Magnetic Particles Extracted from a Deep-Sea Manganese Nodule: Preliminary Observations

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Manganese Nodules (AKA Polymetallic or Ferromanganese Nodules)

U.S. Geological Survey

- Concretions of oxide layers around a central nucleus
- Found globally in abyssal plains
- Currently being considered as a mining resources

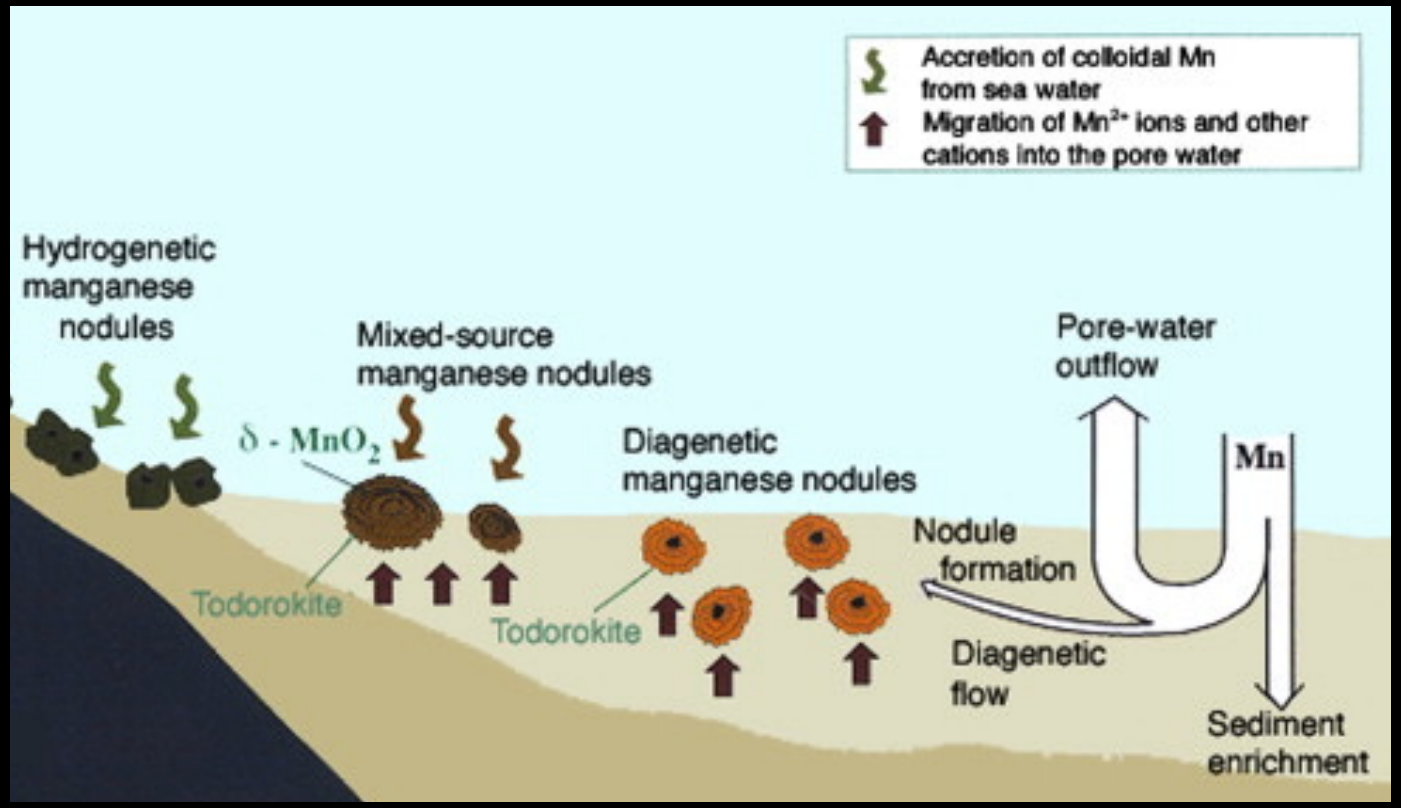
(Kuhn et al., 2017; Glasby et al., 2006; Kuhn et al., 2012;, Dymond et al., 1984;, Knobloch et al., 2017;, Cronan et al., 1976, Hein et al., 2020)

Formation

Hydrogenetic Layers:

- Few mm per million years
- Direct accretion around a nucleus
- Mn2+, Mn4+, Fe2+, Fe3+ and associated elements (Fe, Cu, Ni, Co etc.)

  (Koschinsky et al., 2003; Halbach et al., 1988; Koschinsky and Halbach, 1995; Hein et al., 2020)

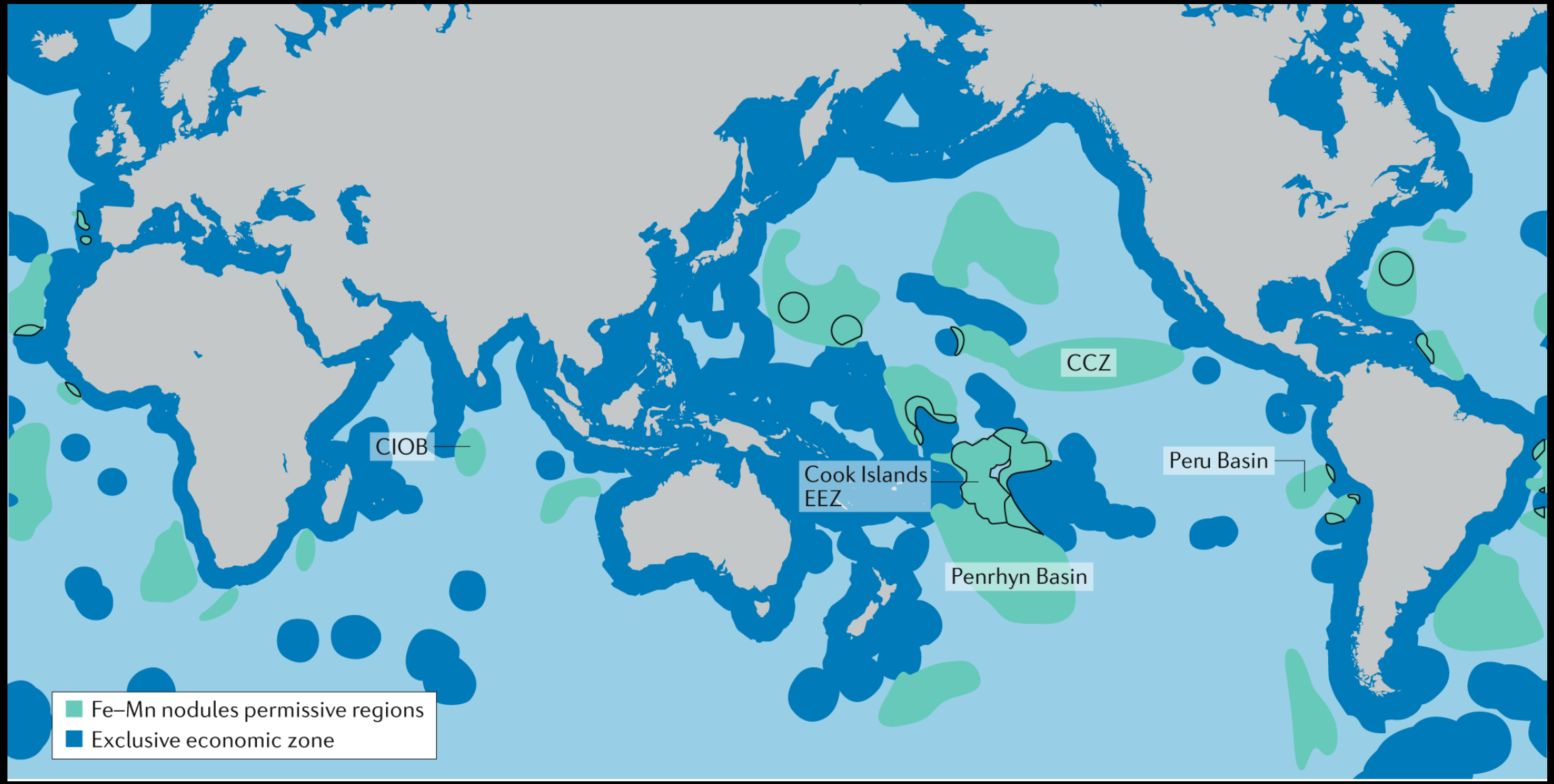


Hein et al., 2020

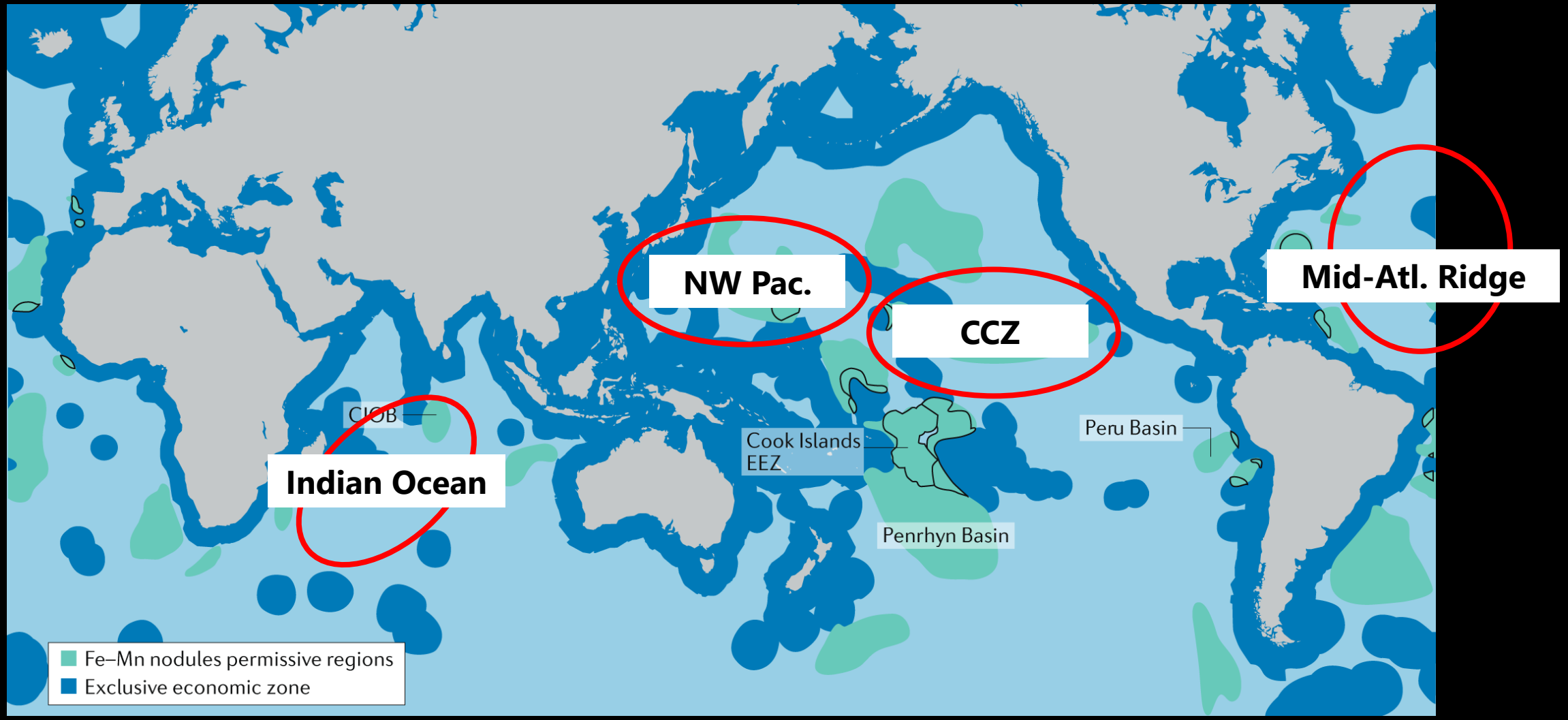
Diagenetic Layers**:**

- 10s of mm per million years
- Organic matter oxidation reduces/dissolves Mn oxides and elements (Ni, Cu, etc.)
- Elements re-oxidized by ocean water after diffusing upwards to sediment surface (Halbach et al., 1982; Dymond et al., 1984; Hein et al., 2020);
- Enhanced Mn/Fe ratios and elevated concentrations of Mn, Fe, Cu, Ni, and Co
- (Kuhn et al., 2017; Dymond et al., 1984; International Seabed Authority; Halbach et al., 1982; Halbach et al., 1988; Hein et al., 2020)

- Remaining on substrate surface, accumulating higher concentration interplanetary material (such as spheres)



Hein et al. 2020 and *Hein et al., 2013*.



