MDE Minerals Consulting

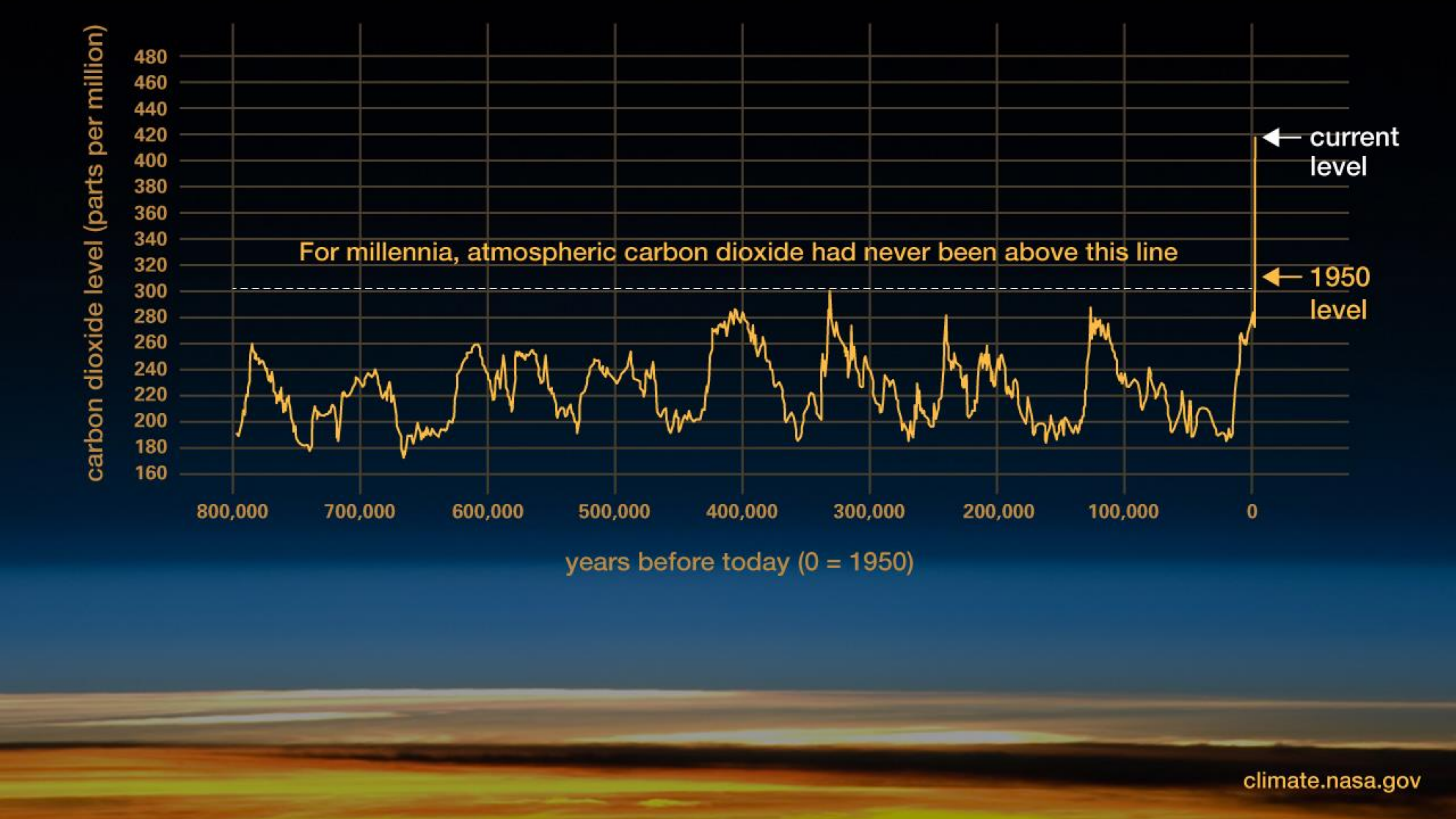
# Geometallurgy of Cobaltiferous Copper Ores of the Chilean Iron Belt

29th International Applied Geochemistry Symposium

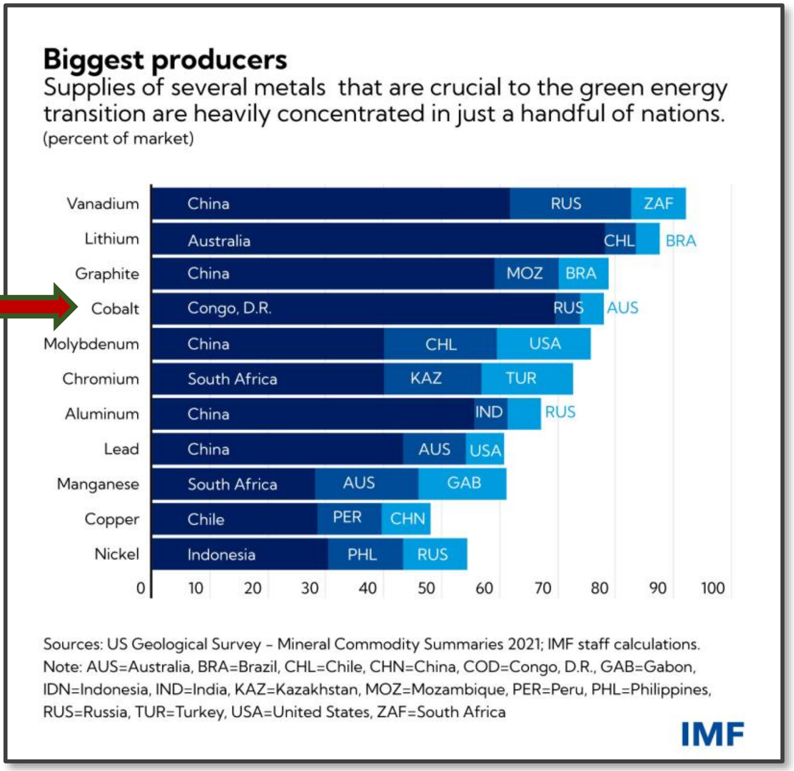
**Romke Kuyvenhoven**, Viña del Mar, Chile, 27 October 2022

