ARMALCOLITE: COMPOSITIONAL DATA AND ASSOCIATED OPAQUE OXIDES.

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Three distinct compositional types of armalcolites are now recognized in the lunar samples: (A) intermediate members of the solid solution series $FeTi_2O_5$-$MgTi_2O_5$(1); (B) Zr-enriched $FeTi_2O_5$-$MgTi_2O_5$(2); and (C) Cr-Zr-Ca enriched $FeTi_2O_5$-$MgTi_2O_5$(2-5). New electron microprobe analyses for type A from Apollo 11 (10021), 12 (12070) and 14 (14191, 14321) and data for types B and C from Apollo 15 (15102) and 16 (61156) have been determined. Type A contains TiO_2 and FeO as major components (70-75wt% and 15-20wt% respectively). MgO (6-10wt%), Cr_2O_3 (1-2.5wt%) and Al_2O_3 (1-2wt%) are also present. Type B contains less TiO_2 (68-70wt%); FeO is lower (14-16wt%) and MgO is in the range 7-9wt%. The Al_2O_3 (1wt%) and Cr_2O_3 (0.9-1.5wt%) contents of type B are lower than that of type A, but the distinguishing factors are that ZrO_2 (2.0-3.9wt%), Nb_2O_5 (0.5wt%), Y_2O_3 (0.5wt%) and CaO (0.6wt%) are also present. Type C is contrasted from types A and B by having even lower concentrations of TiO_2 (66wt%), FeO (8.5wt%) and MgO (2.5wt%), and higher contents of Cr_2O_3 (10wt%), ZrO_2 (6wt%) and CaO (3.5wt%). Types B and C and the occurrence of a possibly new Zr-Fe titanate suggest a complete solid solution series between armalcolite and zirkelite ($CaZrTiO_5$) but with Cr_2O_3 enrichment (2).

Distinguishing textural and mineral associations among these compositional types are as follows: (1) Type A is usually mantled by magnesian ilmenite and is observed in Apollo 11 and 14 (Fig 1). This ilmenite appears to have formed by reaction of early formed armalcolite + liquid; the ilmenite is saturated in TiO_2 as evidenced by exsolved lamellae of rutile (Fig 1); (2) An unusual occurrence of armalcolite veining both ilmenite and niobian rutile, and interpreted as a reaction product of TiO_2+$(MgTiO_3$-$FeTiO_3)_{ss}$, was observed in 12070 (Fig 2); (3) Zr-armalcolite and Cr-Zr-Ca-armalcolite are unmantled, but associated rutile + ilmenite are present in intimate grain boundary contact (Figs 3-4). Rutile is present in euhedral to subhedral crystals and is also present as lamellae in ilmenite. Baddeleyite, zirkelite and chromite are also commonly associated. The true origin of these intergrowths is unknown, but solid state reconstitution is favored with perhaps decomposition of a preexisting mineral. Positive evidence for decomposition of armalcolite is provided by a single crystal in 14321 (Fig 5). A two phase assemblage, rutile + $(geikielite\text{-}ilmenite)_{ss}$, is distributed throughout the armalcolite host in approximately 1:1 proportions; further evidence for decomposition is provided by predictable minor element partitioning - Nb_2O_5 enters rutile and ZrO_2 enters $(FeTiO_3$-$MgTiO_3)_{ss}$. Fig 6 shows that somewhat higher proportions of FeO are present in the ilmenite than would be expected by decomposition of the primary armalcolite. Most of the analysed areas in the armalcolite are enriched in $MgTi_2O_5$ with respect to those in Apollo 11 and do not fall on the solid solution join, suggesting that decomposition is initiated by MgO enrichment of armalcolite with rutile and FeO enriched $ilmenite\text{-}geikielite_{ss}$. The reaction of TiO_2+$(FeMg)TiO_3$→$(FeMg)Ti_2O_5$ and the decomposition of armalcolite→$(ilmenite\text{-}geikielite)_{ss}$+rutile are the first recorded occurrences in the lunar samples.

