SHERGOTTITE QUE 94201: TEXTURE, MINERAL COMPOSITIONS, AND COMPARISON WITH OTHER BASALTIC SHERGOTTITES. R.P. Harvey¹, T.J. McCoy² and L.A. Leshin³ ¹Dept. of Geological Sciences, Case Western Reserve Univ., Cleveland, OH 44106 USA. ²Code SN4, NASA/Johnson Space Center, Houston, TX 77058 USA. ³Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095 USA.

Introduction. The basaltic shergottites (Shergotty, Zagami and EET A79001) exhibit evidence for complex, multi-stage petrogenesis [e.g., 1] involving a range of pressures and cooling histories, as well as complex physical processes occurring in near-surface magma bodies [2-4]. The recently described 12.0 gram shergottite QUE 94201 [5] provides an opportunity to gain further insights into this petrogenesis. The description of QUE 94201 as a coarse-grained mixture of subequal pyroxene (pigeonite, $F_{ss} = 69$) and maskelynite suggests similarities to the dark, mottled lithology of Zagami described by [4]. Our examination of QUE 94201 (PTS 4, 6 and 38) confirms the similarity to the dark, mottled lithology of Zagami. Both are coarse-grained, FeO-rich lithologies with pockets of late-stage phases (e.g., phosphates, Fe,Ti-oxides, fayalite-SiO₂ intergrowths; essentially identical to the DN pockets of [6]). However, QUE 94201 crystallized from a melt more fractionated than Zagami.

Texture. QUE 94201 is coarse-grained, consisting of subequal Fe-rich pigeonite and maskelynite. Modal analysis of PTS 38 (recalculated to exclude 29.5 vol.% shock-melt pockets) contains 52.3% pyroxene, 41.3% maskelynite, 2.4% whitlockite, 2.0% Fe,Ti-oxides, 1.7% fayalite-SiO₂ intergrowth and 0.2% sulfides. QUE 94201 is more maskelynite-rich than other basaltic shergottites and comparable in the abundance of late-stage phases to the dark, mottled lithology of Zagami [4]. Most pyroxene and maskelynite grains exceed 1 mm in length (up to 3 mm) and are somewhat elongated. The grain size variation among basaltic shergottites is normal Zagami < dark, mottled Zagami = QUE 94201 < Shergotty. A foliation indicated by aligned, elongated maskelynite appears to be present in some sections (e.g., PTS 4), but is less marked in other sections of this small meteorite. Neither phase forms a self-supporting lattice of crystals, suggesting co-crystallization of pyroxene and maskelynite during formation of QUE 94201. No amphibole-bearing melt inclusions were noted in pyroxene.

QUE 94201 contains a variety of late-stage phases. Large Fe-Ti oxides (ulvospinel, rutile, ilmenite) (≤ 1.5 mm) and whitlockite (≤ 400 μm) occur interstitial to pyroxene and feldspar. These phases are elongate and sometimes exhibit a skeletal morphology. A striking feature of QUE 94201 is the presence of pockets of late-stage crystallization products. These pockets are similar to the cm-sized DN pockets in Zagami [6]. The characteristic feature of these pockets is the presence of an intergrowth of fayalite and SiO₂. Fayalite typically occurs as "dendrites" with inclusions and intergrowths of abundant SiO₂, maskelynite, whitlockite, Fe-Ti oxides and sulfides and minor augite, chlorapatite and a Zr-rich phase, probably baddeleyite. These mesostasis patches are generally less than 500 μm across, but reach up to 1 mm. The pockets generally follow grain boundaries at the interstices of large pyroxene grains, but are occasionally intricately mixed with surrounding pyroxene. Fayalite-silica intergrowths are also found in the cores of large skeletal phosphate grains adjacent to these pockets.

Like all basaltic shergottites, QUE 94201 has experienced shock. Feldspar is transformed to maskelynite and pyroxene exhibits mosaicism and planar fractures. Shock-melt pockets are common, but heterogeneously distributed, in QUE 94201, reaching 5 mm in diameter (PTS 38). These pockets are vesicular and include relict, highly-shocked pyroxene grains. They resemble shock melts in the Zagami dark, mottled lithology [7], which formed in situ. They differ from some shock melts in normal Zagami [2] and EET A79001 [3], which migrated along fractures.

