MORPHOLOGY AND CHEMICAL COMPOSITION OF METALLIC MOUNDS PRODUCED BY H₂
AND C REDUCTION OF MATERIAL OF SIMULATED LUNAR COMPOSITION. James L. Carter,
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A joint project was initiated with David S. McKay at NASA/MSC, Houston to
test the possibility of producing by reduction processes complex metallic iron
and iron sulfide mounds which are similar to those observed by numerous workers
on the surface of lunar glass particles (e.g., Agrell, et al. 1970; Carter and
similar to dark brown lunar glass was made from reagent grade chemicals.

The preliminary experiment involved placing approximately one gram of
ground glass with various amounts of sulfur in weight percent (0.0, 0.24, 0.49,
1.0) in carbon crucibles and placing them in a glow bar furnace with an
argon atmosphere at 1450°C for five minutes, quenching in air and storing the
resulting glass sphere in a plastic vial. Other samples were placed in alumina
boats in a glow bar furnace for three minutes at 1450°C and flushed with argon,
then a gas consisting of 5% H₂, 95% argon was flowed over the samples for two
minutes. One sample was reduced with the hydrogen mixture for fifteen minutes.

Preliminary results of the scanning electron microscope and electron
microprobe examinations are shown in Table 1. The complex iron sulfide and
metallic iron mounds formed by reduction with hydrogen are generally layered
(cross section shown schematically in Fig. 1). The outer layer is iron sul-
fide or a mixture of iron sulfide and metallic iron, the interior is metallic
iron and the mound material next to the silicate host is iron sulfide. Some-
times the mounds are multilayered. Sometimes the complex mounds have a thin
waist of iron sulfide. Similar waists of iron sulfide around metallic iron
mounds have been seen on lunar glasses (Agrell, et al 1970; Carter, 1971).
Dimples are sometimes present. The silicate surface of the dimple is covered
by dendritic sheafs of iron sulfide and isolated metallic iron mounds. In some
complex mounds spherules of silicate material are present. In one example, one
to five micron in diameter spherules occur on the surface of an ameboid-shaped
group of metallic iron and iron sulfide mounds. The spherules consist of a
particle of what appears to be aluminum oxide which is surrounded by silicate
material and in turn the margin of the spherule is surrounded by iron sulfide.
No metallic mounds with inclusions of silicate spherules have been recognized
on lunar glasses.

The complex iron sulfide and metallic iron mounds formed by reduction
with carbon are generally layered (cross section shown schematically in Fig.
2). The interior of a mound is a mixture of iron sulfide and metallic iron.
The outer layer of pure metallic iron is generally discontinuous. The surface
of the mound next to the silicate host is iron sulfide. The mounds commonly
have a waist of metallic iron. No complex iron sulfide and metallic iron
mounds on lunar silicate spherules have been recognized with waists of metallic
iron. There is a void beneath a mound. The silicate surface of the void is
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Covered with mounds or stringers of iron sulfide.

These data suggest that 1) the ratio of sulfur to iron is of fundamental importance to the morphological nature of metallic mounds, 2) the growth time is important to the morphological nature of metallic mounds, and 3) most metallic mounds on lunar glass spheres did not form by reducing processes in situ. However, during the melting of lunar soil such as during a major meteoritic event hydrogen, as a result of trapped solar winds in the lunar soil, may play at least a secondary role in the formation of metallic iron and may be responsible in part for the formation of metallic iron mounds with waists of iron sulfide.

Table 1. Description of mounds.

<table>
<thead>
<tr>
<th>Reducing Wt. %</th>
<th>Description of mounds</th>
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<tbody>
<tr>
<td>S</td>
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<tr>
<td>H₂ 0.0</td>
<td>Mounds occur as irregular stringers or web-like metallic iron objects with crinkled surfaces. Others are flat, porous, fan-shaped metallic iron objects up to 20 microns in longest dimension. A fifteen minute run resulted in a massive network of connected circular metallic iron mounds with crinkled surfaces.</td>
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<tr>
<td>C 0.0</td>
<td>Numerous individual metallic iron mounds occur up to 50 microns in diameter which are surrounded by smaller metallic iron mounds.</td>
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<tr>
<td>H₂ 0.24</td>
<td>Mounds occur as trains of connected metallic iron octahedra. Also irregularly shaped ameboid-like complex metallic iron and iron sulfide mounds occur.</td>
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<tr>
<td>C 0.24</td>
<td>Numerous individual mounds occur up to 100 microns in diameter. Some of the larger mounds are surrounded by masses of coalesced small metallic iron mounds. Some mounds are complex mixtures of iron sulfide and metallic iron; others are porous, dendritic, iron sulfide. Dimples with an inner dimple are common. The silicate surface of the inner dimple is covered with iron sulfide mounds.</td>
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| H₂ 0.49       | Individual complex iron sulfide and metallic iron mounds occur up to 200 microns in diameter. Trains of connecting circular metallic iron mounds (2-15 microns in diameter) with rough surfaces are present also. The larger mounds in the trains have six-sided flat-topped metallic iron objects on their surface. The metallic iron trains grade into areas of dendritic metallic iron mounds. Occasionally ameboid-shape complex iron sulfide and metallic iron mounds up to 300 microns in longest dimension are seen. Shrinkage cracks around their margins are poorly developed. Dimples are common. Some dimples have isolated circular metallic iron mounds and irregular dendritic areas of iron sulfide on their surface. One to five microns in diameter spherules occur on the surface of some of the ameboid-shape mounds. The spherules consist of a particle of what appears to be aluminum oxide which is surrounded by silicate material and in turn the margin of the spherule is sur-
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C 0.49 Numerous mounds occur up to 150 microns in diameter. Some of the larger mounds are surrounded by masses of coalesced small metallic iron mounds. The mounds consist of metallic iron that is surrounded by a mixture of iron sulfide and metallic iron. Metallic iron margins are common. Dimples with an inner dimple are common. The silicate surface of the inner dimple is covered with mounds and stringers of iron sulfide.

H₂ 1.0 Individual mounds occur up to 300 microns in diameter and are complex mixtures of dendritic iron sulfide and metallic iron. Some mounds 10-50 microns in diameter have a patchy layer of metallic iron over a core consisting of a mixture of iron sulfide and metallic iron. Some mounds have a thin waist of iron sulfide. The larger mounds have well developed cooling cracks around their margins. Some larger mounds contain spherules of silicate material. Dimples are common. The upper margin of the dimple is textured and has dendritic areas of iron sulfide on its surface. Individual octahedra of metallic iron approximately five microns in diameter occur.

C 1.0 Numerous complex individual mounds of metallic iron and iron sulfide occur up to 200 microns in diameter and are sometimes surrounded by masses of coalesced small metallic iron mounds. Individual mounds have metallic iron margins. Dimples with an inner dimple are common. The silicate surface of the inner dimple is covered with iron sulfide mounds.

Fig. 1. Schematic cross section of complex mound formed by reduction with hydrogen.
Fig. 2. Schematic cross section of complex mound formed by reduction with carbon.