

**EVALUATING THE RELATIONSHIP BETWEEN CM AND CO CHONDRITES USING CHROMIUM, TITANIUM, AND OXYGEN ISOTOPES.** Z. A. Torrano<sup>1</sup>, D. L. Schrader<sup>1,2</sup>, R. C. Greenwood<sup>3</sup>, V. K. Rai<sup>1</sup>, and M. Wadhwa<sup>1</sup>, <sup>1</sup>School of Earth and Space Exploration ([ztorrano@asu.edu](mailto:ztorrano@asu.edu)), <sup>2</sup>Center for Meteorite Studies, Arizona State University, Tempe, AZ, USA, <sup>3</sup>Planetary and Space Sciences, The Open University, Milton Keynes, UK.

**Introduction:** Combined Cr, Ti, and O isotopic systematics can be used as a powerful tracer of genetic relationships between meteorites [e.g., 1, 2]. Thus far, efforts to determine the combined Cr, Ti, and O isotopic compositions of ungrouped meteorites for evaluating their genetic relationships have focused primarily on ungrouped achondrites [e.g., 2]. In this work, we extend these investigations to ungrouped chondrites with the goal of evaluating the relationship between CM and CO chondrites. Studies of CM (and CM-like ungrouped) chondrites are particularly important as these meteorites may be analogs for the carbonaceous asteroids targeted by the ongoing OSIRIS-REx and Hayabusa2 sample return missions [e.g., 3, 4].

A genetic relationship between CM (Mighei-like) and CO (Ormans-like) carbonaceous chondrites has been suggested based on textural and geochemical similarities [e.g., 5]. However, there are differences between the two groups in mean chondrule size, abundance of relict grains [6], and the amount of water estimated to be present in their respective parent bodies (with COs being essentially dry and CMs having experienced extensive aqueous alteration [7]). Another important difference is the compositional gap between the two groups in oxygen three-isotope space [7]. Several meteorites (predominantly C2-ungrouped chondrites) plot in the gap between the CM and CO chondrites in oxygen three-isotope space and exhibit transitional features between the two groups [8].

A compositional gap also seems to exist between CM and CO chondrites in  $\epsilon^{50}\text{Ti}$  vs.  $\epsilon^{54}\text{Cr}$  space [e.g., 1], although their full isotopic ranges are not well constrained. The Ti and Cr isotopic compositions of the ungrouped chondrites identified by [8] that plot in the CM–CO compositional gap in oxygen three-isotope space have not yet been determined. This work is part of an ongoing study in which we are acquiring the combined Cr, Ti, and O isotope compositions of ungrouped chondrites that either have previously published O-isotope values that plot in the CM–CO gap or are documented as having mineralogic/geochemical characteristics similar to CM and/or CO chondrites. We report here the Cr and Ti isotopic compositions of Grosvenor Mountains (GRO) 95566, MacAlpine Hills (MAC) 87300, MAC 87301, Elephant Moraine (EET) 83355, and Lewis Cliff (LEW) 85332 with the goal of providing constraints on the relationship between CM and CO chondrites.

**Methods:** All samples were powdered and chemically processed for Cr and Ti analyses in the Isotope

Cosmochemistry and Geochronology Laboratory (ICGL) at Arizona State University (ASU). For each sample, ~30 mg (taken from powdered and homogenized aliquots prepared from ~100–250 mg interior chips of each sample) was digested using HF:HNO<sub>3</sub> in a Parr bomb, and then brought into solution. A ~5% aliquot of each solution was reserved for determining elemental concentrations using the iCAP-Q quadrupole ICPMS in the W. M. Keck Laboratory for Environmental Biogeochemistry at ASU. The remainder of each solution was processed for Cr and Ti purification.

Chromium separation and purification was conducted using procedures modified from [9, 10]. Purified Cr samples and standards were analyzed on the Thermo Neptune Multicollector Inductively Coupled Plasma Mass Spectrometer (MC-ICPMS) in the ICGL at ASU following [11–14]. Samples and standards (800 ppb Cr concentration) were introduced using an Elemental Scientific Apex-Q desolvating nebulizer and measurements were conducted in high-resolution mode (mass resolving power >8000) to avoid polyatomic interferences. The intensities of <sup>50</sup>Cr, <sup>52</sup>Cr, <sup>53</sup>Cr, and <sup>54</sup>Cr were measured, along with <sup>49</sup>Ti, <sup>51</sup>V, and <sup>56</sup>Fe to monitor and correct for isobaric interferences. The Cr isotopic data are reported relative to the NBS 979 Cr standard after internal normalization to <sup>50</sup>Cr/<sup>52</sup>Cr (=0.051859; [15]) using an exponential fractionation law. Homogenized Allende CV chondrite and DTS-1 terrestrial rock standard were chemically processed and analyzed alongside the samples to assess the accuracy and precision of our analyses.

