

## ALH82106/130 and the Fractionation of Augite - bearing Ureilites

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**INTRODUCTION:** The ureilite Allan Hills 82106/130 [1-6] contains about 40% olivine ( $Fo_{90-99}$ ), about 40% pigeonite ( $Eng_0Wo_{4.9}$ ) and about 10% augite. Pigeonite grain size is typically in excess of 15 $\mu$ m (1). ALH82106,7 and 82130,10 each contain a single poikilitic pyroxene grain with olivine, augite and opaque inclusions. The olivine is almost opaque because of clouding with metal, graphite, and Cr-bearing troilite. The poikilitic pigeonite is comminuted into subgrains that obscure some details of the texture but has submicron inclusions of the same phases as the olivine and exsolution lamellae of augite. Rounded augite crystals are an obvious feature of these sections. The bulk composition of the pyroxene ( $Eng_0Wo_9$ ) suggests initial crystallization of opx from a magma rather than pigeonite (7) which is presumably shock induced (4). The assemblage appears to be consistent with crystallization at, or near, the oliv-pig-aug minimum point in the system oliv -  $SiO_2$  - diops.

**Mineral Compositions:** The poikilitic pigeonite is essentially uniform ( $Eng_1Wo_{4.7}$ ) in both thin sections. More magnesian compositions produced by reduction ( $Eng_8Wo_{1.3}$ ) are relatively rare. The augite grains define a compositional tie line with the pigeonite consistent with a temperature of about 1200°C (using 7). The olivine is heterogeneous. Core compositions range from  $Fo_{95}$  to  $Fo_{99.2}$ . The olivine rims are generally more magnesian than the cores ( $Fo_{96}$  and  $Fo_{99.6}$ ). These rims result from in situ reduction by reaction with graphite (1, 3, 4, 5). The amount of reduction experienced by the olivine is variable and is probably controlled by local kinetics as much as by large scale reduction reactions.

**DISCUSSION:** Fractional crystallization with simultaneous reduction of Fe from the silicates and removal as metallic iron has been suggested as the mechanism of formation of ureilites (1, 8). Since iron is constantly being removed from this system the ratio  $Fe/(Fe+Mg)$  will not increase as the liquid phase evolves and cannot be used as a fractionation index. If reduction is more rapid than fractionation, the  $Fe/(Fe+Mg)$  of the silicates will tend to decrease whereas if fractionation is dominant, then the  $Fe/(Fe+Mg)$  ratio will tend to increase. The relative influences of these two processes have not been assessed yet.

The crystallization of augite as an early phase in ureilites such as ALH82106/130 or the more Fe-rich Y74130 (4) suggests that the fractionation history of these ureilites can be approximated in the plane cpx - oliv -  $SiO_2$  (Fig 1). Similarly, the high Ca of ureilite olivine suggests that it equilibrated with a calcic phase which may be either augite or the feldspar seen in the polymict ureilites (9) and suggests that the liquids from which ureilites accumulated were probably fairly calcic. If reduction during fractionation increases the  $Mg/(Mg+Fe)$  of the system, the olivine field will expand as fractionation progresses. The pigeonite stability field will also shrink away from the olivine - silica join, limiting the range of compositions that may crystallize pigeonite. Liquids in equilibrium with the progressively more magnesian silicates will therefore become increasingly more  $SiO_2$  and cpx rich. As fractionation progresses the opx stability field will expand toward increasingly calcic compositions and may, therefore, overtake the crystallization of the liquid to produce the opx seen in 82106/130.

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Migration of equilibrium liquid compositions as a function of increasing mg# will move rapidly toward the cpx - oliv - pig minimum of the system. The tendency of fractionating liquids to cross the pigeonite field to the SiO<sub>2</sub> saturated join will be effectively suppressed by the migration of the olivine saturated surface toward higher SiO<sub>2</sub> with increasing mg#

Y74130 is an augite bearing Fe-rich ureilite with little or no pigeonite. In contrast, ALH82106/130 is Mg-rich and has augite and opx/pigeonite. These two differ because of the effect of mg# on the crystallization of the olivine -augite - pigeonite peritectic (Fig. 1). For systems with mg# near 0.8, augite (A) at the peritectic lies within the augite stability field while pigeonite (P) is in the olivine field (7). Reaction at the minimum is, therefore, L - pig. = oliv. + aug., the assemblage seen in Y74130. For Mg-rich systems, however, both augite (A') and pigeonite (P') lie in the olivine field so that reaction at the minimum is L - oliv. = pig. + aug (Fig. 1). This reaction can readily generate the assemblage seen in ALH82106/130. If reduction during fractionation is the mechanism linking ureilite compositions it is very difficult to produce both the Fe rich Y74130 and ALH82130 from the same magma. More plausibly Y74130 may be an early partial melt at R that escaped the more extensive reduction and fractionation that produced other ureilites while ALH82106/130 is a late differentiate produced at R' after other less Mg-rich and less calcic ureilites had crystallized.

The Fe/(Fe+Mg) of the pigeonite is probably closer to that of the original crystallizing assemblage than that in olivine, as Fe/Mg diffusion is much slower in pyroxene, but variations in Fe/Mn have been used to provide evidence for reduction of even the pigeonite cores (3,8,10). Mn has the same general properties as Fe in silicate magmatic systems but is reduced to metal only at extremely low oxygen fugacities. The ratio Mn/(Mn+Mg) should, therefore, be a fractionation index for ureilites behaving like Fe/(Fe+Mg) in more oxidized systems. The Mn/(Mn+Mg) ratios of ureilitic olivine, pigeonite and augite are significantly different, however, indicating that variation of this ratio with fractionation will be sensitive to the crystallization sequence for the assemblages observed. Consistent data of sufficient precision are rare but the available data suggest that Mn/(Mn+Mg) in pigeonite varies and may be correlated with the crystallization sequences that may link some ureilites to a common magma. Further tests of the usefulness of this ratio in ureilitic systems are currently being developed.

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FIGURE 1: Oliv - SiO<sub>2</sub> - Aug. ternary with boundaries for Mg/(Mg+Fe) = 1 (lines) and inferred boundaries (dashed) for mg# > 0.8. Solid symbols are for phases in Fe free system, open symbols for Fe bearing system. Minimum point R or R' represents the compositions of the augite bearing ureilites.

