Introduction: The Khatyrka CV3(ox) meteorite [1] was discovered as a result of an expedition to the Chu- kotka region of eastern Siberia in 2011, the goal of which was to find samples containing Al₆₃Cu₁₂Fe₁₃ (icosahedrite), a natural quasicrystal, and other metallic Al-bearing phases. Although these alloys are closely associated with the meteorite, explaining the presence of metallic aluminum remains a challenge owing to the extreme low oxygen fugacity requirements. A technical obstacle in resolving the mystery has been the fact that small gaps tend to open up between the metal alloys and the silicates when the samples are heated to harden the epoxies used to mount polished sections, owing to differential thermal expansion between metal and silicate. Although some examples of contacts have been reported in the past [2], in the continuing process of studying more grains of this meteorite, we have discovered the first case in which three different lithologies – CAI, melted ferromagnesian material derived from the CV3 matrix, and khatyrkite (CuAl₂) – occur together with mutual contacts that are perfectly preserved. These contacts reveal how the silicates in both olivine-rich material and a CAI have been locally reduced by the metallic aluminum in the alloys, and how the alloys have in turn been partially dissolved by the silicate melts during what we interpret to be a major reheating event due to impact melting. We report here petrologic and mineral chemical studies, and oxygen isotope analyses, of the components of this sample.

Analytical methods: Petrologic and mineral chemical studies of Grain #129 were done at the Smithsonian using a FEI NOVA NanoSEM 600 field-emission gun scanning electron microscope and a JEOL JXA 8900 5-spectrometer electron microprobe. Oxygen isotopes were measured with a Cameca ims-7f GEO ion microprobe at Caltech using similar techniques as described in [2]. A lower primary Cs⁺ beam current (~80 pA) was used in this analytical session, so that small mineral phases could be measured with a beam size of ~2-3 μm. San Carlos olivine was used as a standard for instrumental mass fractionation correction.

Description and Mineral Chemistry: Grain #129 (Fig. 1) is just under 300 μm in maximum dimension, and consists of three lithologies: a fragment of a Type A calcium-aluminum-rich inclusion (CAI), a round vesicular object that resembles a chondrule but which in fact is likely an impact melt droplet, and Cu-Al metal alloy that is primarily khatyrkite (CuAl₂) and which partially envelops the other lithologies. The CAI super-ficially is a piece of an ordinary compact Type A, consisting of melilitite (Al₅₂), spinel, and perovskite. Closer inspection reveals it to be cross-cut by glass veins that vary from feldspathic to pyroxenic in composition, and generally containing some FeO. One edge of the CAI is mantled by layered ferromagnesian melt like that in the impact melt droplet. Also present are numerous round bubbles that commonly have expansion cracks radiating from them. Near contacts with the Cu-Al alloy (Fig. 2), the glass contains tiny Fe-metal beads (Ni-free) that formed by reduction of FeO in the melt. The chondrule-like object consists mostly of olivine, minor feldspathic glass, and Fe-Ni metal. The large central hole, and numerous smaller ones, are vesicles. Away from the contact with the Cu-Al metal the chondrule is very fine grained and preserves textures very similar to the characteristic “barrel-shaped” olivine grains that are distinctive of CV3 matrix. Near the contact with the large metal grain at lower left, the textures are coarser and consist of complexly zoned olivine phenocrysts in glass. In the droplet interior the metal beads are very Ni-rich, but at the contact with the Cu-Al metal many of the small beads consist almost exclusively of Fe with no Ni. We interpret these Ni-free ones to have formed by in situ reduction of FeO-bearing glass. The Cu-Al metal itself contains, in addition to khatyrkite, eutectoid intergrowths of khatyrkite with nearly pure (~ 93%) Al.

Oxygen isotopes: Phases in the CAI spread out along the carbonaceous chondrite anhydrous minerals (CCAM) line. Spinel is unusually 16O-rich, δ¹⁷O = 18O ~ -70‰, whereas the melilitite plots farther up the CCAM line. Olivine and glass in the melt droplet plot along CCAM just below the terrestrial fractionation line. Further studies are planned to better elucidate the unusual composition of the spinel.

Discussion: We have discovered in Grain 129 direct contacts between the Cu-Al metal and the other components of Khaytanka that reveal unmistakable evidence for in situ reduction of iron in glass by the metallic aluminum in the alloy. These features make it clear that the metal and silicates were in contact at the time of a severe heating event. The results are consistent
with previous evidence [3] indicating that Khatyrka was subjected to a high-velocity impact event (e.g., the presence of high-pressure phases, such as ahrensite and stishovite). Our continuing studies hopefully will elucidate further how this remarkable assemblage formed.


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**Fig. 1.** BSE image of Khatyrka Grain 129. The Cu-Al alloys (white) are in direct contact with, and partially enclose, a CAI and an impact melt droplet that consists mainly of partially melted CV3 matrix.

**Fig. 2.** BSE image of contact between the CAI and the Cu-Al metal, showing tiny beads of metallic Fe formed by in situ reduction of the iron-bearing glass.

**Fig. 3.** BSE image of contact between the impact melt droplet and the Cu-Al metal, showing the latter to be highly corroded at the contact. At the interface between the metal and the silicates is a very thin dark zone consisting of FeO-poor glass that contains tiny beads of Fe metal, again formed by in situ reduction of the glass at the contact.