LUNAR METAL PARTICLES FROM LUNA 24 AND APOLLO 16 SAMPLES: GEOCHEMICAL INVESTIGATION. M.A. Maslov,
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Introduction. The abundances of siderophile elements in lunar highland rocks have been one of the main
questions in discussion about origin of the Moon (1,2,3). At present most of the siderophiles are concen-
trated in metal particles occurring in the highland rocks (e.g. 4,5). The metal particles have usually
meteoritic Ni/Co ratio (e.g. 6,7) that supposes their meteoritic origin, and therefore extralunar source
of the highland siderophiles. However the latter at least partly can be also of indigenous lunar origin
because there are evidences of reduction of lunar silicates and metal-silicate equilibration during
impact metamorphism of the highland rocks that can lead to mixing of lunar and meteoritic siderophiles
in the metal grains (3,4,5,8,9). As an approach to estimate of intensity of the such processes we studied
in detail microstructure, bulk composition (by electron microprobe) and trace element pattern (by
NAA) of three metal particles from Luna 24 and Apollo 16 samples.

The particle 3255 (0.1 mg) from the Apollo 16 sample 65900 is a metal fragment of polycrystalline
Fe (Fe2) with Neumann lines. There are some inclusions of lunar highland silicates in the particle, and
the same silicate material occurring locally in the contact with the metal. The phase composition and
microstructure suggest slow suboxidation of the fragment probably in equilibrium with lunar silicates.
The chemical composition of 3255 (Table, Fig.) corresponds closely to one of IIAB iron meteorites
except for lower Ge and very high Tb contents.

The particle 1904 (5.7 mg) is a metal fragment from Luna 24 regolith sample 24067. It is character-
ized by a microstructure which is more fine-grained on the margins of the particle. The bulk composi-
tion of 1904 (Table) is in a field below 750°C. The features suggest that the fragment cooled very
quickly at least below 750°C and could not be equilibrated with lunar silicates during the cooling. As a
model one can assume the rapid cooling of the particle on the lunar surface. The fragment is not similar
to iron meteoritic groups in bulk composition and trace element pattern (Table, Fig.), but its chemistry
is compatible with chondritic metal. When normalized to CI siderophile abundances, the 1904 element
pattern has only slight V-anomaly and depletion in Ga and Ge. The Ga and Ge depletion can be reduced
especially using normalization to LL element contents.

The particle 1905 (0.4 mg) is a spherule separated from Luna 24 glass fragment (regolith sample
24067). It has a globular microstructure and consists of $\alpha$ and $\gamma$ phases, and troilite. The compositions
of $\alpha$ and $\gamma$ are (wt.2): Fe 93.5; Ni 3.3; Co 0.27; P 1.2; and Fe 96.1; Ni 2.5; Co 0.28; P 0.13 respectively.
The sulphide contains 0.15 Ni and 0.1 Co. The bulk composition of the particle (Table) resides in $\alpha$-$\gamma$
regions of Fe-Ni-P diagram (10) up to $850^\circ$C. Below this temperature $\alpha$-phosphide association must be
stable in the compositional area. Its absence supposed rapid cooling of the particles from $850^\circ$C that is
compatible with occurrence of the spherule in glass. In bulk composition the metal 1905 differs essentially
from any meteoritic metal in low Ni and Co, and high P and S contents. In terms of element relation-
ships the 1905 element pattern is most near to the II group of iron meteorites (Fig.1), excluding P and
S anomalies, higher $\alpha$/Ni and P/Ni and lower Ga/Ni and Ge/Ni ratios. These differences are significant
but approximation to element patterns of other meteorite groups (including CI) is worse. The glass, in
which the spherule was found, contains small metal-sulphide spherules (similar in composition to 1905),
minute chromite crystals, and unaltered clasts of plagioclase, olivine, pyroxene and cristobalite. Bulk
composition of the glass is (wt.%) SiO$_2$: 45.6; TiO$_2$: 0.84; Al$_2$O$_3$: 13.50; CaO: 0.44; FeO: 18.2; MgO:
0.27; MnO: 0.23; GaO: 11.5; Na$_2$O: 0.28; K$_2$O: 0.05; P$_2$O$_5$: 0.09. It differs from the compositions of Luna
24 main basalt types, and probably could be produced by mixing of Luna 24 ferrobasalt and Mg-rich
components (e.g.11).

Discussion. Formation of lunar crust material must lead to differentiation of siderophiles due to
metal and olivine fractionation. Therefore metal produced by reduction of lunar crust silicates even
with addition of depleted in Ir primary matter (3) and by mixing of lunar and meteoritic siderophiles
would have had nonmeteoritic element pattern. In fact the metal observed in lunar basalt and pristine
rocks (12) is not similar in composition to meteoritic metal. From our geochemical data there is no
doubt that the 3255 and 1904 particles have meteoritic origin. Their compositional differences with mete-
oritic precursors are only expressed in Ge (probably Ga) depletion for the both particles and sharp W
anomaly for the 3255 metal. From the high volatility of Ge, its deficiency could be produced by evapora-
tion of the element from metal liquid during impact melting. The W anomaly in the 3255 metal, as it has
been proposed for other lunar metal particles (3,4,5) could be related with extraction of lunar W from
silicates by metal-silicate equilibrating through suboxidation annealing processes. In fact thermal his-
tory of the 3255 particle suggests that the metal in contrast to 1904 metal (without W anomaly) could
be equilibrated with lunar silicates.

The particle 1905 is different drastically from meteorite material. However meteoritic Ni/Ir, Ni/Mn
and Ni/Co ratios assume that meteoritic component resides in the metal. The occurrence of the metal in
Lunar metal particles

Nazarov, M.A. et al

Impact melted glass supports its meteoritic origin. If the particle was not formed from unknown meteoritic source, the presence about 50% of lunar component (mostly Fe, P, S, probably W), and the loss of meteoritic volatiles (Ge and Ga) must be postulated. The thermal history of the particle suggests that the lunar and meteoritic components could be mixed due to reduction of silicate melt during short time liquid metal-silicate melt equilibration. The process did not lead to essential extraction of W relatively to P, in contrast to the case of 3255 metal-silicate subequilibration resulted in W (but not P) anomaly. It conforms with experimental data (e.g.,13) showing preferable partitioning of P relatively to W in liquid metal, and vice versa in case of solid metal.

In summary our geochemical data support the view (3,4,5,6,9) that composition of meteoritic metal could be modified at lunar conditions. Intensity and chemical effect of the compositional modification were controlled strongly by thermal history of metal particles. The high-temperature (even short time) liquid equilibration would lead to more intensive change of metal composition in compare to the subsolidus long-time annealing. However final siderophile distribution between silicates and metal would be rather controlled by the subsolidus annealing. In the case of highland 3255 metal this process did not caused essential compositional modification of the meteoritic metal. At least in the case it means that surrounding this metal highland silicates did not contain high siderophile contents, except for V, that compatible with chemistry of the fractionated crust material (without primary component (J)) which must be enriched in W due to its incompatible behaviour, but not other siderophiles.

Fig. The composition of the metal particles plotted on Au-Ir-Ge (A) and Au-Ir-Wi (B) diagrams. The data were normalized to abundances in CI chondrites.

Table
Chemical composition of metal particles.

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<th>3255</th>
<th>1904</th>
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<tr>
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<tr>
<td>S</td>
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<td>-</td>
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<tr>
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<tr>
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Units are ppm, except for Fe, Ni, Co, P (wt.%).

REFERENCES: