

TAURUS-LITTROW CRYSTALLINE ROCKS: OPAQUE MINERALOGY AND GEO-CHEMISTRY.

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Opaque minerals in samples 74220, 74242, 74243, 70215, 72015 and 79155 were studied in reflected light and with the electron microprobe. The samples studied include a variety of rocks: microgabbros, pyroxene rich basalts, and vitrophyres. The opaque minerals encountered in the studied samples are: armalcolite, ulvöspinel, ilmenite, rutile, Al-Ti-chromite, cobaltian metallic Fe, and minor baddeleyite, tranquillityite and zirconolite. The frequency of the Fe-Ti oxides among each other depends on the grain size which is again a function of the cooling history. Chromian ulvöspinel occurs in the various rock types mainly as discrete idiomorphic grains either as inclusions in the pyroxene or in the plagioclase rich silicate groundmass. No chromite cores were observed. In addition to the isolated ulvöspinel grains two unique assemblages were encountered 1) ulvöspinel as inclusion in armalcolite without any reaction. 2) Ulvöspinel + rutile also without any reaction between them. No evidence for subsolidus reduction of ulvöspinel to ilmenite + chromite + Fe (1) was found. The compositions of 80 grains from sample 74242 are shown in Fig. 1 (open triangles). The chemistry of individual ulvöspinel grains in other samples studied is similar to the range shown in Fig. 1. Our probe analyses indicate that the  $TiO_2/TiO_2+Cr_2O_3+Al_2O_3$  ratio varies only between 0.3 and 0.5 (Fig. 1). In the fine grained basalts there is textural and chemical evidence for a) exsolution of ilmenite and b) reaction between the basaltic melt and the crystallized ulvöspinel. Both processes seem to go hand in hand giving rise to ilmenite + Al-Ti-chromite. This newly formed Al-Ti chromite deposited around the ilmenite exsolution lamellae and at the boundary between the ilmenite reaction rim and the host spinel. Optical properties and chemistry differ considerably from chromite formed by subsolidus reduction of ulvöspinel. Compared to the parent spinel this chromite is considerably enriched in  $Al_2O_3$  (20.5%) and has a higher MgO content (5.82 vs. 4.2%). During subsolidus reduction the "exsolving" ilmenite becomes enriched in MgO, whereas during the reaction between ulvöspinel and silicate melt the host spinel will be enriched in both trivalent cations and  $Mg^{+2}$ . This partitioning is significant and may be used as an additional criterion for recognition between secondary chromites formed by the two different processes. Sample 74242 contains a unique fragment consisting of 60% cobaltian Fe, 30% chromite (solid triangles in Fig. 1), and 10% anorthitic maskelynite + barian K-feldspar (3.7% BaO) + orthopyroxene. Individual grains of ilmenite occur at the boundary between chromite and metal. This lithic fragment may represent a new rare type perhaps a lunar pegmatite and demonstrates that metal rich lenses or dykes are expected to be present in layered mare basins.

In coarse grained microgabbros ilmenite is the dominant opaque and armalcolite is only an accessory phase occurring mainly enclosed in the pyroxene. The amount of armalcolite increases in the fine grained pyroxene rich basalts and vitrophyres. Two optically distinct armalcolite types (1) were encountered: a tan variety occurring mainly as idiomorphic inclusions in pyroxenes, and a grey variety usually mantled by ilmenite and enriched in vitro-

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phyres. Quantitative electron microprobe analyses indicate that the two types differ in their minor element chemistry: the grey type being enriched in  $\text{Cr}_2\text{O}_3$  and  $\text{MgO}$  compared to tan armalcolite. We find textural evidence for ilmenite rim to be formed due to one of the following processes: a) Reaction between basaltic liquid and armalcolite (1) b) Reaction between armalcolite and metallic Fe (2) c) simple overgrowth of ilmenite on preexisting armalcolite and d) partial breakdown of armalcolite to rutile+ilmenite. Reaction a is predominant in the vitrophyres. Armalcolite with ilmenite reaction rim which in turn

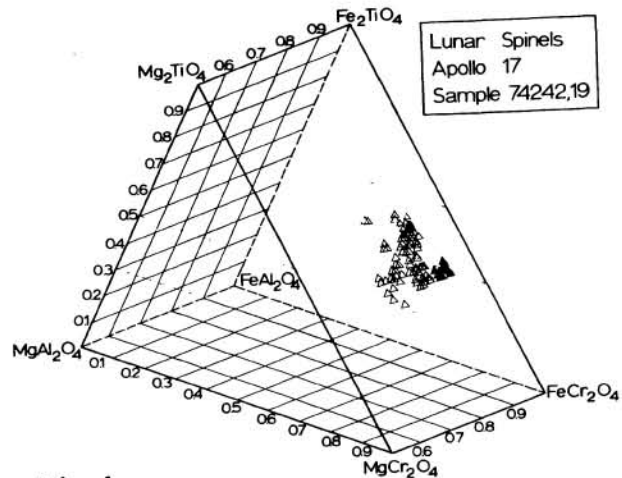


Fig.1

is surrounded by a new armalcolite reaction rim was also observed indicating that fluctuations in  $f_{\text{O}_2}$  and/or temperature took place during the crystallization of the Fe-Ti oxides. Reaction b is mainly observed in the medium grained basalts and is characterized by the assemblage armalcolite+ilmenite+Fe. Our numerous probe analyses indicate that the majority of armalcolites are cation deficient (total cations range from 2.91 to 2.97). Furthermore, while the 8f site is stuffed with  $\text{Ti}^{4+}$ , the divalent cations ( $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$ ) do not exceed 0.85. Probably the trivalent cations are also located in the 4c site. Figures 2, 3, 4 and 5 show the cationic distribution on the basis of 5 oxygens in both grey and tan armalcolites. Two distinct cationic substitutions were discovered in the grey armalcolite a  $\text{Mg}^{2+} + \text{Cr}^{3+} + \text{Fe}^{2+}$  for  $\text{Ti}^{4+}$  connected with reaction between basaltic liquid and armalcolite b  $\text{Mg}^{2+} + \text{Cr}^{3+} + \text{Ti}^{4+}$  for  $\text{Fe}^{2+}$  connected with the reaction armalcolite+Fe. Ti-rich cation deficient armalcolite+ilmenite. These two substitutions are well demonstrated in Fig. 3, 4 and 5 by the abrupt "change" in the trend for "ortho-armalcolite". In sample 75055 a breakdown of tranquillityite to  $\text{ZrO}_2$ +ilmenite+?pyroxene was observed. In the same sample zirconolite with more than 20%  $\text{Y}_2\text{O}_3$  was encountered. Baddeleyite in the studied samples contains the highest  $\text{HfO}_2$  content ever found in a lunar mineral (2 wt %).

**References.** (1) Haggerty S.E. (1973), Apollo 17: Armalcolite paragenesis and subsolidus reduction of chromian-ulvöspinel and chromian-picroilmenite, Trans. Amer. Geophys. Union, Vol. 54, 6, pp. 593-594. (2) Harzman, M.J., and Lindsley D.H. (1973), The armalcolite join ( $\text{FeTi}_2\text{O}_5$ - $\text{MgTi}_2\text{O}_5$ ) with and without excess  $\text{Fe}^0$ : indirect evidence for  $\text{Ti}^{3+}$  on the moon. Geol. Soc. Amer. Abstract pp. 653-654.

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