'ironstones' or FeOx mineralization
Stratabound lensoid & irregular bodies at intrusive contact	Tabular, pipe-like & irregular bodies, dykes & veins	Pipe-like & irregular bodies, vent or fault controlled	Stratabound, breccia or fault controlled
Monometallic Fe and related FeOx-Cu-Au deposits	Monometallic Fe & related Cu-FeOx porphyry deposits	Polymetallic: Fe, Cu, Au, Ag, REE	Polymetallic: Cu, Au, Ag, Bi, Co, W
Alteration: Sodic	Alteration: Sodic	Alteration: Potassic	Alteration: Potassic
Magnitogorsk deposit, Russia	Kiirunavaara deposit, Sweden	Olympic Dam deposit, Australia	Osborne & Starra deposits, Australia

Source → *Proximal* → *Distal*

Alkaline-carbonatite magma

Phalaborwa-type	Bayan Obo-type
Within or marginal to intrusion	Hosted by country rock
Veins, layers, disseminations and aggregates; late intrusive phase	Veins, layers, disseminations and aggregates, stratabound lenses
Low Ti magnetite, apatite, olivine, phlogopite, carbonate, fluorite, Cu sulphides, pyrite, PGE, Au, Ag, uranothorianite, baddeleyite	Magnetite (replacive and/or pre-existing), hematite, bastnaesite, phlogopite, Fe-Ti-Cr-Nb oxides, fluorite, monazite, carbonate
Zoning in ore; Na & K alteration	Zoning in ore; Na & K alteration
Phalaborwa deposit, South Africa	Bayan Obo deposit, China

IOCG *sensu stricto* criteria

(from Groves et al., 2007, Economic Geology)

- Formed by magmatic–hydrothermal processes
- Cu ± Au as economic minerals
- Structurally controlled
- Surrounded by alteration and/or brecciation zones more regional in scale relative to the deposit
- Depleted SiO_2 of altered rock
- Abundant Ti iron oxides or iron silicates
- Have a temporal, but no necessarily spatial, relationship to causative intrusions

IOCG

Many possible fluid sources

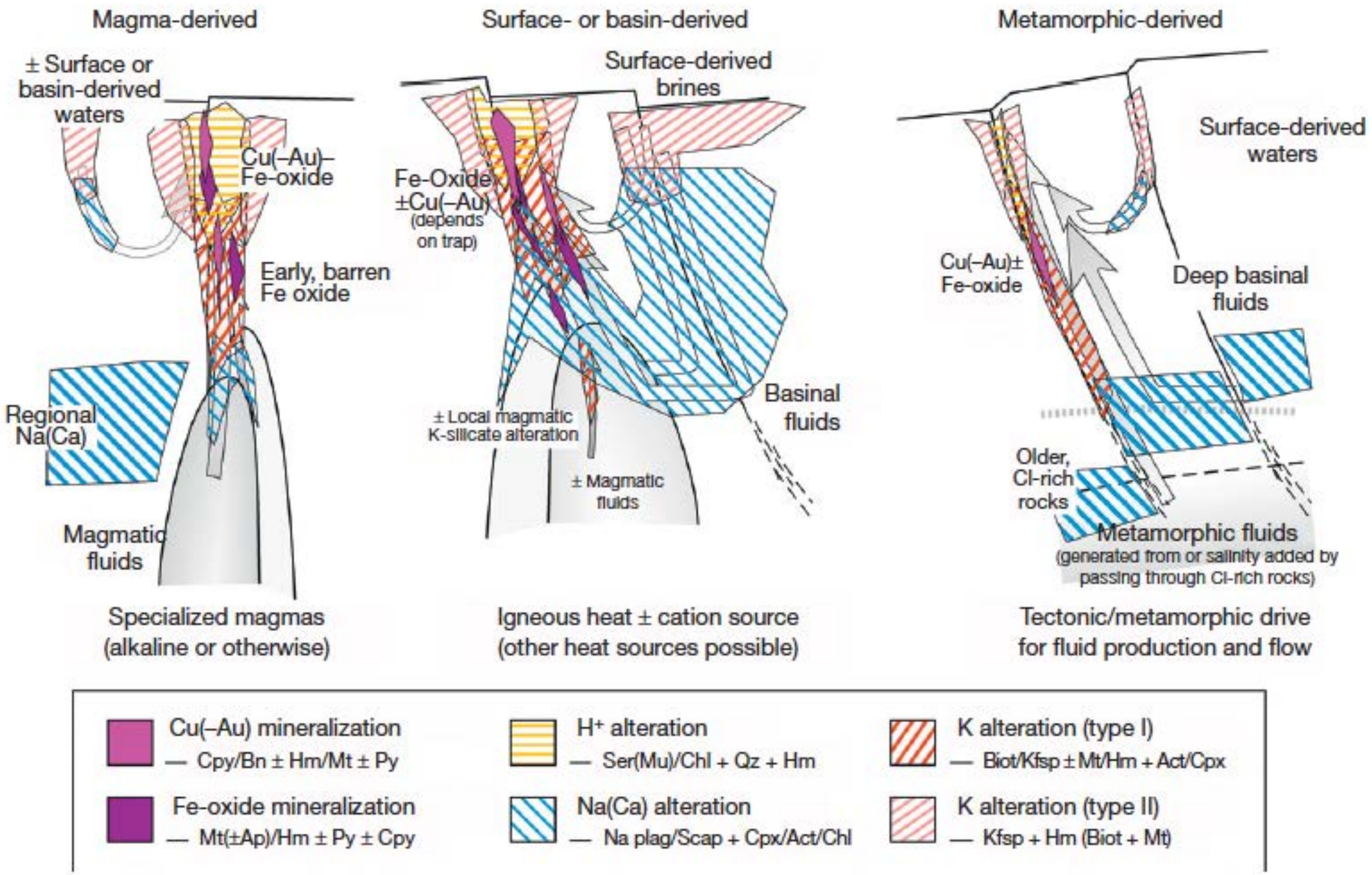


Figure 1 Alternative hydrothermal origins and architectures for IOCG systems illustrating possible fluid sources, paths, and distribution of alteration and ores (modified from Barton MD and Johnson DA (2004) Footprints of Fe-oxide (–Cu–Au) systems: SEG 2004 Predictive Mineral Discovery Under Cover. *Centre for Global Metallogeny, University of Western Australia* Special Publication 33: 112–116). Deposits show far more varied geometries that are illustrated here. Multiple fluid sources are possible in all cases. (a) Magmatic source implies distinctive composition and proximity to source; regional Na(–Ca) is coincidental. (b) Evaporitic source implies coeval or older brine source, necessary but indifferent to type of heat source, and available upper crustal plumbing. (c) Metamorphic source implies metaevaporitic (or conceivably mantle) Cl source with regional plumbing. A fourth hypothesis involving immiscible Fe oxide–P-rich liquids is not illustrated (see text) but has some parallels with (a).