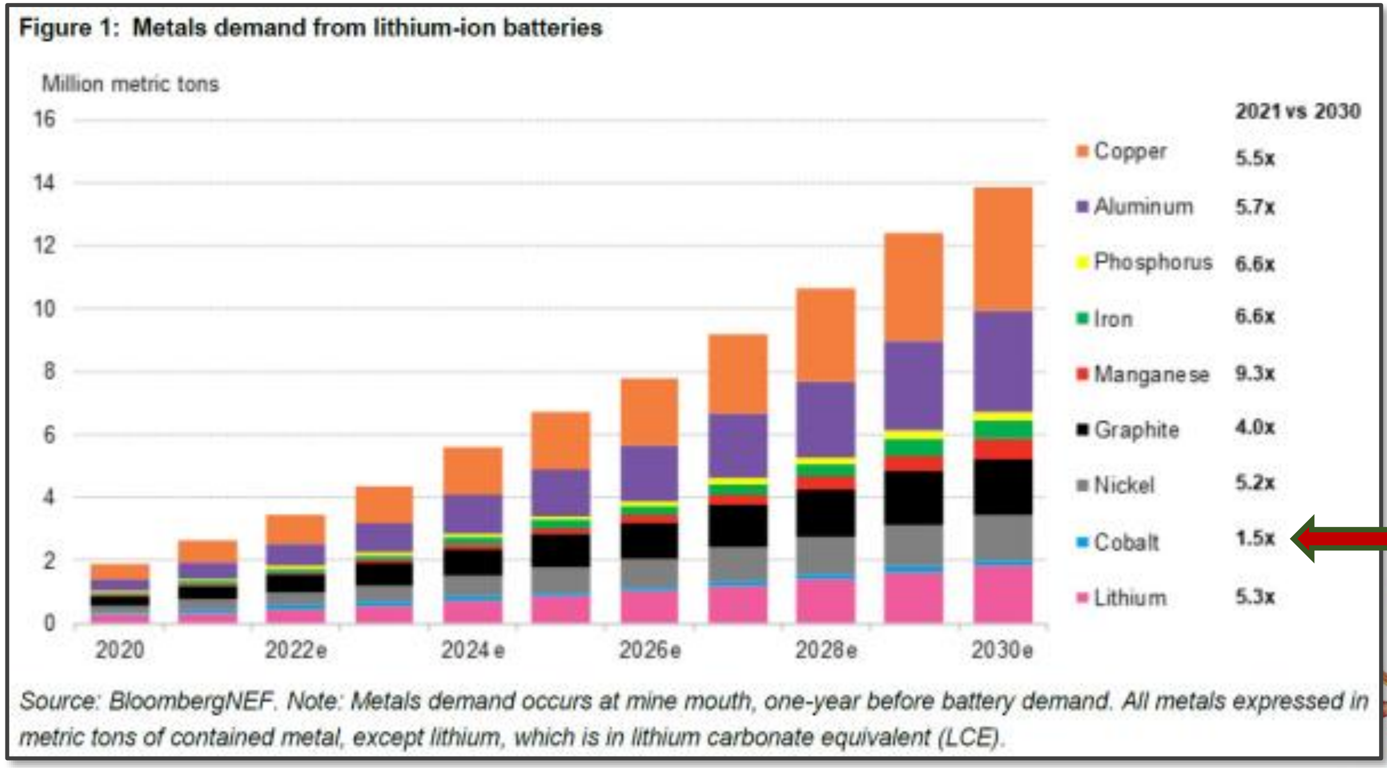
# Outline

- Why cobalt?
  - ➢A quick look at what's happening in the world
- How could cobalt be relevant for Chile?
  - ➢Chile is a copper mining country
- Why copper ores?
  - ➢The reasoning behind the recovery of low-grade cobalt
- Why geometallurgy?
  - ➢Inherent relation between geology and process performance


carbon dioxide level (parts per million)
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
For millennia, atmospheric carbon dioxide had never been above this line
current level
1950 level
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
years before today (0 = 1950)
climate.nasa.gov

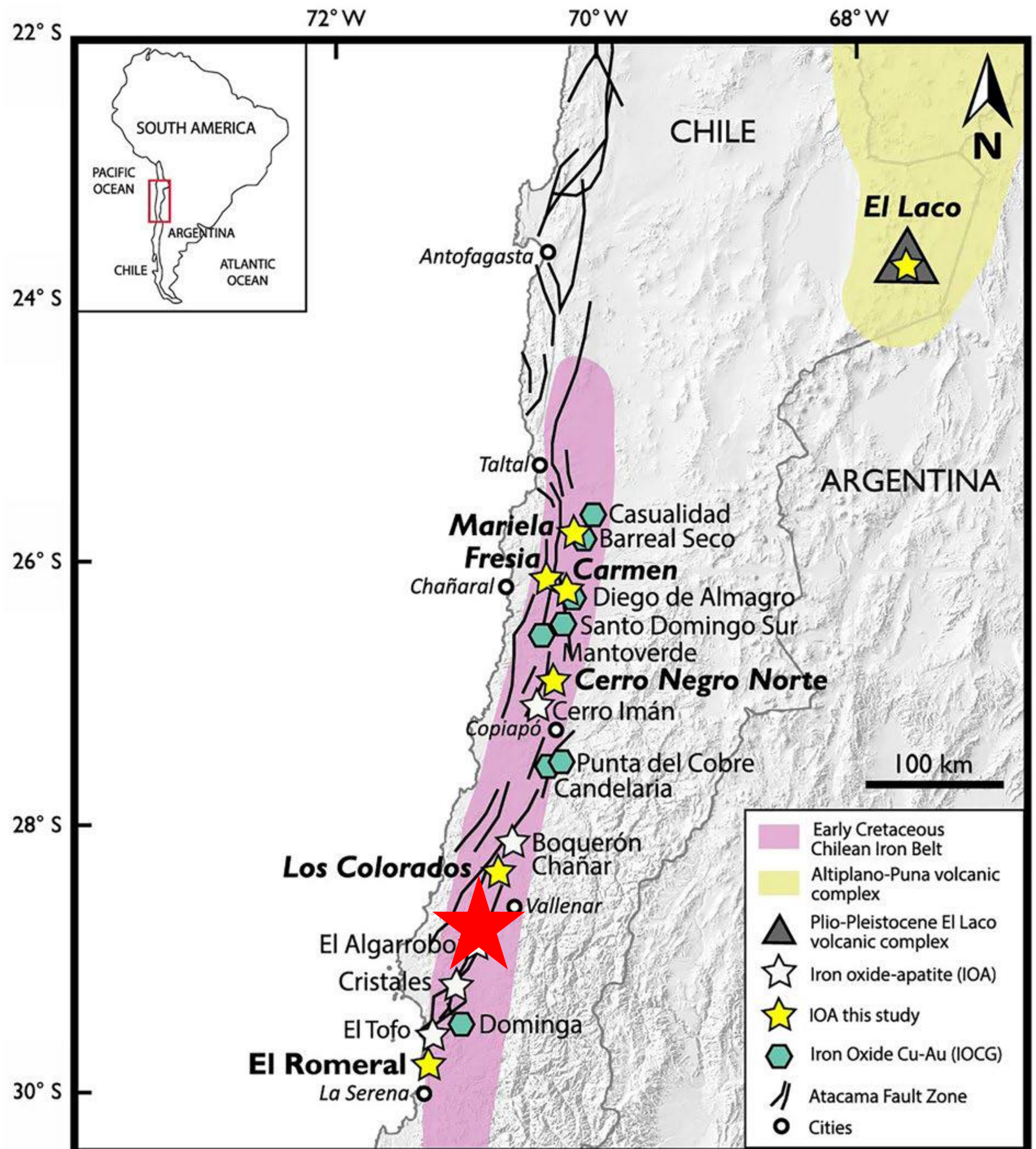
# Metals demand for energy transition




https://www.imf.org/en/Blogs/Articles/2021/12/08/metals-demand-from-energy-transition-may-top-current-global-supply

https://www.greencarcongress.com/2021/07/20210701-bnef.html



72° W
70° W
68° W
22° S
24° S
26° S
28° S
30° S
SOUTH AMERICA
PACIFIC OCEAN
ARGENTINA
CHILE
ATLANTIC OCEAN
CHILE
N
El Laco
Antofagasta
ARGENTINA
Taltal
Mariela
Casualidad
Barreal Seco
Fresia
Carmen
Chañaral
Diego de Almagro
Santo Domingo Sur
Mantoverde
Cerro Negro Norte
Cerro Imán
Copiapó
Punta del Cobre
Candelaria
100 km
Boquerón Chañar
Los Colorados
Vallenar
El Algarrobo
Cristales
El Tofo
Dominga
El Romeral
La Serena
Early Cretaceous Chilean Iron Belt
Altiplano-Puna volcanic complex
Plio-Pleistocene El Laco volcanic complex
Iron oxide-apatite (IOA)
IOA this study
Iron Oxide Cu-Au (IOCG)
Atacama Fault Zone
Cities




