PETROGENESIS OF UREILITE METEORITES: EVIDENCE OF MAGMATIC PROCESSES FROM MINERAL CHEMISTRY AND MODAL MINERALOGY. S. J. Singletary¹ T. L. Grove¹, and Cyrena A. Goodrich² ¹Massachusetts Institute of Technology, Dept. of Earth, Atm. And Planet. Science, Cambridge, MA 02139, ²Max-Planck-Institut für Chemie, PO Box 3060, D-55020 Mainz, Germany (jumper@mit.edu, tlgrove@mit.edu, goodrich@mpch-mainz.mpg.de).

Introduction: Ureilites represent an enigmatic group of achondrites that are comprised of ~90% anhedral olivine and pyroxene and <10% dark interstitial material consisting of a mixture of silicate, carbon, metal, carbides and sulfides [1]. Although ureilites resemble igneous rocks their mode of origin remains controversial. The competing hypotheses include origin as products of fractional crystallization, residues of partial melting, or a nebular origin. We have used electron microprobe image analysis to quantitatively estimate the mineral proportions and determined the silicate phase compositions in 20 ureilite samples. These new data are combined with the results of experiments to calculate the precipitation temperatures for the olivine + pyroxene assemblage and the stoichiometric coefficients for the smelting reaction between liquid, silicate minerals, carbon and iron. We find that there is a variation in mineral composition and mode that is consistent with a smelting process for part of the ureilite group, but that this process can not explain all of the variability observed among the ureilites.

Experimental Constraints: Key pieces of information for developing a model of ureilite formation are the temperature at which the minerals were in equilibrium with liquid and the composition of that liquid. Several temperature estimates have been made with the use of a two-pyroxene thermometer for those ureilites that contain augite and orthopyroxene [2]. However, the majority of ureilite samples in our collection contain pigeonite as the sole pyroxene phase and deny us the use of the two-pyroxene thermometer.

“One-pyroxene” thermometer. We have developed a temperature calibration that uses the coexistence of pigeonite with olivine and silicate melt to develop a thermometer that generates temperature estimates (±15-20 °C) for those ureilites that contain augite and orthopyroxene [2]. However, the majority of ureilite samples in our collection contain pigeonite as the sole pyroxene phase and deny us the use of the two-pyroxene thermometer.

Smelting reaction coefficients. Our experimental results have been combined with those of Walker and Grove [5] to determine the reaction coefficients of the smelting reaction. This reaction can be used to develop a model for the change in residue mineral composition and modal proportions that would be expected to occur during a smelting reaction. The coefficients of this reaction are:

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0.43 \text{ C} + 1 \text{ liquid} + 0.71 \text{ olivine} = 1.29 \text{ pigeonite} + 0.43 \text{ Fe} + 0.43 \text{ CO}
\]

The reaction is written so that decompression-smelting proceeds to the right hand side of the reaction.

Figure 1. Plots of olivine Fo content vs modal % pigeonite and estimated temperature showing the two fairly distinct groupings of our sample suite. The arrow in the lower panel indicates the change in modal % pyroxene and Fo content that would result from 12 % smelting.
Modal and Mineral Compositional Systematics:
When we overlay the predicted trends of composition and modal change to our data (Fig.1) a trend produced by smelting is permitted for the lower Fo, lower temperature group of ureilites. The arrow indicates the effects of 12 wt.% decompression smelting. The higher temperature, higher Fo group of ureilites does not show as well-defined a trend of reduction melting. In the Fo vs % pigeonite plot, the high temperature samples scatter about a near-constant value of modal proportions. The most clearly defined correlation in the high-Fo group is a positive correlation between Fo content and temperature.

Predicted Liquid Compositions. When the compositions of liquids are calculated from olivine + pigeonite + melt equilibria, the resulting melt compositions contain: 52 to 58 wt. % SiO₂, 5 to 11 wt. % Al₂O₃, 6 to 11 wt. % FeO, 8 to 13 wt. % MgO and high CaO (from 11 to 16 wt. %).

Conclusions The 20 ureilites in our sample suite record magmatic temperatures in the range of 1170 to 1260 °C. Their mineral compositions and modal mineralogy variations are consistent with a model of ureilites as residues of a smelting process. The smelting trend is best defined in the lower temperature group of ureilites and less well defined in the high temperature, magnesian samples. A possible interpretation of the high temperature grouping is that it represents a deeper sampling of a ureilite parent body, perhaps at pressures high enough to suppress the smelting reaction.