Regions currently contracted to be explored by the International Seabed Authority (International Seabed Authority). After *Hein et al. 2020* and *Hein et al., 2013*. Nodule exploration regions include NW Pac., parts of Indian Ocean, and CCZ

Nodules and Deep-Sea Mining

- The Clarion-Clipperton Zone nodules are estimated to contain:
  - **270+ megatons Ni**
  - **40+ megatons of Co**
  - other critical metals and REES
- Several time greater than land-based resources/reserves (Hein and Koschinsky, 2014: Lusty et al., 2018; Hein et al., 2020)

Element	Clarion-Clipperton zone (CCZ)	Global reserves and resources on land[b]	Global reserves on land
Manganese (Mn)	5992	5200	630
Copper (Cu)	226	1000+	690
Titanium (Ti)	67	899	414
Rare earth oxides	15	150	110
Nickel (Ni)	274	150	80
Vanadium (V)	9.4	38	14
Molybdenum (Mo)	12	19	10
Lithium (Li)	2.8	14	13
Cobalt (Co)	44	13	7.5
Tungsten (W)	1.3	6.3	3.1
Niobium (Nb)	0.46	3	3
Arsenic (As)	1.4	1.6	1
Thorium (Th)	0.32	1.2	1.2
Bismuth (Bi)	0.18	0.7	0.3
Yttrium (Y)	2	0.5	0.5
Platinum group metals	0.003	0.08	0.07
Tellurium (Te)	0.08	0.05	0.02
Thallium (TI)	4.2	0.0007	0.0004

Clarion-Clipperton Zone nodule resource estimates compared to terrestrial reserve base (US Geological Survey, 2009) and terrestrial resources (US Geological Survey, 2019) from *Visbeck and Gelpke* (2014) after *Kuhn et al., 2017*.

Environmental Implications

- Methods of processing being developed to help mine and process manganese nodules more sustainably (such as in Sommerfeld et al., 2018).

Ecosystem Impacts:

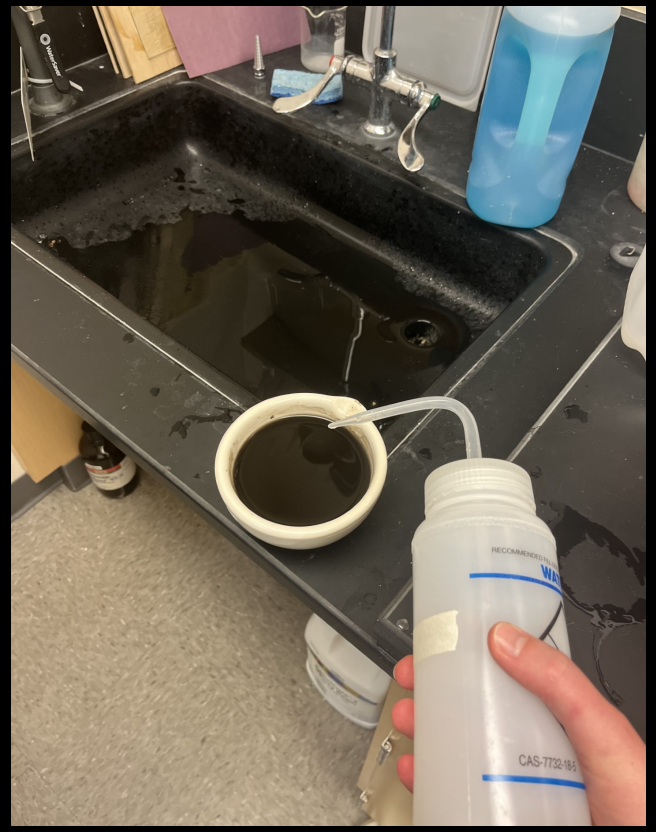
- Nodules often act as a substrate for seafloor-dwelling organisms (Purser et al., 2016)
- The extraction of nodules will cause sediment pollution in the water column (Paul et al., 2018)

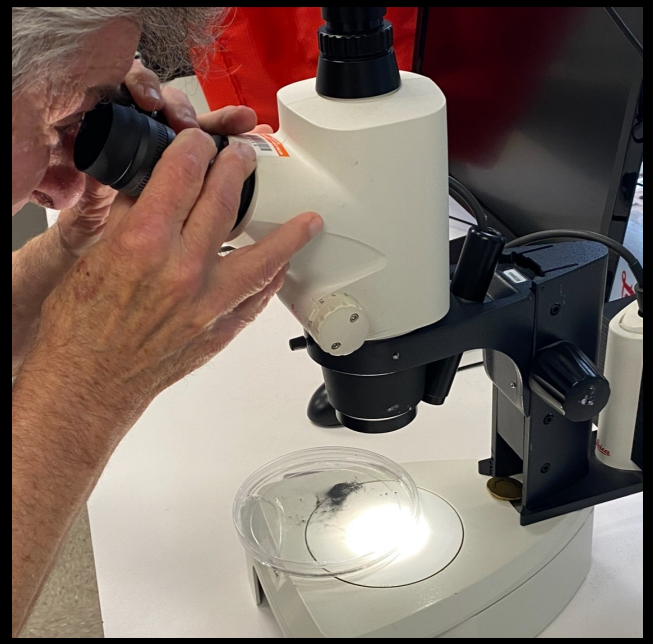
These and other issues within the mining process should be considered and their impacts minimized before substantial extraction takes place.

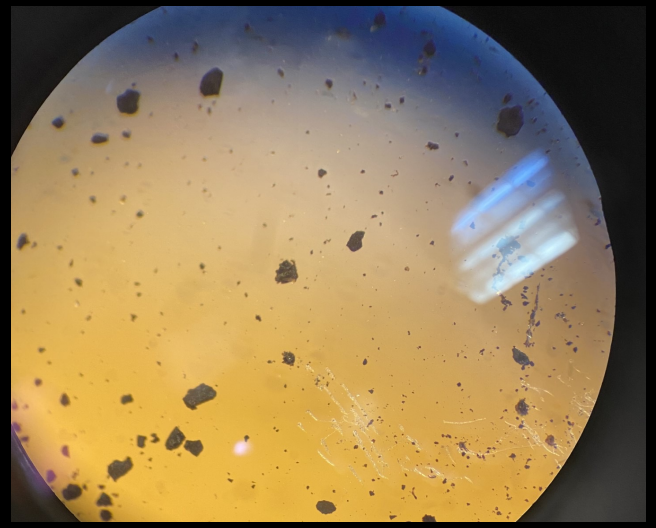
Project Purpose

- Understand the magnetic fractions of manganese nodules
  - micrometeorite spheres
  - Ti-Fe oxide mineral
  - metallic Ni and Fe particles

- Discuss Implications
  - What do our analyses say about formation?







Methodology

1) Obtained several nodules from Pacific and Atlantic Oceans

2) Ground the nodule using porcelain mortar and pestle

3) Decant light material

4) Use cellophane-wrapped magnet to extract magnetic fraction

5) SEM/EDS Analysis

Sample “Pacific B” (NMNH 116492-60 DH 6)

Mass/Dimensions: 18.23 g; 3 cm x 4 cm

Location: 21^0 21’ 00” N, 114^0 06’ 00” W (Rancinelli & Perkins, 1973)

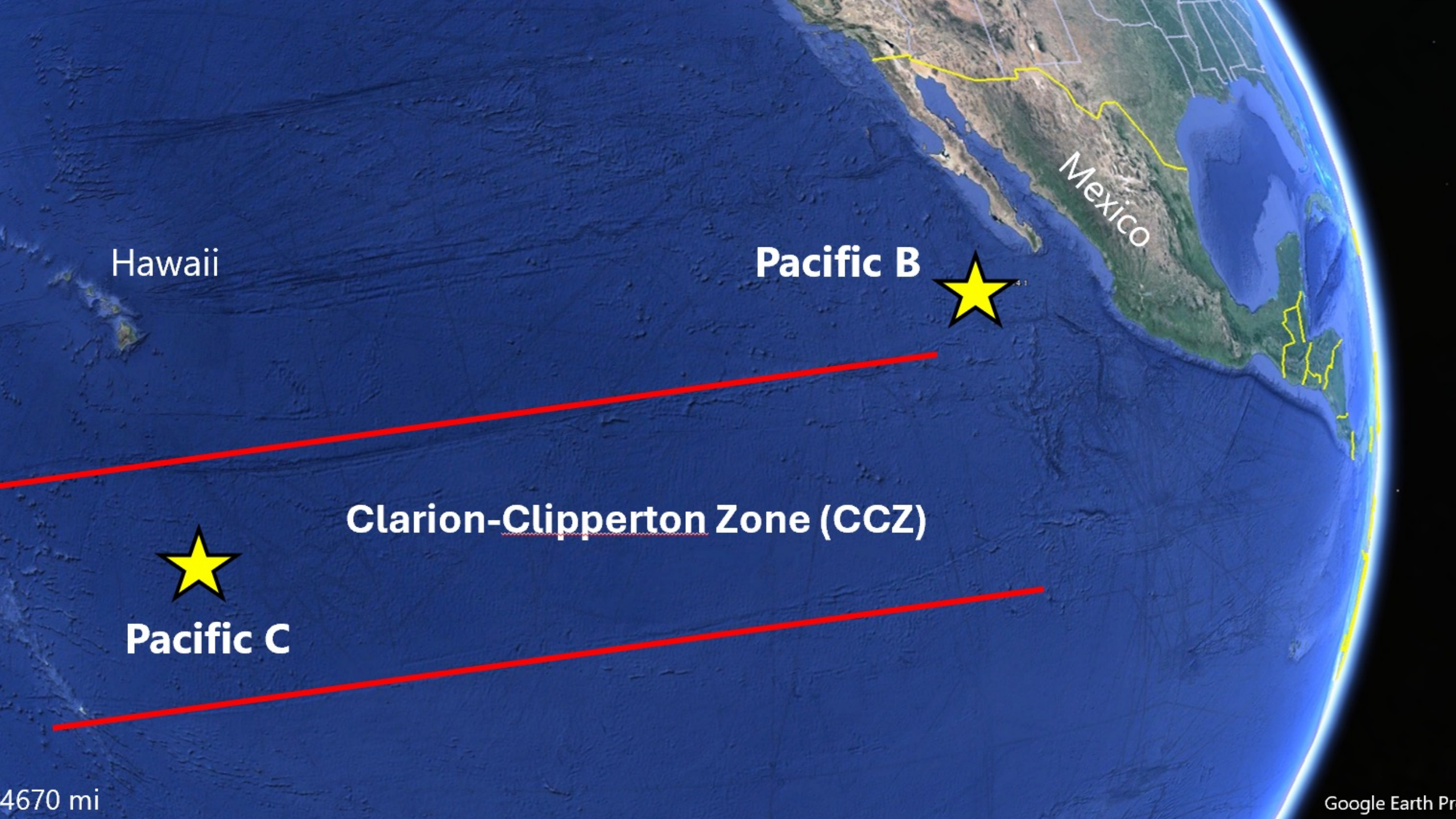
- Off the coast of the Baja California Peninsula (California Seamount Province)
- Just northeast of the CCZ

