REGOLITH PROCESSES: NONEQUILIBRIUM OF THE METAL PHASE., H. K. Mao and P. M. Bell, Geophysical Laboratory, 2801 Upton St., N. W., Wash., D.C. 20008.

Problems associated with the metal phase in lunar rocks are major. The metal phase in lunar lavas is often in a metallic iron-troilite association defined by the eutectic relationship of Brett and Bell (1). However, metallic phases in soils and breccias are not so simply explained. These metal phases contain varying amounts of nickel and cobalt and are associated with schreibersite and troilite, depending on the bulk concentration of phosphorus and sulphur in the assemblage. The origin of the metal phase in soils and breccias could be lunar, meteoritic, or could be the result of annealing and diffusion during later processes in the lunar regolith.

The probability of either a lunar or meteoritic origin of a given metal phase assemblage has been previously assessed on the basis of the Ni-Co-Fe ratio of the iron alloy (2). Furthermore, the very fractionation history of anorthosite rocks has been postulated on the basis of metal phase composition. In the present study the problem of the chemistry of the metal phase has been addressed by studying metal phases, in rocks with three fundamental characteristics: 1) the rocks contain so-called "lunar" metal phases; 2) the rocks are breccias and contain so-called "meteoritic" metal phases in restricted zones; 3) the rocks have been heated by contact with molten rock of different bulk composition. The purpose has been to determine evolutionary steps in the metal composition that occurred in response to regolith heating processes. With this objective, Apollo 16 rock 60015 serves as an excellent example for this discussion. This rock has been "classified" with the first two characteristics above (2), and is an anorthositic breccia, coated with a rind of glassy quench product, rich in iron and magnesium. A liquid considerably more mafic than the anorthositic breccia has heated the breccia and has reacted with it in a narrow zone during freezing to a vitric texture of glass, crystal, and metal.

The metal phases consist of metallic iron, iron-nickel-cobalt alloy, and varying amounts of troilite and schreibersite. The occurrence is in the form of spheres or subpheres (diameter range 0.001-50.0 μm with most less than 5 μm), and it is evident that the metal phases were <u>liquid</u> in most cases. The mafic rind consisted of a <u>two-liquid</u> assemblage, as did the melted reaction zone with anorthosite. The range in cobalt content is approximately 0.01-1.5 weight percent, and given the high frequency of metallic grains less than 5 μm in diameter, the resulting analytical uncertainty in cobalt determination makes cobalt a poor indicator. However, nickel (and, to a lesser extent sulfur and phosphorus) serves as an excellent indicator of chemical reaction during regolith heating because nickel ranges in concentration between approximately 0 and 30 weight percent. The process is one of nonequilibrium during quenching. While such a process tends to dispell theories that link metal composition to the pre-brecciation history of lunar anorthosite formation, the very rapidity of the quench has preserved hard evidence of a major process in the lunar regolith.

The metallic phase in the various parts of 60015 can be classed as follows:

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a) high nickel (b) intermediate to low nickel c) gradational nickel d) troilite containing assemblages e) schreibersite containing phases. Analysis of the metal phase is used to support postulation of the following processes: 1) two liquid reaction with a third anorthositic liquid results generally in the metallic phase being relatively "enriched" in nickel; 2) growth of the metallic phase follows the pattern of being first high in nickel and later low in nickel, consistent with the thermodynamics of a silicate liquid-iron-nickel system; 3) sulphur reactions to produce troilite in transient equilibrium with iron alloy are two fold: a) metal-rich liquid gains sulphur from mafic or anorthositic liquid resulting in relatively high nickel concentration in the alloy; b) metal-rich liquid loses sulphur to mafic or anorthositic-liquid resulting in relatively low nickel concentration in the alloy; 4) precipitation of metallic iron by regolith heating of anorthositic fragments which had originally crystallized at higher temperatures (and appropriately lower oxygen fugacities).

Documentation of the above processes on the basis of nickel and sulphur content provide convincing evidence that cobalt and phosphorus behave in a similar way. The regolith heating process is evidently major in the production of metal phases in the lunar surface. Meteoritic metal, if present, loses its chemical identity in the process, and a range of metal phase compositions result.

References

(1) Brett, R. and P. M. Bell, 1969, Earth Planet. Sci. Lett., vol. 6, p. 479-482.

(2) Hewins, R. H. and J. I. Goldstein, 1975, Proc. Lunar Sci. Conf. 6th p. 343-362.