NANOMINERALOGY OF LUNAR BEADS: DISCOVERY OF FeS NANOCRYSTALS ON YELLOW BEADS, CONDENSED FROM VOLCANIC VAPORS ON THE MOON. Chi Ma[1], Yang Liu[2]; [1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA (chima@caltech.edu); [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA (yang.liu@jpl.nasa.gov).

Introduction: Our ongoing nanomineralogy investigation of lunar beads (green, orange, yellow and black) from Apollo regolith samples has been revealing new and exciting discoveries since 2018. We have identified new phases most likely derived from volcanic condensates, including a zinc chlorohydroxosulfate mineral and a Na-K-sulfate on orange beads in Apollo 74220 [1,2], ZnS nanocrystals on green beads in Apollo 15366 and on a yellow bead in Apollo 15426 [3,4], and ZnS and halite (NaCl) nanocrystals on a black bead from Apollo 73001, 226 [5, this meeting].

Here, we present the discovery of nano-sized native iron and FeS condensates on the outer surface of three pristine yellow beads (all fragments) from Apollo sample 15426, 194 (Figs. 1-4) and discuss their origin and significance for lunar volatile research. We characterized surface mineralogy of the beads using a ZEISS 1550VP field-emission scanning electron microscope (SEM) for high-resolution backscatter electron (BSE) and secondary electron (SE) imaging with an Oxford X-Max SDD X-ray energy-dispersive spectroscopy (EDS) for elemental analysis and a HKL electron back-scatter diffraction (EBSD) system for crystal structure analysis.

Occurrence, chemistry, and crystallography: We observed a thin layer of iron sulfide (FeS) nanocrystals fully covering the surface of three yellow bead fragments (Figs. 1-4). Native iron (Fe) is evenly scattered on the bead surface at nanoscales, underneath the FeS layer. Two euhedral chromite crystals were observed on one of the three yellow beads with native Fe and FeS nanocrystals on top (Fig. 4).

Native iron occurs as more-or-less spherical grains, ~150-350 nm in diameter (Fig. 2). The FeS phase occurs as euhedral crystals in two sizes: ~ 20 to 30 nm and 60 to 100 nm in diameter (Fig. 3). Its composition by SEM-EDS at low-voltages implies a formula of ~FeS. Native iron contains minor Ni.

We attempted EBSD but were unable to acquire structural information on the FeS phase due to its small size. The FeS phase may be mineral troilite. Native iron likely has the *bcc* structure.

In addition to the three yellow bead fragments presented here, we previously discovered ZnS nanocrystals on one yellow bead [4] (Fig. 5).

Comparison to other types of beads: The interior of those yellow beads contains ~4.5 wt.% TiO_2, in contrast to <0.5 wt.% TiO_2 in Apollo 15 green glass

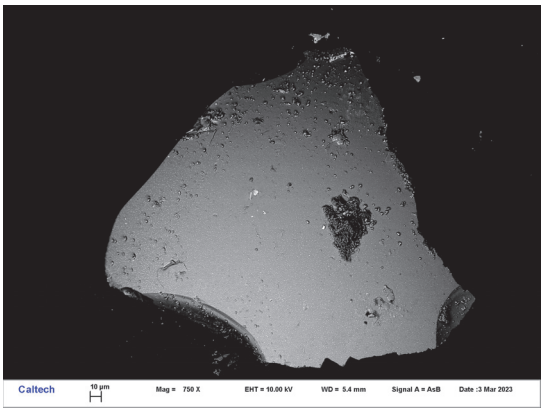

Fig. 1. BSE image showing a yellow bead fragment from Apollo 15426, 194 with native Fe and FeS on the surface.

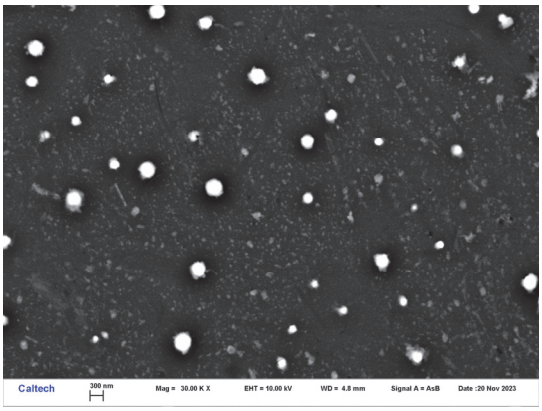

Fig. 2. Enlarged BSE image in Fig. 1 showing scattered native Fe (brightest grains) with a layer of FeS nanocrystals on the bead surface.

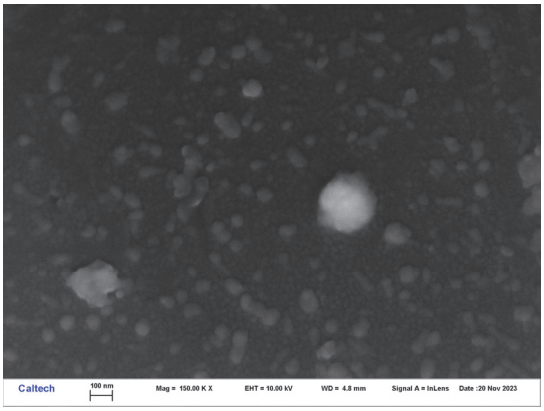

Fig. 3. Further enlarged SE image showing FeS nanocrystals on the bead surface with one Fe grain on the right side.

beads from the same Apollo sample. Apollo 15 yellow beads fall in the low-Ti basalt, whereas Apollo 17 orange and black beads belong to high-Ti basalt classification of lunar mare basalts.