Wide range of *P*, *T*, *X*

Table 2 Synopsis of ranges in *P*, *T*, and fluid compositions for selected IOCG regions

Region	P *(kb)/T (°C)*[a]	*Principal fluid compositions (wt% $NaCl_{eq}$, cations, CO_2)*	*Comments*	*Key recent references*
Andes, coastal Chile and Peru	<0.5–1.5/150–550 (>800[b])	6–50% Na(–Ca ± Fe ± K ± Mg); V-rich (boiling), late fluids dilute, ±CO_2 ('melt' inclusions[b])	Commonly high-*T* saline, low-*T* dilute ('melt' in Mt-Ap-Act[b])	Broman et al. (1999), Chen (2010), Kreiner (2011), and Velasco and Tornos (2009)
Australia, Gawler	<0.5–1.5?/150–540	2–23%, >25% Na(–Ca–K–Fe, minor Cu), rare CO_2, lower-*T* fluids dilute	Unmixing/boiling (Moonta, Olympic Dam)	Bastrakov et al. (2007), Morales-Ruano et al. (2002), and Oreskes and Einaudi (1992)
Australia, Cloncurry	1.5–4/220–550	5–40% Na(–Ca); 30–70% Na(–Ca–K–Fe, variable Cu); CO_2-rich	Multiple populations reflect complex history and contrasting systems	Baker et al. (2008), Fisher and Kendrick (2008), and Rusk et al. (2010)
Australia, Tennant Crk	2.5–5(?)/300–400	10–20% Na(–Ca) [Fe]; 1–10/20–35% [Cu], variable CH_4, CO_2	Fe precedes Cu–Au–Bi, mixing inferred	Skirrow and Walshe (2002) and Zaw et al. (1994)
Brazil, Carajas	<1? (Salobo, >2?)/ 150–570	Mostly 25–50% Na(–Ca–K–Fe) mix with cooler dilute; minor CO_2	Mostly shallow; Salobo deep/metamorphosed	Torresi et al. (2012) and Xavier et al. (2009, 2010)
Canada, Great Bear	0.5–1.5?/150–450	15–35% Na(–K–Ca); minor CO_2	Fluid data for five element veins + petrography	Changkakoti et al., 1986 and Mumin et al., 2010
Canada, Wernecke	0.4–2.4/185–350	24–42% Na–Ca, no CO_2	—	Hunt et al. (2011)
Russia, Siberian trap	<0.5–1.5/130–420 (rarely >600)	27–47% Na(–Ca–Fe), no CO_2 nor V-rich (boiling?), solid-rich	Also 'melt' inclusions, multiphase solid-rich	Soloviev (2010a)
N Baltic	<1–3?/120–500	12–45% Na(–Ca–K), minor CO_2 ± methane	Mix of metamorphic and premet systems	Billstrom et al., 2010 and Gleeson and Smith, 2009
United States, western	<0.5–1.5/150–550	25–50% Na(–Ca ± Fe ± K), no CO_2	Jurassic and Tertiary Fe ± Cu	Barton et al. (2011a), Johnson (2000), and Wilkins et al. (1986)

[a]Pressure and temperature ranges are based on reported petrologic and geologic estimates for pressure and reported fluid inclusion homogenization temperatures, isotope partitioning, and phase equilibria for temperature.
[b]Data reported for selected Mt–Ap–Act rocks.

Olympic Dam – Australia

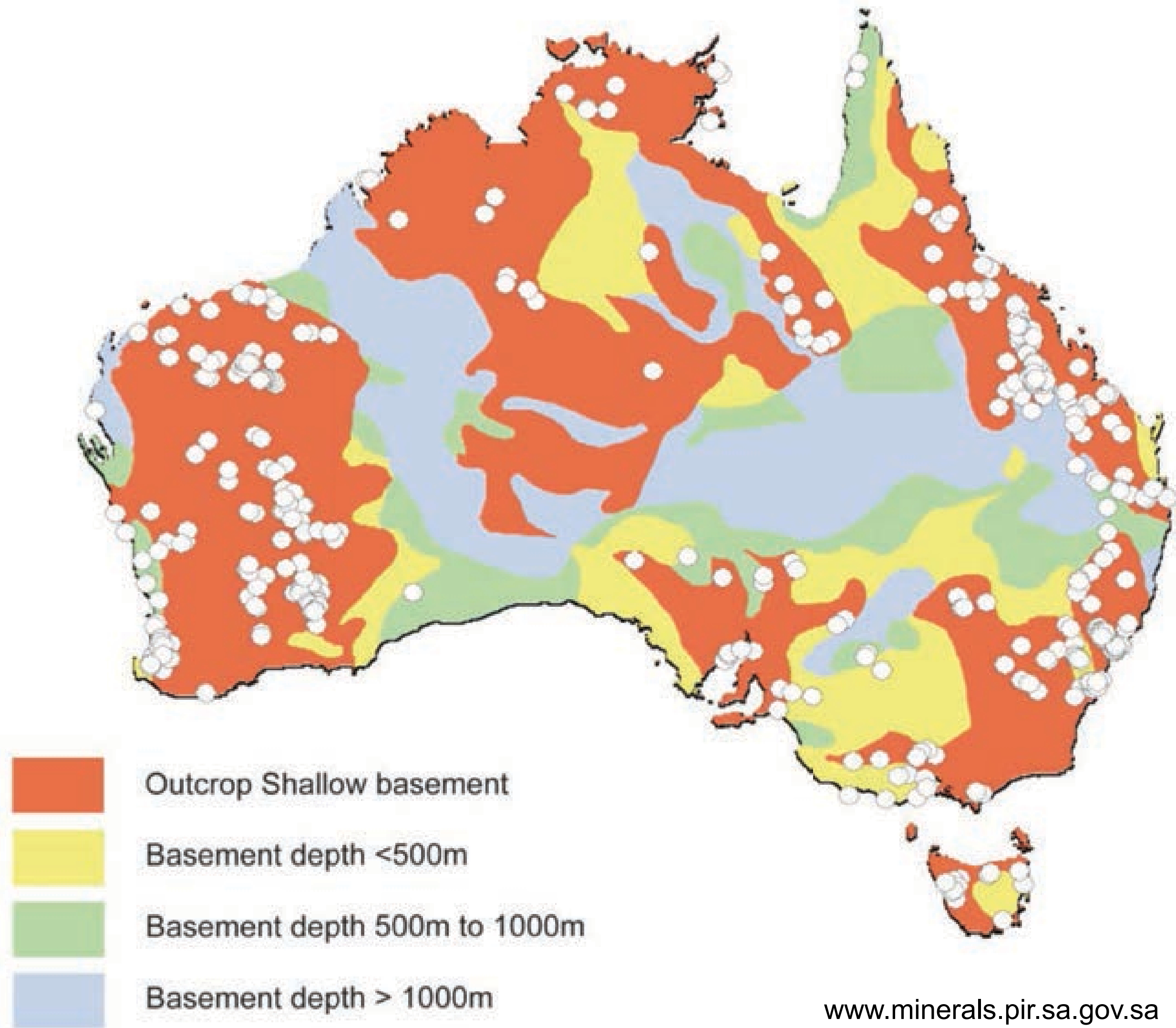
- South Australia
- Discovered in 1975 by drilling of gravity and magnetic anomalies
- Ore body 350 m beneath sedimentary cover
- Operational by 1988
- Owned (100%) by BHP Billiton
- Largest U deposit in the world
- 4th largest Cu deposit
- 5th largest Au deposit
- 2.95 Gt reserves:
  - 1.2% Cu
  - 0.04% U
  - 75 Moz Au
  - 566M oz Ag