# Preliminary characterization and testing

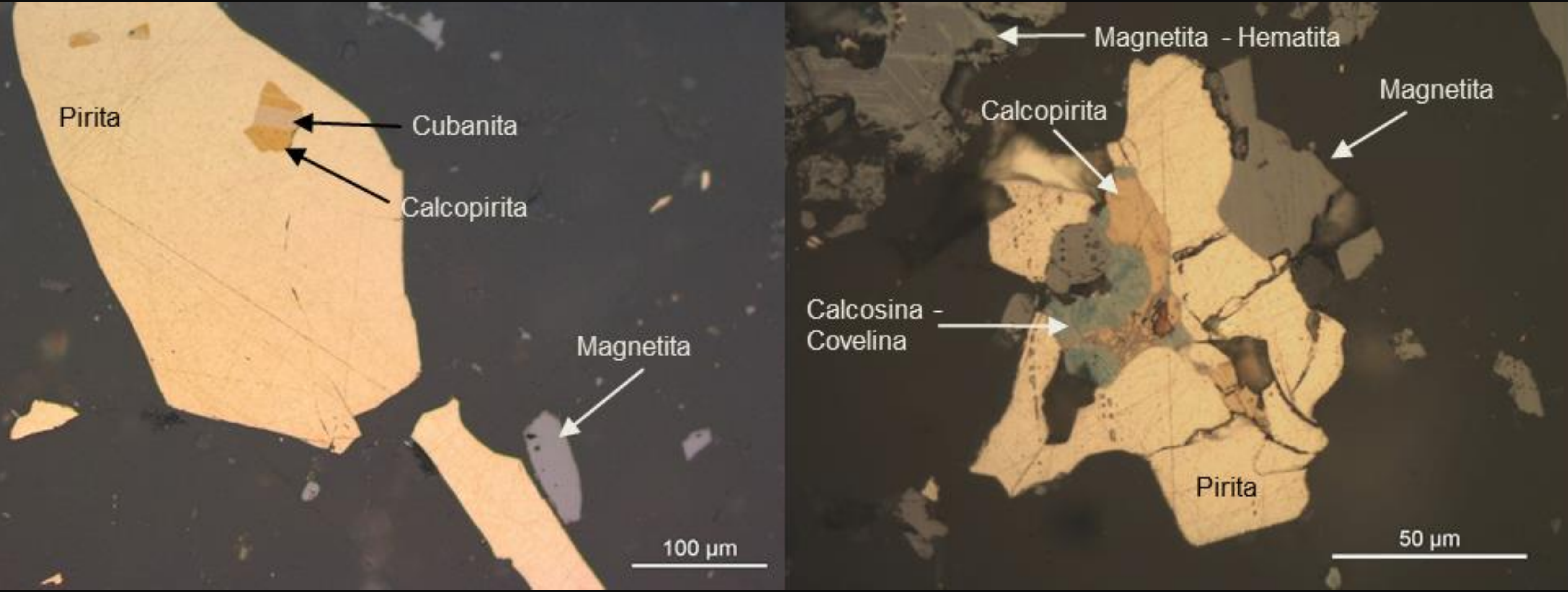
- A total of fifteen grab samples were selected at the La Estrella property for the exploratory stage
  - Cu: 0.2-1.0%
  - Co: 200-1500 ppm
  - Ni: 250-3000 ppm
  - Fe >> 40%
  - Va: 500-3000 ppm

# Composites were made for preliminary testing

| | Cu (%) | Fe (%) | S (%) | As (ppm) | Co (ppm) | Ni (ppm) |
|---|---|---|---|---|---|---|
| Composite 1 | 0.79 | 41.8 | 19.5 | 210 | 1090 | 1830 |
| Composite 2 | 0.42 | 46.4 | 11.1 | 11 | 580 | 1150 |
| Composite 3 | 0.22 | 55.2 | 4.7 | < 3 | 320 | 560 |

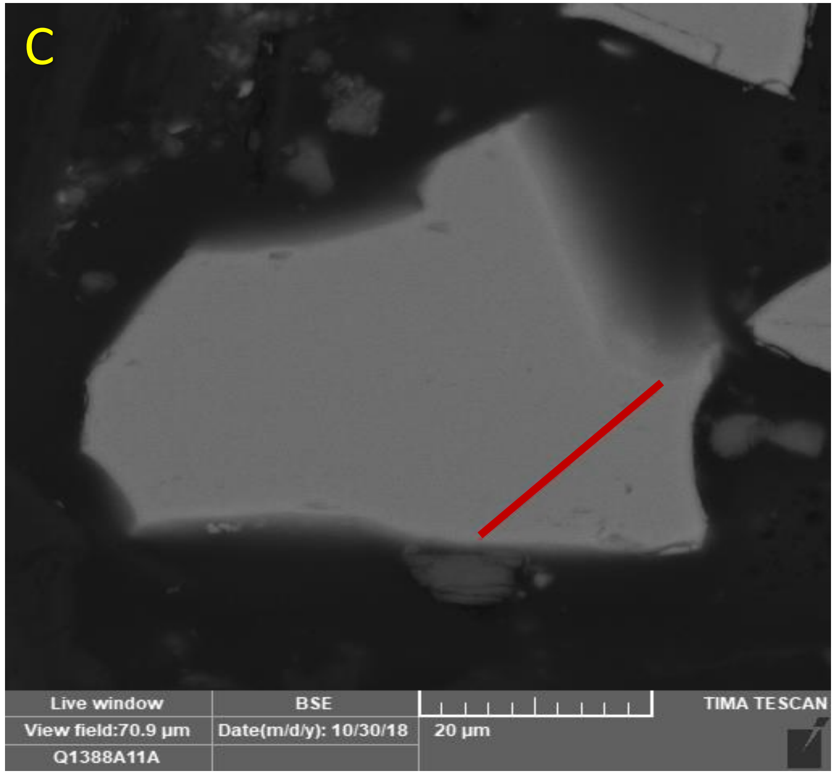
| | Apatite | Magnetite | Chalcopyrite | Pyrite | Fe-magn (%) | kWh/mt |
|---|---|---|---|---|---|---|
| Composite 1 | 10.3 | 28.6 | 1.49 | 29.1 | 87.0 | 8.5 |
| Composite 2 | 9.8 | 43.9 | 0.81 | 17.3 | 92.5 | 7.9 |
| Composite 3 | 7.0 | 65.6 | 0.33 | 6.5 | 91.2 | 8.3 |

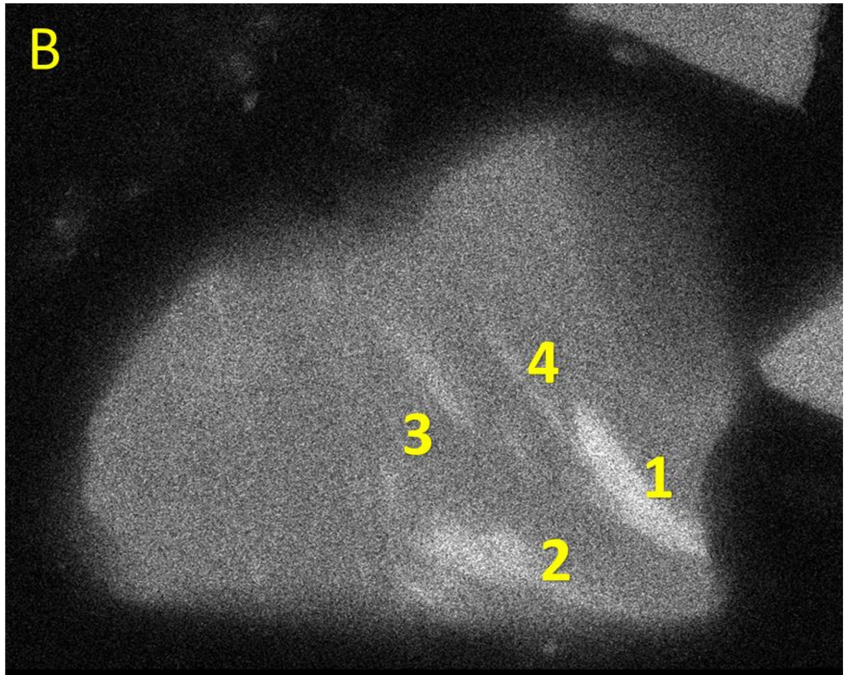
Source: Townley, Kuyvenhoven (2018)



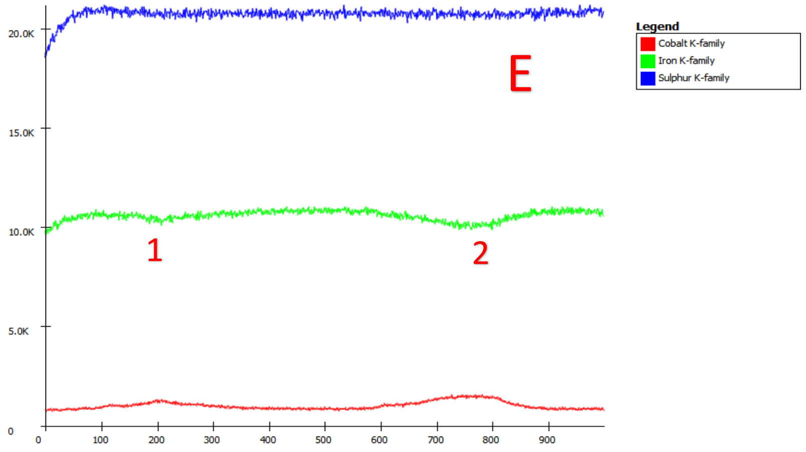
Pirita
Cubanita
Calcopirita
Magnetita
100 µm
Magnetita - Hematita
Magnetita
Calcopirita
Calcosina - Covelina
Pirita
50 µm

