A CAI Micrometeorite S. Taylor[1], J. S. Delaney[2,4] and G.F. Herzog[3,4] (1) CRREL, 72 Lyme Road, Hanover, NH 03755, (2) Dept. of Earth & Planetary Sciences, (3) Dept. of Chemistry and Chemical Biology, (4) Rutgers University, 610 Taylor Rd, Piscataway NJ 08854, USA.

Introduction: Micrometeorites (MMs) are terrestrially collected extraterrestrial dust particles smaller than about two millimeters. All have been heated to some degree and about 80% have been melted entering the Earth's atmosphere [1]. Many unmelted and partially melted MMs have textures and compositions that are consistent with formation from precursor grains found in carbonaceous chondrites [2,3]. Although the original textures of melted micrometeorite precursors are lost, the elemental compositions are again consistent with an origin in material related to C-chondrites [3]. As C-chondrites contain calcium aluminum inclusions (CAIs), such inclusions should be present in MM collections, particularly as CAIs melt only at very high temperatures and therefore seem likely to survive atmospheric entry heating. CAIs and their constituent refractory minerals such as spinel, peroskovite, hibonite, corundum and fassaite have been found in IDPs and unmelted MMs [4,5] and in grains from Comet Wild 2 [6,7]. These refractory minerals are often small, <10µm in the reported MM samples, and come from unmelted micrometeorites. A search for CAIs in the much larger number of partially melted MMs revealed numerous spinel relict grains ~100µm [8]. Here we report on a unique micrometeorite that appears to be a CAI based on the assemblage of minerals it contains.

Experimental Methods: SP95-36-155 (SP-155) was collected in 1995 from the South Pole water well (SPWW). It was one of ~770 micrometeorites from the central plateau sample [1]. Preliminary SEM/EDAX imaging and semi-quantitative analysis of SP-155 was done using an FEI XL-30 at Dartmouth College. The results showed SP-155 to be highly unusual, both in texture and composition.We then performed more detailed analyses of the MM using the JEOL JXA-8600 electron microprobe at Rutgers University.

Results: SP-155 is a compact (200 µm ×150 µm), CAI with an igneous texture (Fig. 1). It consists of two distinct regions: core and rim (Fig. 2). The core contains micron scale euhedral to subhedral spinel grains ($MgAl_2O_4$, dark phase) intergrown with the pyroxene fassaite ($Ca(Mg,Ti,Al)(Al,Si)_2O_6$, brighter phase) and minor perovskite ($CaTiO_3$, very bright phase). The core fassaite is exceptional as it is very TiO_x (16-20%) and Al_2O_3 (15-18%) rich (Fig. 2, Table 1). The high Ti concentrations suggest that a significant fraction is Ti^{3+} [9] although Ti^{4+} is probably also present. All core phases have very low FeO.

The rim, like the core, is dominated by a phase that is compositionally fassaite, but with much lower TiO_2 (3-4%) and Al_2O_3 (9-15%). It is texturally homogeneous but compositionally zoned, increasing in FeO content from interior to exterior. This 'glass' also contains vesicles suggesting that it melted. The rim contains a prominent, concentric band of Mg-olivine ($Fo_{>99}$) near its exterior surface. The forsterite is relatively CaO-rich (0.6-0.85%) and fluoresces under the electron beam. The edge of the particle is decorated with small magnetite crystals that coalesce in a few areas to form a magnetite rim.

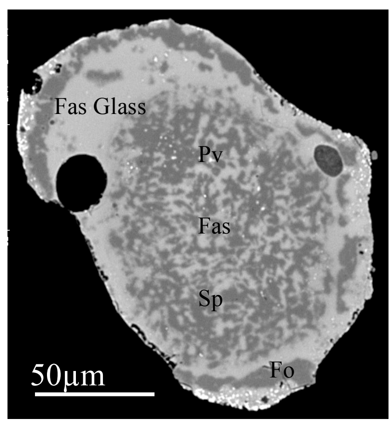

Fig. 1. SEM image of SP-155 showing location of forsterite (Fo), Spinel (Sp), Fassaite (Fas), Peroskovite (Pv) and glass having a fassaite-like composition.

Table 1. Low beam current microprobe analyses

	Fas (core) n=5	Ol n=6	Sp n=2	Pv n=1
MgO	6.6± 0.3	58.6 ± 0.9	29.1 ± 0.1	3.3
Al_2O_3	16.1 ± 0.9	0.1± 0.1	69.7± 0.6	8.2
SiO_2	31.8 ± 0.6	42.9 ± 0.7	0.3 ± 0.1	2.2
CaO	24.5 ± 0.4	0.7 ± 0.1	0.3 ± 0.1	34.4
TiO_2	18.2 ± 0.9	0.0 ± 0.0	0.8±0.0	49.2
FeO	0.4 ± 0.1	0.4 ± 0.3	0.2 ± 0.1	0.1
TOTAL	97.5 ± 0.8	102.8 ± 1.1	100.3 ± 0.5	97.4