http://www.australia-mining.com/images/olympic-dam.gif


http://resources2.news.com.au

Geophysics is an essential exploration tool in Australia

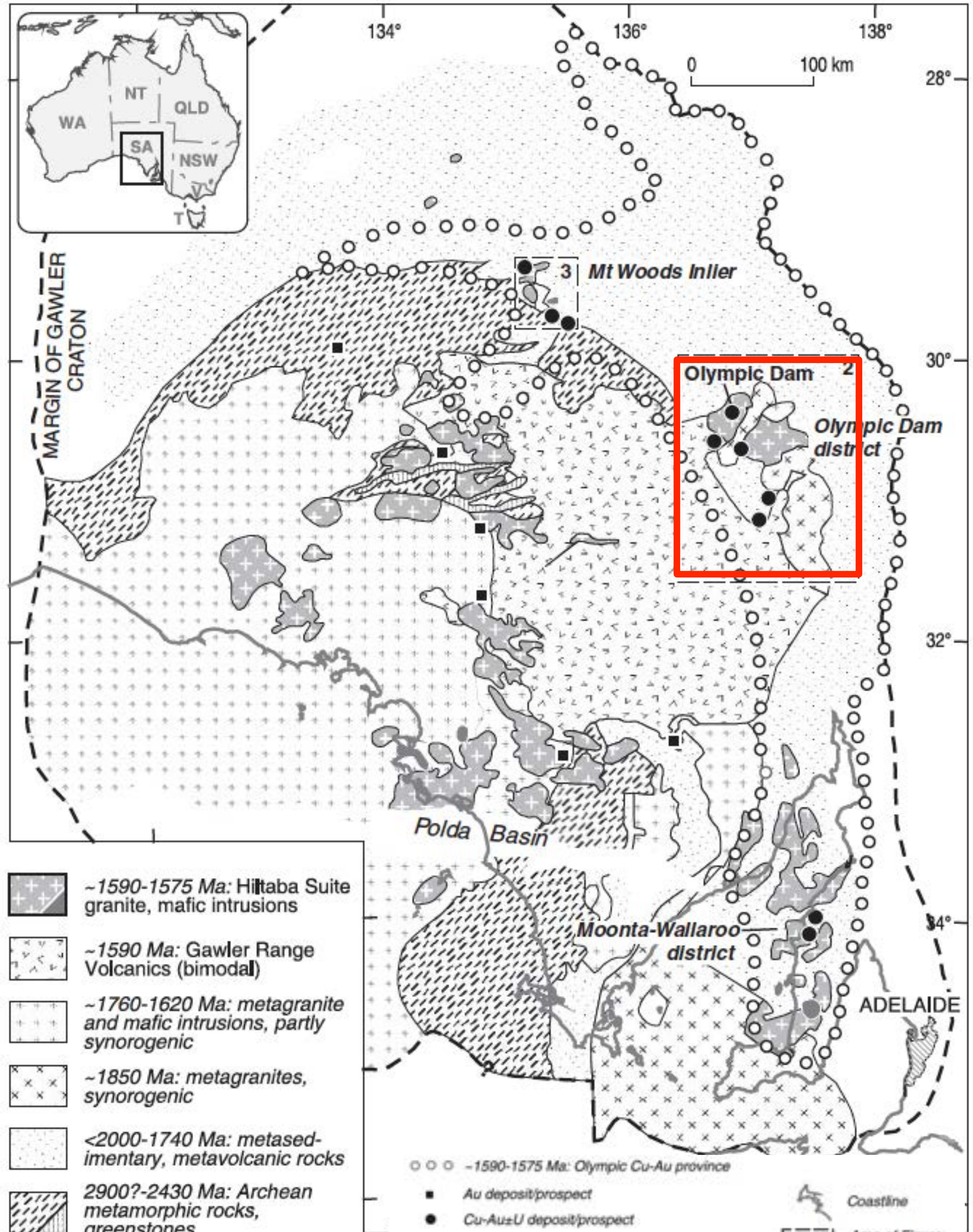
Moon Plain, SA (Courtesy of Steve Hill)



