Europlanet TA Scientific Report

PROJECT LEADER

Project number: 20-EPN2-098	
Name: Ashley King	
Home Institution: Natural History Museum, London	
TA Facility visited: ETH Zürich Geo- & Cosmochemistry Noble Gas Laboratory	

Project Title: Constraining the Thermal History of Water-Rich Asteroids Using Noble Gas Analysis of Heated CM Chondrites

Scientific Report Summary.

In this TNA visit, we investigated the abundance and isotopic composition of noble gases (He – Xe) in CM chondrites that record both aqueous and thermal metamorphism. These unusual meteorites are likely good analogues for the types of material found on the surfaces of primitive C-type asteroids; however, the timing and mechanism of the metamorphism remains unknown.

We measured He – Xe in five CM chondrites that experienced peak metamorphic temperatures of <300°C to >750°C using stepped-heating and the "ALBATROS" mass spectrometer at the ETH Zürich Geo- and Cosmochemistry Noble Gas Laboratory. Preliminary results show that the concentrations of ^{4}He and ^{22}Ne are depleted in the lowest temperature steps (300 and 450°C) for all samples, consistent with degassing during (a) metamorphic event(s). Peaks in the concentration of both light and heavy noble gases in the 660°C and 800°C steps agree with previous estimates of metamorphic temperatures based on mineralogy and H_2O loss. Isotopic compositions are mainly a mixture of primordial (so-called Q/HL) and cosmogenic components. In addition, EET 96029 and WIS 91600 contain a trapped solar wind component, suggesting that these meteorites may have been heated by impacts during residence in the asteroid regolith. Comparison of our data to unheated CM chondrites will be used to further constrain the thermal history of C-type asteroids in the early solar system.

Full Scientific Report on the outcome of your TNA visit

In the meteorite collections there are >30 CM carbonaceous chondrites that experienced both low temperature (<150°C) aqueous alteration followed by short-lived thermal metamorphism (300 - 1000°C). However, important questions remain regarding the nature of the thermal metamorphism – Where and when did it occur? Was it a single event or episodic? What was main source of heat? Furthermore, there are clear discrepancies between peak metamorphic temperatures inferred from the separate response of minerals and organics to heating. As the surfaces of many C-rich asteroids are likely to be a mixture of both hydrated and dehydrated materials, and with C-rich asteroids and moons the focus of several current and future space missions (e.g., Hayabusa2, OSIRIS-REx, Lucy, MMX), there is a need to better understand their thermal evolution.

Our aim in this project was to investigate the abundance and isotopic composition of noble gases (He – Xe) in heated CM chondrite powders for which we have previously determined the degree of aqueous and thermal alteration using X-ray diffraction (XRD), thermogravimetric analyses (TGA) and infrared (IR) spectroscopy. Noble gases are powerful tracers of alteration and can place constraints on the timing, location, and mechanism of thermal metamorphism. Samples of five heated CM chondrites (peak temperatures ranging from <300°C to >750°C) were sent to the ETH Zürich Geo- and Cosmochemistry Noble Gas Laboratory ~2 months ahead of our visit so they could be loaded and pumped down in the ultrahigh vacuum system. During our visit, we then measured He – Xe in each sample using the "ALBATROS" mass spectrometer. The noble gases were extracted from the samples using stepped-heating at temperatures of ~300°C, 450°C, 660°C, 800°C, 1000°C, and 1750°C. A series of blanks and calibrations were acquired at regular intervals throughout the experimental run. Data processing (e.g., blank corrections, calibrations) is ongoing and the following is a qualitative description of our preliminary results.

QUE 93005: The concentration of ^{4}He rises to a peak in the 660°C step before decreasing at higher temperatures. Similarly, the ^{22}Ne concentration peaks at 660°C, but is also relatively high in the 300°C step (Fig. 1). The Ne isotopic composition is a mixture of cosmogenic and primordial (mostly Q/HL) components (Fig. 2). ^{36}Ar, ^{84}Kr, and ^{132}Xe concentrations peak at 660°C. *EET 96029 & WIS 91600*: ^{4}He and ^{22}Ne concentrations peak in the 660°C step, with Ne isotopes indicating the presence of a trapped solar wind component. Cumulative release patterns for ^{36}Ar, ^{84}Kr, and ^{132}Xe form a plateau between 660 and 800°C, although the highest concentrations are seen in the 300°C step. Xe isotopes indicate that this step contains a significant (~90%) contribution from air. *PCA 91008:* Concentrations of the light noble gases peak at 660°C, with Ne isotopic compositions a mixture of primordial and cosmogenic components. In contrast, ^{36}Ar, ^{84}Kr, and ^{132}Xe concentrations rise to a peak in the 800°C step. *PCA 02012*: In all steps the overall concentration of both light and heavy noble gases is lower relative to the other samples analysed. Nevertheless, ^{4}He, ^{22}Ne, ^{36}Ar, ^{84}Kr, and ^{132}Xe concentrations do rise to a peak in the 800°C step. Isotopic compositions are a mixture of primordial and cosmogenic components.