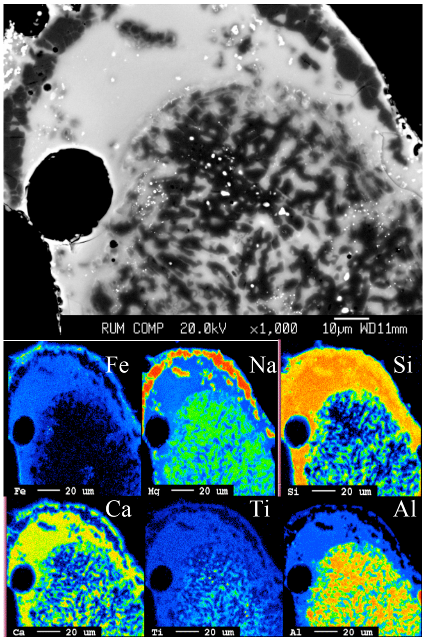

Fig. 2. A high resolution image and Si, Fe, Mg, Ca, Ti and Al elemental maps for the top section of SP-155. The Si map shows the clear demarcation between the core and rim.

Discussion: The core assemblage resembles those seen in Type A and B1 CAIs except that it contains no melilite (Fig. 3). If SP-155 is indeed related to the Type B1 inclusions then it derived from a CV-chondrite since such inclusions are known only in CV meteorites [10]. The absence of melilite is unusual and suggests that SP-155 could be a fragment of a larger CAI or be part of a Wark-Lovering rim assemblage.

The inferred presence of Ti^{3+} is consistent with Type A and B1 CAIs and implies original crystallization at the extremely low oxygen fugacity typical of their formation [9, 11]. The absence of Fe in the core also attests to the low original fugacity. We infer the core has not been oxidized appreciably by either the Earth's atmosphere or the water in the SPWW.

The rim assemblage of fassaitic glass, forsterite and magnetite is thermodynamically unstable and is significantly more SiO_2 rich and more oxidized than the interior of the inclusion. The rim may have formed when a CAI and a rind of matrix from its CV host chondrite melted during atmospheric entry. Melting and mixing of host and exterior fassaite could have produced a fassaitic glass with higher SiO_2 and FeO and lower TiO_2 and Al_2O_3 concentrations.

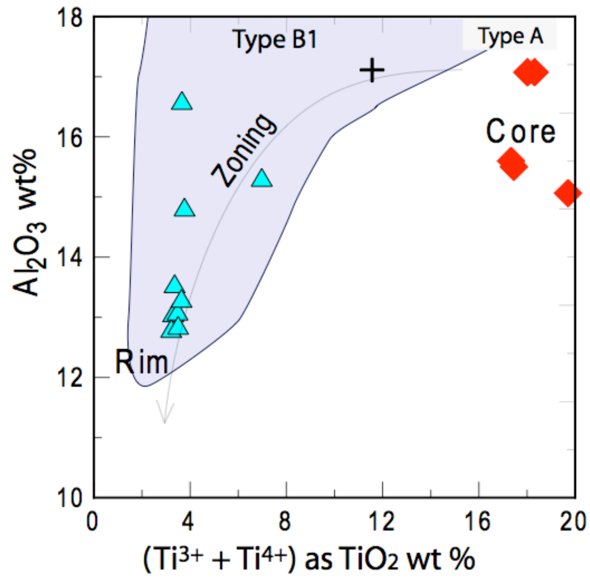

Fig. 3. TiO_2-Al_2O_3 relationships for fassaite (red diamonds) and fassaite glass (blue tringles) and interface between core and rim (cross). The field in blue is the range of Type B1 inclusions [10]. The range of Type A inclusions is just outside the top of the plot.

Rapid nucleation and growth of refractory forsterite would produce the observed Fo rim that somewhat armors the inclusion.

Alternately, the variation in the fassaite compositions may reflect an original rim sequence on SP-155. A large increase in fO_2 during atmospheric entry could have oxidized any Ti_2O_3 and FeO already present in the rim to TiO_2 and Fe_2O_3, respectively.

SP-155 is much larger than any previously reported CAI or refractory phases found in MM and IDPs [5]. If the type B1 designation is correct, SP-155 is the first micrometeorite containing a nearly intact CAI from a CV (or any other) chondrite. Since SP-155 and a porphyritic spherule containing relict spinels were both from the flux calibrated plateau sample we estimate at ~0.2% the abundance of CAI-related material in the MM flux.

References: [1] Taylor et al. (1998) *Nature*, 392, 899-903. [2] Kurat et al. (1994) GCA, 58, 3879-3904. [3] Brownlee et al. (1998) M&PS 32, 157–175. [4] Hoppe et al. (2001) 32nd LPSC, 1914.pdf. [5] Greshake et al. (1996) *Meteortics*, 31, 739-748. [6] Simon et al. M&PS 43, 1861-1877. [7] Matzel et al. M&PS 44, A136. [8]Taylor et al. (2008) 39th LPSC,1628.pdf. [9] Simon et al. 1991 GCA, 55, 2635-2655. [10] Brearley and Jones (1998) Rev. Mineral 36, 3-398. [11] Grossman et al. (2008) Rev. Mineral 68, 93-140.