**Extraterrestrial Photosynthesis by Chang’E-5 Lunar Soil**

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**Characterization of the CE-5 sample**

The XRD data of the lunar soil was analyzed with the XRD data of materials commonly known in the lunar regolith, including augite, pigeonite, plagioclase, orthopyroxene, ilmenite, rutile, pyrite, olivine, chromite, cristobalite, quartz, and metal oxides[S1](#_ENREF_27). According to the CNN identification, soft-basis analysisS[21](#_ENREF_21) and artificial correction upon some certain signals, the ratio of the minerals was approximately determined. Compared with the Apollo data, the percentage of plagioclase and orthopyroxene are much lower, while the augite is more abundant. Besides, some peaks are not present in the minerals known above. Thus, new minerals have been found in addition to the ones known from Apollo. The fitted result is shown in Extended Data Table 1 and the element components shown in Extended Data Fig. 1 and Extended Data Table 2.

The peak occurs at ~5.5º was found to be from the zeolite Linde Type L (LTL)S[2](#_ENREF_27), whose chemical formula is Si36O72. This material has a porous structure, which is in accordance with the Brunauer-Emmett-Teller (BET) measurement (Extended Data Fig. 7). Peak at ~10º was found to be clintonite (Si1.2Al3.03CaFe.21Mg2.16O12H2), and ~22.7º were explained with silica (SiO2).YeelimiteS[3](#_ENREF_29) was found responsible for the peak ~23.8º. The ~25.15º and ~28.5º peaks show the existence of titanium oxides (Anatase TiO2, TinO2n-1). The peak at ~30º is abnormally high than the apollo data, which is due to the higher ratio of augite in the CE-5 sample. Peaks at ~44.5º are also new in the CE-5 sample, which are found due to the presence of troiliteS[4](#_ENREF_30) (FeS) and PyrrhotiteS[5](#_ENREF_30) (Fe(1-x)S). The Sulfur also appears as pyrite (Fe2S) according to the peak at ~56º. This explains the sulfur element found and the iron abundance in the CE-5 sample. The large peak at ~61º is from olivine ((Mg, Fe)2SiO4), ~66º is from MgFe(SiO3)2, ~70º from ilmenite (FeTiO3), and ~72º from pyrrhotite (FeS). The peak occurs at ~67.5º (The Apollo data did not cover this range.) was found to be oxide of Aluminum (AlxOy) and Lorenzenite (Na2Ti2Si2O9).

The chemical formula of the components can be used to calculate the element ratio, where oxygen, silicon elements were most abundant. Iron and Titanium were found higher than those from lunar highlands as the most abundant components contain Iron, and Titanium appears in both the oxides and the acid radicals. Details are listed in Extended Data Table 1. The calibration for Apollo glass can be referred to in the reference of this publicationS[6](#_ENREF_27), and has been replaced by several oxides and silicates in our analysis as they were found present by the CNN and have chemical formulae that meet the synthesis conditions of the Apollo calibration sample.



**Figure S1 | Performance of water electrolysis by CE-5 lunar soil in a 3-electrode electrochemical system.** a) hydrogen evolution reaction, and b) oxygen evolution reaction in basic solution (1 M KOH).



**Figure S2 | Photovoltaic-driven water electrolysis by lunar soil.** a) Photograph of the 2-electrode water electrolysis system. b) Performance of water electrolysis in a 2-electrode system. b) photovoltaic-driven water splitting in 1500 s. Relatively low stability may be caused by electrochemical corrosion of carbon substrate and lunar soil.



**Figure S3 |** The performance of PC full water splitting.



**Figure S4 |** Proton nuclear magnetic resonance spectroscopy (H-NMR) of CH3OH.



**Figure S5 |** Mass spectroscopy (MS) of 13CH3OH + H+.



**Figure S6 |** Comparison of PTC performance using dry ice and gas as the source of CO2. For the purpose of accommodating to the extreme lunar temperature environment, dry ice was used as the CO2 source and was directly heated to the reaction temperature to test the adaptability of PTC process.

**Reference:**

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