MINERALOGICAL STUDIES OF UREILITES: MINOR PHASES AND INCLUSIONS AND THEIR IMPLICATIONS

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Ureilites are achondritic meteorites made up mainly of equilibrated olivine and pigeonite set in a C-matrix. Nearly all aspects of their genesis are controversial and condensate, cumulate, residua and fractional crystallization models have been presented. Since the Berkley et al. [1] study of Non-Antarctic ureilites appeared, many new Antarctic ureilites have become available. This study emphasizes Antarctic ureilites, and reexamines the Non-Antarctic, to gather and integrate all relevant mineralogical data on major, but especially minor phases. The 15 Antarctic meteorites are far more diverse than the 11 Non-Antarctic ones (Fig. 1). These data, and minor phase data not shown, combined with data from the N. Haig/Nilpena polymict ureilite [2] show that ureilites are more complex assemblages than originally realized and display distinct fractionation trends (Fig. 3). In this study 15 ureilites were modally analyzed and scrutinized for minor phases within, and interstitial to, the major phases. Minor phases are present as inclusions, blebs, isolated grains, rims and interstitial veins. These include ol, pig, cpx, opx, plag, Si-bearing metal, sulfides, chromite and chlorapatite.

Host Olivine. The most common inclusion is pig, but other inclusions are cpx, plag, SiO_2, Ni-free metal, chromite, and sometimes ol. Pig inclusions generally have the same composition as host pig Ol inclusions are sometimes more Mg-rich than host olivine, probably due to in situ reduction. Cpx is included in ol in Kenna, Novo Urei, Y74659 and ALHA 81101. In Kenna, cpx is associated with plag (An_{70}; Fig. 2), chromite, and Ni-free metal. Sometimes cpx is not equilibrated with the host ol and pig Host ol usually has uniform composition, but ALHA 81101, Y74154 and N. Haig/Nilpena have a range of compositions.

Host Pigeonite. The most common inclusion is ol, usually the same composition as host olivine. In RKPA 80239, several ol inclusions show clear evidence of in situ reduction. Inclusions show no evidence of being more Mg-rich than host ol. However, ALHA 82106/82130 differs in that it contains ol inclusions in host pig that are more Fe-rich (up to Fo_{95}) than the host ol (Fo_{98}). These inclusions constitute evidence for reverse magmatic fractionation and support the data of Goodrich and Berkley [3]. Cpx is rarely found as inclusions in pig (e.g., Y790981) and is similar to that in host ol. Host pig usually has uniform composition, but sometimes has considerable variation (ALHA 81101, Y74154 and N. Haig/Nilpena). Two ureilites, Y74659 and Y791538, have two coexisting host pig compositions.

Clinopyroxene. Cpx is a major phase in two ureilites (ALHA 82106/82130, Y74130), is included in host ol and pig, is present as mineral fragments in ALHA 78019, and in N. Haig/Nilpena [1]. These data have resulted in the generalized cpx trend (Fig. 3), which has not been recognized previously in ureilites.

Orthopyroxene. Opx forms thin reduction rims on host ol, often followed by a reduced ol rim, with sulfide in between. The opx ranges from Wo_{1-2} En_{90-100}. Opx is present as a major phase in Y74130 [4]. Enstatites are found in N. Haig/Nilpena; they may be reduced ureilitic opx, or from enstatite meteorites.

Plagioclase and Feldspathic Glass. Interstitial feldspathic glass is found as tiny veinlet-like material in most ureilites (Fig. 2). Feldspar compositions were calculated from the Na/Al ratio and found to be about An_{40-80} (no K_2O), similar to isolated feldspar grains in N. Haig/Nilpena [1]. The ureilitic range is schematically shown in Fig. 3, and was not previously recognized in ureilites.

Si-bearing FeNi. Metal is present as blebs and inclusions in host phases, as isolated grains and in interstitial veins. Interstitial vein metal is often Si-bearing, whereas the other metal is not. These results are similar to those of [5], except that we find wider compositional ranges of Si-bearing metal from 9 ureilites (see [2]).

Conclusions. (1) Ureilites should not be subdivided into 2 or 3 groups, as there is a continuum of compositions, shown especially by Antarctic ureilites (Fig. 3). (2) Ureilites have major and minor phases which have consistent patterns, indicative of fractionation trends (Fig. 3). The cpx and K_2O-free plag (An_{40-80}) trends indicate the existence of fractionated cpx-plag-bearing alkali-poor associated rocks. (3) Ol inclusions in ALHA 82106 give evidence of reverse fractionation. Ol and pig inclusions in host pig and ol, respectively, indicate simultaneous crystallization of both phases for at least part of the cooling history. (4) Cpx-plag-bearing associated rock types are significant in interpreting the unusual REE patterns of ureilites. Separation of plag-bearing melts was responsible for the negative Eu anomalies. REE patterns of the cpx would help resolve cumulate vs. residua hypotheses. (5) Ureilites appear to be ol-pig cumulates which were held at high T for an extended period of time, during which interstitial melts were extracted. The cumulate assemblage was then quenched (perhaps by planetary shattering) to preserve the high T event. (6) The cpx-plag associated rock types may be related to ADOR, a fassaitic clinopyroxenite equivalent to a Ca-Al-Ti-rich cpx-plag rock type. Fragments of this rock type are present in N. Haig/Nilpena [2].