Sample “Pacific C” (NMNH 116526-33 Dj41)

Mass/Dimensions: 14.40 g; 3.5 x 2 cm

Location: 9^0 22’ N, 151^0 28’ 4” W;

- In the Southwest region of the CCZ


Hawaii
Pacific B
Mexico
Clarion-Clipperton Zone (CCZ)
Pacific C
4670 mi
Google Earth Pr

Preliminary Results:

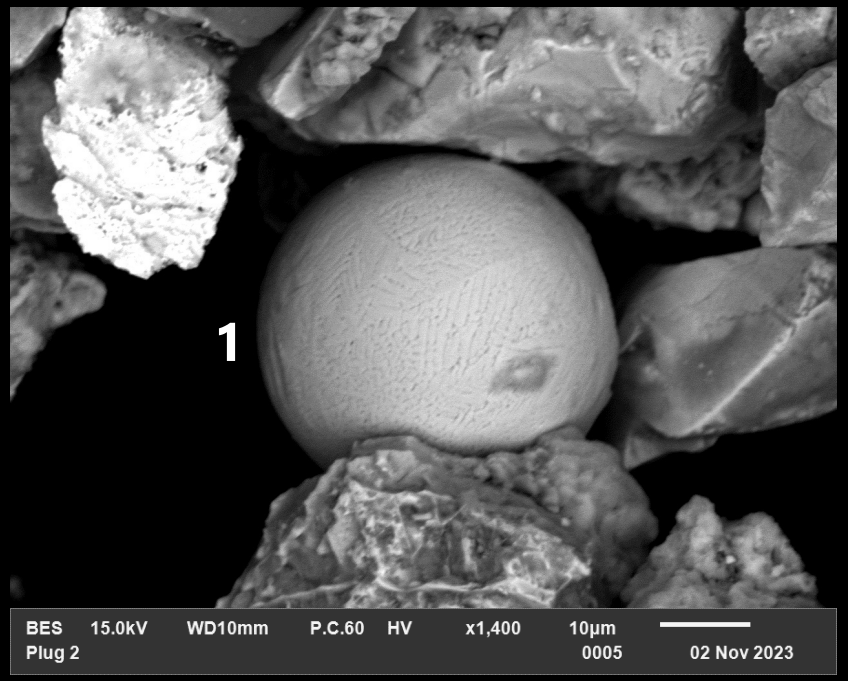
Pacific B Nodule

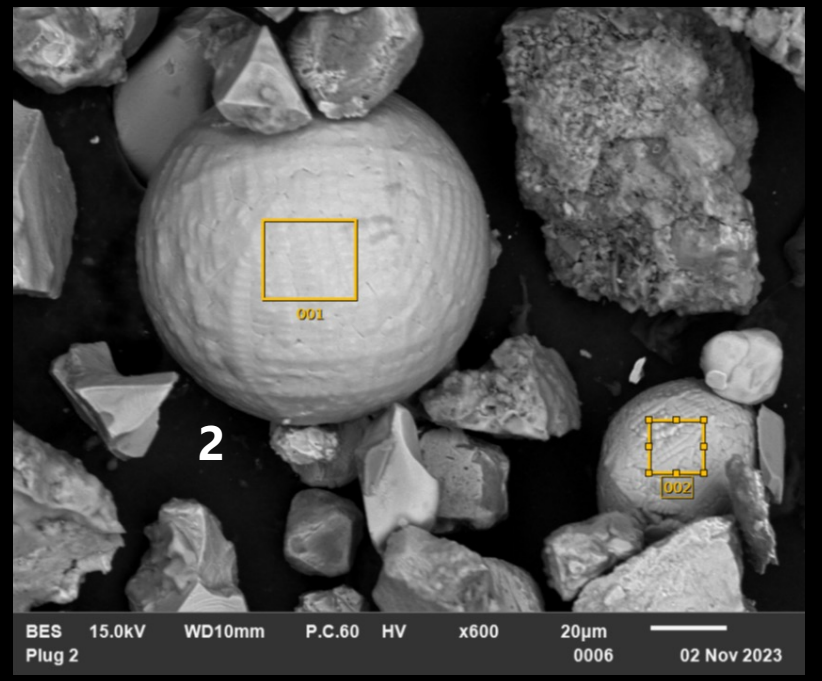
- 9 Spheres (4 each plug, 1 in cross section)
- Ti-Fe Oxide (Subhedral)
- Metallic Nickel Particles

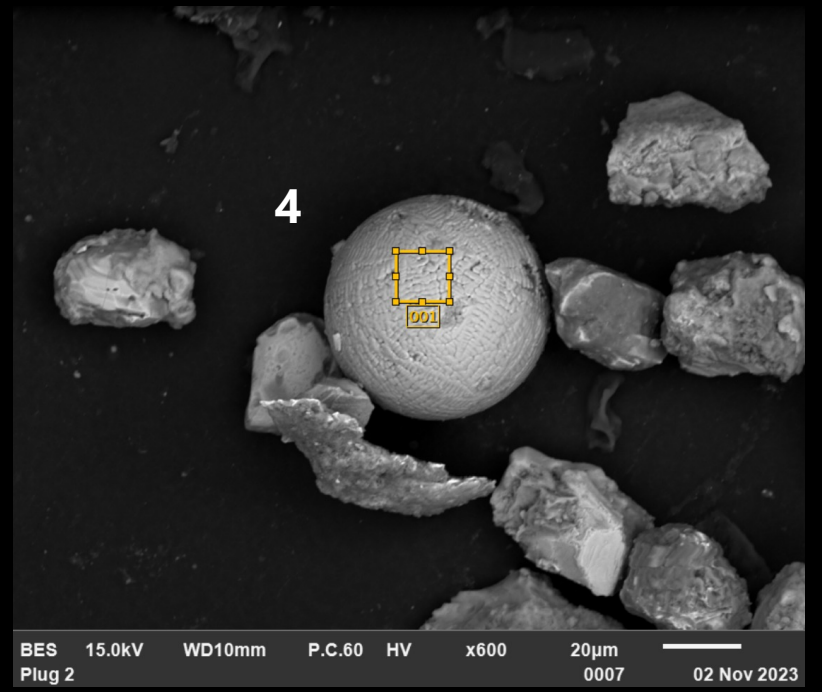
Pacific C Nodule (within CCZ)