www.minerals.pir.sa.gov.sa

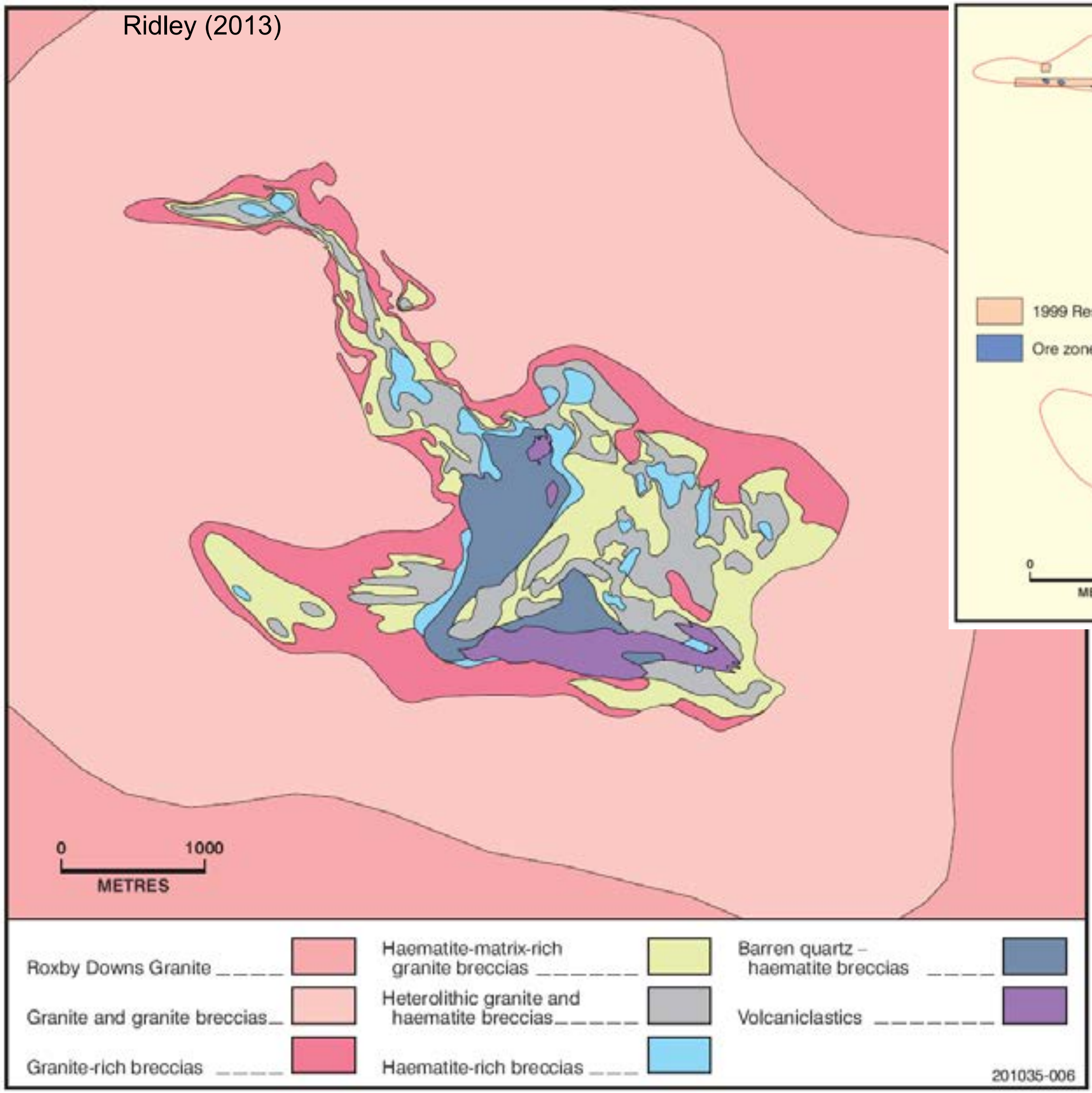
Olympic dam – geology

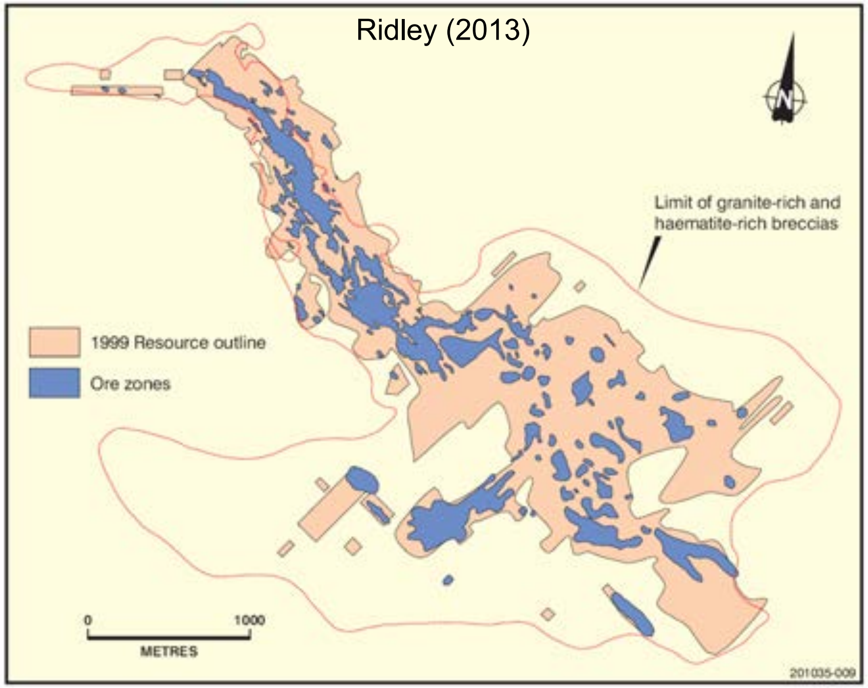
- Meoproterozoic craton (Gawler Craton)
- Sedimentary rocks at surface
- Volcanic and volcaniclastic rocks intruded by granites (A-type; anorogenic granite)
- Ore hosted in 1.6 Ga granite (K, U, Th rich)
- Mineralizing event was a few M.y. after granite crystallization



Evgeniy et al. (2007)

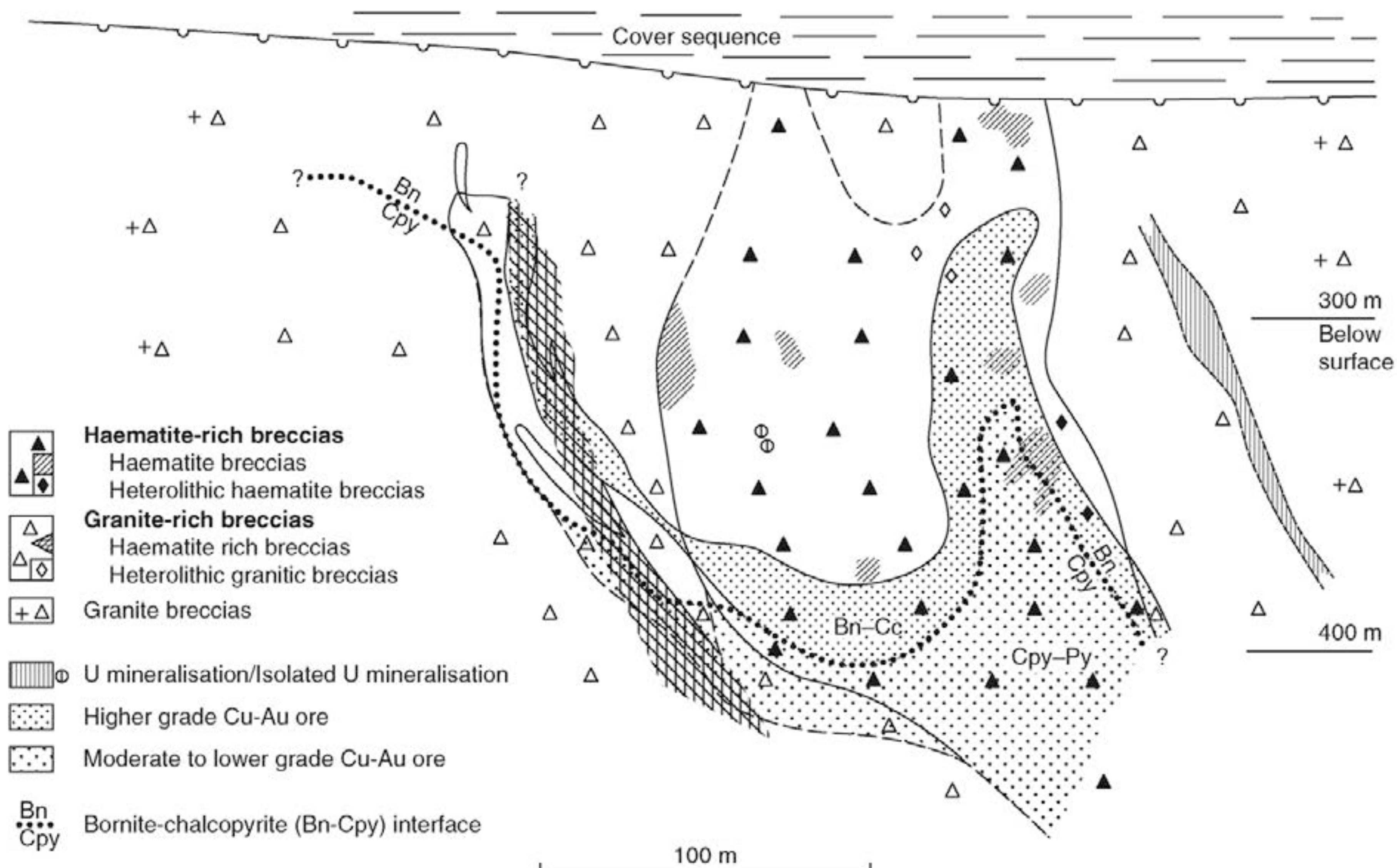
Olympic Dam – ore hosted in hematite-rich breccias





- Ore hosted in hematite-rich breccias (hematite matrix)
- Halo of less brecciated granites
- Brecciation decreases outwards
- Covered by sedimentary rocks

Ore straddles the bornite–chalcocite boundary

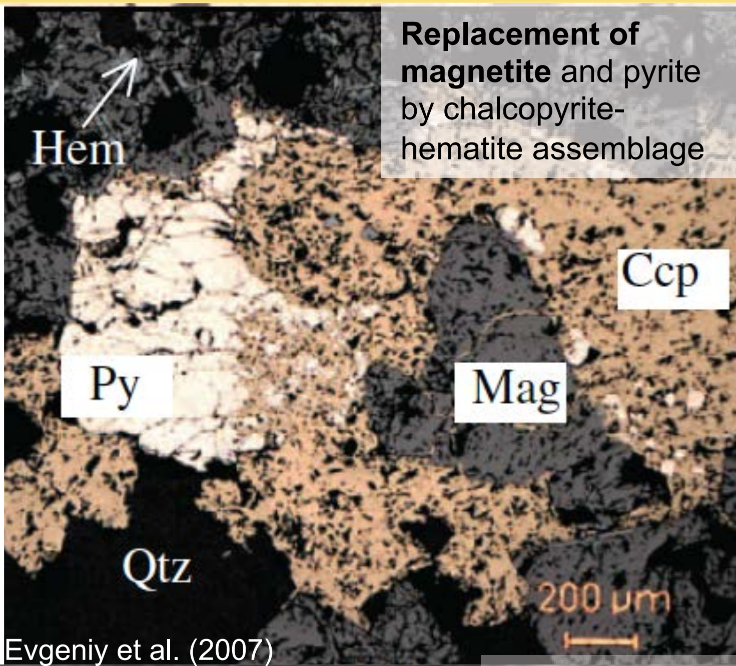


Ridley (2013)