Cracks in QUE 94201 are pervasively filled with variable mixtures of Ca- and Fe-K-sulfates. Fe-K-sulfates are sometimes observed rimming Fe-sulfides. These sulfates are also observed filling vesicles in the fusion crust and, thus, are almost certainly of Antarctic origin.

Mineral Compositions. Pyroxenes in QUE 94201 are strongly zoned and rich in FeO, with pigeonite up to $F_{ss} = 85$. Pyroxene zoning records a prolonged history. Unlike other
shergottites, some Mg-rich pyroxene cores exhibit sector-type growth. Fig. 1 illustrates a pyroxene grain with multiple episodes of growth. Zone 3 contains a pigeonite core (-Fs_{29}Wo_{14}) surrounded by sectors of augite (-Fs_{21}Wo_{34}) and sub-calcic augite (-Fs_{25-26}Wo_{20-26}). Zone 2 is an overgrowth of Fe-rich pigeonite and Zone 1 is an overgrowth of mixed pigeonite (up to Fs_{71}) and augite. Pigeonite shows the most marked zoning and FeO-rich compositions adjacent to the fayalite-SiO_2 intergrowths and least FeO-rich compositions adjacent to maskelynite. Pyroxene compositions in QUE 94201 are comparable to the range observed in the dark, mottled lithology of Zagami. QUE 94201 contains whitlockite with 5-6 wt.% FeO and Fa_{96-99} (-1 wt.% MnO) in the fayalite-SiO_2 intergrowths. QUE 94201 whitlockite is richer in FeO than normal Zagami (-3 wt.%) or the dark, mottled lithology (-3.5 wt.%), but comparable to Zagami DN (-5 wt.%). Studies of the D/H ratio of hydrous minerals and shock melts are planned to elucidate the role of volatiles in the evolution of QUE 94201.

**Crystallization History.** The FeO-enriched QUE 94201 probably represents a residual liquid after fractional crystallization of Mg-rich pyroxene in a magma chamber and/or a near-surface magma body. However, QUE 94201 does not preserve the multiple lithologies produced by near-surface differentiation seen in the larger Zagami. Pyroxene fractionation (mostly pigeonite) enriched the melt in relatively incompatible elements (e.g., Ca, Al, Na, P, S). During crystallization of QUE 94201, pyroxene and plagioclase were co-crystallizing and the enrichment of Ca, Al and Na produced maskelynite abundances greater than other shergottites. The occurrence of sector-type intergrowths has not been reported in other shergottites. Sector zoning appears to be a common feature among experimentally produced crystals (e.g., [8]), particularly for minor and trace elements, and is almost certainly a product of crystal growth (e.g., [9]). The formation of sectors of augite and sub-calcic augite in some QUE 94201 pyroxenes may reflect the Ca-rich nature of the QUE 94201 melt. Other shergottites crystallized from melts much less enriched in Ca and, thus, did not develop this feature. Late crystallization in localized melt pockets produced the Fe-rich pyroxene overgrowths. As pyroxene crystallization continued, these small volumes of melt became increasingly enriched in Ti, P, and S, and large oxides, phosphates and sulfides crystallized. As the Fe content of the melt exceeded the stability field for pigeonite, pyroxene crystallization was replaced by fayalite-SiO_2 intergrowths and other minerals enriched in incompatible elements (e.g., Zr). The crystallization of these melt pockets has been discussed by [6]. Late-stage melt pockets in QUE 94201 differ from Zagami in containing relatively scarce apatite, possibly reflecting the lower volatile abundance in this melt.

Shergottites appear to have experienced prolonged magmatic histories. These complex, multi-stage histories probably involved crystallization in both magma chambers and thick, near-surface magma bodies [2,4], the latter possibly the 10 m thick flows common on Mars, producing a range of lithologies from relatively early-stage, FeO-poor basalts (e.g., normal Zagami, Shergotty) to late-stage, FeO-rich basalts (e.g., dark, mottled Zagami, QUE 94201). The FeO-rich minerals and abundant late-stage melt pockets and maskelynite all argue that QUE 94201 is the most evolved member of this basaltic shergottite evolutionary trend.

**References**


**FIG. 1.** Sector growth pyroxene in (a) Ca/(Ca+Mg+Fe) image (brighter = more Wo) and (b) outline. Non-pyroxene phases have been masked out. FOV = 1 mm. Multiple stages of growth are indicated, including sector-type growth in the core of the crystal. Details are given in text.