REFERENCES. (1) Berkley et al. (1980) GCA 44, 1579-1597. (2) Prinz et al. (1986) this volume. (3) Goodrich and Berkley (1985) LPSC XVI, 280-281. (4) Takeda and Yanai (1982) NIPR 25, 7th Symp., 97-123. (5) Berkley and Jones (1982), Proc. 13th LPSC, JGR 87 A353-A364.

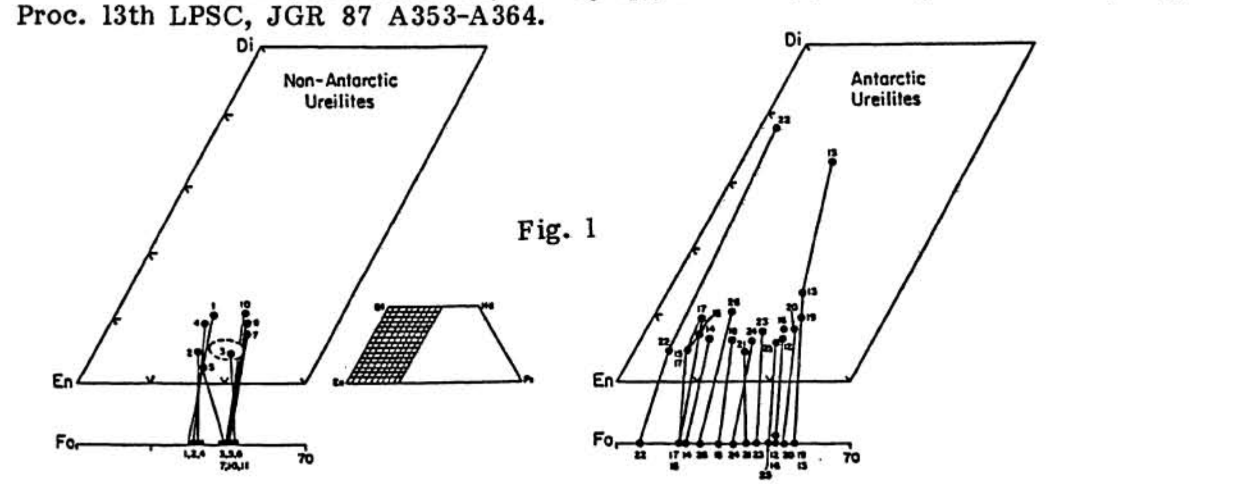

Fig. 1

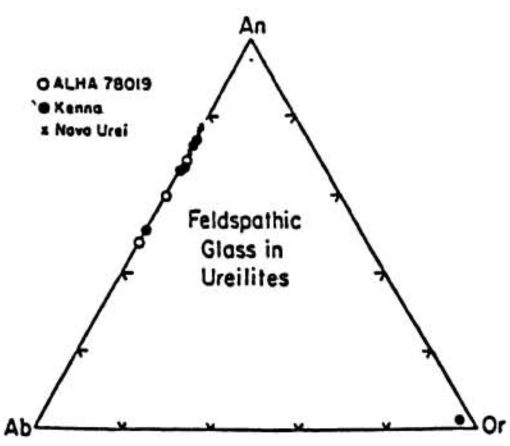

Fig. 2

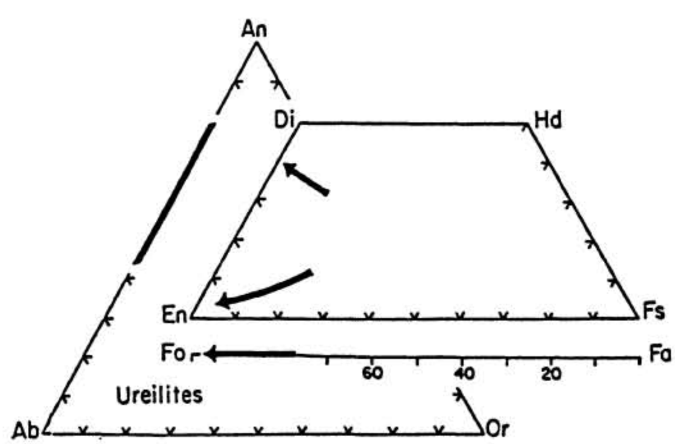

Fig. 3