

Metamorphosed Clasts in the CV Carbonaceous Chondrite Breccias Mokoia and Yamato-86009: Evidence for Strong Thermal Metamorphism on the CV Parent Asteroid

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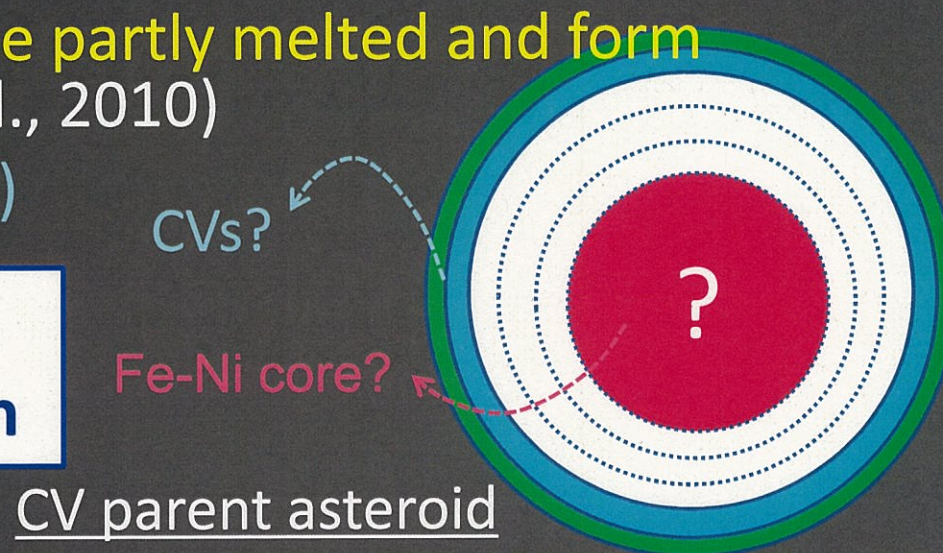
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Thermal metamorphism in CV chondrites

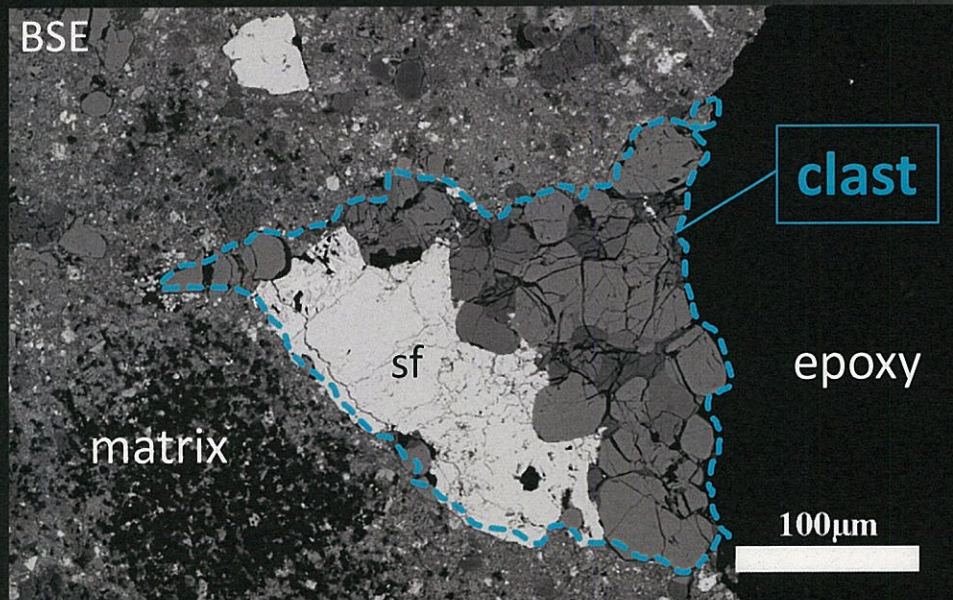
CV3 chondrites

- **Petrologic subtypes: 3.1 – >3.7** (Bonval et al., 2006)
- Most metamorphosed CV chondrite is Allende
 - Peak metamorphic T: **~500–600 °C** (e.g., ol-sp thermometer: Weinbruch et al., 1994)
- Paleomagnetic record of Allende
 - **CV parent asteroid might be partly melted and form Fe-Ni core** (e.g., Weiss et al., 2010)
 - ⇔ Impact? (Bland et al., 2011)