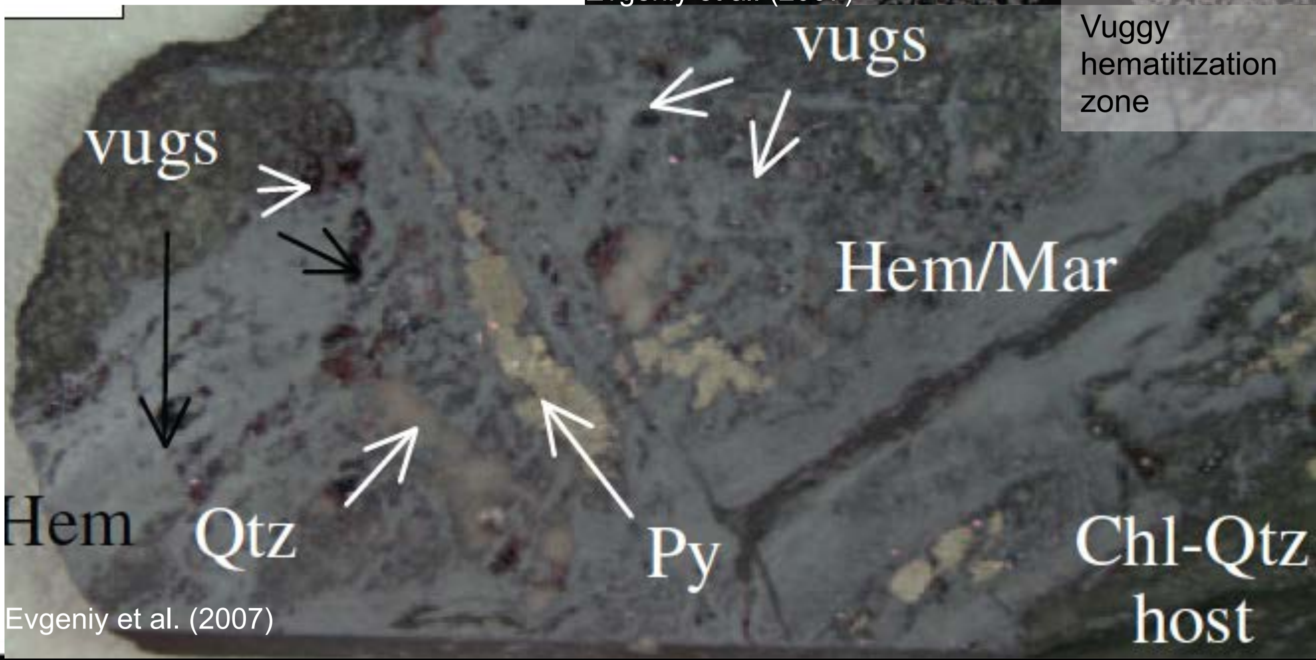
Olympic Dam – ore

Hosted in hematite-rich breccias

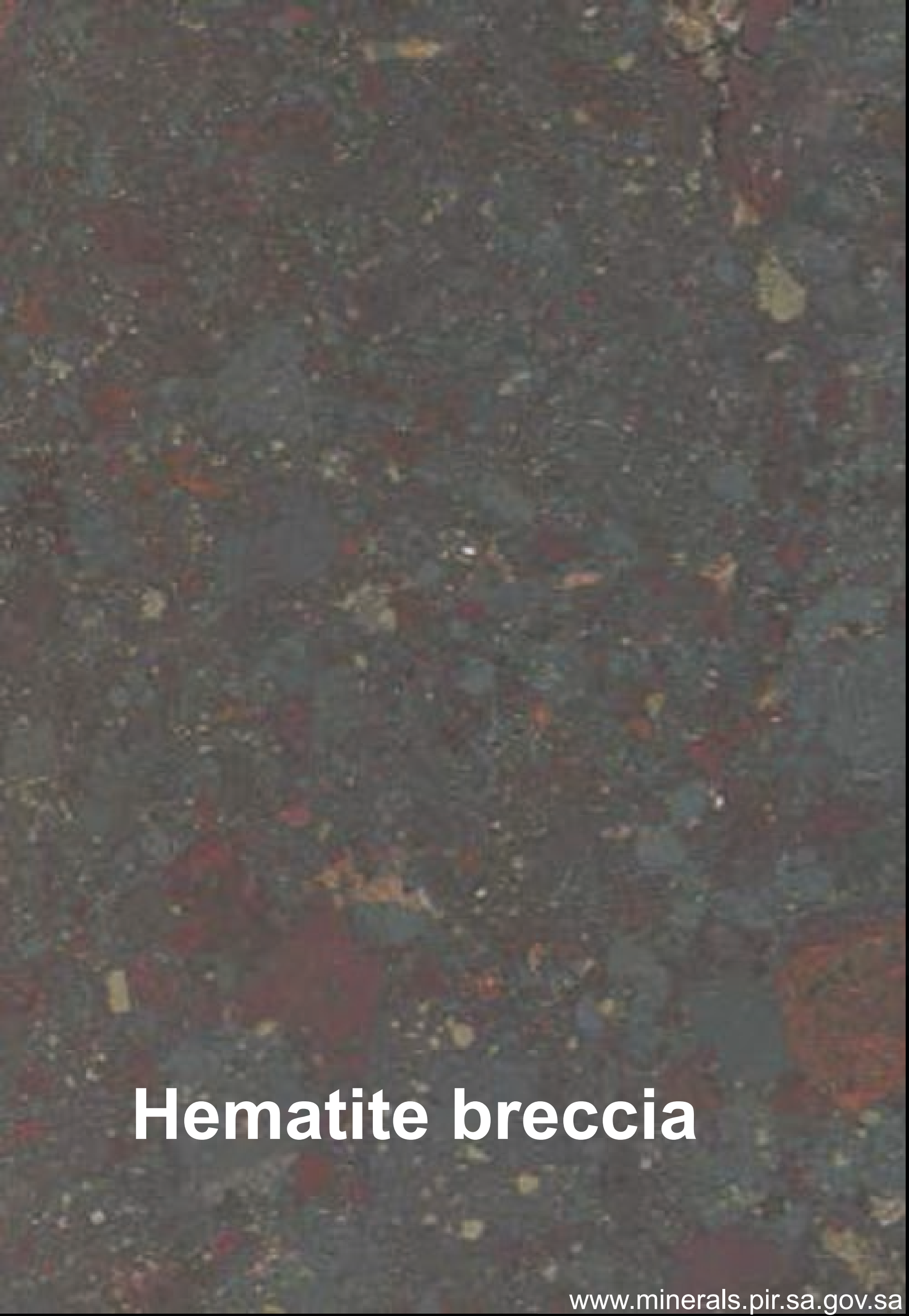
Polymetallic: chalcocite, bornite, chalcopyrite, pitchblende, argentite (Ag_2S), gold, REE-minerals



Evgeniy et al. (2007)



