

Phoenix Lander's Thermal Evolved Gas Analyzer (TEGA) Sample Descriptions.

B. Sutter, P.B. Niles, P.D. Archer.

The objective of this document was to provide a brief guide of soils analyzed by the TEGA instrument and the sols on which those analyses occurred as well as the sols when atmospheric analyses occurred. Knowledge of the sols on which soil analyses occurred will enable the TEGA data users to easily locate atmospheric and soil data sets in the PDS.

Phoenix landing site samples analyzed by TEGA consisted of either scooped loose unconsolidated surface material, scraped icy soil, or rasped (drilled) then scraped icy soil that was allowed to dry through sublimation (Boynton, et al., 2009; Sutter et al., 2024). The Icy Soil Acquisition Device (ISAD) at the end of the Robotic Arm (RA) consisted of a drill bit (named a rasp), scraping blades, and scoop. Drilled material from the icy surface was collected by the rasp that cut into the icy surface causing cuttings to “ballistically” enter the rear chamber of the scoop (Bonitz et al., 2008). The ISAD scoop would gravitationally deliver soil to a slanted 1 mm mesh screen over each TEGA thermal analyzer (TA) oven. The screen was mechanically agitated to avoid soil clumping which enabled the soil to pass through the transfer mechanism (funnel + sample transfer port) to the TEGA oven. The screen agitation was not always successful at avoiding sample clumping, as the soil ended up being much more cohesive than expected.

Soils delivered into a thermal analyzer (TA) oven typically underwent four heating ramps consisting of low-, mid-, and two high temperature ramps (Table 1). After each heating, the soil was allowed to cool to Mars ambient temperature (~ -80 to -30 °C depending on the time of day). The low-temperature heating (ambient to 33°C) was used to search for water ice while the mid-temperature heating (ambient to 121-177°C) searched for any adsorbed gases or water and detect evolved water from hydrated salts. The mid-temperature heating also served to dry the sample by removing potentially high amounts of adsorbed and hydrated salt water that could require long purge times and thus interfere with detection of higher temperature water releases. The high temperature heating of all samples (~1000°C) was used to characterize the evolved gas behavior of any phases (mineral or organic) that thermally decomposed at higher temperatures. The second high temperature analysis was conducted as a reheat to establish a baseline control for comparison to the evolved gas data collected in the first high temperature heating. There were exceptions in some cases as to how samples were heated (Table 1).

The Baby Bear (BB) surface soil was acquired from the Goldilocks trench on the left side of the robotic arm workspace (Figure 1). The Baby Bear surface sample was collected from the top ~4 cm of a trough (~20 cm deep) between icy polygons where surface fines accumulated in subsurface cracks of the ice-rich permafrost (Arvidson et al., 2009, Mellon et al., 2009; Sutter et al., 2024).

All the remaining soil samples were derived from the Wonderland Polygon on the right side of the robotic arm workspace (Figure 1). The Rosy Red surface soil consisted of two samples analyzed early (Rosy Red 3a) and later (Rosy Red 3b) in the mission (Table 1) and were acquired from the surface of the Rosy Red 3 trench area (Figure 1). The Wicked Witch-1 and -2 (WW1, WW2) subsurface samples were derived from the ice table in the 5 cm deep Snow White trench (Figure 1). The WW2 sample was initially described as a blank in the 2008 TEGA PDS documentation but was subsequently argued that the TA1 oven had some sample which was

referred to as the WW2 sample (Sutter et al., 2024). The Burning Coals (BC) subsurface sample was acquired just above the ice table from the Burn Alive trench.

Two other samples include the organic free blank (OFB) and the empty oven analysis. The OFB analysis consisted of a low carbon containing fluorophlogopite (1.6 ppm C) that was intended to go through the entire sample acquisition and analytical processes (rasp, scooping, heating) to check for terrestrial organic contamination in the sample handling chain or the TEGA instrument (Ming et al., 2008). An OFB *test* heating procedure (no OFB added) was conducted on the already analyzed WW1 sample in the TA0 oven on sol 118. The sol 118 analysis did not have OFB added to the TA0 oven and was just a test to evaluate the heating procedure that was supposed to be used on the actual OFB. After this test, delivery attempts of the OFB to the TA2 oven (sol 122) failed because the low-density nature of the rasped OFB material allowed the martian wind to blow material over the entrance of TA2 instead of into the oven, thus no analysis was conducted (Sutter et al., 2024). An empty TA3 oven analysis (sol 151) was attempted to detect and quantify any terrestrial organic contamination or other CO₂ sources from the TEGA instrument. The mass spectrometer unfortunately had a voltage shutdown early in the TA3 oven analysis and no EGA data was collected above 65°C.

Atmospheric data was collected on 4 separate sols during the day and at night on one sol (Table 1). The main goal of the atmospheric analyses was to acquire best possible data on atmospheric H₂O (¹⁸O/¹⁶O and D/H) and CO₂ isotopes (Niles et al., 2010).