Thermal evolution of CV asteroid is not well-known



Metamorphosed clasts in CV3 chondrites



Metamorphosed clast in Y-86009 (CV) (Jogo et al., 2008)

- Olivine-rich aggregates
- Triple junctions
- Compositionally uniform ol & cpx
- Metamorphic T:
>750–800 °C (ol-sp & cpx thermometers: Krot and Hutcheon, 1997)



Clasts formed by prolonged annealing in asteroidal interior
(e.g., Krot and Hutcheon, 1997)

Genetic relationship between CV chondrites?

Purpose of this study

✓ **Genetic relationship between metamorphosed clasts and CV chondrites?**

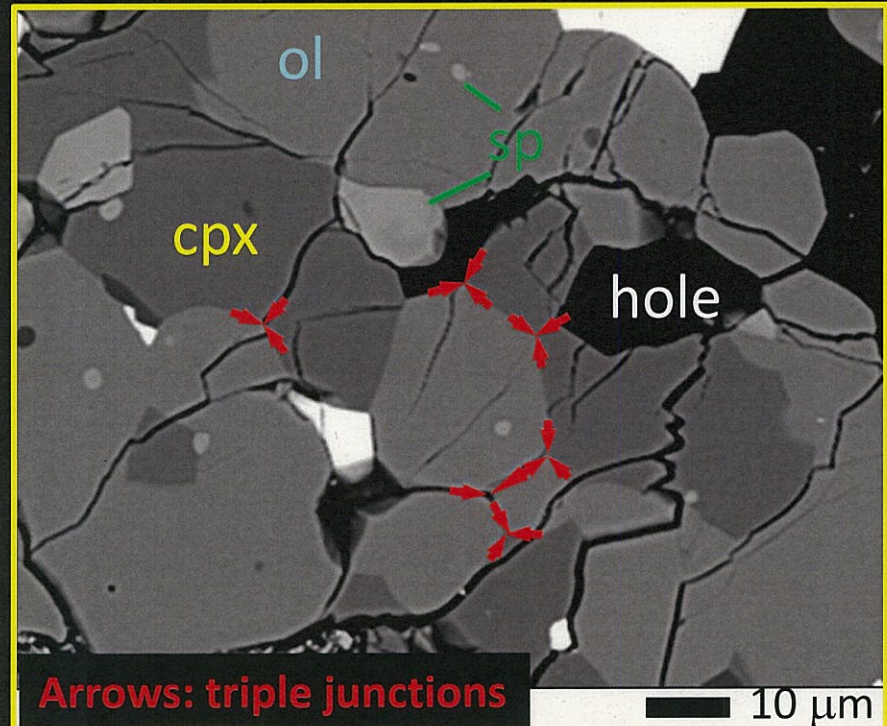
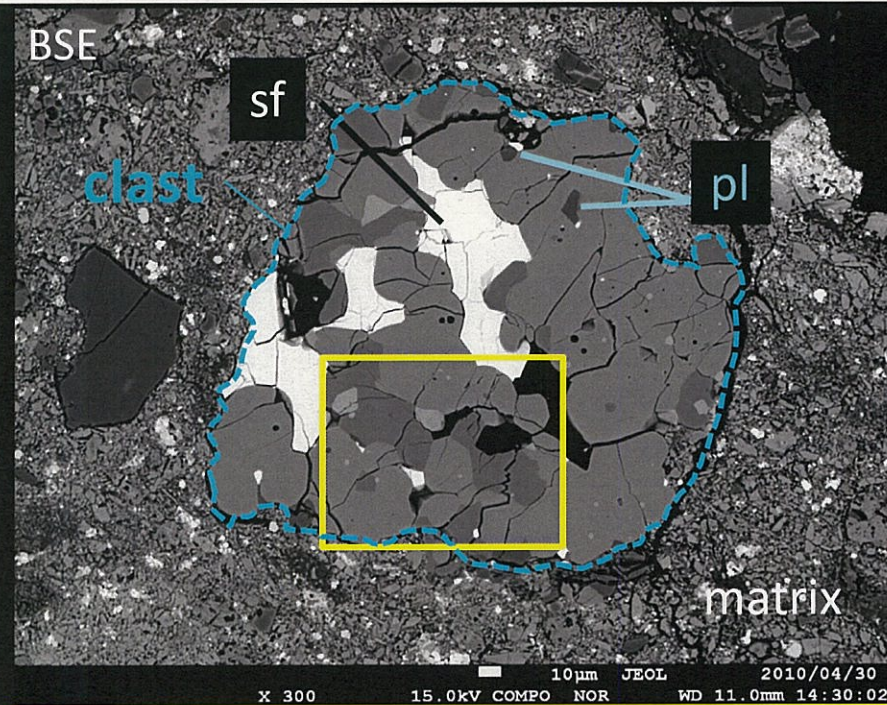
→ **Constraints on the internal structure and thermal history of CV asteroid**

