Experimental martian eclogite with a QUE 94201 composition J.J. Papike (jpapike@unm.edu), P.V. Burger, C.K. Shearer, F.M. McCubbin, and S.M. Elardo. Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico, 87131

Introduction: The martian upper mantle is likely dominated by garnet-bearing lithologies such as eclogite (garnet clinopyroxenite), garnet peridotite, and garnet lherzolite. These lithologies should start appearing at pressures between 2 and 3 GPa on Mars. At 4 GPa, or 360 kilometers depth, (based on 90 kilometers depth ~ 1 GPa), plagioclase should disappear while garnet should become an important phase. In this study, we use high-pressure techniques to synthesize a martian eclogite. These experiments are based on the composition of martian meteorite QUE 94201, an evolved liquid. The resultant eclogite (garnet clinopyroxenite) was produced in a multianvil cell at a pressure of 4 GPa, and an fO_2 ~ IW + 2.5, and contains pyropic garnet, omphacite (with a high jadeite component), the oxide phases ilmenite and rutile, a phosphate similar to merrillite, and a silica phase (likely coesite), and may be representative of martian melts whose ascent has been arrested in the upper mantle. The crystallization sequence is likely garnet and omphacite, followed by oxides, "merrillite-like phase" and coesite. An important observation is that a significant phosphorus component (1000-4000 ppm P_2O_5) enters the garnet structure at 4 Gpa, suggesting that garnet may be an important reservoir for P in the martian upper mantle along with the "merrillite-like" phase. The major crystal chemical factor in the change from basalt to eclogite is the coordination of Al. In plagioclase, Al is in 4-fold coordination, while in eclogite, it is in 6-fold coordination in both garnet and omphacite, thus leading to a higher density assemblage. We predict that eclogite is an important lithology in the upper mantle of Mars in a region not yet sampled.

Laboratory and Analytical Methods: The experiment reported here was conducted under nominally anhydrous conditions (i.e., with no added H_2O) within a high-purity graphite capsule with a press-fit lid produced at Arizona State University. Both starting materials and capsule were stored in a dessicator until use. The experiment was pressurized cold and then heated while maintaining pressure. The run was conducted in a Walker-style multi-anvil press at the Institute of Meteoritics at the University of New Mexico using the procedure, cell assembly, and calibrations described by [1]. The run product was analyzed using a combination of optical microscopy and electron probe micro-analysis (EPMA), specifically relying on backscattered electron imaging (BSE), wavelength-dispersive spectroscopy (WDS) and quantitative point analyses.

Eclogite Petrography: Figure 1 illustrates the texture and mineralogy of the 4 Gpa charge. The BSE plus WDS Mg, Al, Ti, P, and Na maps clearly show the two prominent phases, garnet and omphacitic pyroxene. The Ti map shows the location of the Ti-Fe phases, rutile and ilmenite, and the P map shows high P concentrations in garnet as well as a phosphate phase similar to merrillite. The estimated mode is 54% omphacite, 35% garnet, 6% ilmenite, 4% SiO_2 phase, and trace rutile and phosphate (calculated using least-squares mass balance). A very