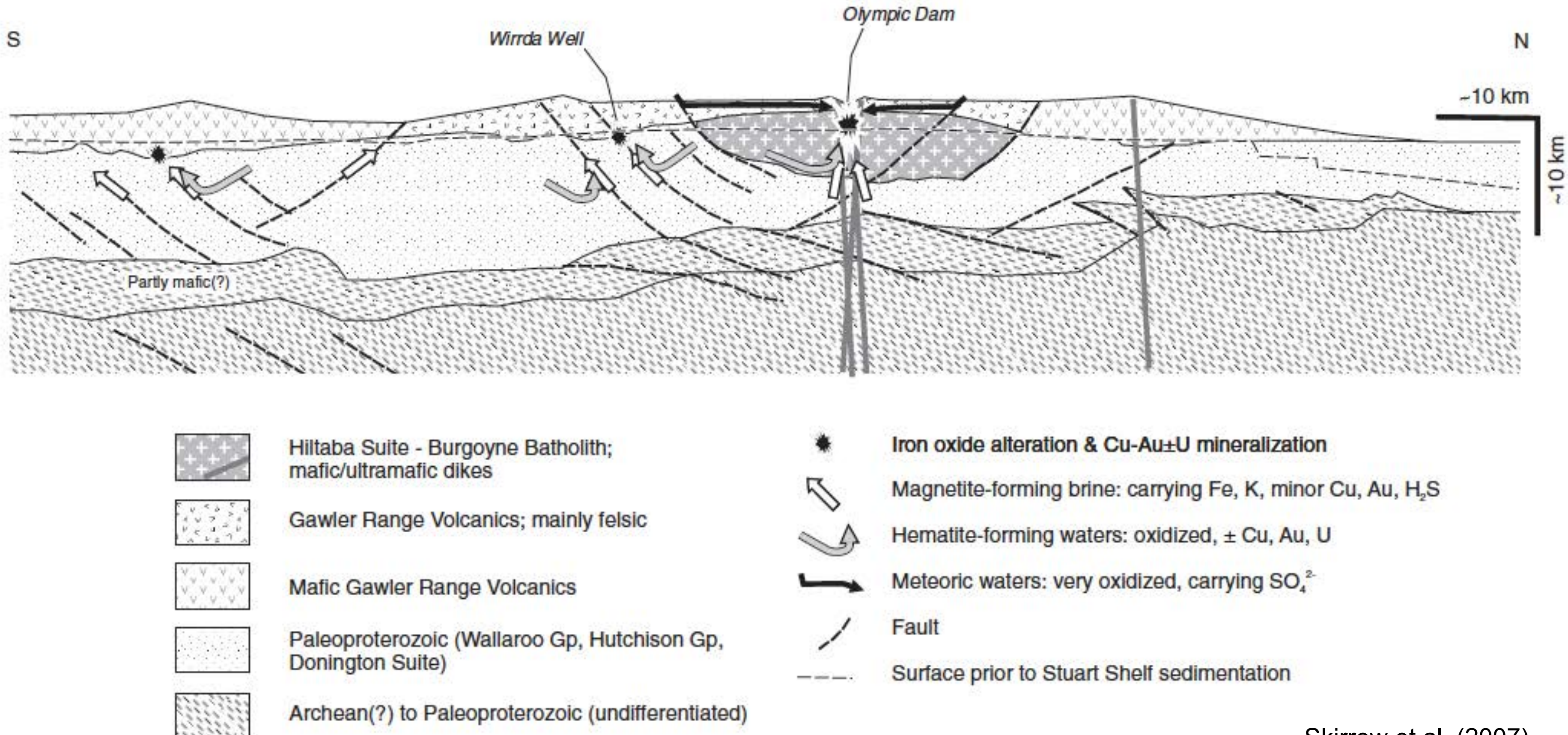
Evgeniy et al. (2007)


Hematite breccia
www.minerals.pir.sa.gov.sa


Olympic Dam – ore
www.minerals.pir.sa.gov.sa

Olympic dam – genetic model (??)

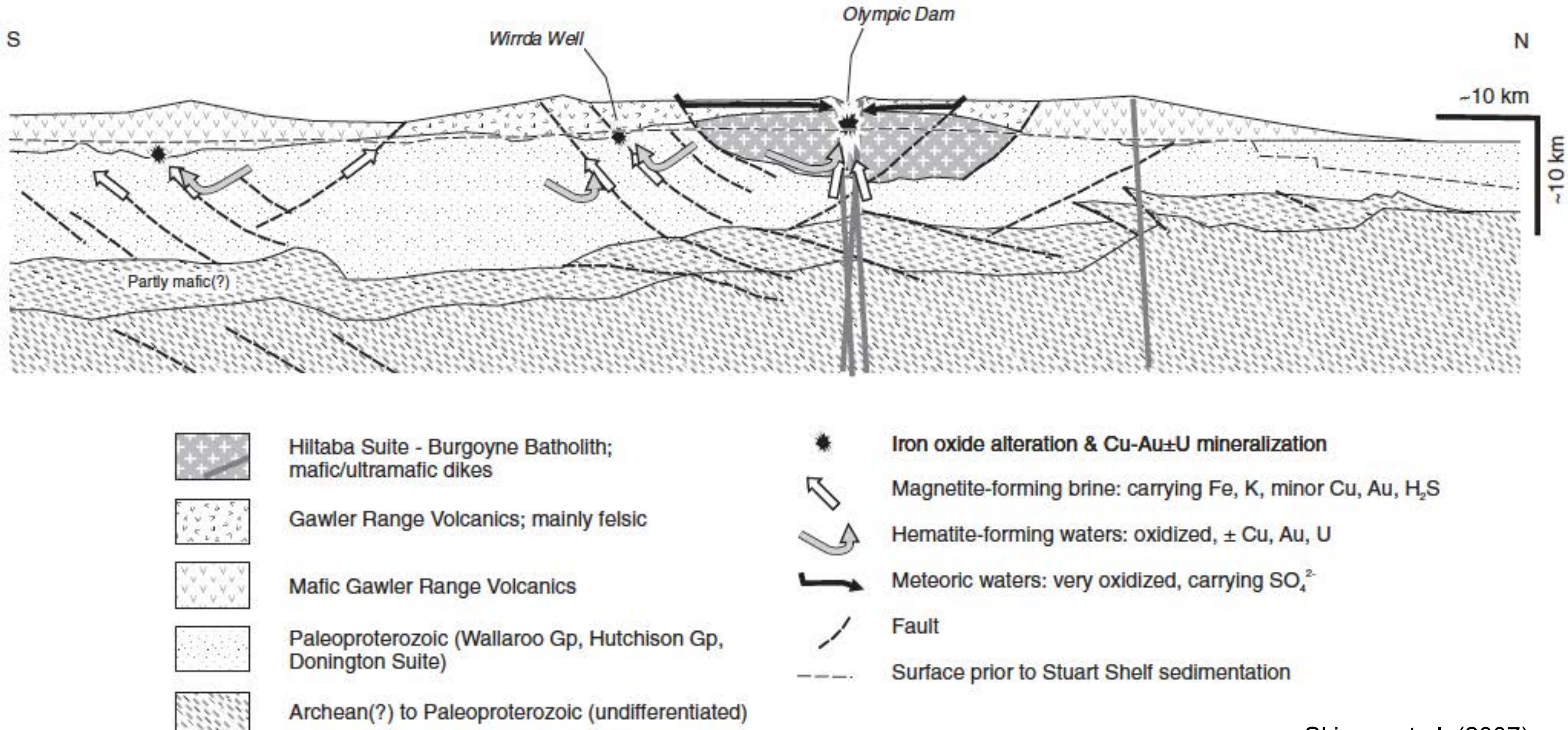
1. Volcanism (extrusive) and brecciation at ~1590 Ma
2. High-temperature magnetite-forming (Fe-rich) brines (source??) interact with sedimentary and felsic igneous rocks causing extensive hydrothermal alteration



Skirrow et al. (2007)

Olympic dam – genetic model (??)

3. Hematite-forming waters (oxidized) interact with mafic–ultramafic rocks (leach Cu) and granite (leach Cu and U?)
4. Waters interact with meteoric (SO_4^{2-} rich) waters resulting in ore mineral precipitation



Skirrow et al. (2007)

IOCGs in the NWT

<u>NICO</u>

- Owned by Fortune Minerals (London, Ontario)
- Discovered in 1996
- Status: environmental approval, now raising $$, 2018 start??
- 21.8 Mt reserves at:
  - 1.08g/t Au
  - **0.16% Bi (<u>12% of global reserves</u>)**
  - 0.13% Co