- No spheres
- Fe Oxides, Ti-Fe Oxide
- Metallic Ni, Fe, and Ni-Fe Particles

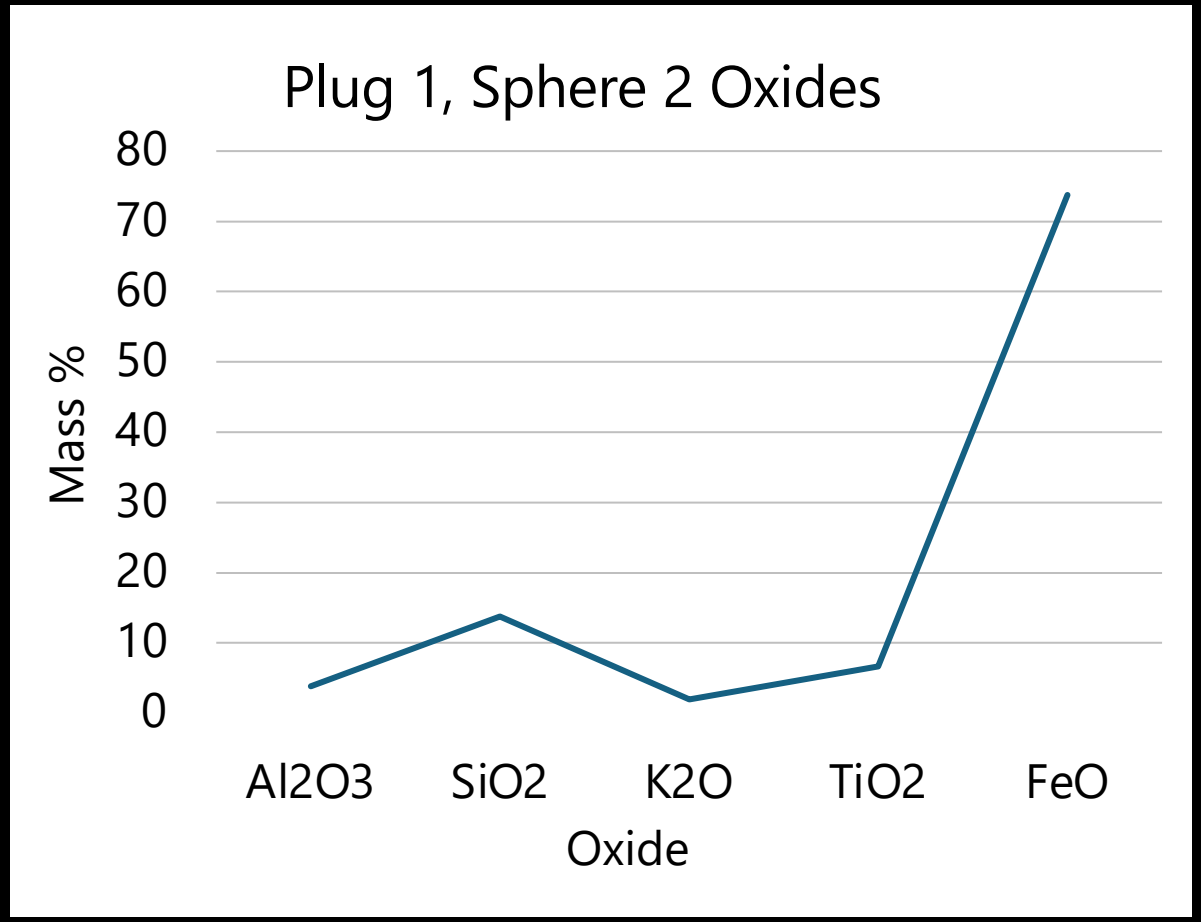
Pacific B Spheres

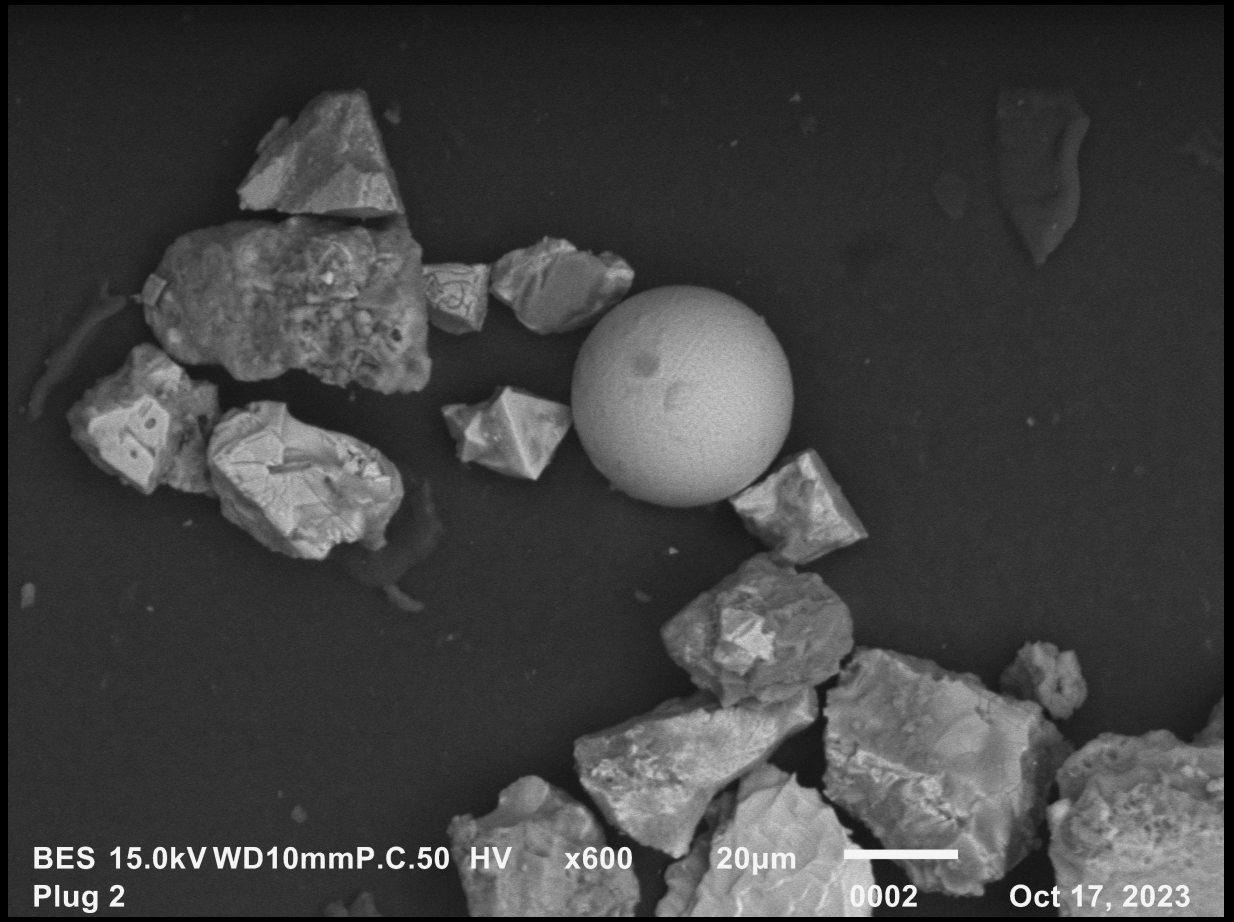




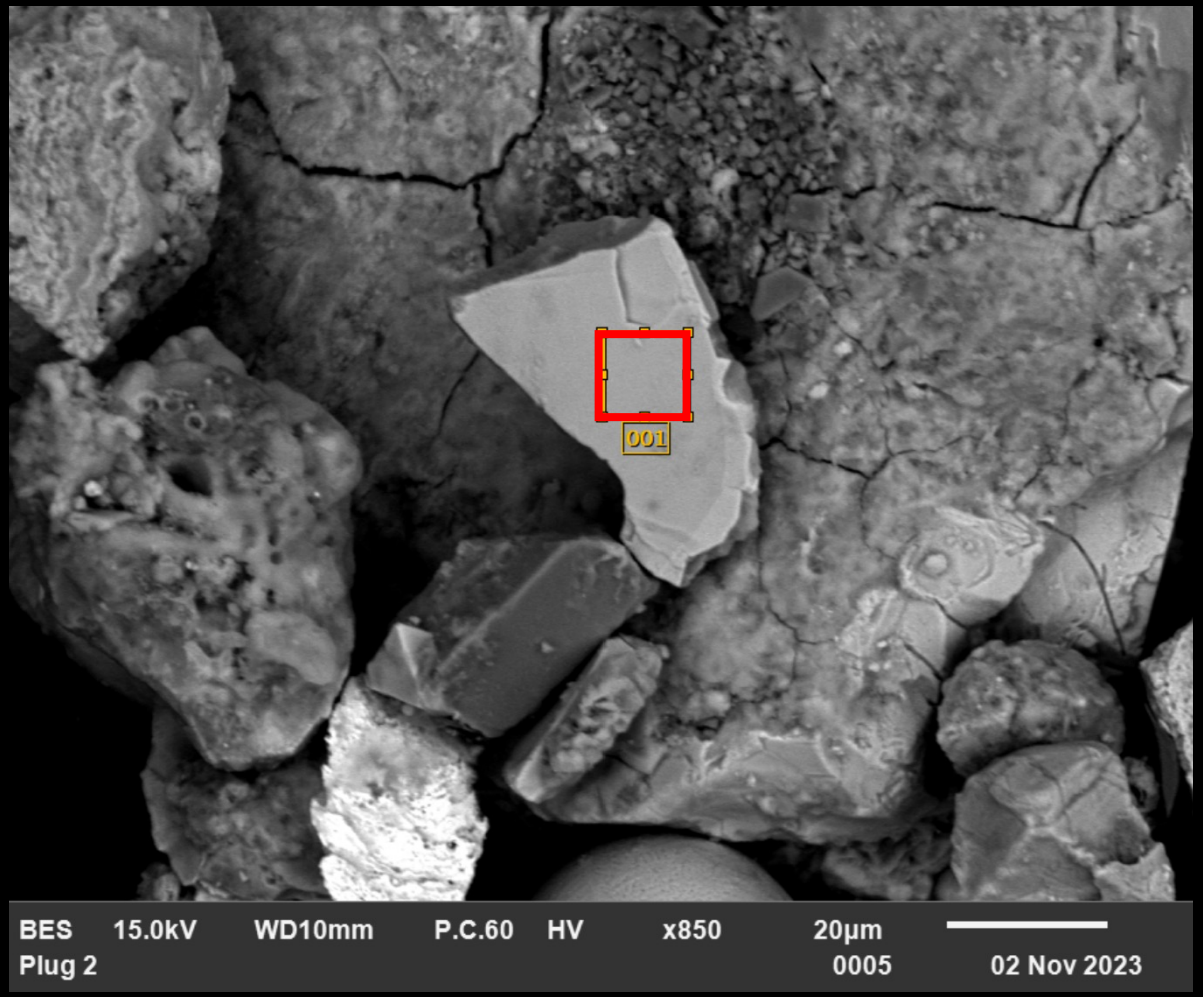