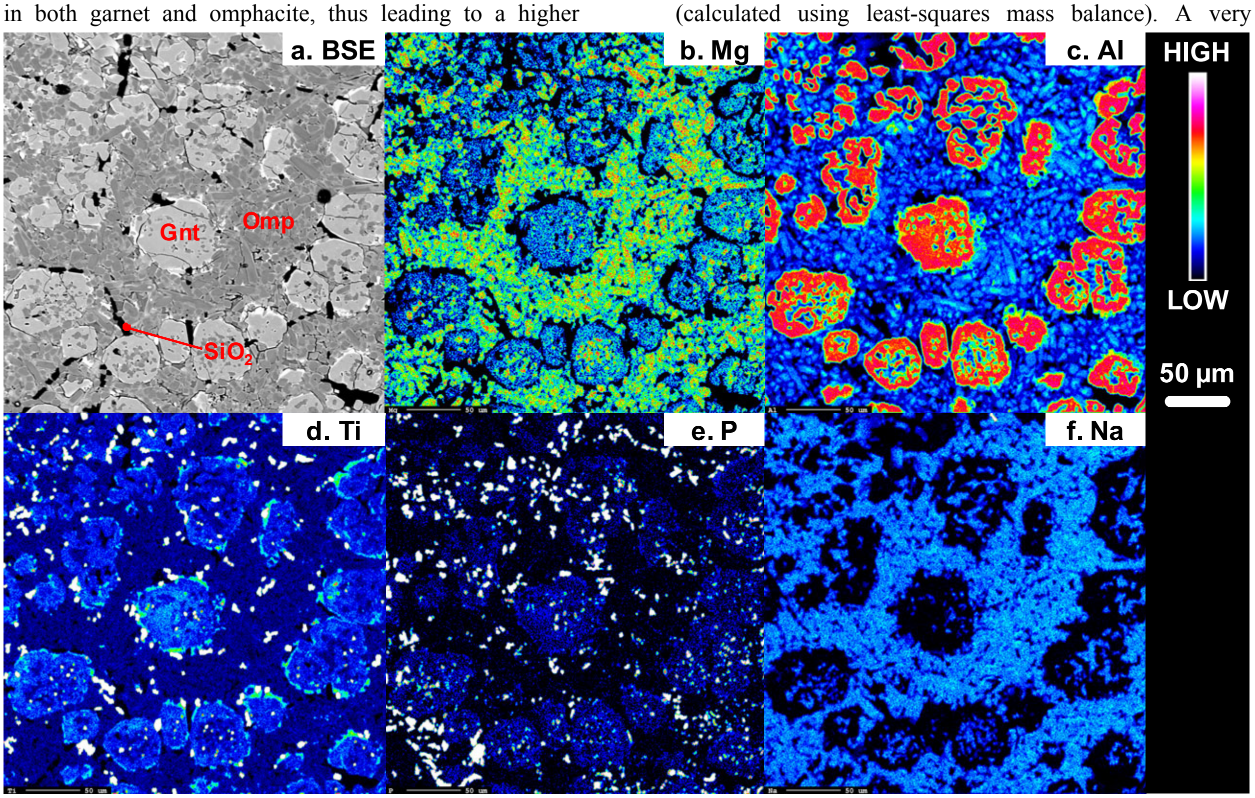

Figure 1. BSE and WDS maps from experimental eclogite.

interesting discovery involves phosphorus. In the QUE 94201 meteorite, most P occurs in merrillite and apatite. In our experimental eclogite, most of the P substitutes into garnet with the merrillite-like phase crystallizing later in the crystallization sequence. Our analyses on the merrillite-like phase are not robust partly because of small grain size, resulting in beam overlap. There is also detectable amounts of P in pyroxene but at an order of magnitude lower in concentration. The minor silica phase is likely coesite based on the P-T conditions of the experiment.

Pyroxene Chemistry in QUE 94201 Basalt vs. Experimental Eclogite: Pyroxene is arguably one of the most powerful petrologic recorders in the crusts and upper mantles of the terrestrial planets. For Mars, pyroxene is an important crustal and mantle component down to depths of ~ 1300 km [2]. Figure 2 illustrates the compositions of QUE 94201 pyroxene from the meteorite (2a) and the experimental eclogite (2b). QUE 94201 pyroxene begins crystallizing as a liquidus phase and the composition evolves from pigeonite to augite as the melt becomes enriched in Ca and Al due to the delayed nucleation of plagioclase. At the onset of plagioclase crystallization, Ca and Al decrease in the pyroxene, while increasing Fe leads to zoning from pigeonite to pyroxferroite. Ninety eight percent of pyroxenes in martian meteorites have compositions that fall between the end members diopside – hedenbergite – enstatite – ferrosilite (i.e., in the pyroxene quadrilateral). The pyroxene found in our experimental eclogite, however, is different, with the important components being diopside, hedenbergite, jadeite ($NaAlSi_2O_6$) and acmite ($NaFe^{3+}Si_2O_6$). This significant change in pyroxene chemistry is a response to pressure and the disappearance of plagioclase. Omphacite gains most of the Na lost from plagioclase and some of the Al which is shared with garnet. The omphacite shows limited compositional zoning compared to pyroxene in the QUE meteorite though slight iron (Fe^{3+}) enrichment is found in the rims.

