TAURUS LITTROW PYROCLASTIC DEPOSIT – AN OPTIMUM FEEDSTOCK FOR LUNAR OXYGEN

Carlton Allen
NASA Johnson Space Center
• Oxygen is a potentially abundant lunar resource vital for life support and spacecraft propulsion.

• Oxygen can be extracted from ice deposits near the poles.

• Oxygen can also be extracted from oxides and silicates at any location on the Moon.
Over 20 different processes have been proposed for oxygen production on the Moon.

Among the simplest and best studied processes is the reduction of oxides, particularly FeO, in lunar minerals and glass using hydrogen gas.

Oxygen can be extracted from lunar soils and pyroclastic glass by exposing the samples to flowing hydrogen at subsolidus temperatures (~1050 °C).
• All major FeO-bearing phases contribute oxygen, with extraction from ilmenite and glass significantly more efficient than from olivine and pyroxene.
• Total oxygen yield is directly correlated to each sample’s abundance of FeO, but not correlated to any other oxide.

\[ \text{Oxygen Yield} = 0.19 \times \text{Fe}^{2+} - 0.55 \quad r^2 = 0.87 \]

Allen et al, 1996
• Pyroclastic glass may be an optimum feedstock for lunar oxygen production using the hydrogen reduction process, based on oxygen yield.

• Telescopic observations and orbital images of the Moon reveal at least 75 lunar pyroclastic deposits, interpreted as the products of explosive volcanic eruptions.
The deposits are understood to be composed primarily of sub-millimeter beads of basaltic composition, ranging from glassy to partially-crystallized.

Delano (1986) documented 25 distinct pyroclastic bead compositions in lunar soil samples, with a range of FeO abundances from 17 - 25 wt%. 

Apollo 17 orange and black glass – samples of the Taurus Littrow deposit
• The FeO-rich species, represented by the isochemical orange and black glasses collected by the Apollo 17 astronauts, promise particularly high yields.

Allen et al, 1996
• The Taurus Littrow regional pyroclastic deposit, located in eastern Mare Serenitatis, extends across the Apollo 17 landing site.

• Shorty crater “orange soil” samples this deposit.
A future mission to demonstrate oxygen production on the lunar surface could yield maximum results if targeted to an FeO-rich pyroclastic deposit such as Taurus Littrow.
• Analyses by the Diviner and LROC NAC instruments on LRO provide new information to support landing site selection.

• Diviner is a near- and thermal-infrared mapping radiometer that measures soil temperature and composition.
Three channels centered near 8 μm are used to calculate the emissivity maximum known as the Christiansen feature (CF).

CF values are particularly sensitive to silica polymerization in lunar soil and glass.
• Given the restricted mineralogy of lunar materials, CF values are closely correlated FeO abundances in soils and glasses.

• This is the basis for assessing pyroclastic deposits as oxygen resources.

FeO = 74.24 \times CF - 599.9 \quad r^2 = 0.90

Allen et al, 2012
• A 20 km\(^2\) region of interest in the Taurus Littrow deposit was selected, based on high Diviner CF values and low albedo.

• This is one of the least-contaminated sections of the deposit, with material that is uniform in composition.
• The averaged CF value in the region of interest is 8.37 µm, corresponding to an FeO abundance of 21.5 wt. %.

• The standard deviation of these values is 0.03 µm, corresponding to an uncertainty in FeO abundance of +/- 2.2 wt. %.
• 21.5 wt. % FeO corresponds to 16.7 wt. % Fe$^{2+}$

• This value predicts an oxygen yield from hydrogen reduction of $\sim 4.0$ wt. %.
• The surface is extremely smooth, with uniform albedo and very few craters or other landing hazards.
• This ~100 m diameter crater ejected distinct rays of dark material, indicating that the deposit has a thickness of at least 10 m in this location.
• An oxygen production demonstration mission to Taurus Littrow will encounter a deposit at least 10 m thick with few landing hazards and a uniform composition.

• The predicted oxygen yield is ~4 wt. %, among the highest values on the Moon.