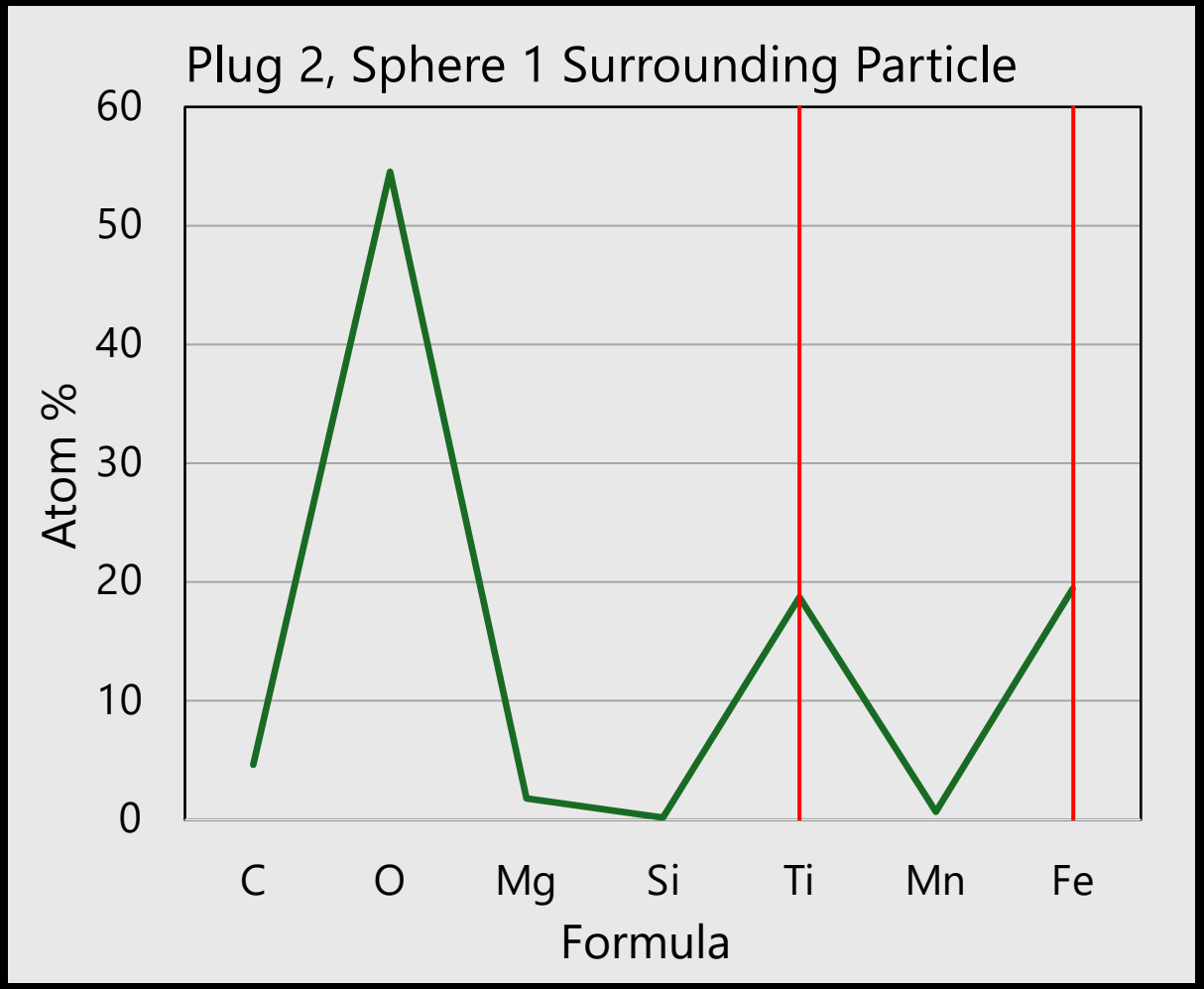
Sphere Composition



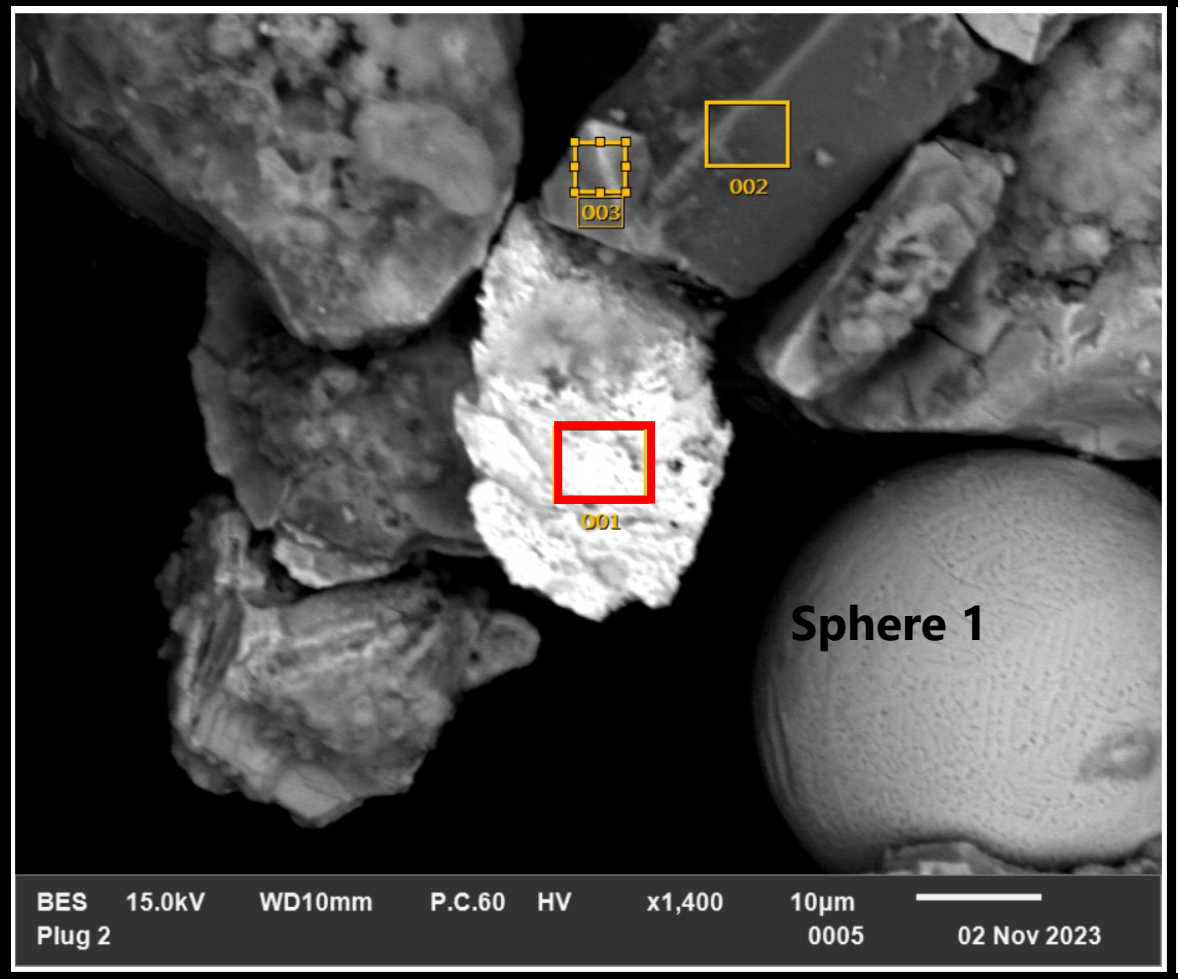


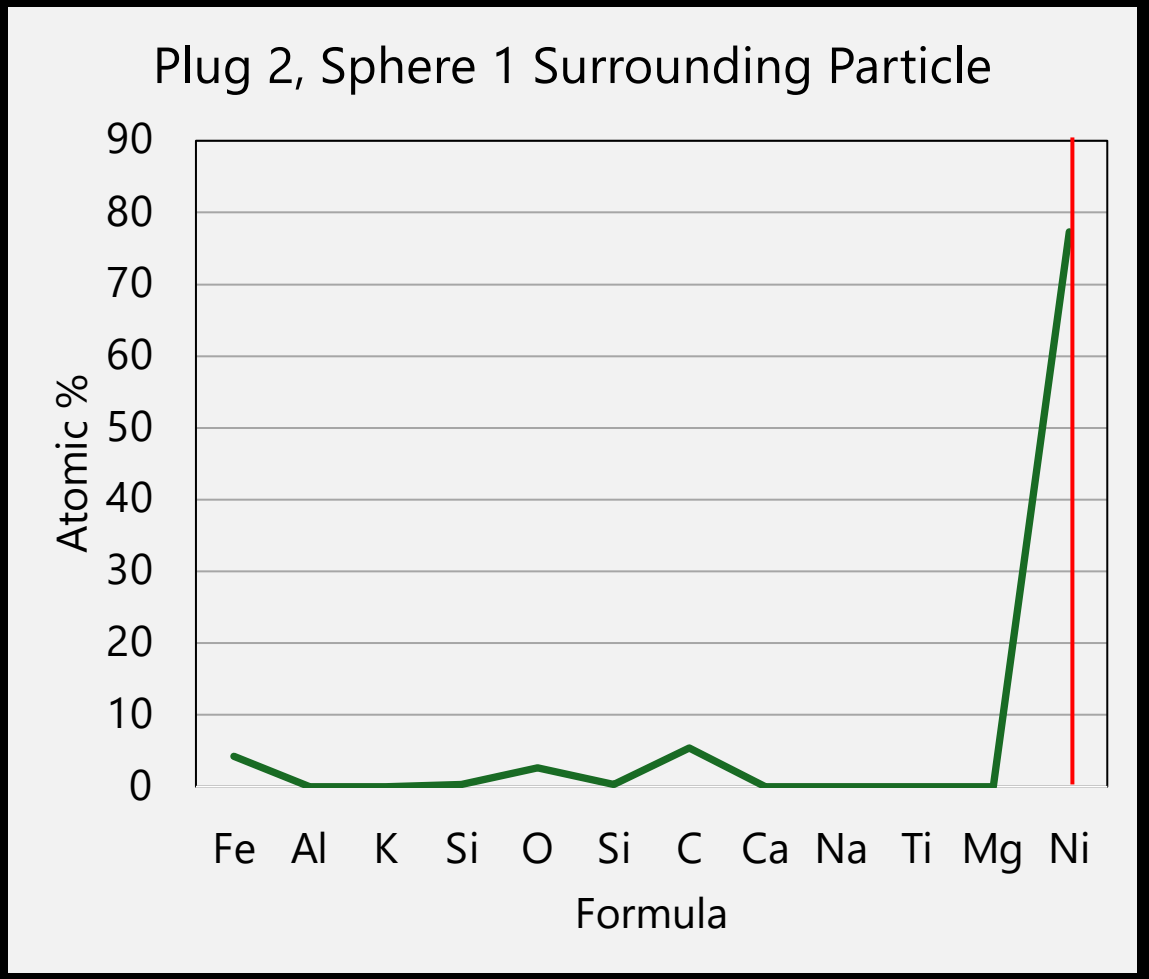
Pacific B: Ti-Fe Oxide Particle



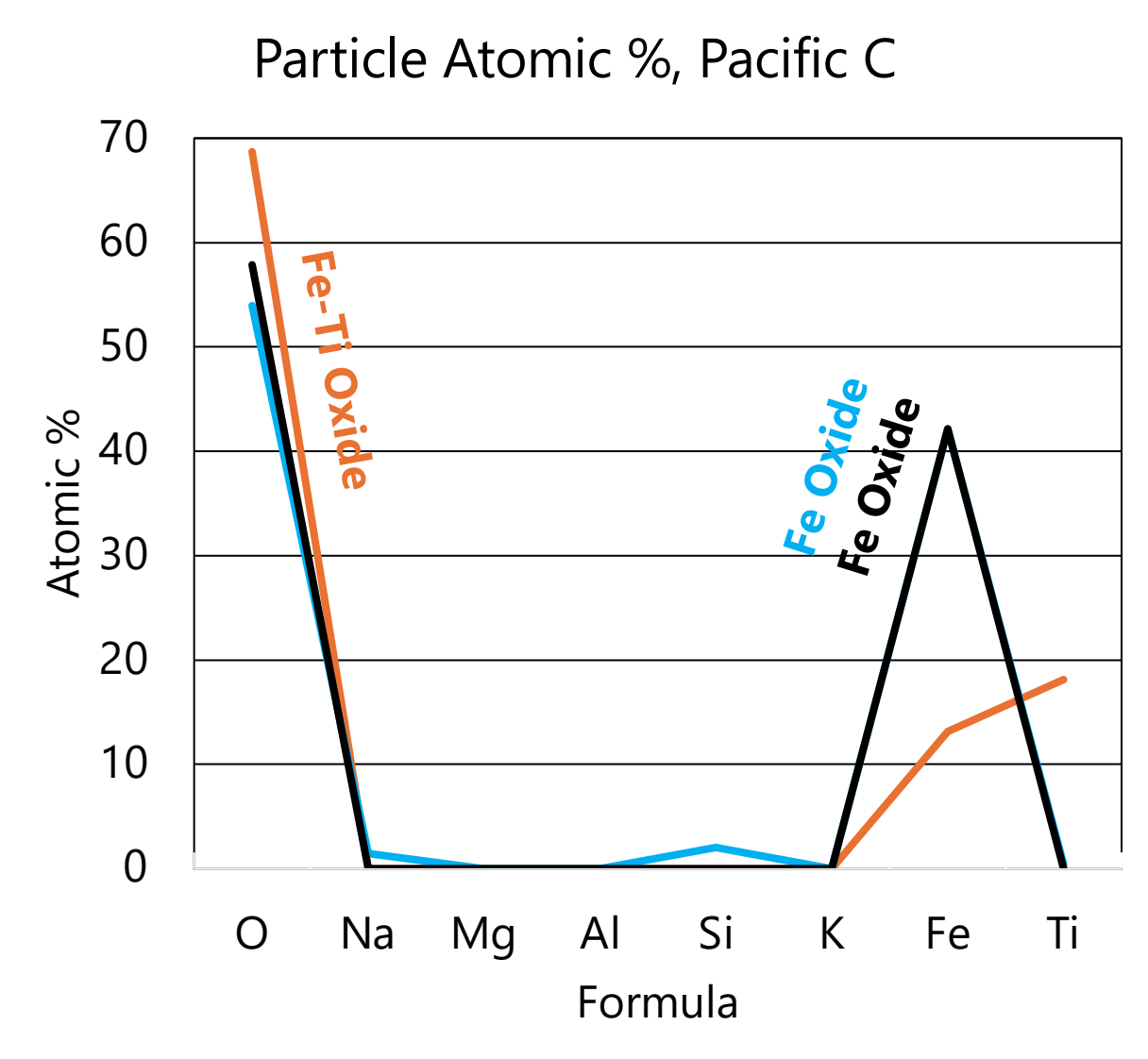


