# Magma fertility: Concepts and JCU research at NQ

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# Magma fertility

**Miners' dream to have the magic power to predict whether there is mineralisation associated with an igneous rock, and/or the metal endowment, using igneous features**

# Concepts

1. Metal and associated element concentration in causative intrusions
2. Redox state of causative intrusions
3. Fractionation of causative intrusions
4. Water content of causative intrusions

# Metal and associated elements

1. Higher Sn, ± W, Li, Rb, Be, B, F:
   A. "Specialised" vs. "precursor" granitoids of Tischendorf (1977)

| | "Spezialized" | "Precursor" |
|---|---|---|
| Rb | 550±200 ppm | 250±50 ppm |
| Li | 400±200 ppm | 130±50 ppm |
| Sn | 30± 20 ppm | 10± 5 ppm |
| W | 7± 3 ppm | 3± 1.5 ppm |

   B. Higher Sn in ore-related granitoids, typically>10ppm; exact threshold varies in different districts (e.g., NQ, NSW, TAS; Hesp and Rigby)

- Cu-Au-Zn-Pb: No reported anomalies in causative intrusions

# Redox state

A. Mostly about fertile magmas; most contrast between Sn-W vs. Cu-Au

1. Magnetite vs. ilmenite series (Ishihara et al., 1979)
2. $Fe_2O_3$/FeO (wt%): Blevin and Chappell (1992); Blevin et al (1996)
3. $Fe_2O_3/(Fe_2O_3+FeO)$; redox boundary: 0.4 (Meinert, 1995)
   - >0.4: Cu, Cu-Au, Fe, Zn, Mo skarns
   - <0.4: Au-only skarns and Sn skarns
   - W: can be related to both
4. ΔOx; redox boundary at 0; Porphyry Cu-Au (Cadia?) = 0.5-0.8 (Blevin, 2004)

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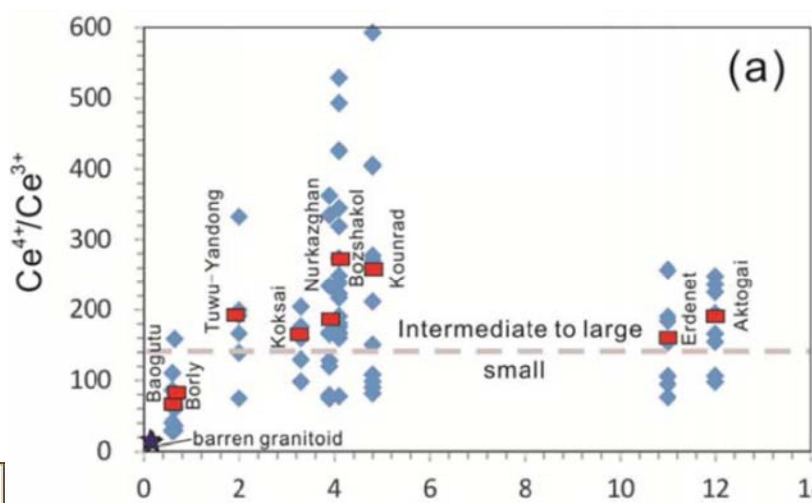
# Redox state

5. Zircon $Ce^{4+}/Ce^{3+}$ ratio. 29-252 in Shen et al (2015)
   - 9 porphyry Cu deposits from Central Asian Orogenic Belt
     - 5 large (4-12 Mt Cu): 74-592
     - 2 intermediate (1.5-4 Mt Cu): 74-332
     - 2 small deposits (<1.5 Mt Cu): 28-158
   - 9 barren granitoids from Australia (Belousova et al., 2002)
   - ? How about the Sn-W intrusions?