For each sample, the concentration of the light noble gases appears to be depleted in the lowest temperature (i.e., 300 and 450°C) steps, consistent with degassing during (a) thermal metamorphic event(s) on the parent body(ies). The exception is QUE 93005, where the ^{22}Ne concentrations are similar in the 300°C and 660°C steps. This is consistent with previous studies showing that QUE 93005 was likely never heated to >300°C. For EET 96029 and WIS 91600, the concentrations of ^{4}He and ^{22}Ne clearly rise to a peak in the 660°C step, which agrees with their estimated metamorphic temperatures of 300 - 500°C. Unlike the other samples, both meteorites contain a solar wind component, suggesting that they spent a period of time in the asteroid regolith and were thus exposed to impact heating. In PCA 91008, ^{4}He and ^{22}Ne concentrations peak at 660°C, whereas ^{36}Ar, ^{84}Kr and ^{132}Xe instead peak at 800°C, possibly because this meteorite records higher metamorphic temperatures (500 - 750°C). PCA 02012 experienced the highest metamorphic temperature (>750°C), with peaks in ^{4}He, ^{22}Ne, ^{36}Ar, ^{84}Kr, and ^{132}Xe in the 800°C step, but overall the noble concentration are low due to extensive outgassing.

Our next steps are to compare absolute concentrations of the noble gases to previously analysed unheated and heated CM chondrites, and explore fractionation effects (e.g., He/Ne) related to preferential loss during thermal metamorphism.

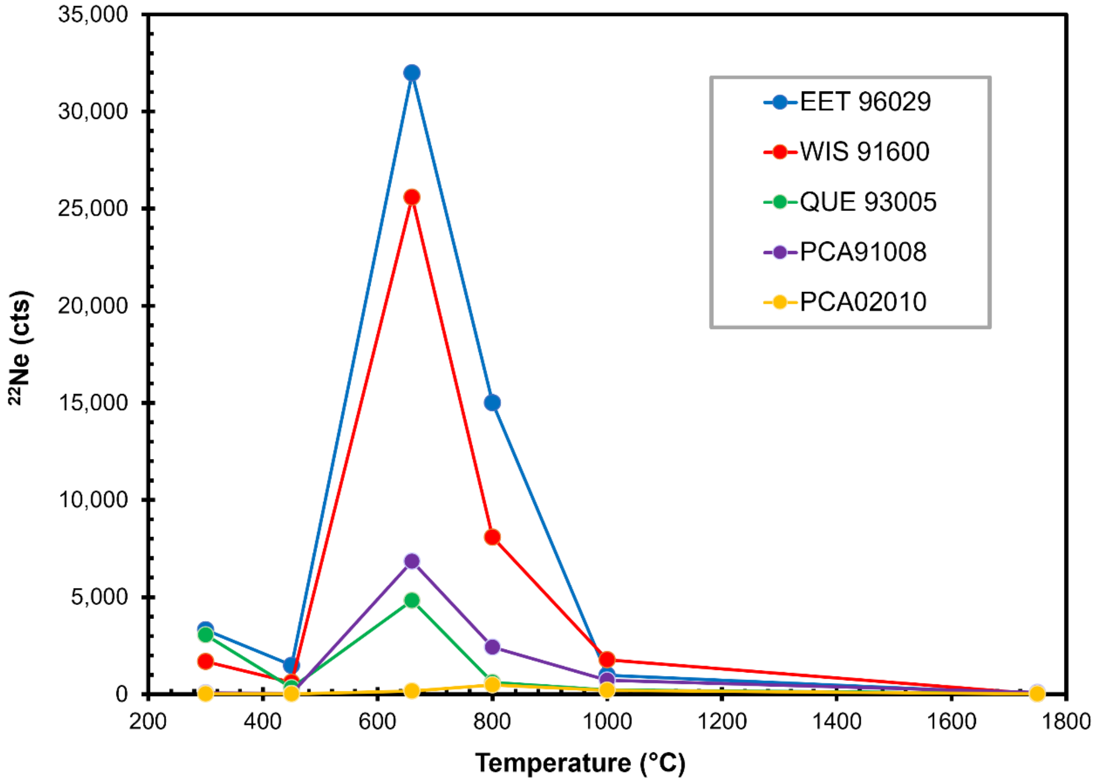

Figure 1. Cumulative ^{22}Ne release during stepped-heating of heated CM chondrites.