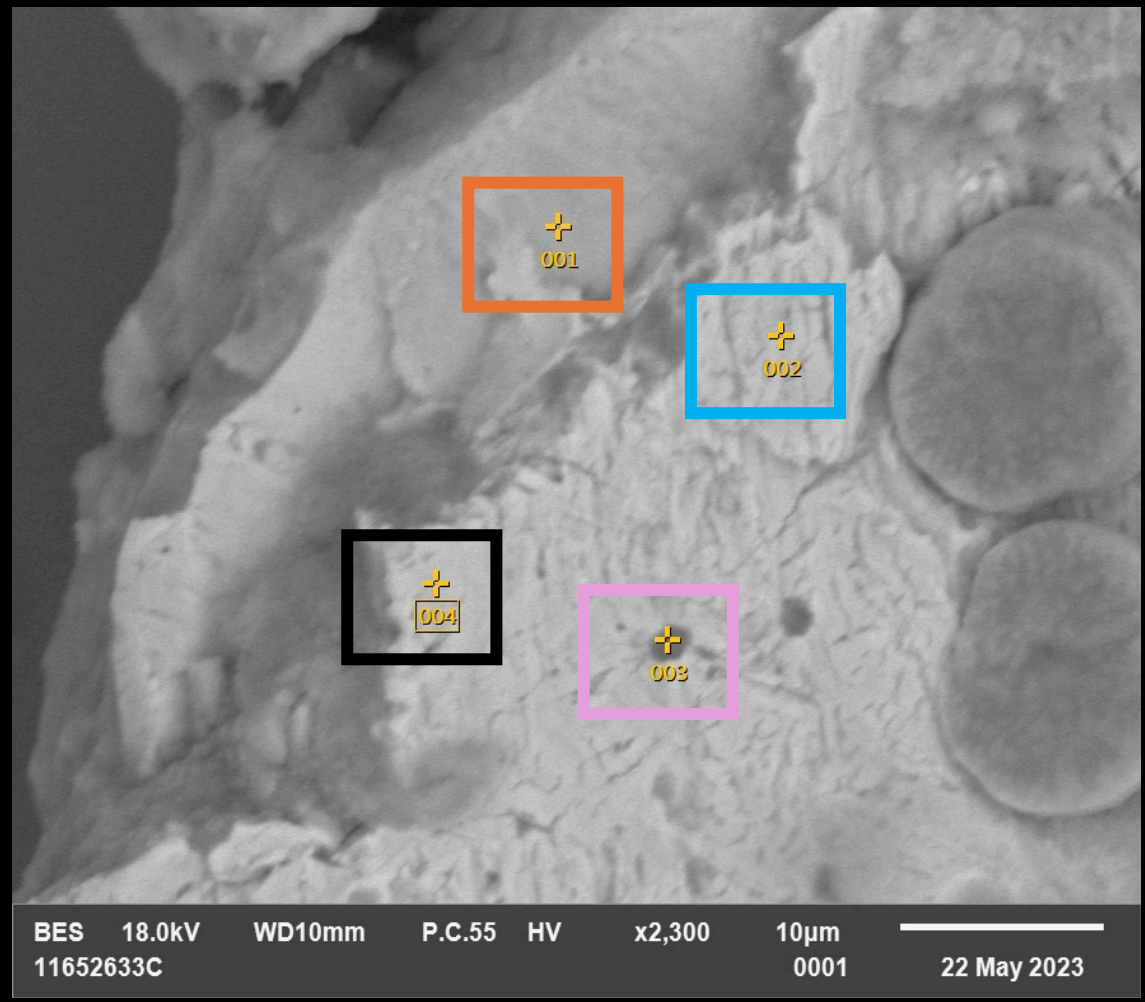
Pacific B: Metallic Ni Particle



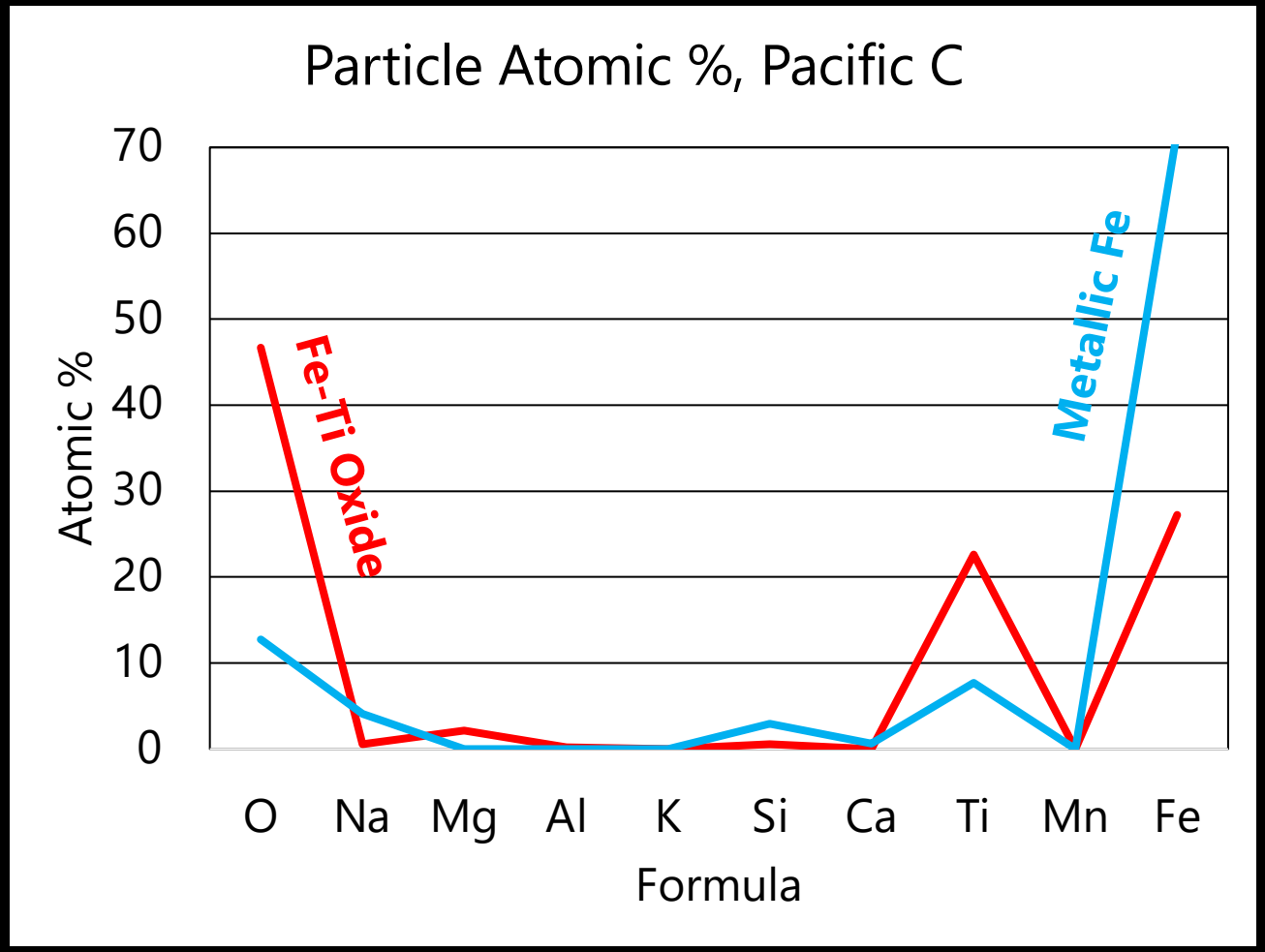


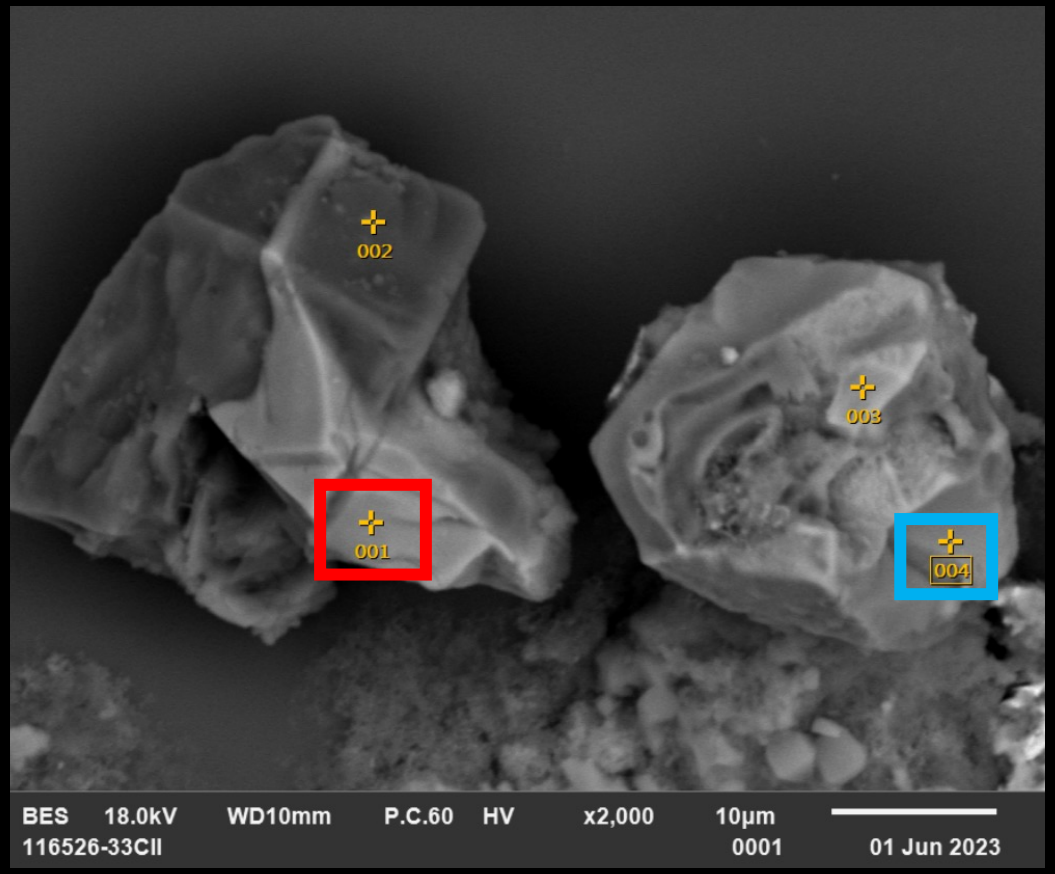
Pacific C: Particle: Fe-Oxides and Fe-Ti Oxides