Zircon more resistant to alteration and weathering




*Shen et al (2015)*

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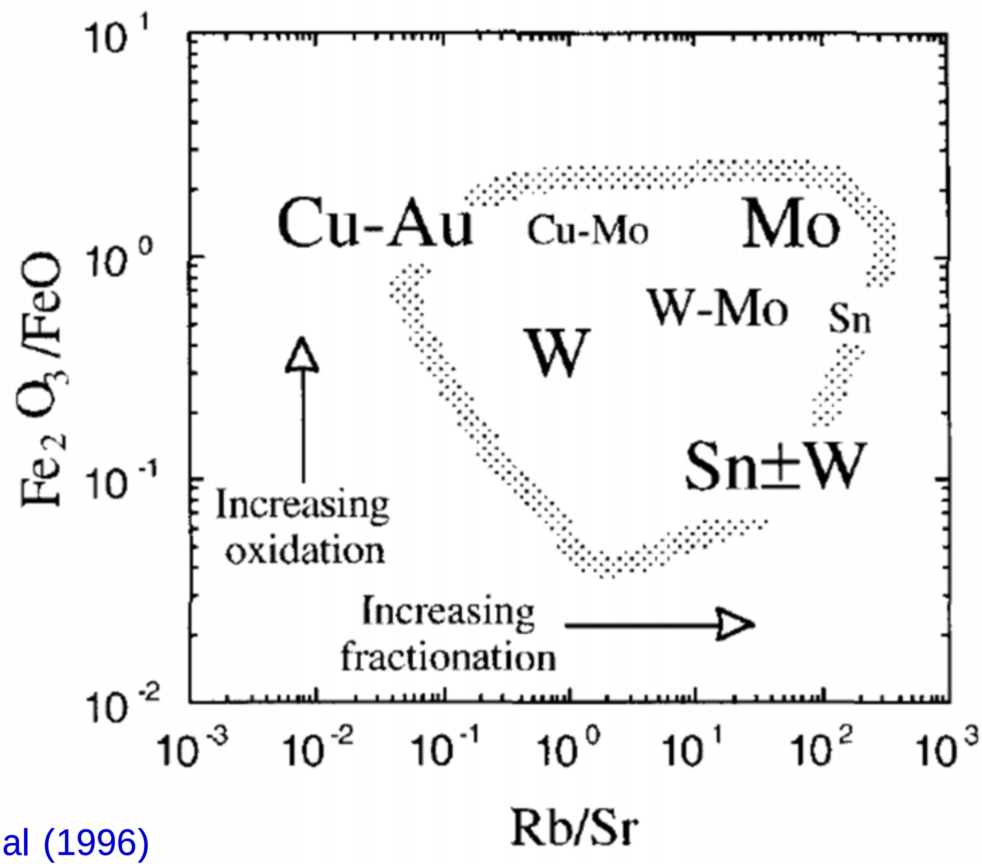
# Fractionation

A. **Mostly about fertile magmas; most contrast between Sn-W vs. Cu-Au**

1. **Rb/Sr (Blevin and Chappell, 1992; Blevin et al., 1996)**
2. **Rb/Sc (Meinert, 1995)**
3. **K/Rb; Unevolved > 400; moderately evolved 200-400; highly evolved <200 (Blevin, 2004)**



# Redox - Fractionation




Blevin et al (1996)

# Composition

A. **Mostly about fertile magmas; most contrast between Sn-W vs. Cu-Au**

1. **Most Sn-Mo granite high-K; Cu porphyries have a wide range: low-, medium- and high-K (Blevin, 2004)**
2. **Mo-Sn granitoids are $SiO_2$-rich whereas Cu intrusions having lower $SiO_2$ (Blevin, 2004)**

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# Water content

➢ **Fertile magmas are unusually rich in $H_2O$**

**Loucks (2014):**

- 135 major Phanerozoic deposits (one to multiple samples of fresh or weakly altered intrusive rocks related to mineralisation)
- Barren magma: 2640 volcanic and shallow intrusions; Neogene to Quaternary; Chile, Japan, and Aleutian arc)