Dendritic pyroxene and olivine, which are common in the glass at the very surface of 74220 orange beads [1], are not observed on that of these three yellow beads. Previously reported condensates on 74220 orange beads, the zinc chlorohydroxosulfate mineral, Na-K-sulfate and ZnS nanocrystals are also absent on these yellow beads. Compared to orange and yellow beads, ZnS nanocrystals are common on the surface of green beads from 15366 and 15426 (Fig. 6). We have not observed such FeS nanocrystals on green or orange beads. Further studies are planned to determine the frequency of its occurrence.

Origin and significance: This is the first discovery of FeS nanocrystal coating on lunar pyroclastic beads. Native Fe and FeS nanocrystals are most likely condensates from vapors during the volcanic eruption that formed those yellow beads on the Moon, just like nano-sized ZnS condensate on green beads and a different yellow bead [4] (Fig. 5). Native Fe is underneath FeS nanocrystals so iron condensed earlier than FeS on the yellow beads.

To date, our studies of vapor condensates have revealed different gas products on different types of volcanic beads. The different vapor condensates between green, yellow, orange and black beads suggest some fundamental differences in their gas properties. FeS nanocrystal coating is not observed in green, orange and black beads yet. Potential causes could be gas pressure and gas chemistry between different eruptions, which may further imply the mantle source heterogeneity. Further systematic studies will help to distinguish different causes. Our ongoing nanomineralogy investigation of lunar basalts has also led to a few exciting discoveries [6,7], providing complementary views of volcanic gas and dissolved volatiles in effusive eruptions on the Moon. We are going to examine more Apollo samples.

References: [1] Ma C. and Liu Y. (2019) *American Mineralogist*, 104, 447-452. [2] Liu Y. and Ma C. (2022) *Icarus*, 382, 115044. [3] Liu Y. et al. (2020) *51st LPSC,* Abstract 1166. [4] Ma C. and Liu Y. (2023) *54th LPSC*, Abstract 1420. [5] Liu Y. and Ma C. (2024) *55th LPSC*, Abstract 1057, this meeting. [6] Liu Y. and Ma C. (2024) *55th LPSC*, Abstract 1058, this meeting. [7] Liu, Y. et al. (2023) *86th MetSoc,* Abstract 6029.

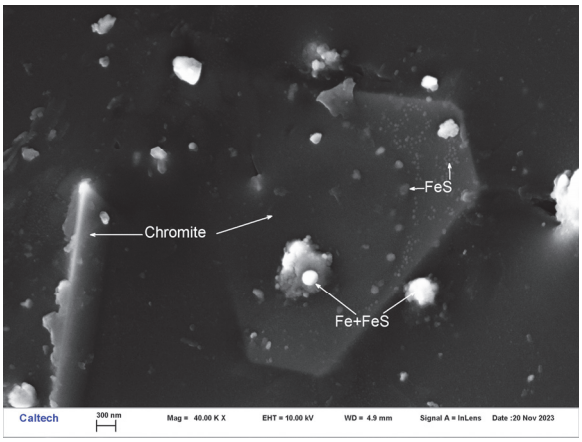

Fig. 4. Enlarged SE image showing two chromite crystals embedded in the yellow glass bead surface with native Fe and FeS nanocrystals sitting on top.

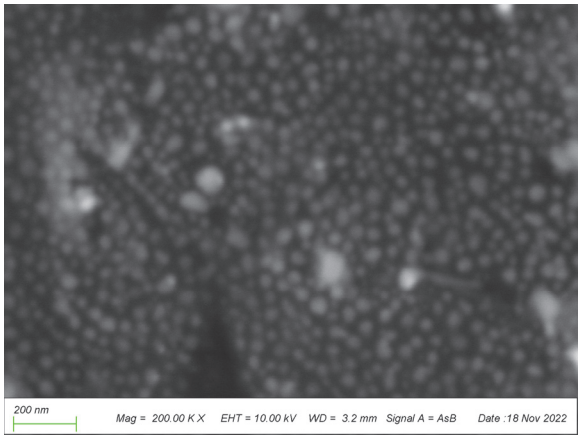

Fig. 5. High-magnification BSE image showing ZnS nanocrystals on the surface of a different yellow bead [4].

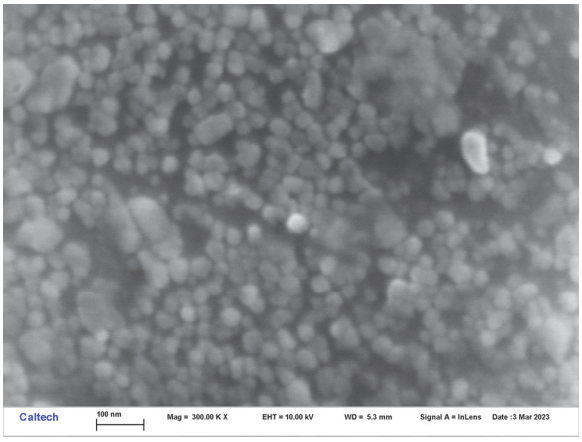

Fig. 6. High-magnification SE image showing ZnS nanocrystals on the surface of a green bead from Apollo 15426, 194.