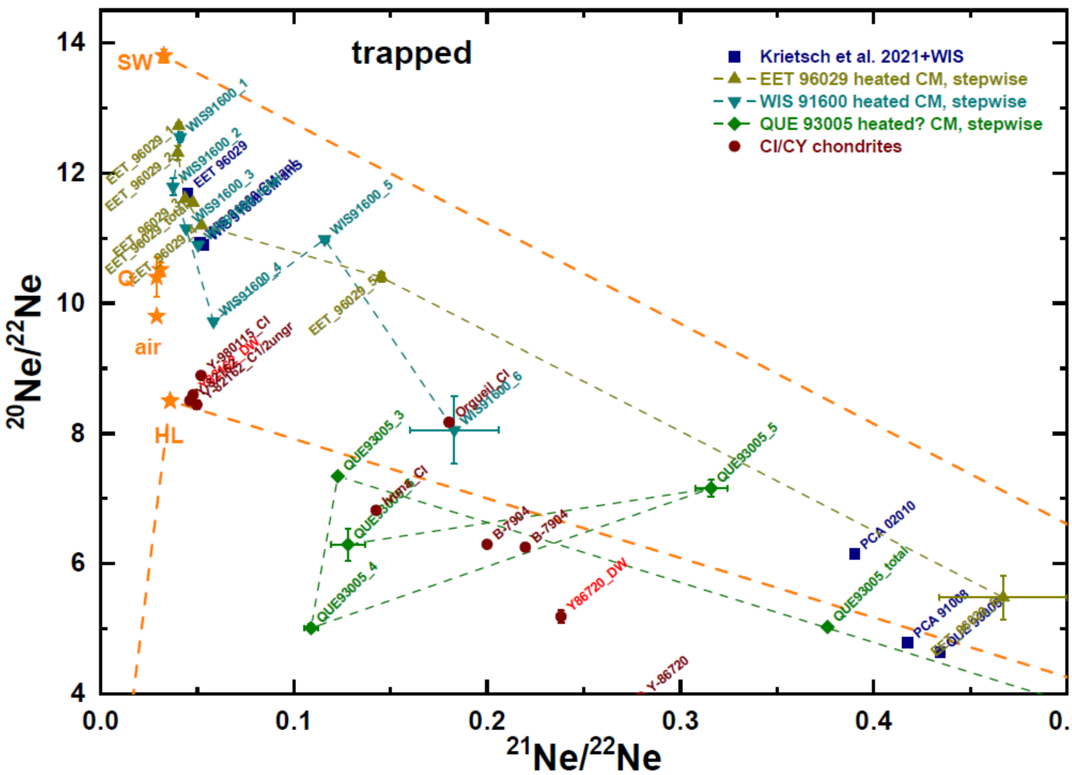

Figure 2. Neon isotopic compositions during stepped-heating of the heated CM chondrites EET 96029, WIS 91600, and QUE 93005.

- Give details of any publications arising/planned (include conference abstracts etc)

We anticipate submission of an abstract to the Lunar & Planetary Science conference in January 2024, followed soon after by a full publication in a high-profile, peer-reviewed journal (likely Geochimica et Cosmochimica Acta).

- Host confirmation

Please can hosts fill in/check this table confirming the breakdown of time for this TA project:

Dates for travel to accommodation for TA visit (if physical visit by applicant)	Start Date of TA project at facility	Number of lab/field days spent on TA Visit pre-analytical preparation	Number of days in lab/field site for TA Visit	Number of days spent in lab for TA Visit data analysis	End Date of TA project at facility	Dates for travel home (if physical visit by applicant)
Departed: 08-12-22 Arrived: 27-11-22	28-11-22	[3]	10	[2]	08-12-22	Departed: 08-12-22 Arrived: 27-11-22

The host is required to approve the report agreeing it is an accurate account of the research performed.

Host Name	Henner Busemann
Host Signature	H. Busemann
Date	27.06.2023

- Project Leader confirmation

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YES / NO

Project Leader Name	Ashley King
Project Leader Signature	A. King
Date	27/06/2023