Garnet chemistry: Garnet is an extremely important phase in our eclogite assemblage. Analyses are presented in a ternary diagram in Figure 3. This is the first attempt produce an eclogite assemblage with a martian melt composition. The garnet compositions in Figure 3 show that the most important garnet components are grossular ($Ca_3Al_2Si_3O_{12}$), andradite $Ca_3Fe^{3+}{}_2Si_3O_{12}$, pyrope ($Mg_3Al_2Si_3O_{12}$), and almandine ($Fe^{2+}{}_3Al_2Si_3O_{12}$). The pyrope content is an indicator of high pressure; pyrope is not stable at low pressures because Mg is too small to be coordinated in the X-site. However, at high pressure, the oxygen ligands are brought in closer proximity to the Mg cation, and pyrope is stabilized. Garnet takes a significant amount of the Al that was in plagioclase at low pressure.

Acknowledgements: This research was supported by a NASA Cosmochemistry grant to CKS. The starting mix was provided by John Jones and Loan Lee of JSC, whose assistance we very much appreciate.

References: [1]Agee et al. (1995) Journal of Geophysical Research 100, 17,725. [2] Bertka and Fei (1997) Journal of Geophysical Research, 102, 5251.

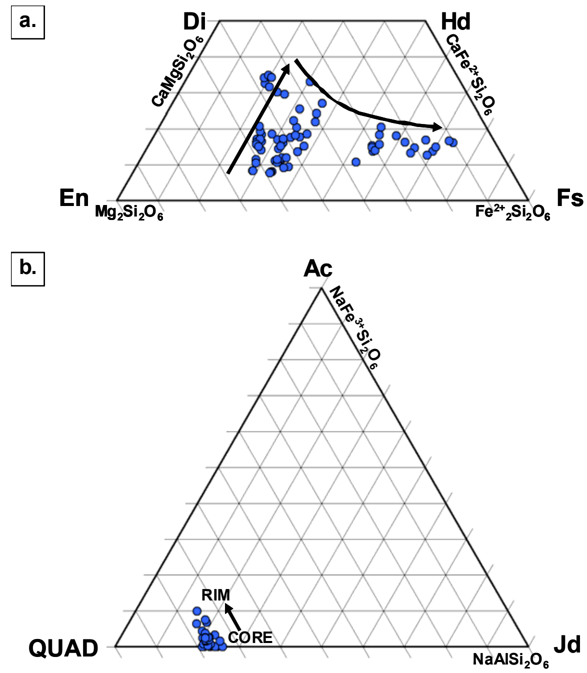

Figure 2. a. Chemistry of pyroxenes from the natural martian basalt, QUE 94201. b. Pyroxene chemistry from the experimental eclogite.

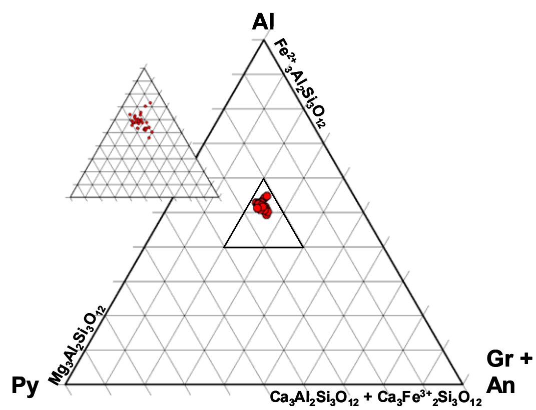

Figure 3. Garnet chemistry for the experimental eclogite.