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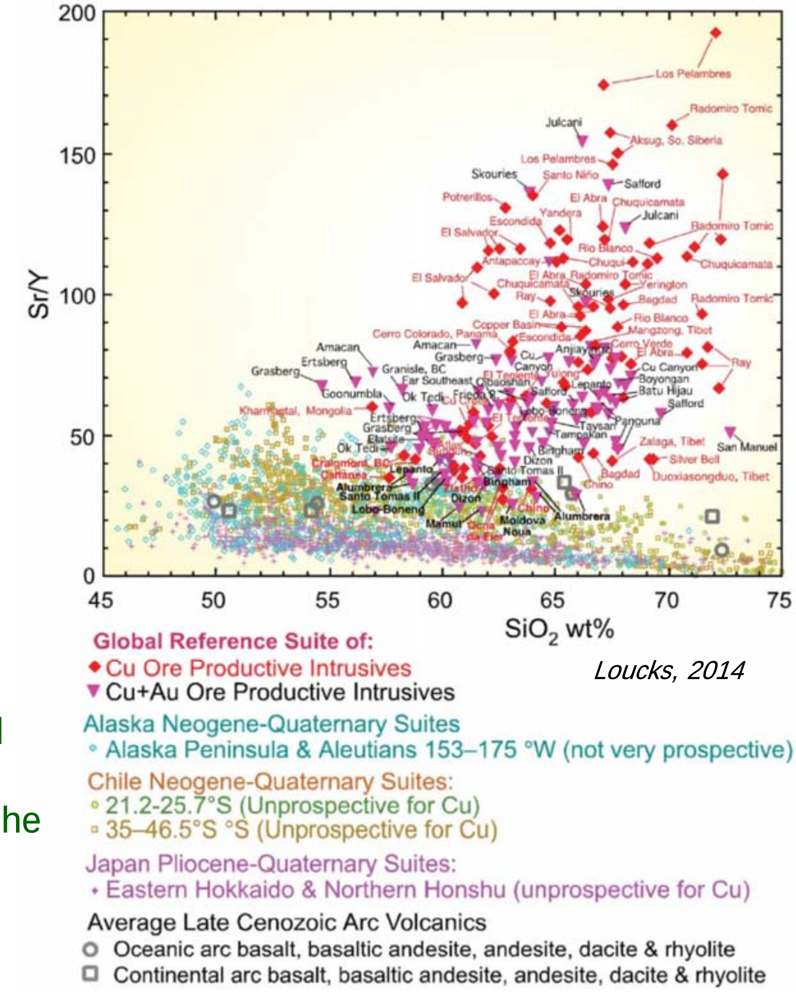
# Conclusion

### Favourable magmatic rocks:

- Sr/Y > 35
- V/Sc > 32.5 – 0.385 x wt% $SiO_2$ ($SiO_2$ 58-70%)




*Loucks, 2014*

### Conditions of use:

- Necessary but not sufficient
- Arc interval has experienced compressive orogenic deformation shortly before the magmatism