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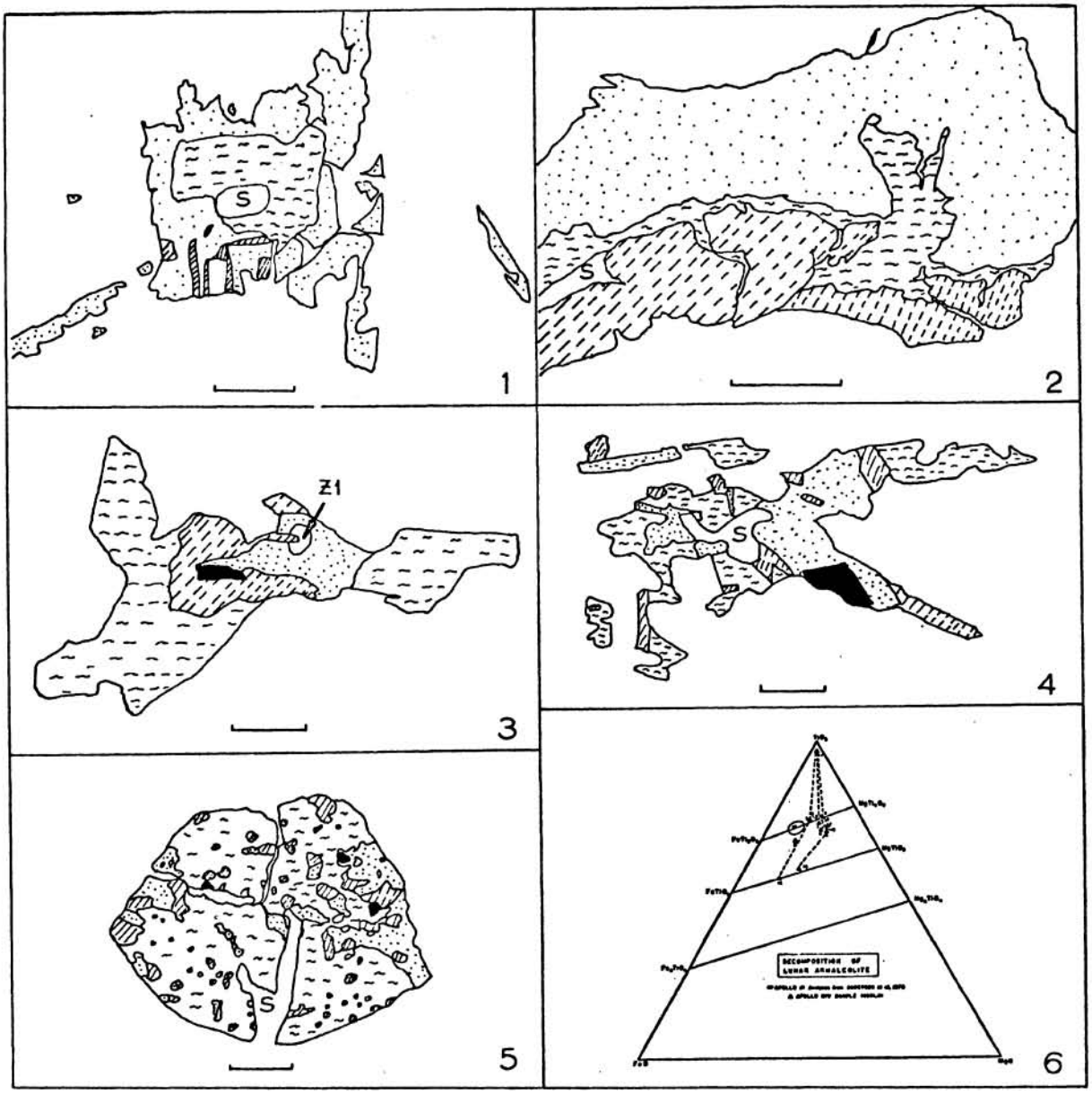

Fig 1. Armalcolite (Type A) core mantled by ilmenite which has oriented exsolved lamellae of rutile (10021).
Fig 2. Armalcolite (Type A) between niobian rutile and ilmenite (12070).
Fig 3. Armalcolite (Type B) flanking rutile, ilmenite, chromite and phase Z1 (15102).
Fig 4. Armalcolite (Type C) associated with rutile, ilmenite and chromite (61156).

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Fig 5. Armalcolite decomposing to rutile + (ilmenite-geikielite)$_{ss}$. Small chromite crystals are also present (14321).
Fig 6. FeO-MgO-TiO_2 ternary diagram showing Apollo 11 compositions and compositions for phases shown in Fig 5.

Key: Scale bars approx. 25 microns. Horizontal wavy lines are armalcolite, stippled areas are ilmenite, dashed areas are rutile and black crystals are chromite. S refers to silicate inclusions, and Z1 refers to a Zr-Fe-titanate (2).

References.

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