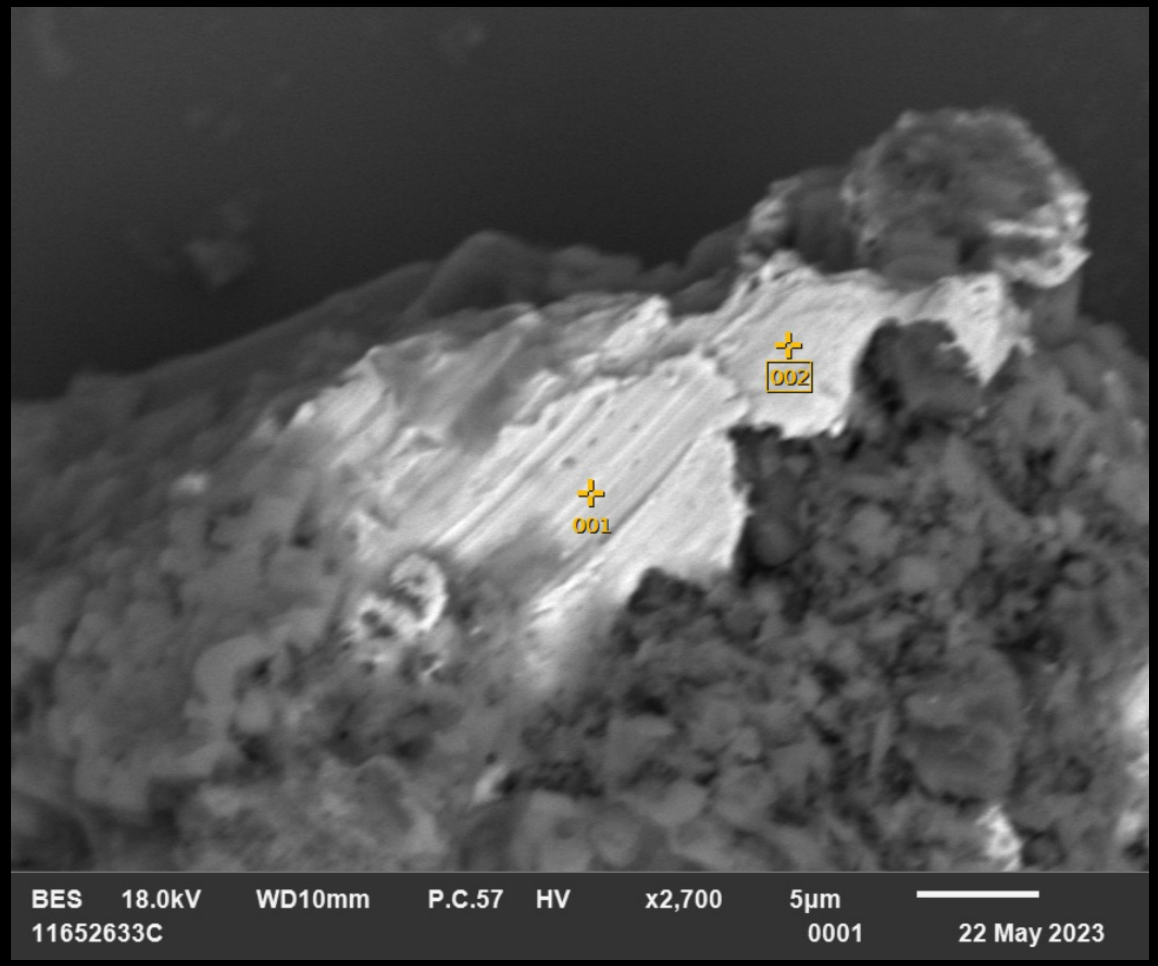


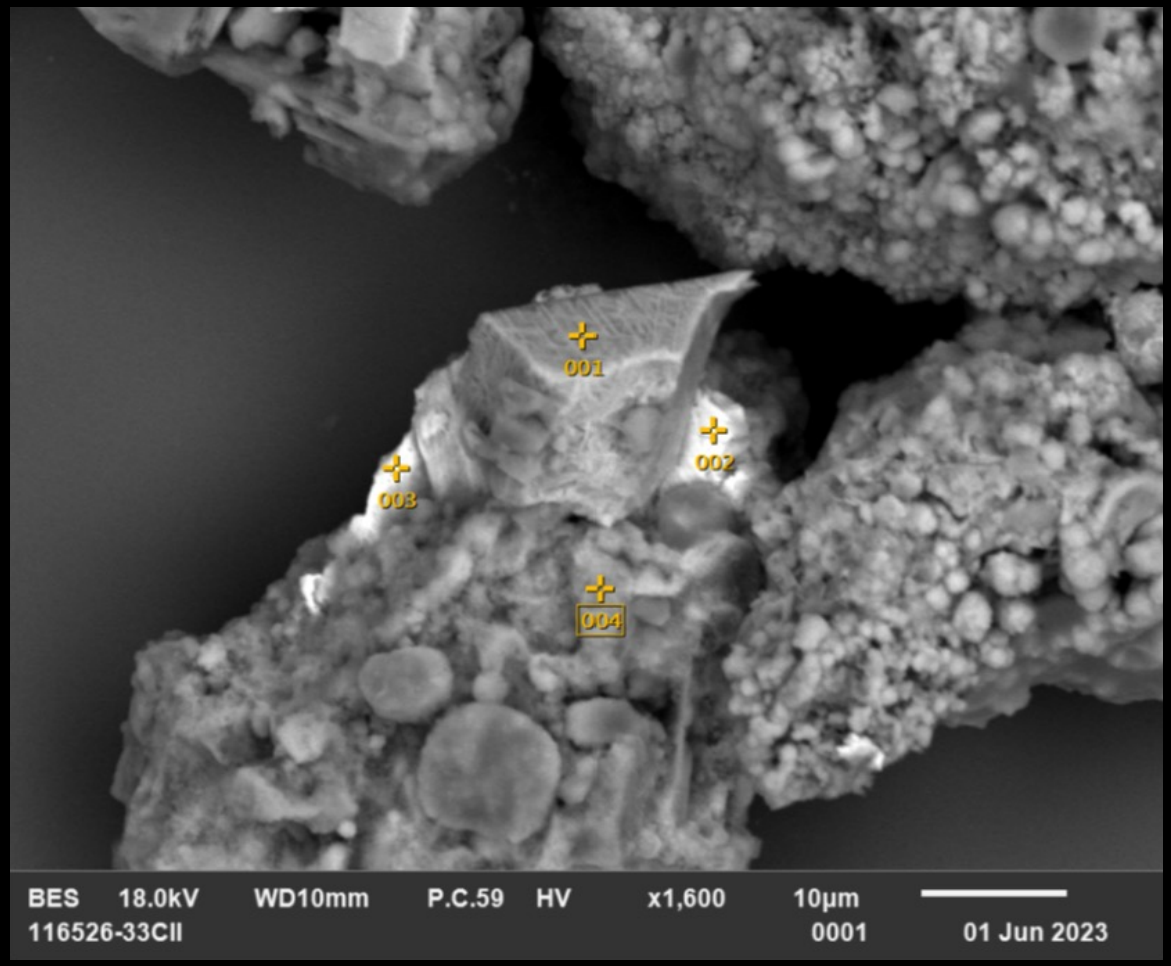
Pacific C: Fe-Ti Oxide, Metallic Fe



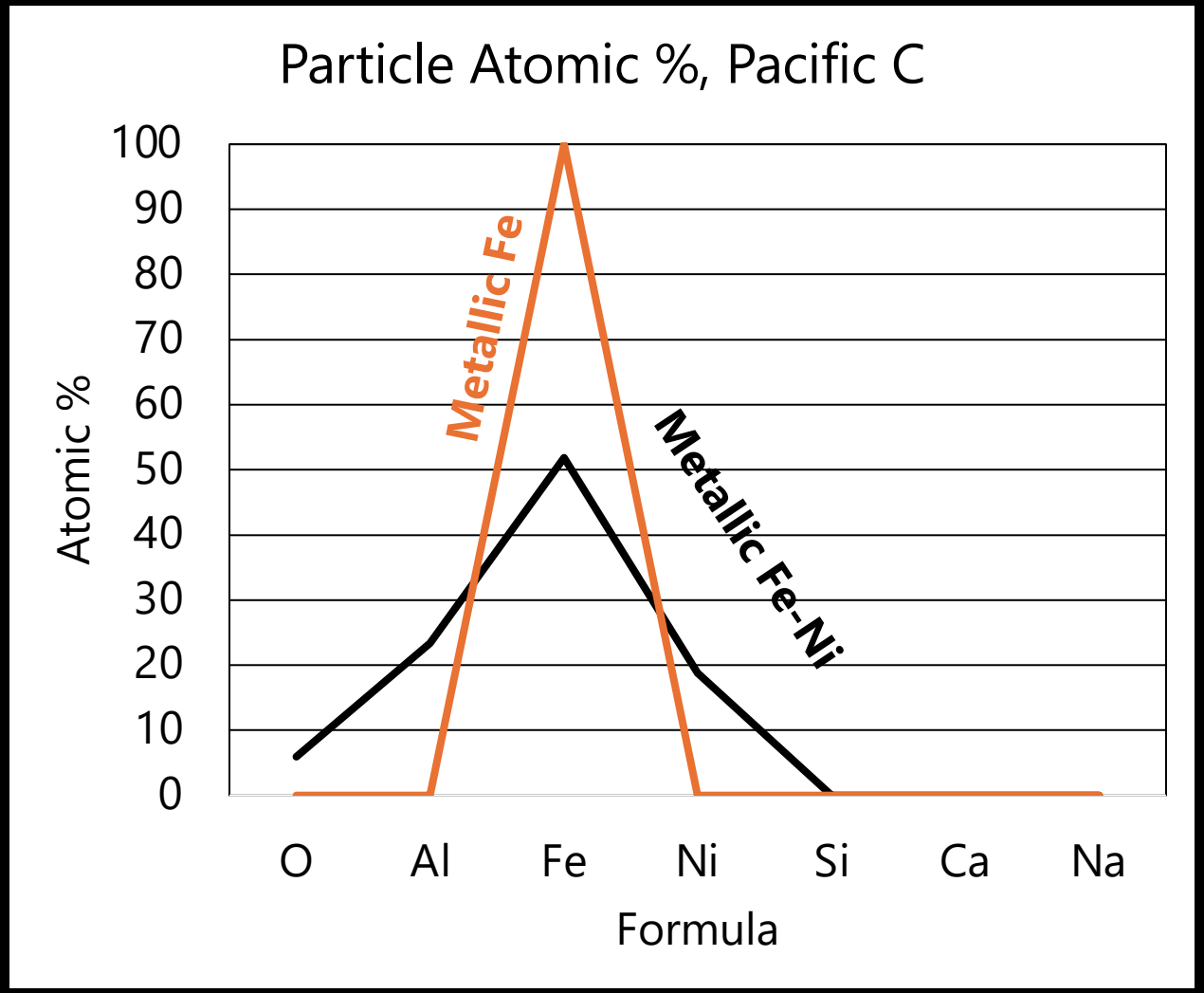


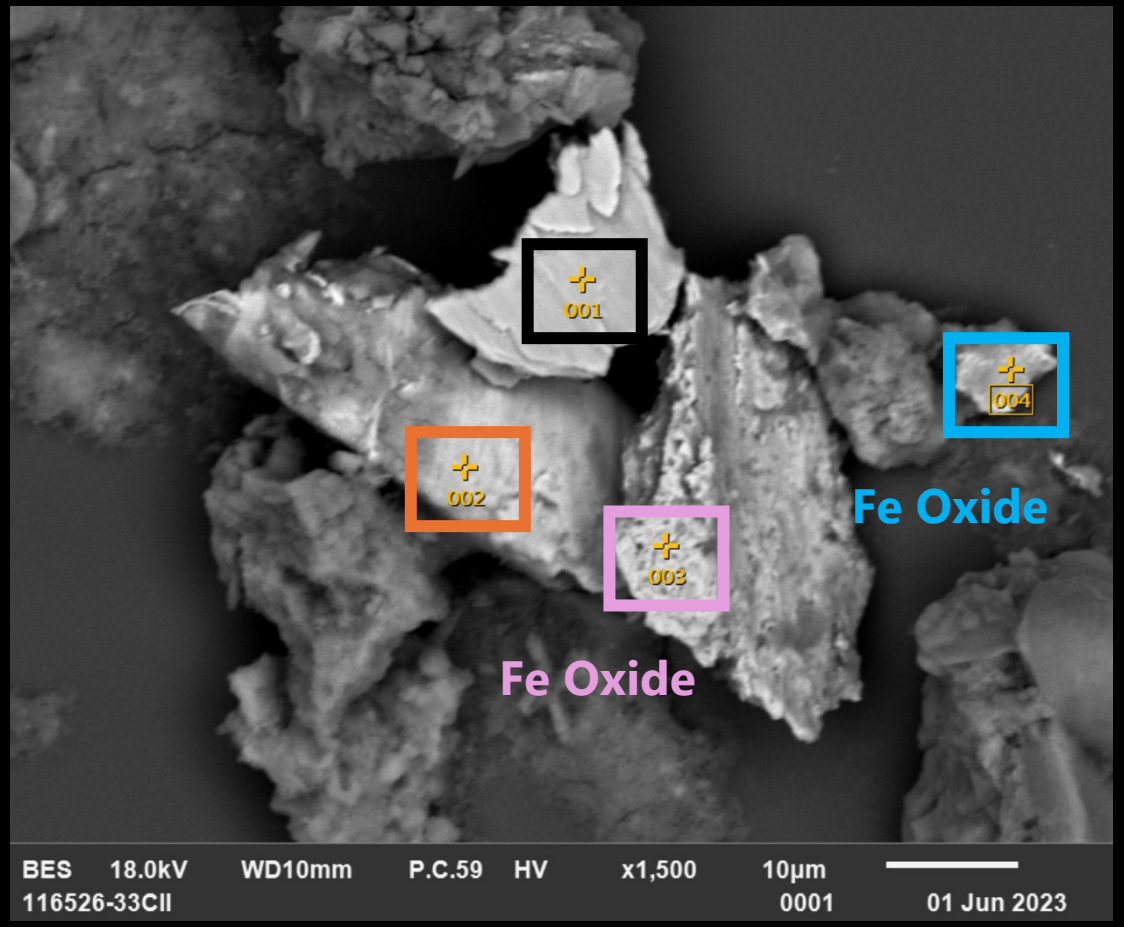
Pacific C: Metallic Nickel Particles





Pacific C: Metallic Ni-Fe and Fe Particles





Next Steps and Questions to Answer

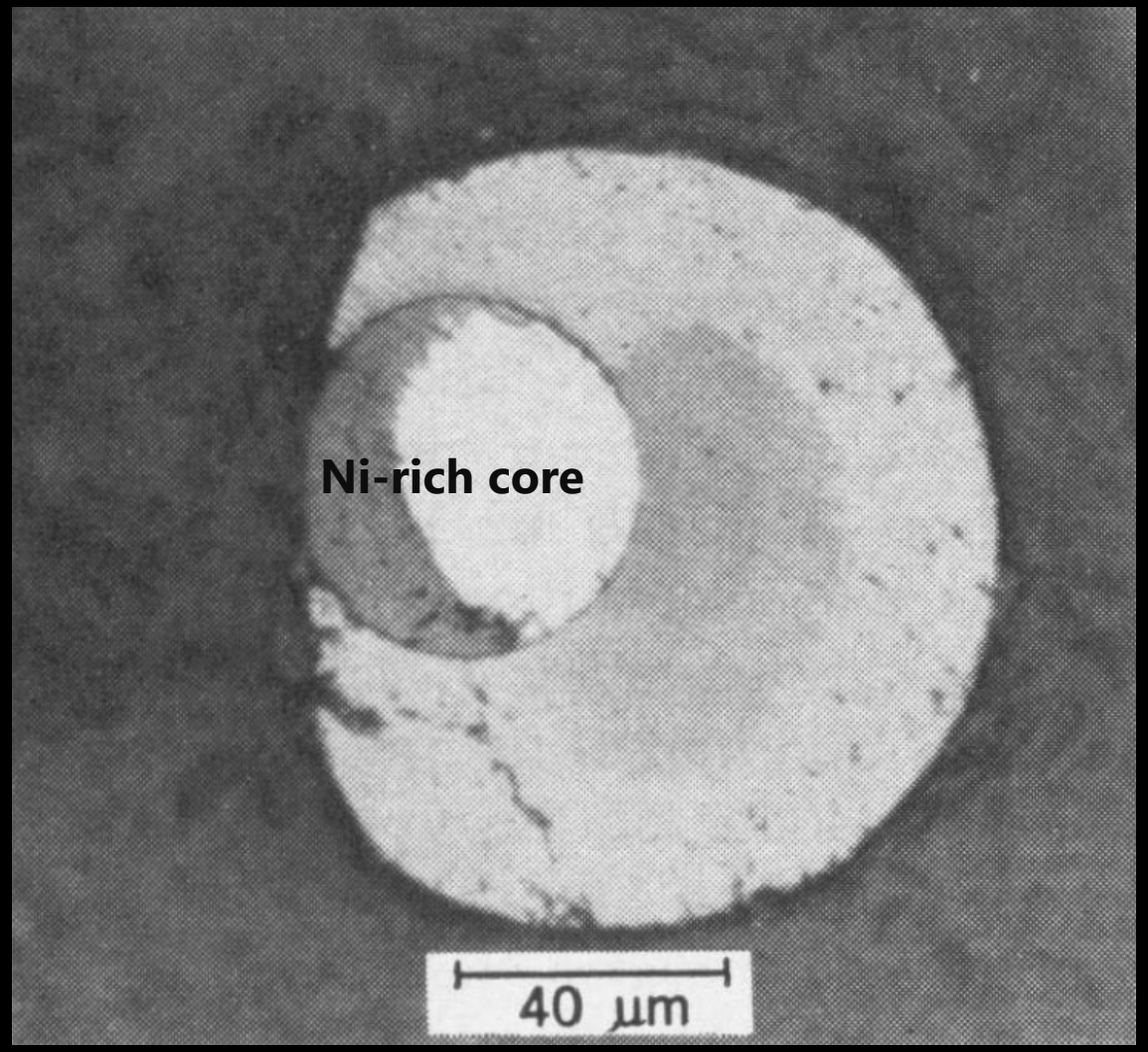
- Oxides other than Fe-Mn become very scarce after a few passes through material with a magnet

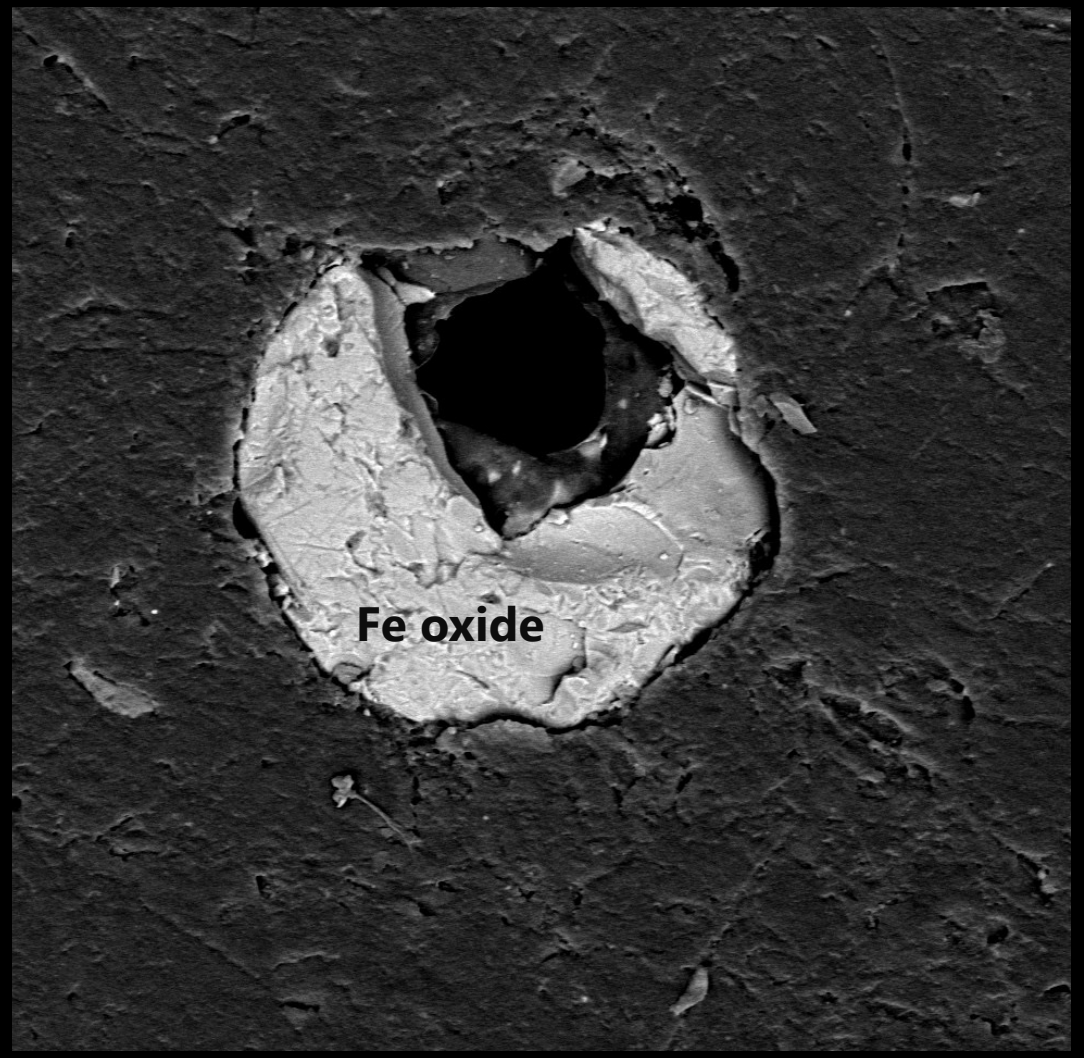
- Fe-Ti Oxide
  - What is the Fe-Ti mineral?
  - Single Crystal XRD

- Spheres from cosmic or meteorite ablation?
  - Cross section and further compositional analysis

- Further describe the processes that form metallic phases
  - How do we get such large metallic particles?

Sphere Cross Section





(Finkelman, 1970)

Acknowledgment

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Title Slide Image: NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts

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