FE-MG-TI OXIDES IN LUNAR MARE BASALTS: CHEMICAL EVOLUTION INTERPRETED FROM EXPERIMENT AND THEORY. D. H. Lindsley, M. J. Hartzman, S. E. Kesson, and M. K. Cushman, Dept. of Earth and Space Sciences, State Univ. of N. Y., Stony Brook, N. Y. 11790

The compositions of several lunar oxide minerals--most armalcolites and ilmenites, and some ulvöspinels--fall essentially in the system $FeO-MgO-TiO_2$. Phase relations in this system can thus aid in the interpretation of the paragenesis of these minerals. Most armalcolites (Arm) are essentially solid solutions between $FeTi_2O_5$ (ferropseudobrookite, Fpb) and $MgTi_2O_5$ (Karrooite, Kar); Fe/(Fe+Mg) is variable but tends to approach 0.5. Both textural reactions (many armalcolites are mantled by ilmenite) and melting experiments on lunar basalts (1) strongly indicate that armalcolite is stable at high temperatures but tends to disappear by reactions of the type:

$(Mg,Fe)Ti_2O_5$ (Arm) + FeO (from melt) = $2(Fe,Mg)TiO_3$ (ilmenite) (A)

Analogy with the $Fe_2TiO_5-FeTi_2O_5$ system suggested that armalcolite might be inherently unstable with respect to magnesian ilmenite plus rutile at low temperatures (2). This is confirmed by experiments in the join $FeTi_2O_5-MgTi_2O_5$ (Fig. 1): for example, $Fe_{0.5}Mg_{0.5}Ti_2O_5$ is not stable below 1030 ± 10°C. Note that extrapolation of data obtained at high pressures (Fig. 2) suggests that the breakdown of pure $MgTi_2O_5$ will occur near 600°C. The partial breakdown of armalcolite to rutile plus FeO-enriched ilmenite (3) is in accord with Fig. 1. Fig. 1 shows the lowest temperature at which armalcolite of a given composition is stable: reaction with liquid or another phase will tend to increase the minimum temperature of stability. On the other hand, if components other than $FeTi_2O_5$ and $MgTi_2O_5$ enter into armalcolite, it may be stabilized to lower temperatures than indicated in Fig. 1. An important example of such stabilization is shown by experiments on Fpb (or Arm) plus Fe^o at temperatures 40-50°C below the minimum stability for each pure phase. The Fpb (or Arm) reacted with 2 wt% Fe^o to form ilmenite + Fpb (or Arm) with unit cell different from that of the starting material, and no rutile. The reaction for $FeTi_2O_5$ appears to be: $4FeTi_2O_5$ (Fpb) + Fe^o = $5FeTiO_3$ (Ilm) + Ti_3O_5 (in solid solution with Fpb). The reaction of approximately 2% Fe^o corresponds to 10-15% Ti_3O_5 entering into the solid solution. The exact reaction for $Fe_{.5}Mg_{.5}Ti_2O_5$ is more difficult to determine, but the absence of rutile from the products at 980° strongly suggests that Ti_3O_5 component also enters into solid solution with armalcolite. These results show that it is risky to melt high-Ti basalt in iron containers without evidence that it was saturated with Fe^o throughout its melting interval.

Molar volumes of armalcolites are approximately 10% greater than those of compositionally equivalent ilmenite + rutile (50.51 ± 0.09 cm^3/mole) and geikielite + rutile (49.68 ± 0.08 cm/mole) (Fig. 3); thus, it is expected that armalcolite will become less stable with increasing pressure.

The schematic T-f_{O_2} section for part of the system $Fe-O-TiO_2$ serves as a model for several important reactions in high-Ti lunar basalts (Fig. 4). The reaction Usp + Fpb = Ilm (Curve A), which is metastable with respect to oxide melting, is analogous to reaction (A) in basalts, with Usp proxying for FeO from the silicate melt at lower temperatures. Curve B is the lower stability limit for $FeTi_2O_5$. Curve C is the reaction Ilm = Usp + Rut and point D represents the combined breakdown and reduction reaction Ilm = Usp + Rut + Fe^{o}; both reactions are observed in Apollo 17 basalts (4) with the important difference that the presence of Cr in the spinel undoubtedly stabilized the breakdown assemblage to higher temperatures.