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# Conclusion

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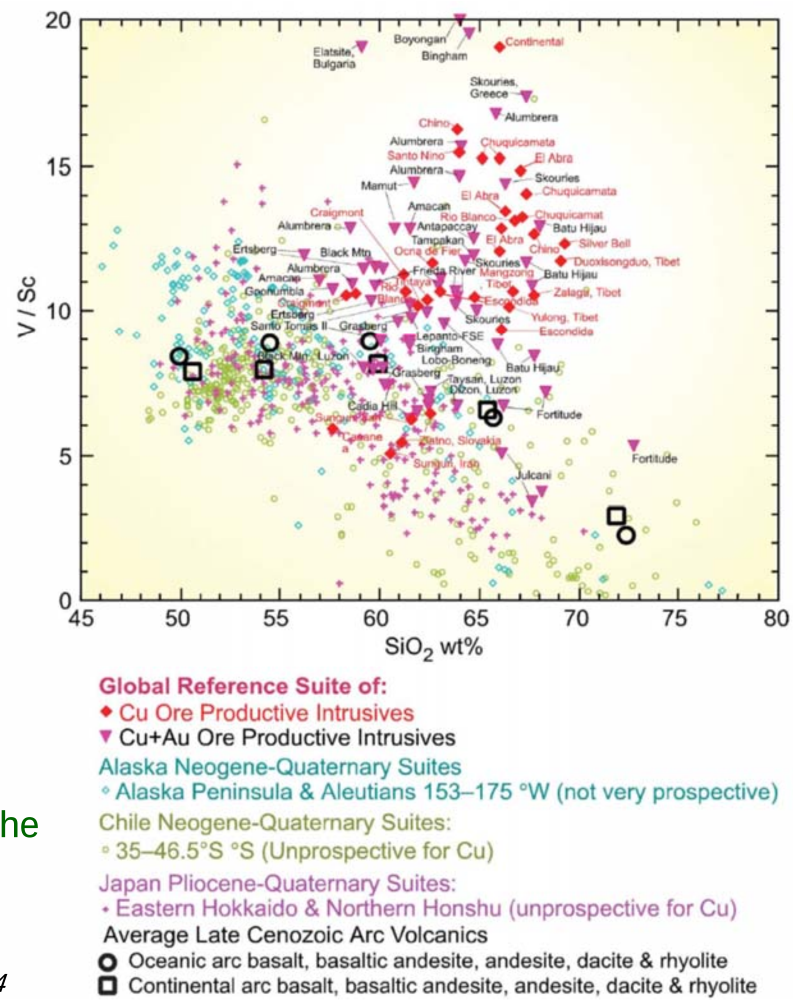


### Conditions of use:

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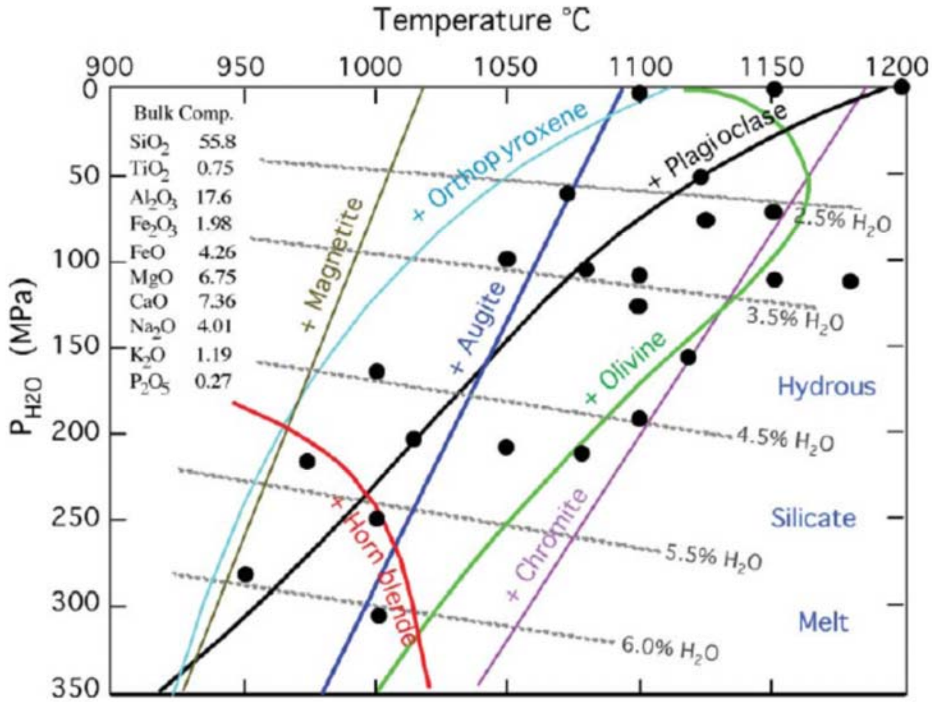
*Loucks, 2014*