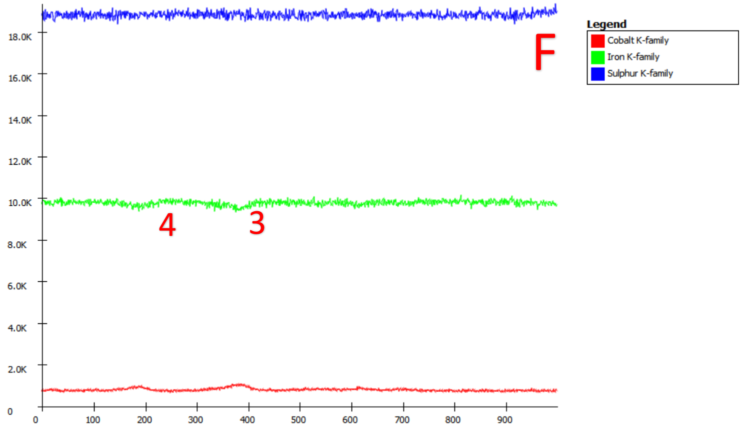
# Line scan to confirm cobalt presence as replacement of iron



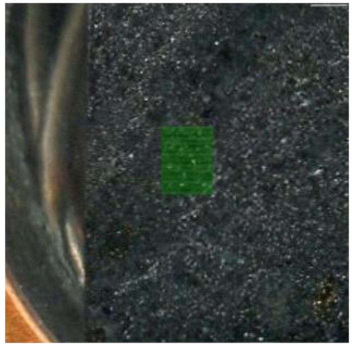

Energy-dispersive X-ray spectroscopy for Co

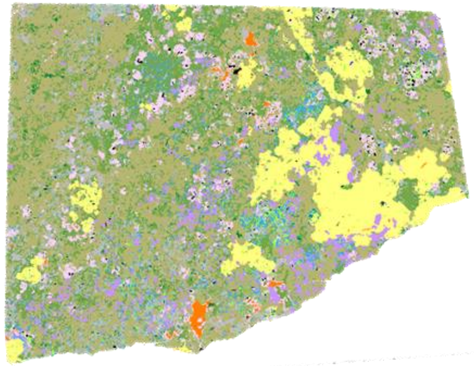


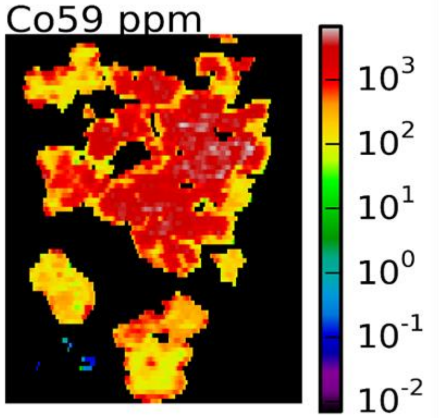



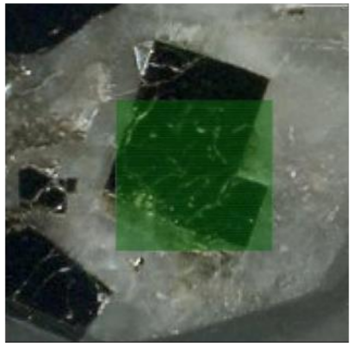

Source: IOCG Ore La Estrella, assayed at SGS Minerals Chile

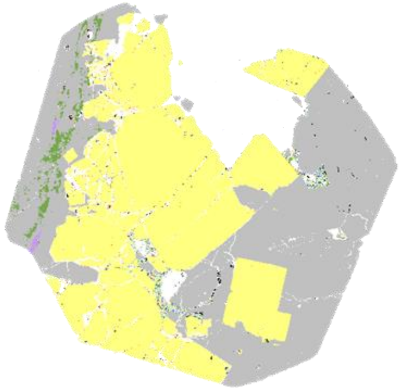
# The use of ICP-MS-LA to visualize cobalt