○ We found 50 metamorphosed clasts in the CV3 breccias Mokoia and Yamato-86009

✓ Mineralogy and petrology

✓ O-isotope compositions of olivine

(UH Cameca ims-1280 ion microprobe)



Arrows: triple junctions

Metamorphosed clasts

- Coarse-grained (10-50 μm), granular, polymineralic rocks composed of:
 - ✓ olivine (Fa_{31-39})
 - ✓ diopside ($\text{Fs}_{7-13}\text{Wo}_{44-53}$)
 - ✓ plagioclase ($\text{An}_{37-84}\text{Ab}_{63-17}$)
 - ✓ Cr-spinel ($\text{Cr}/(\text{Cr}+\text{Al}) = 0.21-0.45$, $\text{Fe}/(\text{Fe}+\text{Mg}) = 0.64-0.77$)
 - ✓ nepheline, sulfides, phosphates, and rare grains of Ni-rich taenite
 - ✓ **low-Ca pyroxene is absent**
- Triple junctions
- Uniform compositions of ol & px within an individual clast (e.g., Fa_{35} , $\text{Fs}_{10-11}\text{Wo}_{48-50}$)
- Metamorphic T: $>700-800\text{ }^{\circ}\text{C}$ (ol-sp & cpx thermometers)

\Rightarrow prolonged annealing

Metamorphosed clast in Mokoia

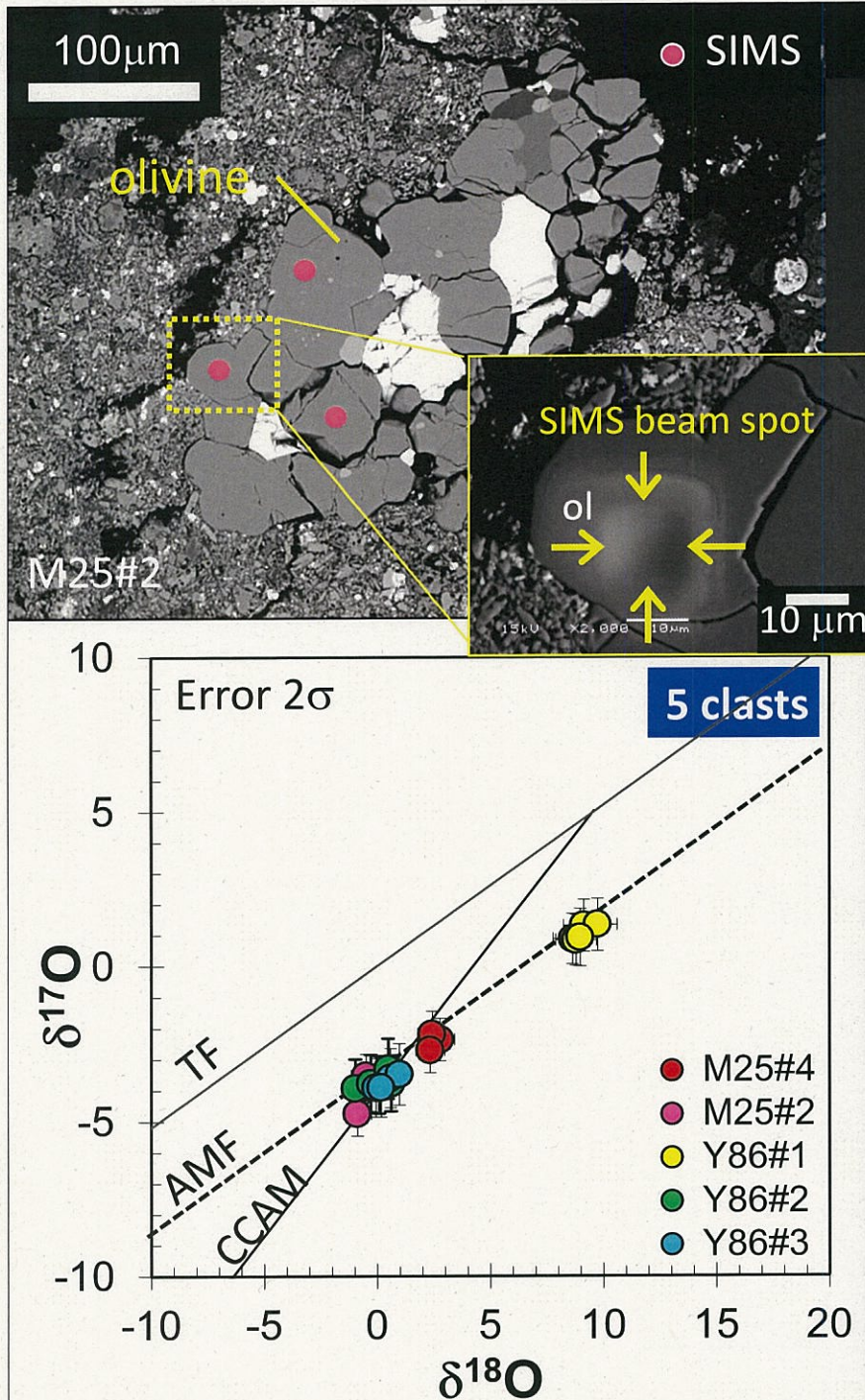
O-isotope compositions of olivine

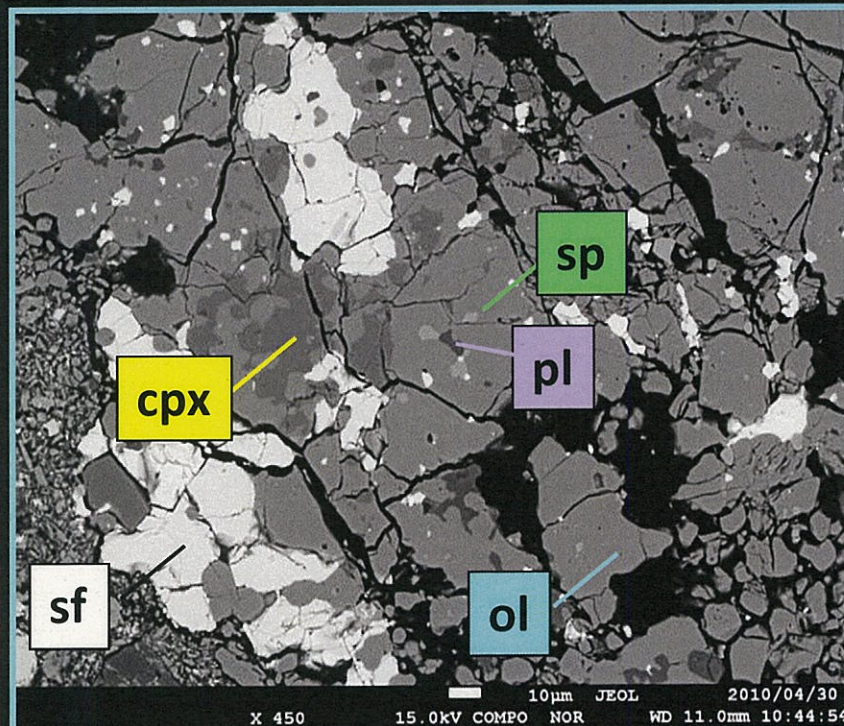