# Water → crystallisation sequence → whole rock trace elements

- More water / OH makes olivine, plagioclase and pyroxene crystallize at lower T, and hornblende at higher T
  - ➢ This affects WR major / trace elements

- Al, Sr: Plagioclase
- Ti, Sc, Y: Hornblende
- V: Magnetite

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*Loucks, 2014*

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# Cu-Au vs. Sn

**Timing of water exsolution from melt affects metal concentration in aqueous fluids**

- ➢ Some elements can be taken into igneous minerals, e.g., Fe, and some Cu → early exsolution is needed to form a good deposit
- ➢ Some trace elements may only become enriched enough at the end of crystallisation (high degree of crystallisatoin), e.g., Sn, Be → late exsolution is better & melt is more fractionated

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*Burnham (1981, 1997)*

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# Timing of water exsolution

1. **Initial water content**
2. **Pressure / depth**

Starting conditions: Dioritic to granitic melt, 2 wt% $H_2O$,

| Pressure | Depth | $H_2O$ solubility | % of crystalli. at water saturation |
|---|---|---|---|
| 5000 bars | 20 km | 10-11 wt% | **80%** |
| 2000 bars | 8 km | 6.3 wt% | **68%** |
| 500 bars | 2 km | 3.0 wt% | **33%** |

- **Cu: needs early water exsolution → shallow**
- **Sn: needs late water exsolution → Deep; or low initial water in melt → smaller deposit**

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*Burnham (1981, 1997)*

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# Our approach

- **Use volcanic rocks instead of intrusive rocks**
  - **By the time the causative intrusion is exposed to the surface, partial to most of the ores have already been eroded away**
  - **If we can find the signals in volcanic rocks, the ores are still preserved below the surface**

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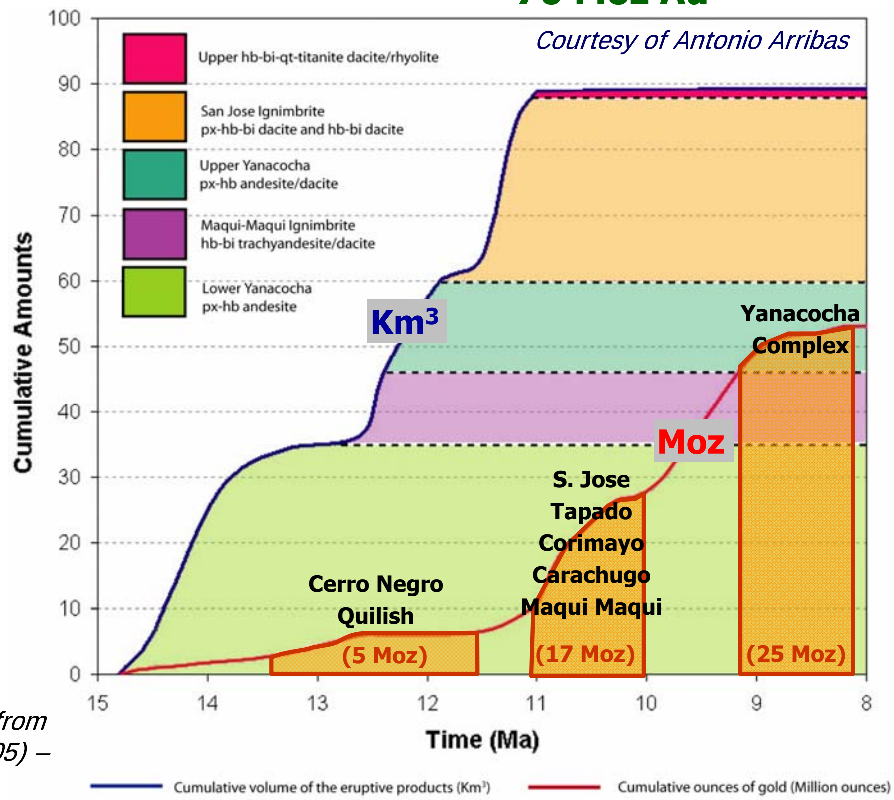
# Using volcanic rocks