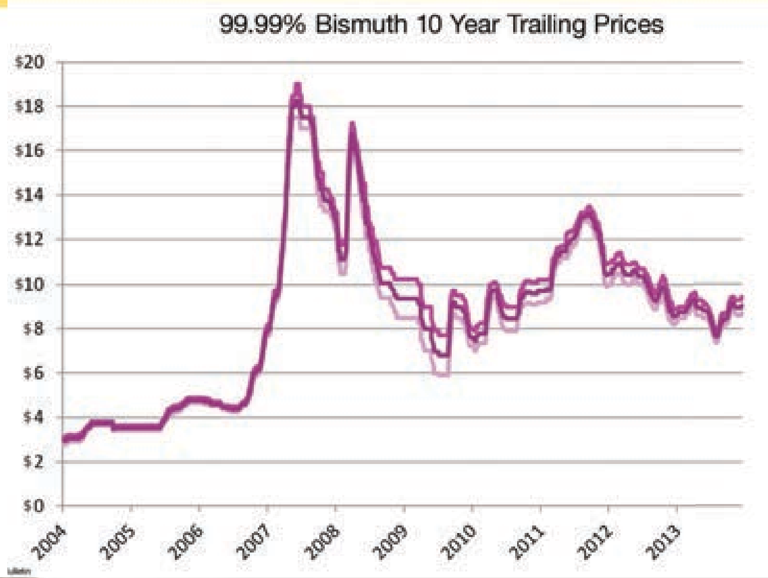
<u>Sue-Diane</u>

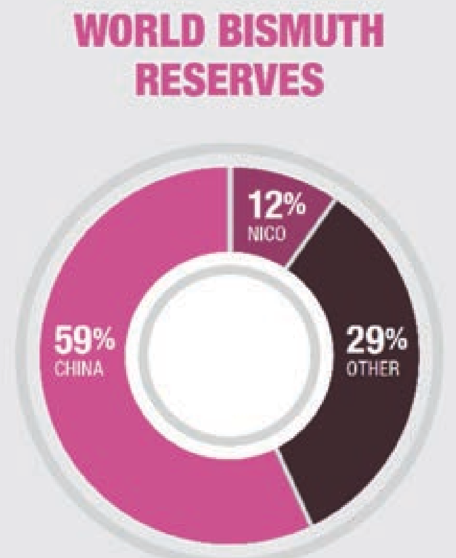
- 4 km north of NICO
- 17 Mt reserves at:
  - 0.72% Cu
  - 2.7 g/t Au
- Owned by Fortune Minerals


http://www.fortuneminerals.com/assets/nico/default.aspx

Bismuth

- Non-toxic
- Expands when cooled
- Low thermal and electrical conductivity
- One of the lowest melting points for metal
- 4th highest supply risk factor (BGS)





Health

- Pepto-Bismol® & similar stomach settling medicines
- Cosmetics
- Lead replacement in potable water sources & electronics
- Catheters & bandages

Other

- Castings, fire retardants, sprinkler systems, lubricating greases

Automotive

- Rust protection undercoating
- Paint pigments & pearlescent coating
- Brake linings & clutch pads