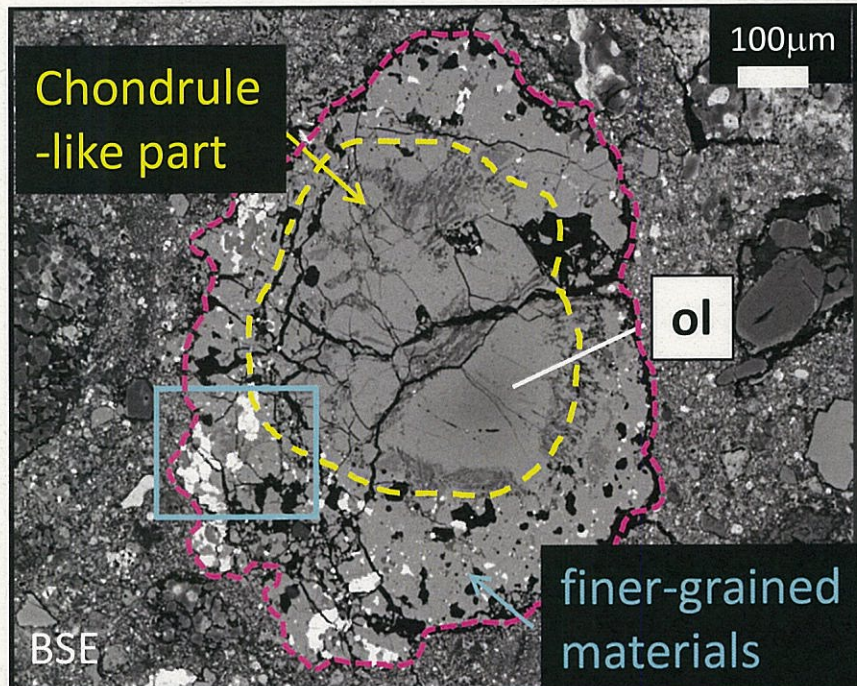
✓ Olivine grains (Fa_{25-39}) in 5 clasts in Mokoia & Y-86009

O-isotope compositions of clasts plot along or near CCAM line and the Allende mass fractionation (AMF) line.

- Uniform O-isotope compositions within individual clast

⇒ Prolonged annealing





Less-metamorphosed clasts

Clast = chondrule + matrix

- No triple junctions
- Variations in ol & px compositions within an individual clast

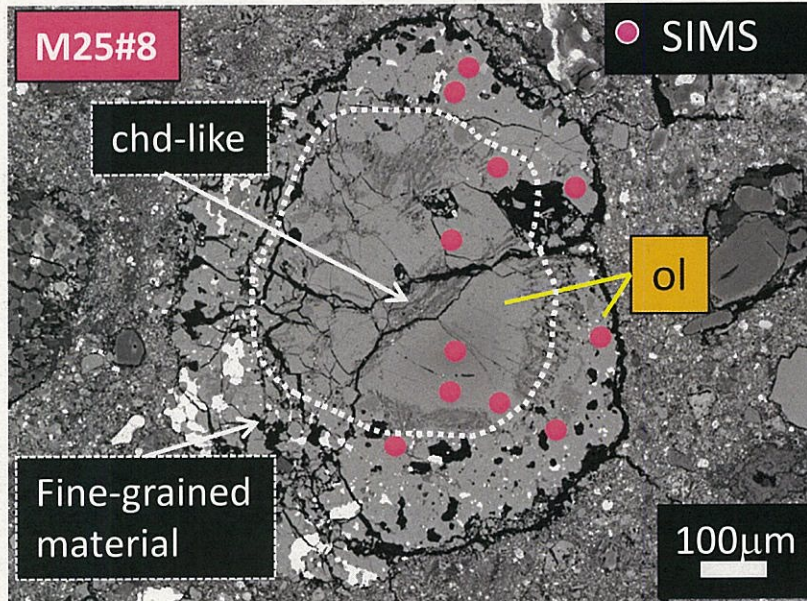
Periphery: re-crystallized finer-grained materials

