SUBSOLIDUS PHASE EQUILIBRIA IN THE SYSTEM

FeO-MgO-Cr$_2$O$_3$-Al$_2$O$_3$-TiO$_2$

B. Stier & E. Woermann, Institut für Kristallographie der RWTH Aachen and A. El Goresy, Max Planck Institut für Kernphysik, Heidelberg, Germany.

The iron titanium phases ulvite, ilmenite and ferropseudobrookite (armalcolite) are dominant among the oxide minerals in lunar basalts. In natural multicomponent systems they are forming solid solutions, mainly with MgO, Cr$_2$O$_3$ and Al$_2$O$_3$. Spinel crystals growing from basaltic magmas generally exhibit chemical zoning with enrichment of Cr in the core and of Ti in the rim of the crystals. In the subsolidus temperature range, however, spinel crystals in contact with ilmenite develop a "reversed zoning" (1) which is controlled by temperature dependent element distributions among spinel and ilmenite. This element partitioning among pairs of coexisting oxide phases may be employed in lunar thermometry.

In previous contributions (2,3) phase equilibria and data on element partitioning have been presented for the ternary systems FeO-Cr$_2$O$_3$-TiO$_2$, FeO-Al$_2$O$_3$-TiO$_2$ and FeO-MgO-TiO$_2$. Special attention was paid to the composition of the spinel phase in the spinel+ilmenite+ferropseudobrookite equilibrium assemblage: In the FeO-Cr$_2$O$_3$-TiO$_2$ system the chromite concentration of this Sp(I,P) increases gradually with decreasing temperature. In the system FeO-Al$_2$O$_3$-TiO$_2$ the spinel phase coexisting with ilmenite and ferropseudobrookite below 1216°C is hercynitic, above 1216°C however, it is ulvitic. In FeO-MgO-TiO$_2$ spinel does not coexist with a pseudobrookite phase in the P-T range investigated.

In the investigation of subsolidus phase relations in the quaternary systems FeO-MgO-Cr$_2$O$_3$-TiO$_2$, FeO-MgO-Al$_2$O$_3$-TiO$_2$ and FeO-Cr$_2$O$_3$-Al$_2$O$_3$-TiO$_2$ in equilibrium with metallic iron at 1 atm total pressure the attention was again focussed on the composition of spinel coexisting with ilmenite and a ferropseudobrookite phase:

Fig. 1: FeO-MgO-Cr$_2$O$_3$-TiO$_2$ at 1250°C. The spinel series is continuous in FeCr$_2$O$_4$-MgCr$_2$O$_4$-Mg$_2$TiO$_4$-Fe$_2$TiO$_4$. Limited solid solution in ilmenite and ferropseudobrookite phases. With increasing Mg-concentration the Cr-concentration of Sp(I,P) increases.

*) Dedicated to Professor Paul Ramdohr on the occasion of his 90th birthday.
System FeO-MgO-Cr$_2$O$_3$-Al$_2$O$_3$-TiO$_2$.

B. Stier et al.

Fig. 2: Spinel solid solution series FeCr$_2$O$_4$-MgCr$_2$O$_4$-Mg$_2$TiO$_4$-Fe$_2$TiO$_4$ with isothermal Sp(I,P) traces. Towards higher Ti-concentrations the spinel coexists with ilmenite solid solutions, towards higher Cr-concentrations with a pseudobrookite phase.

Fig. 3: FeO-MgO-Al$_2$O$_3$-TiO$_2$ at 1250°C. Due to a miscibility gap in the spinel series a four phase assemblage Sp$_1$-Sp$_2$-Ilm-Pps is formed. Two coexisting spinels in this assemblage are connected by a Sp$_1$-Sp$_2$ (I,P) tie line.

Fig. 4: The spinel system FeAl$_2$O$_4$-MgAl$_2$O$_4$-Mg$_2$TiO$_4$-Fe$_2$TiO$_4$ with a miscibility gap between aluminous and titaniferous spinels. Mg is concentrated in aluminous, Fe in titaniferous spinel. A Sp$_1$-Sp$_2$ (I,P) tie line exists in the FeO-Al$_2$O$_3$-TiO$_2$ system at 1216°C. With increasing Mg-concentration it is shifted to higher temperatures. ABCD is a Sp(I,P) isotherm at 1250°C.
In the compositional range investigated the quinary system FeO-MgO-Cr$_2$O$_3$-Al$_2$O$_3$-TiO$_2$ contains five oxide phases: spinel$_1$(ulvitic), spinel$_2$(hercynitic), ilmenite, ferropseudobrookite-armalcolite and rutile. These five phases can be combined in various assemblages: Ten out of ten possible two phase assemblages are observed or deduced, likewise nine out of ten possible three phase assemblages and three out of five possible four phase assemblages. The five phase assemblage is prohibited. These twenty two oxide assemblages have all different compositional and thermal stability ranges. The quinary phase diagram will be helpful in interpreting phase assemblages in natural lunar basalts and in interpreting the petrogenesis of mare basalts.

REFERENCES