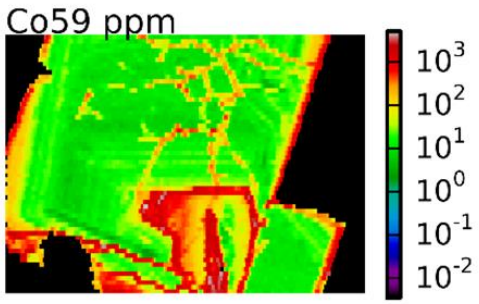




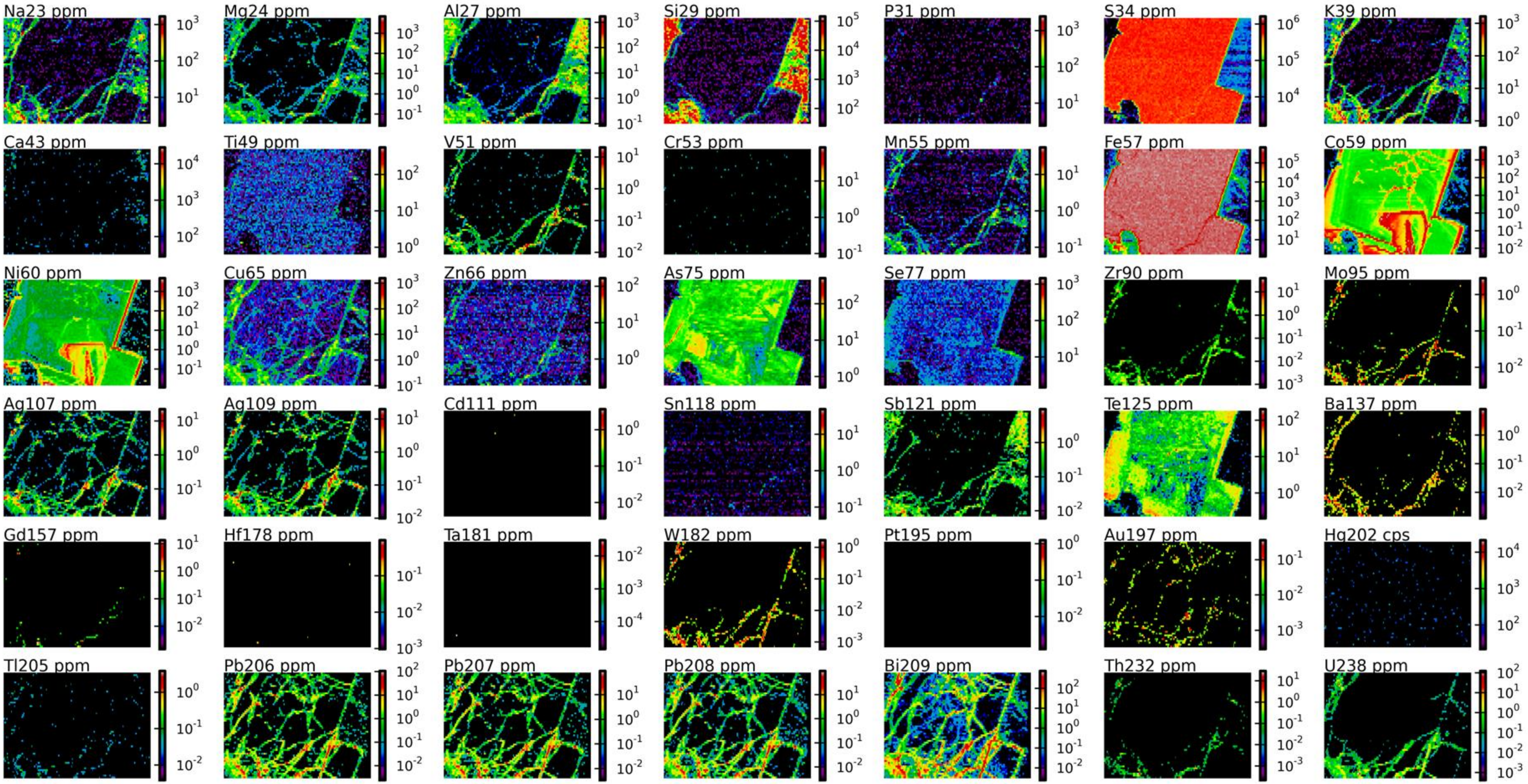




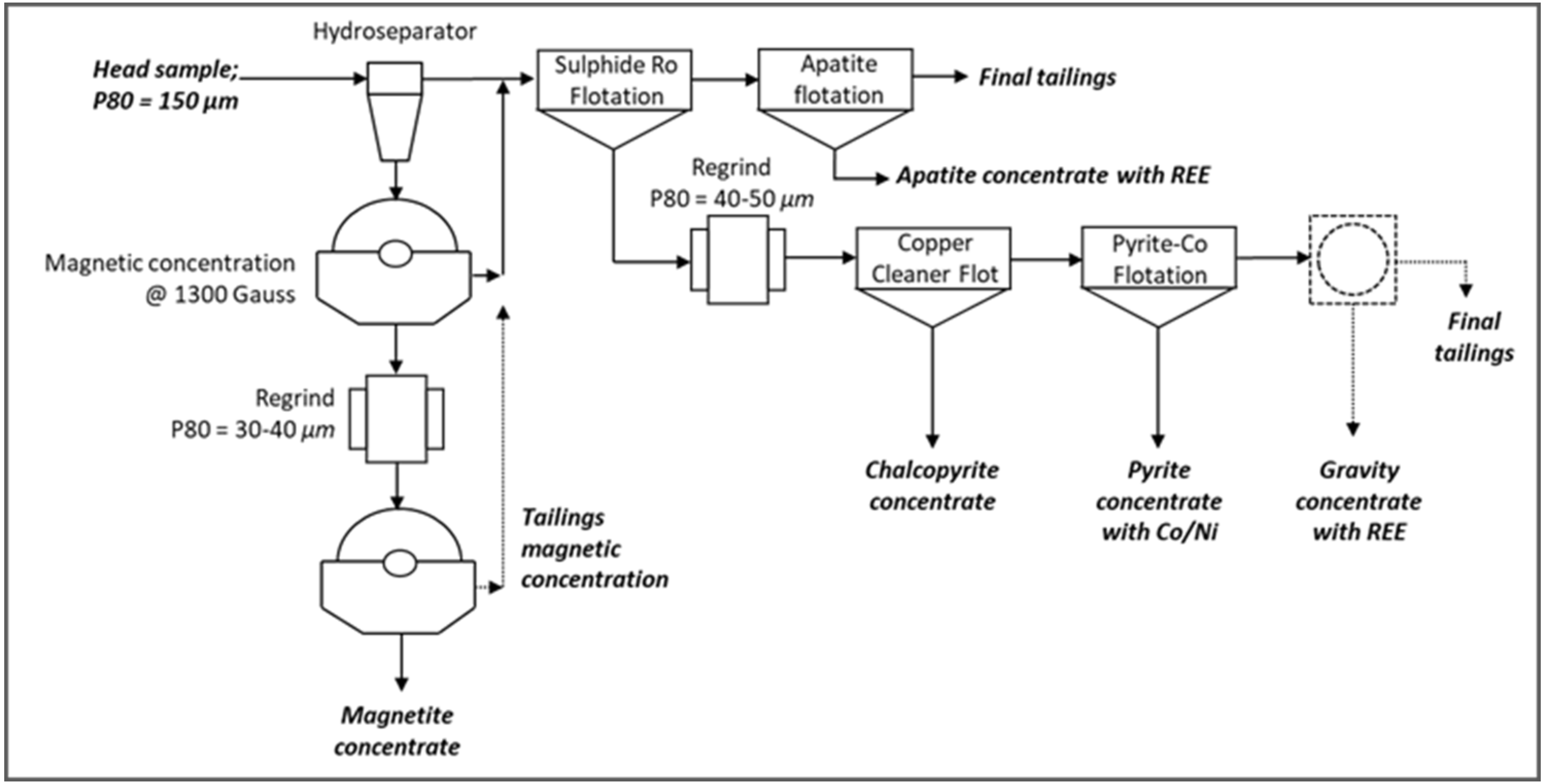



Source: Thesis project Javier Quevedo / IOCG Ore La Estrella, assays done at the University of Tasmania CODES – Centre for Ore Deposit and Earth Sciences



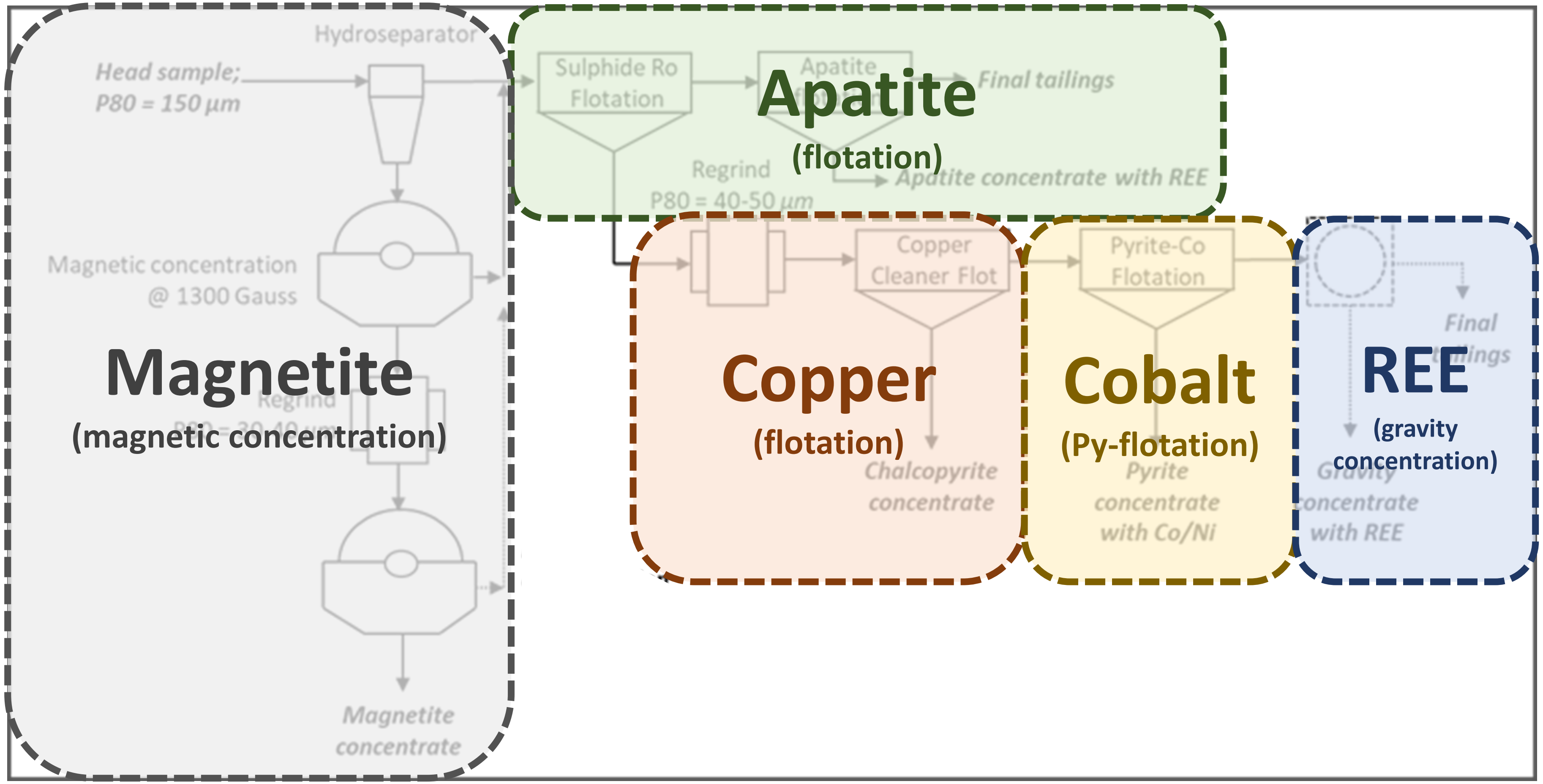
Na23 ppm
Mg24 ppm
Al27 ppm
Si29 ppm
P31 ppm
S34 ppm
K39 ppm
Ca43 ppm
Ti49 ppm
V51 ppm
Cr53 ppm
Mn55 ppm
Fe57 ppm
Co59 ppm
Ni60 ppm
Cu65 ppm
Zn66 ppm
As75 ppm
Se77 ppm
Zr90 ppm
Mo95 ppm
Ag107 ppm
Ag109 ppm
Cd111 ppm
Sn118 ppm
Sb121 ppm
Te125 ppm
Ba137 ppm
Gd157 ppm
Hf178 ppm
Ta181 ppm
W182 ppm
Pt195 ppm
Au197 ppm
Hg202 cps
Tl205 ppm
Pb206 ppm
Pb207 ppm
Pb208 ppm
Bi209 ppm
Th232 ppm
U238 ppm