Olivine (Fa_{38-39}), Ca-rich pyroxene ($\text{Fs}_{10-12}\text{Wo}_{47-51}$), plagioclase ($\text{An}_{70-72}\text{Ab}_{28-31}$), spinel and sulfide

- ✓ Similar mineralogy to clasts
- ✓ Similar bulk chemical compositions to CV_{OxA} Allende coarse-grained rim and matrix

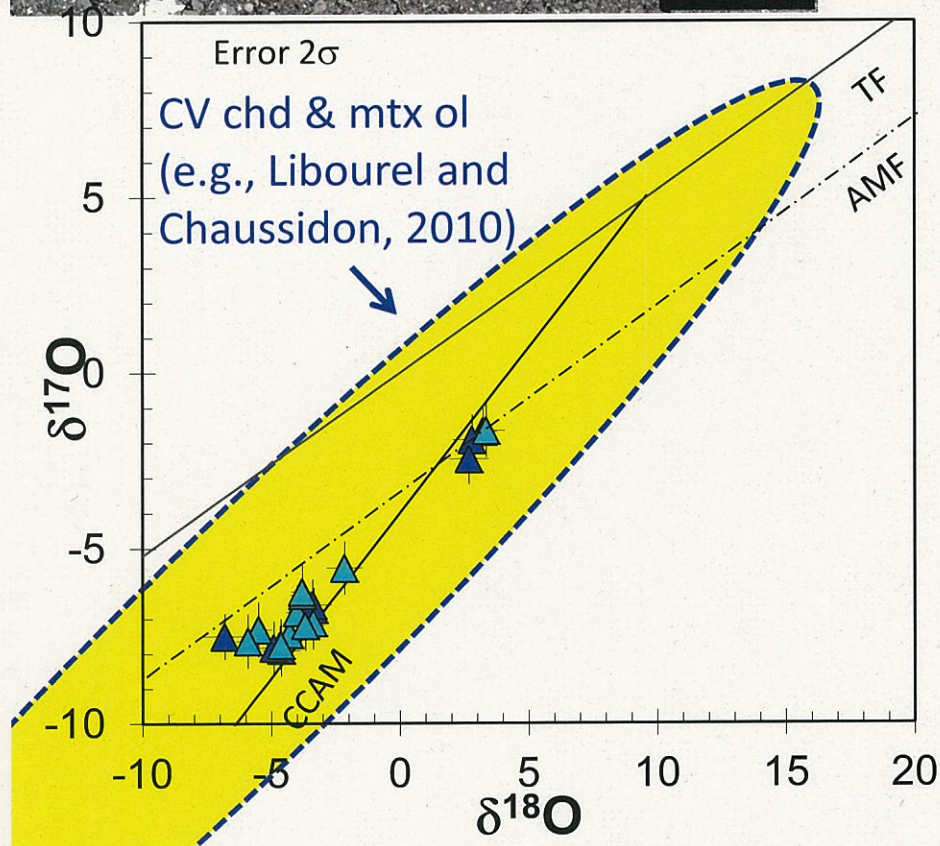
Center: chondrule-like (Fa_{25-30})