Titanium separation and purification was conducted using the procedure detailed in [16]. Purified Ti samples and standards were analyzed on the Thermo Neptune MC-ICPMS in the ICGL at ASU following [16]. Samples and standards (1 ppm Ti concentration) were introduced using a CETAC Aridus II desolvating nebulizer and measurements were conducted in high-resolution mode (mass resolving power >8000) to avoid polyatomic interferences. Data were collected by switching between two different cup configurations: first <sup>44</sup>Ca, <sup>46</sup>Ti, <sup>47</sup>Ti, <sup>48</sup>Ti, and <sup>49</sup>Ti, then <sup>47</sup>Ti, <sup>49</sup>Ti, <sup>50</sup>Ti, <sup>51</sup>V, and <sup>52</sup>Cr. Measurements of <sup>44</sup>Ca, <sup>51</sup>V, and <sup>52</sup>Cr were used to correct for isobaric interferences. The Ti isotopic data are reported relative to the NIST Ti standard after internal normalization to <sup>49</sup>Ti/<sup>47</sup>Ti (=0.749766; [17]) using an exponential fractionation law. Homogenized BCR-2 rock standard was chemically processed and analyzed alongside the samples to assess the accuracy and precision of our analyses.

Oxygen isotopic analyses of fractions of the same homogenized powders used for Cr and Ti analyses are currently being conducted at The Open University via laser-assisted fluorination [18].

**Results and Discussion:** The Cr and Ti isotopic compositions of the samples studied here are shown in Fig. 1.

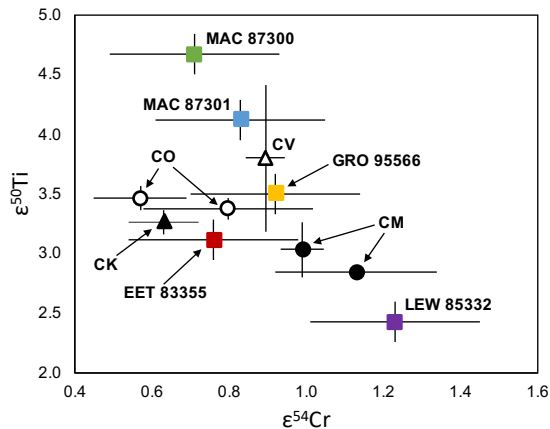


Fig. 1.  $\epsilon^{50}\text{Ti}$  vs.  $\epsilon^{54}\text{Cr}$  for the chondrites studied here (colored symbols). Literature data for CM (black circles), CO (white circles), CV (white triangle), and CK (black triangle) chondrites are from [19–25].

GRO 95566 is classified as a CM-an chondrite and plots near CM chondrites in oxygen three-isotope space [8]. [8] suggests that this sample is part of a “primitive CM” group. This sample plots between CM and CO chondrites in  $\epsilon^{50}\text{Ti}$  vs.  $\epsilon^{54}\text{Cr}$  space (Fig. 1), which is consistent with its CM-an classification.

EET 83355 is classified as a C2-ungrouped chondrite and shows evidence of being heated [26]. This sample also plots between CM and CO chondrites in  $\epsilon^{50}\text{Ti}$  vs.  $\epsilon^{54}\text{Cr}$  space (Fig. 1) suggesting that it may be related to these chondrite groups, and could be a heated CM or CO chondrite.

MAC 87300 and MAC 87301 are classified as C2-ungrouped chondrites and are considered to be paired. Similarities to the CO3 and CM2 chondrites were noted by [27]. MAC 87300 plots near CO chondrites in oxygen three-isotope space [8]. However, these two samples plot away from both CM and CO chondrites in  $\epsilon^{50}\text{Ti}$  vs.  $\epsilon^{54}\text{Cr}$  space (Fig. 1). The distinct Cr and Ti isotopic compositions of these samples suggest either an origin on a distinct parent body from CO and CM chondrites or instead that CO, CM, and certain ungrouped chondrites originated on parent bodies that were heterogeneous in their Cr and Ti isotope compositions. The distinct Cr and Ti isotopic compositions of these paired samples indicate that isotopic variation may be present within an individual carbonaceous chondrite parent body. Such variations may also exist within the CM and CO chondrites, which we will test

through further analyses of samples from these meteorite groups.

LEW 85332 is classified as a C3-ungrouped chondrite and is not considered to be related to the CM or CO chondrites [e.g., 7]. This is supported by its distinctive Cr and Ti isotopic composition (Fig. 1).

**Conclusions:** We have presented here the initial results of an ongoing study of the combined Cr, Ti, and O isotopic compositions of CM, CO, and ungrouped chondrites. These results suggest that (1) GRO 95566 is correctly classified as a CM-an chondrite and may possess intermediate characteristics between CM and CO chondrites, (2) EET 83355 is likely related to CM and CO chondrites and may be a heated CM or CO chondrite, and (3) MAC 87300, MAC 87301, and LEW 85332 are distinct from CM and CO chondrites and should continue to be considered ungrouped chondrites that may have originated on parent bodies distinct from those of CM and CO chondrites. Analyses of Cr, Ti, and O isotopic systematics in additional CM, CO, and ungrouped chondrites are anticipated to provide further insight into potential relationship(s).

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