# La Estrella proposed flowsheet for Co recovery




Source: Townley, Kuyvenhoven (2018)

# La Estrella proposed flowsheet for Co recovery




Source: Townley, Kuyvenhoven (2018)

# Co recovery/grade from low-medium-high Cu IOCG ore

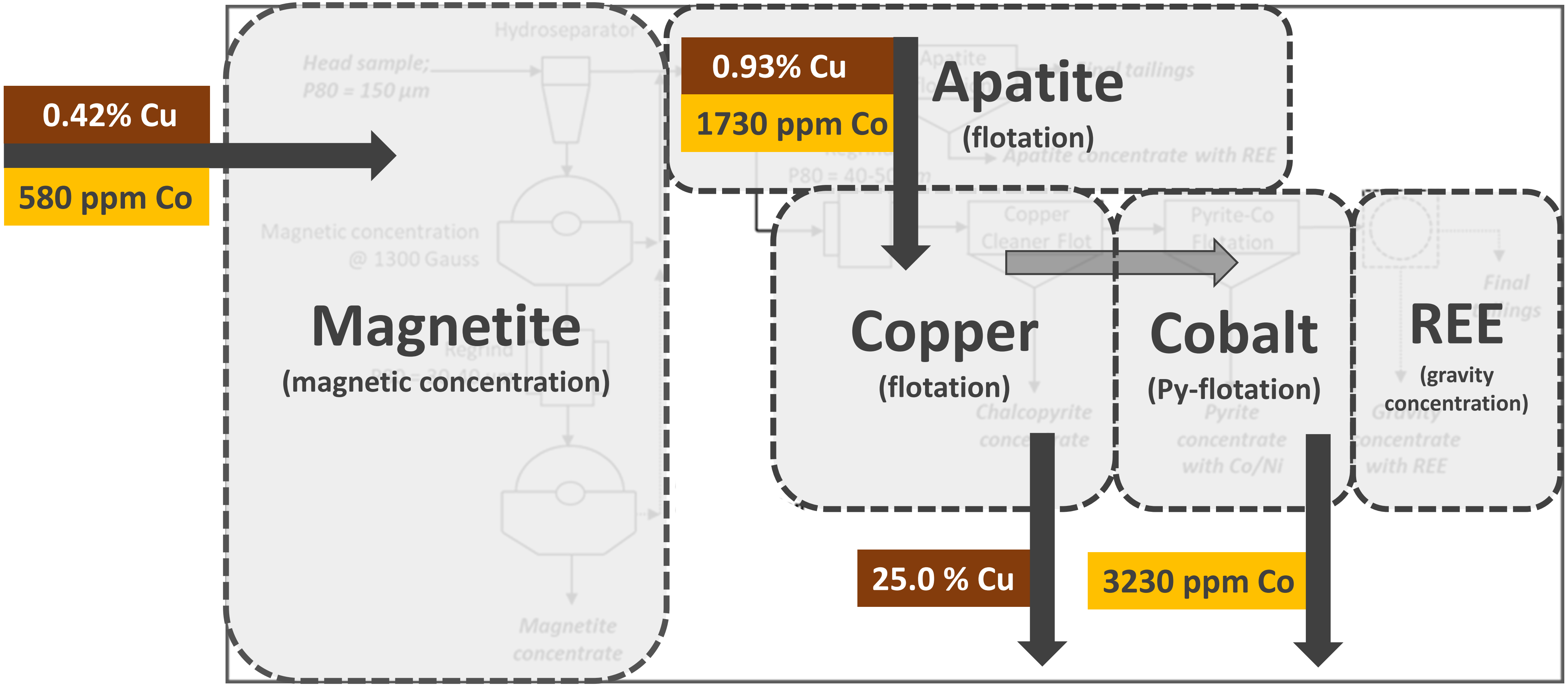
| Product | Element of interest | High grade Cu comp. | | Medium grade Cu comp. | | Low grade Cu comp. | |
|---|---|---|---|---|---|---|---|
| | | Grade | Rec. % | Grade | Rec. % | Grade | Rec. % |
| Copper concentrate | Cu as $CuFeS_2$ | 24.9% | 84 | 25.0% | 83 | 15.5% | 77 |
| Magnetic concentrate | Fe as $Fe_3O_4$ | 69.8% | 57 | 70.7% | 78 | 69.8% | 90 |
| Co-pyrite concentrate | Co as $Fe_xCo_{1-x}S_2$ | 3900 ppm | 86 | 3230 ppm | 77 | 3860 ppm | 44 |
| Co concentration ratio | | 3900 / 1090 = 3.6 | | 3230 / 580 = 5.6 | | 3860 / 320 = 12.1 | |
| Calc. FeS2 grade in Co-pyrite concentrate | | 99.3% | | 91% | | 95.1% | |

| **Sample ID** | **Cu (%)** | **Fe (%)** | **As (ppm)** | **Co (ppm)** | **Ni (ppm)** | **S (%)** |
|---|---|---|---|---|---|---|
| High grade Cu | 0.79 | 41.8 | 210 | 1090 | 1830 | 19.5 |
| Medium grade Cu | 0.42 | 46.4 | 110 | 580 | 1150 | 11.1 |
| Low grade Cu | 0.22 | 55.2 | <30 | 320 | 560 | 4.7 |

**Note: 3% Fe-by-Co replacement would give 15000 ppm Co in pyrite concentrate**

Source: Townley, Kuyvenhoven (2018)

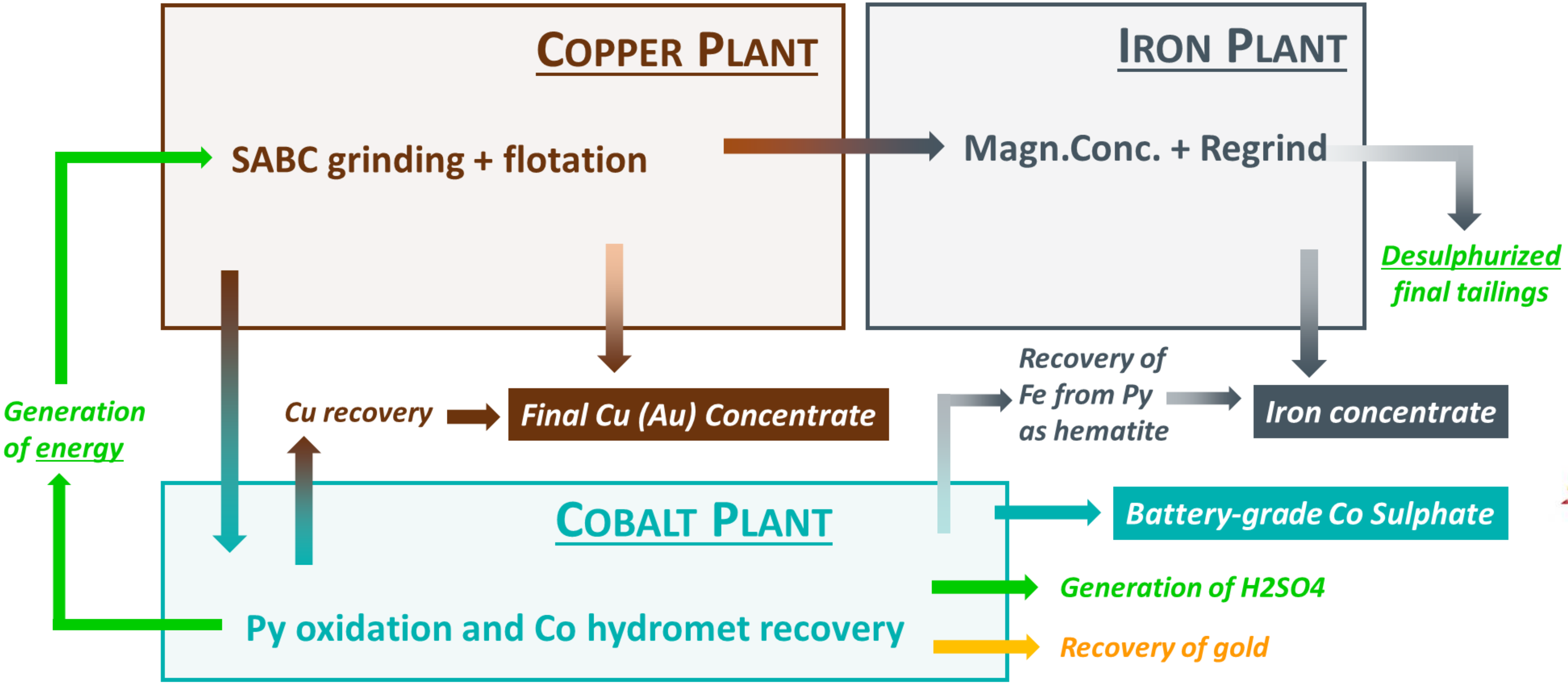
# La Estrella based flowsheet for Co recovery