← Less-metamorphosed clast in CV Mokoia



O-isotopes: Less-metamorphosed clasts

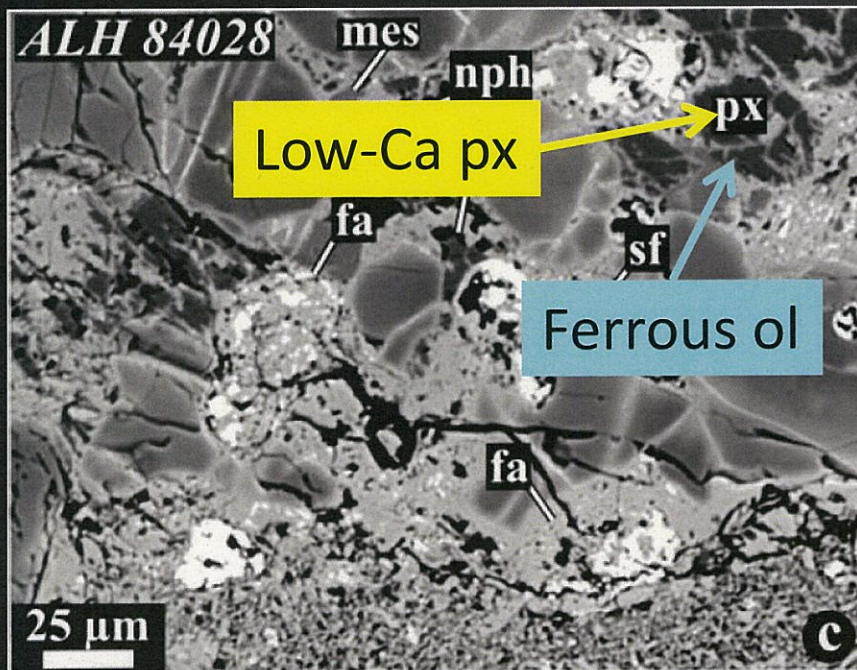
✓ Olivine grains (Fa_{25-39}) in 2 clasts in Mokoia & Y-86009



- O-isotope compositions of olivine grains show a variation within individual clast
⇒ Original O-isotope compositions of precursors
- Similar O-isotope compositions of olivine in CV chondrules and matrix

Genetic relationship between clasts and CV chondrites

- In CV_{OxA} chondrites or Allende dark inclusions, low-Ca pyroxene in chondrules were preferentially replaced by ferroan olivine by **hydrothermal alteration in the CV asteroid** (e.g., Brearley and Krot, 2011)



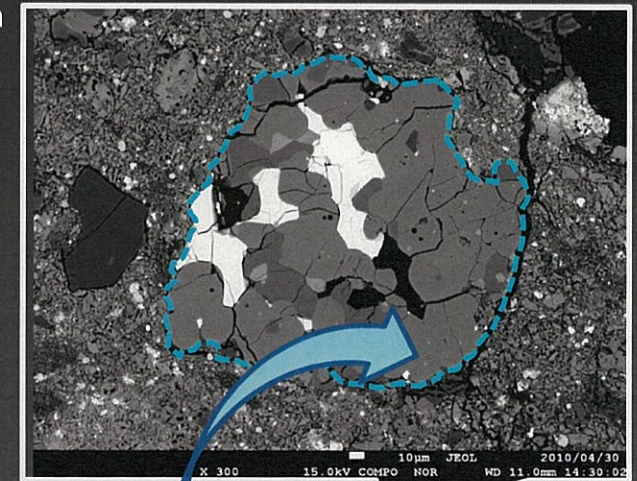
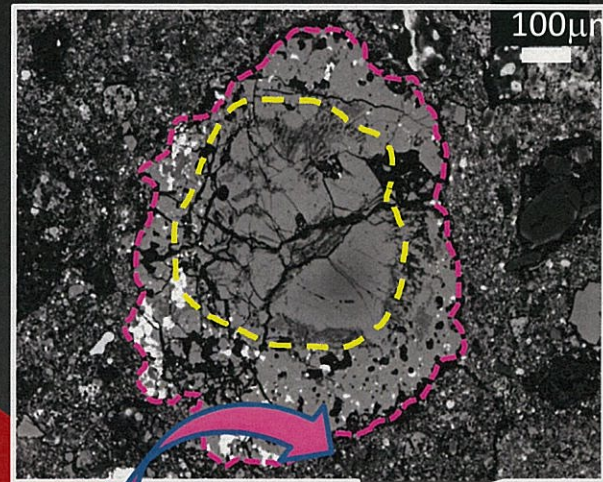
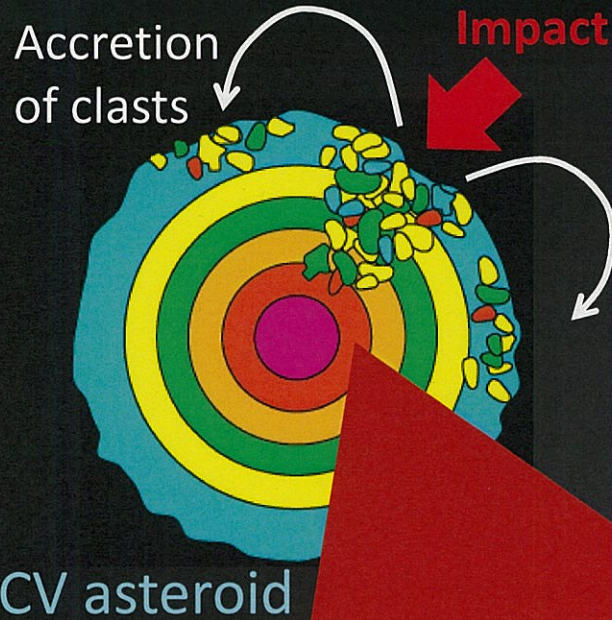
CV_{OxA} Allende (Brearley and Krot, 2011)