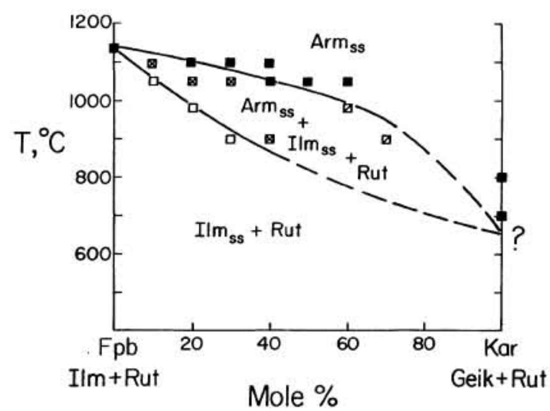

Fig. 1

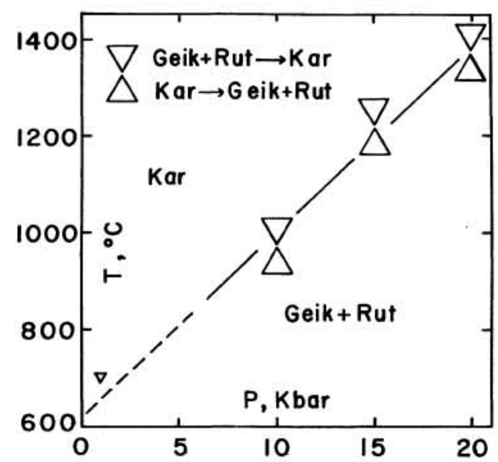

Fig. 2

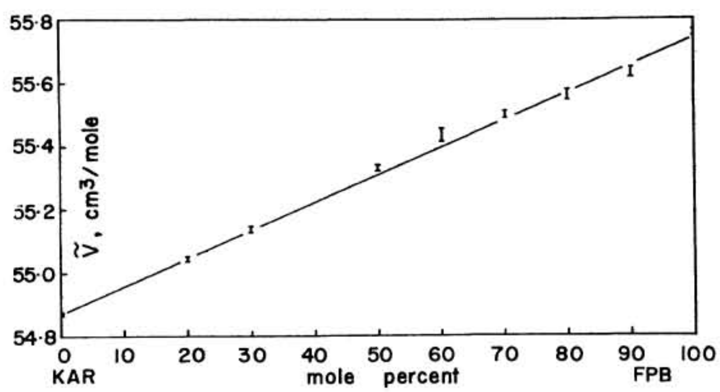

Fig. 3

Fig. 1. Stability of Arm_{ss}. All experiments in evacuated silica-glass capsules, except for pure $MgTi_2O_5$ (P_{H_2O} = 1 kbar in welded Pt capsules). ■ Ilm_{ss} + Rut → Arm_{ss}; □ Arm_{ss} → Ilm_{ss} + Rut; ⧄ Arm_{ss} → Arm_{ss} + Ilm_{ss} + Rut; ⊠ Arm_{ss} → Arm_{ss} + Ilm_{ss} + Rut and Ilm_{ss} + Rut → Arm_{ss} + Ilm_{ss} + Rut.

Fig. 2. P-T stability of $MgTi_2O_5$ (Kar). Geik = $MgTiO_3$, Rut = TiO_2.

Fig. 3. Molar volumes of synthetic $armalcolite_{ss}$.

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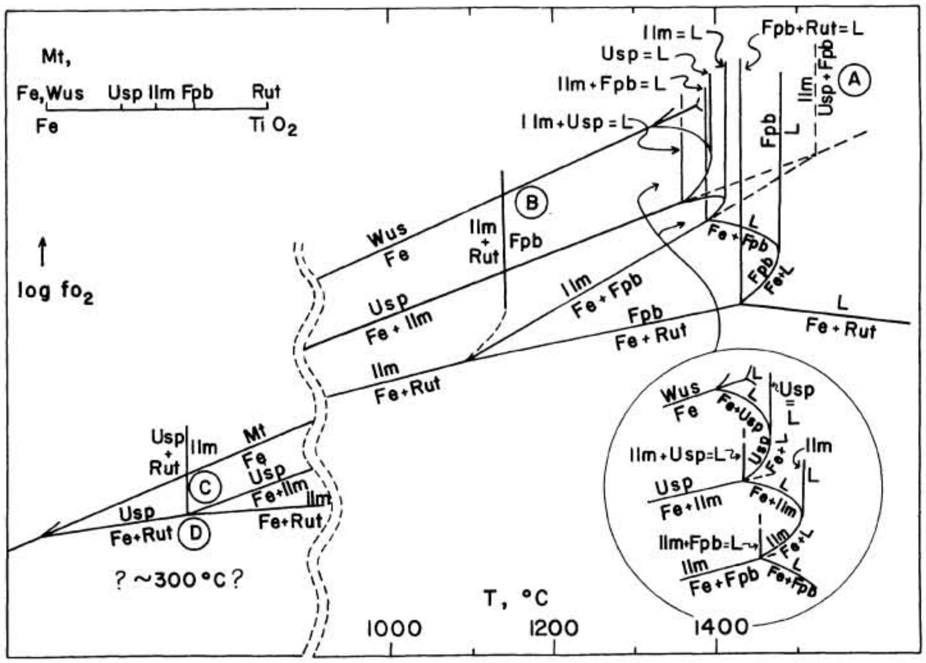

Fig. 4. T-f_{O_2} stability of phases in the system Fe-O-TiO_2 (0<P≤1 atm) based on (5) and analysis of 70 isobarically invariant (4-phase) points. f_{O_2} scale is schematic; temperatures are known in the range 1000-1500°C, but are only schematic at higher and lower values.

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