Source: Townley, Kuyvenhoven (2018)

# Santo Domingo based flowsheet for Co recovery

## (65 ktpd of ore, FS stage)




Source: MSD/Expomin 2021

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# Options for treatment of Co-rich pyrite concentrate

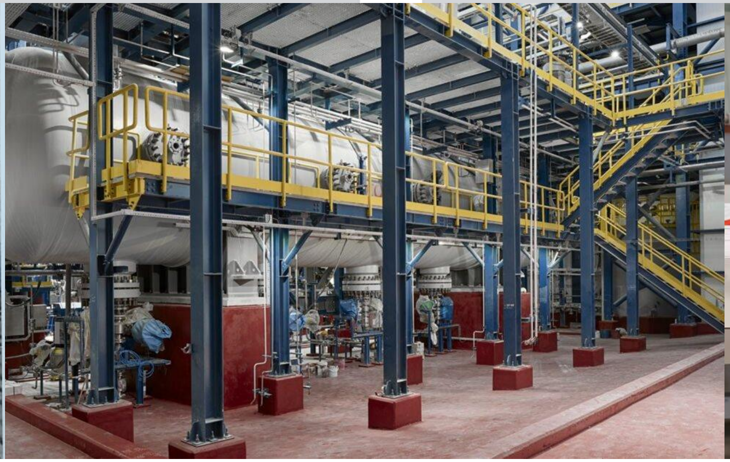
### 1.A Roasting → 1.B Pressure LX

**1.A Roasting**
- Dead roast to oxidize pyrite
- Existing technology
- Process followed by Pressure LX

**1.B Pressure LX**
- Solubilizes all elements
- Existing technology
- Extensive purification required
- Excellent Co recovery

### 2. Bio leach
- Oxidizes pyrite to solubilize cobalt
- Proven as Biocobre® process by Pucobre
- Good Co recovery
- TRL4-5 for cobalt

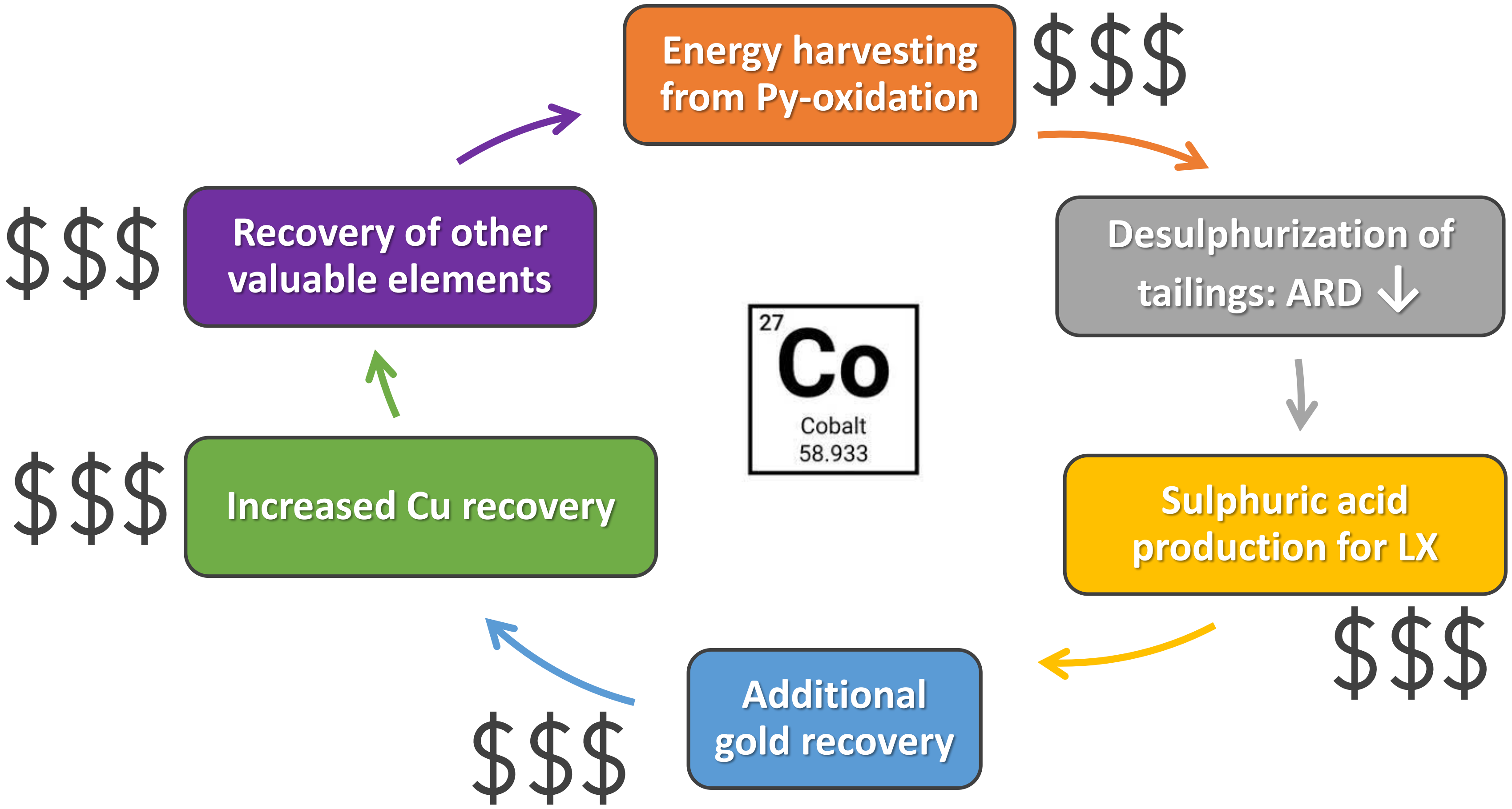
### 3. Acid Leach
- Not proven for Co-applications
- Solution neutralization and handling is big issue
- Less capital intensive




# Cobalt precipitate (hydroxide, carbonate or sulphate)

- Cobalt is precipitated as salt and (usually) shipped to China
- Co SX-EW is technically very complex, and production of Co cathodes is usually avoided by investors