- Fertile periods last for ~**5-20 myrs**

**Example: Yanacocha, Peru; ~70 Moz Au**

- $H_2O$ may be accumulated by inheritance through several cycles of magma chamber replenish and fractional crystallisation
- Volcanic rocks before and/or after mineralisation (no volcanic activity during mineralisation) may contain some information on melt evolution

*Loucks (2014)*




*Base map from Longo (2005) – PhD thesis*

# Temporal/tectonic evolution

Tectonics plays a crucial role in enhancing porphyry mineralisation potential

Contraction tectonic settings are conductive to mineralisation events (e.g., Sillitoe 2010).

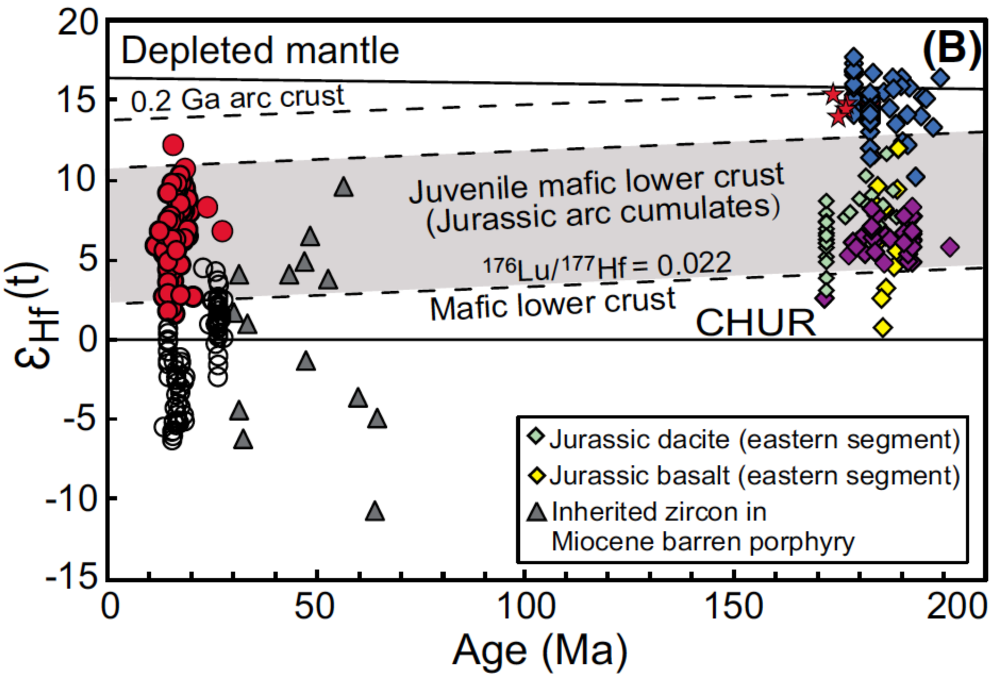
In ancient terranes, reconstructing tectonic conditions requires detailed field relationships, geochronology, and isotope geochemistry.

**Lu-Hf isotope systematics can track mantle and crust contributions to magmas over time, and hence may be very instructive for deciphering tectonic conditions through time**

# Temporal/tectonic evolution

**Tibet – Continental collision related mineralisation**

**Red are mineralized porphyrys**




Hou et al. (Geology; 2015)

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# Our approach

- **First proof of concept: does the parameters work on volcanic rocks?**
- **Then apply the parameters to volcanic rocks in this region → generate a magma fertility map that will also be used for final prospectivity analysis**

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# Thanks!