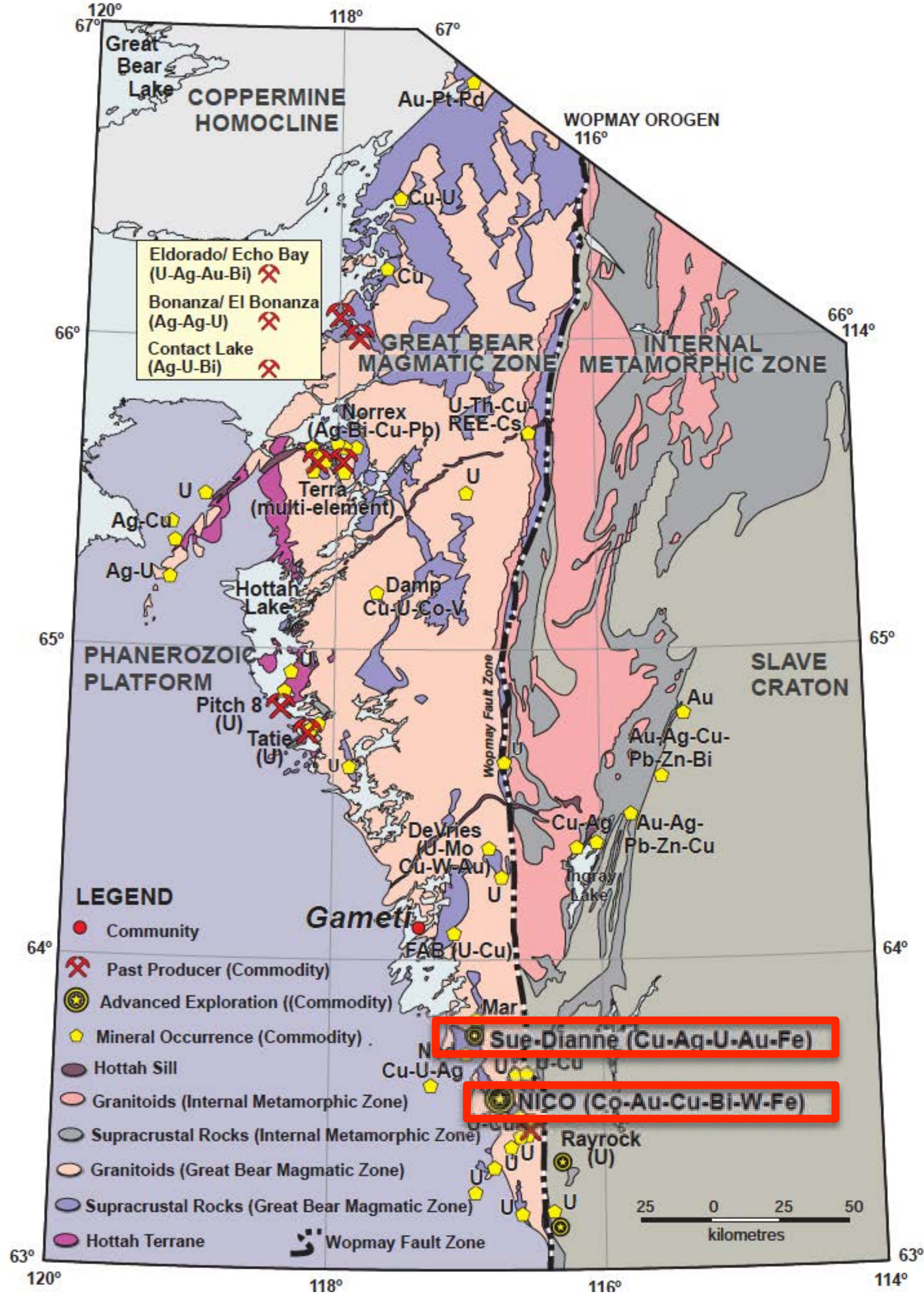
Electronics

- Electronic solders
- Free-machining steel

http://www.fortuneminerals.com

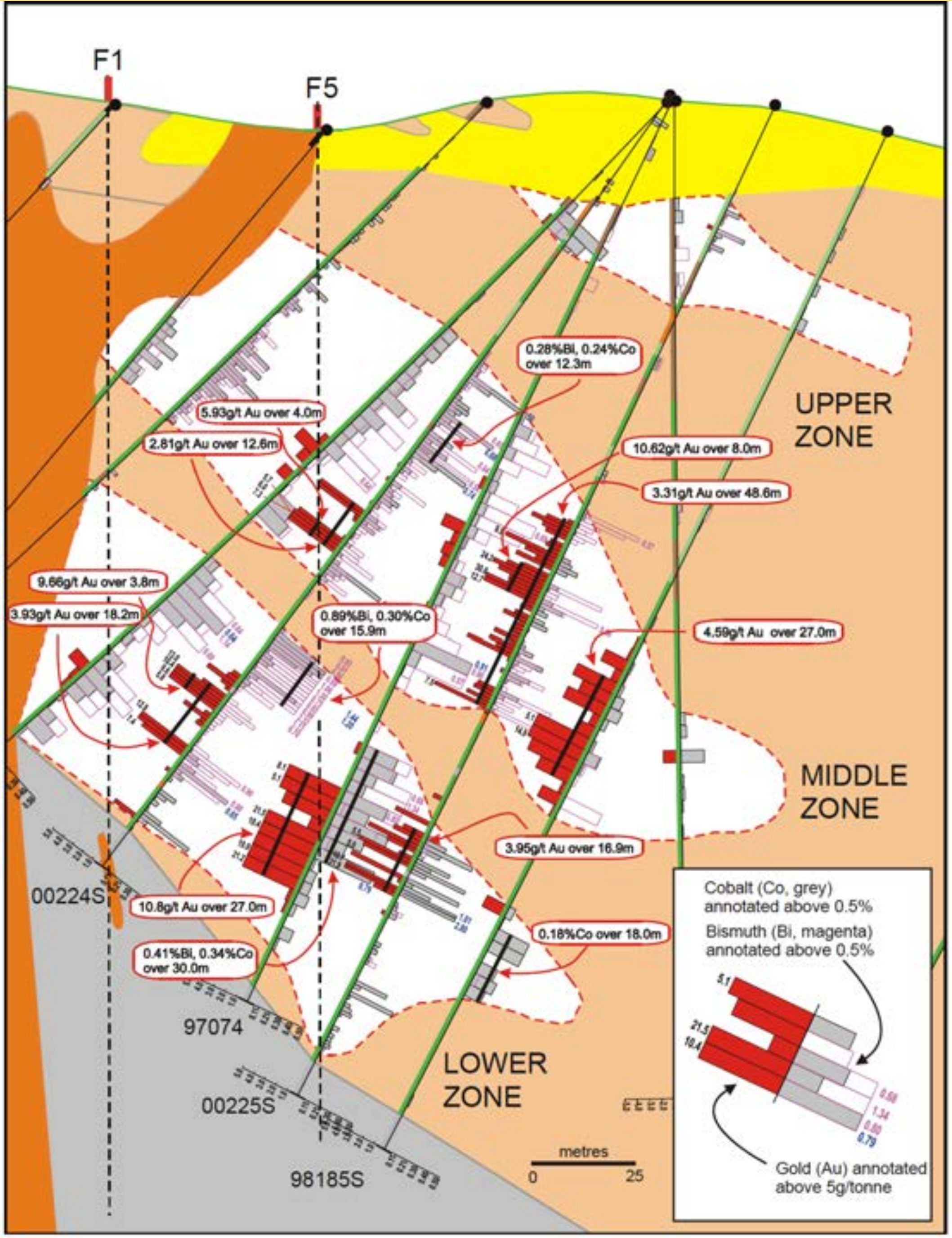
Great Bear Magmatic Zone

- Volcanic–plutonic complex formed during eastward subduction-related magmatism (1.88–1.84 Ga)
- Calc-alkaline felsic to mafic volcanic rocks and associated sedimentary rocks intruded by calc-alkaline to alkaline plutons
- Think "Andean" margin
- Historic mining at northern end (vein-type U, Ag, Co)
- Both IOCG deposits found at the south end of the magmatic zone



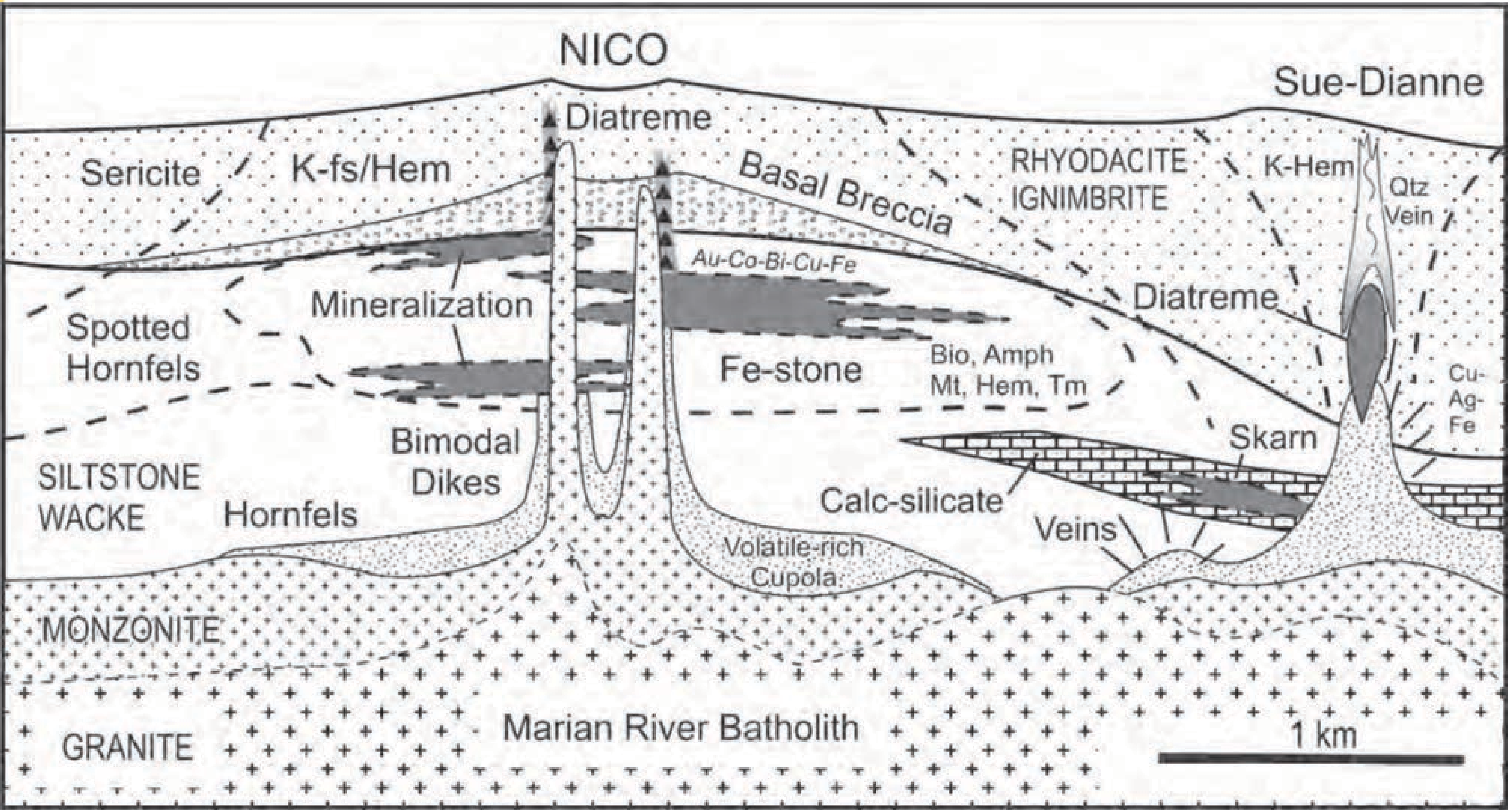
NICO ore

- Hosted biotite–amphibole–magnetite schist
- Amphibole, magnetite, potassic and tourmaline alteration
- Ore textures: replacement, veins, breccias
- Sulfide mineralization is disseminated
- Pyrrhotite, Chalcopyrite, gold/bismuth telluride, chalcopyrite, cobaltite, cobaltian arenopyrite
- Late stage felsic intrusions have removed ore (orange)



Geological setting of NICO and Sue-Dianne

- Ore between granitic intrusion and cogenetic volcanic rocks



Mumin et al. (2007, EMG)

IOCG summary

- Epigenetic
- Usually large and of low grade
- Size, shapes and host rocks are highly variable
- Breccia, veins, stockwork, disseminated
- Abundant Fe-oxide minerals (hematite, magnetite)
- Polymetallic

Fluid: magmatic, meteoric, metamorphic, connate

Source of metals: variable and poorly constrained

Transport: structurally controlled (breccias, faults)

Trap: fluid–rock interaction, fluid mixing