# Secondary benefits from Co recovery

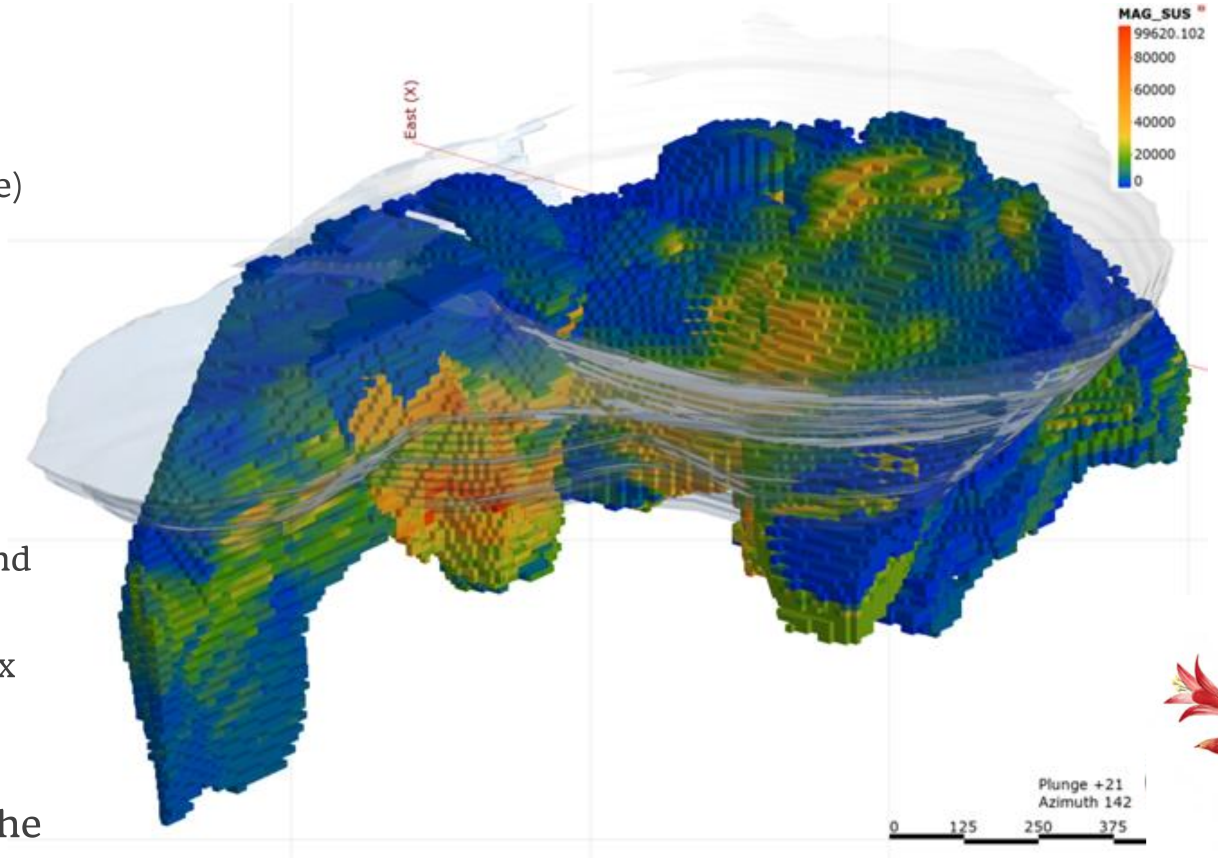



Source: Kuyvenhoven 2022

# Geo-mine-metallurgy of cobaltiferous Cu-ores

- Mine plan optimization for:
  - Copper-equivalent, based on
    - CuTOT, $Fe_3O_4$, Gold, Cobalt, REE (revenue)
    - Neutral tailings (environmental)
    - Energy generation (OPEX)
- Current challenges in-plant related to pyrite activation
  - Pyrite activation happens
  - Activated Py dilutes Cu concentrate grade
  - Aggressive rejection of Py is expensive (lime) and causes lower Cu recoveries
  - Complete mitigation of Py activation is complex
- When cobalt is present and recovered…

  …very strict pyrite rejection impacts less because copper would still be recovered in the cobalt plant




Source: MSD/Expomin 2021

# Reference cases for Co-from-Py process design

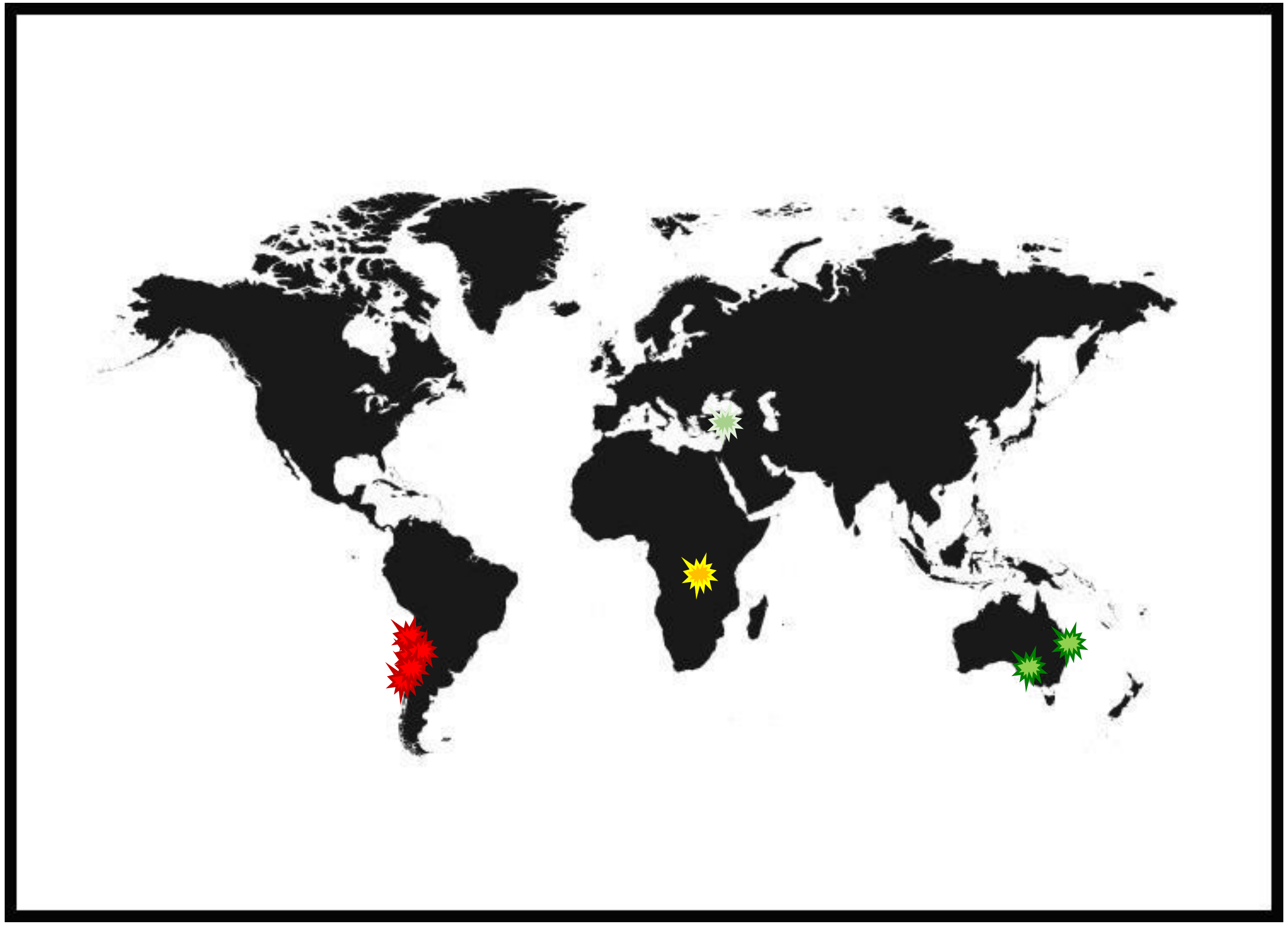
**Santo Domingo, Chile**
Cu-Fe concentrator

**Manto Verde, Chile**
Cu concentrator

**Biocobre, Chile**
Biocobre® conc. LX

**Dominga, Chile**
Fe-Cu concentrator

**El Espino, Chile**
Cu concentrator



**Eti Bakir, Mazidagi, Turkey**
Pyrite concentrate roast
(OPERATION)

**Walford Creek, Australia**
Pyrite concentrate heap leach

**Thackaringa, Australia**
Py thermal decomposition,
then pyrrhotite LX

# Final remarks

- Apart from geological reasons such as consistently decreasing copper grades, there are geopolitical and environmental drivers that determine the feasibility and attractiveness of cobalt recovery in IOCG ores
- The individual metallurgical processes for recovery of different commodities – such as Cu, Co, Fe3O4, Au, REE and/or others – are tightly interrelated and strongly dependent on geochemical and mineralogical characterization of the ore
- The secondary benefits for Co recovery – such as energy generation, desulphurization of tailings and additional recovery of copper and gold – have the potential to outweigh the primary benefit of Co recovery (which is related to the market value of cobalt)
- Last but not least: The treatment of cobaltiferous pyrite concentrate could very well take place in a centralized, regional facility, as is the case for centralized copper smelters and regional water desalination plants

## MDE Minerals Consulting

# Thank you

29th International Applied Geochemistry Symposium

**Romke Kuyvenhoven**, Viña del Mar, Chile, October 2022

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