Clasts

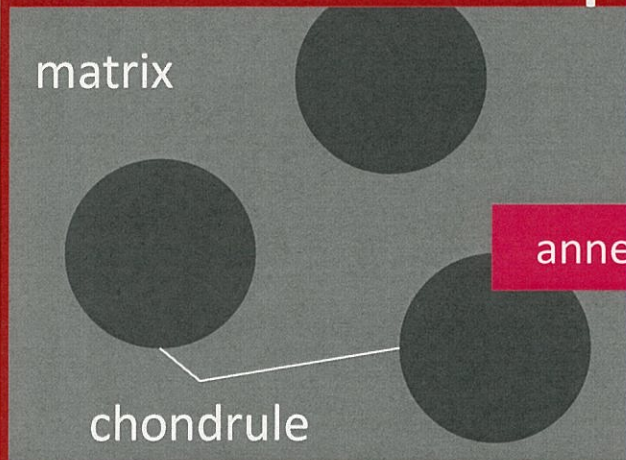
- Absence of low-Ca px
- O-isotope compositions of ol
- Chondrule size
- Bulk chemical composition

**Heavily-altered CV chondrites
could be precursors of the
clasts**

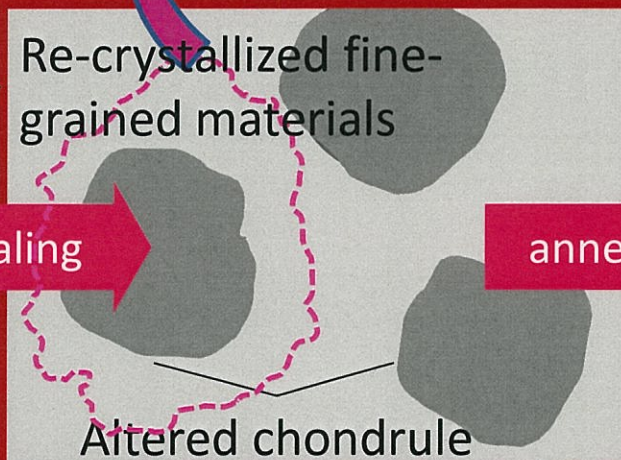
Formation process of clasts



Thermal metamorphism in the interior of the CV asteroid



Heavily-altered CV chondrites



Less-metamorphosed clasts



Metamorphosed clasts (>700-800 °C)

Summary

- We found 50 metamorphic clasts in CV Mokoia and Y-86009 breccias
- The clasts are coarse grained, granular rocks having homogeneous chemical and O-isotopic compositions
⇒ The clasts formed by prolonged annealing ($>700\text{--}800\text{ }^{\circ}\text{C}$)
- Mineralogy and O-isotopic compositions of clasts are most similar to those of CV chondrites
⇒ The clasts formed by annealing of CV-like chondritic materials
⇒ Thermal metamorphism ($>700\text{--}800\text{ }^{\circ}\text{C}$) was occurred in the CV asteroid