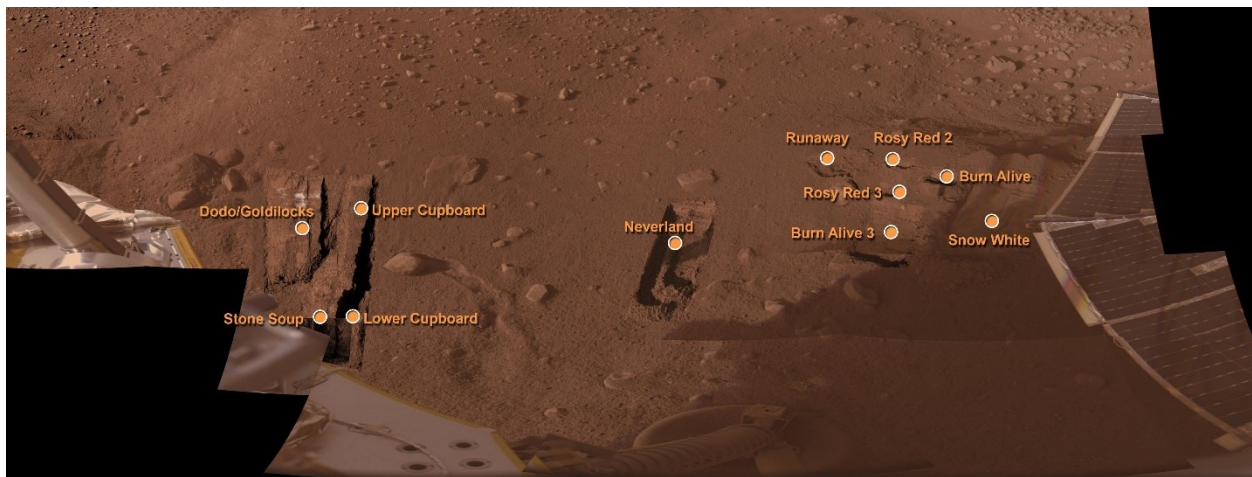


Figure 1. An image of the Phoenix lander trenches taken near the end of the mission. More trenches were dug but this shows where the samples delivered to TEGA were taken. Credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University

Table 1. Description of samples analyzed by the TEGA (TA, thermal analyzer). Atmospheric analysis (ATM), Baby Bear (BB), Wicked Witch (WW), Rosy Red (RR), Organic Free Blank (OFB), and Burning Coals (BC).

Sol	Max Temp (°C)	Oven	Location	Trench	Sample	Sample type
009	-	-	Day ATM	-	-	-
011	-	-	Day ATM	-	-	-
012	-	-	Night ATM	-	-	-
016	-	-	Day ATM	-	-	-
018	33	TA4	Between Polygons	Goldilocks	BB	Surface soil
020	171					
022	1000					
025	1000					
064	33	TA0	Wonderland Polygon	Snow White	WW1	Subsurface icy soil
066	177					
067	340					
068	1000					
069	340					
070	1000	TA5	Wonderland Polygon	Rosy Red 3	RR3a	Surface soil
075	33					
076	1000					
077	1000	TA7	Wonderland Polygon	Burn Alive	BC	Subsurface soil above ice table
089	33					
090	121					
092	121					
118	1000	TA0	High Temp test for OFB using WW1 sample			
129	1000	TA7	Wonderland Polygon	Burn Alive	BC	Subsurface soil above ice table
130	1000					
133	1000	TA1		Snow White	WW2 (Blank)	Subsurface icy soil
134	1000					
140	33, 121	TA6	Rosy Red 3	RR3b	Surface soil	
141	-		Day ATM	-	-	-
141	-	TA2	-	-	OFB	Fluorophlogopite
145	1000	TA6	Wonderland Polygon	Rosy Red 3	RR3b	Surface soil
147	1000					
151	1000	TA3	Empty Oven			

Acknowledgments:

The authors are grateful to the engineers and scientists of the Mars 2007 Phoenix Scout's mission team, who made the mission possible and the reported data available. This work was funded by the Mars Data Analysis Program and the Internal Science Funding Model Mission-Enabling Research work package at Johnson Space Center. The authors gratefully acknowledge NASA Planetary Data System representatives Abigail Knight, Richard Chen, and Jennifer Ward and reviewers Heather Franz and Amy McAdam for useful comments and edits that significantly improved the data sets and documentation.

References

- Arvidson, R. E., Bonitz, R.G., Robinson, M.L., Carsten, J.L., Volpe, R.A., Trebi-Ollennu, A., et al., (2009). Results from the Mars Phoenix Lander Robotic Arm experiment. *J. Geophys. Res.*, 114, E00E02, doi:10.1029/2009JE003408.
- Boynton, W.V., Ming, D.W., Kounaves, S. P., Young, S. M. M., Arvidson, R. E., Hecht, M. H., et al. (2009). Evidence for calcium carbonate at the Mars Phoenix landing site. *Science*, 325, 61-64.
- Bonitz, R.G., Lori Shiraishi, L., Robinson, M., Arvidson, R.E., Chu, P.C., Wilson, J.J., et al. (2008). NASA Mars 2007 Phoenix Lander robotic arm and Icy Soil Acquisition Device. *J. Geophys. Res.*, 113, E00A01, doi:10.1029/2007JE003030.
- Mellon, M.T., Malin, M.C., Arvidson, R.E., Searls, M.L., Sizemore, H.G., Heet, T.L. et al. (2009). The periglacial landscape at the Phoenix landing site, *J. Geophys. Res.*, 114, E00E06, doi:10.1029/2009JE003418.
- Ming, D. W., et al. (2008), Mars 2007 Phoenix Scout mission Organic Free Blank: Method to distinguish Mars organics from terrestrial organics, *J. Geophys. Res.*, 113, E00A21, doi:10.1029/2007JE003061.
- Niles, P.B., Boynton, W.V., Hoffman, J.H., Ming, D.W., & Hamara, D. (2010). Stable isotope measurements of Martian atmospheric CO₂ at the Phoenix Landing site. *Science*, 329, 1334-1337.
- Sutter B., Archer, P.D., Niles, P.B., Ming, D.W., Hamara, D., Boynton, W.V. 2024. Organic carbon and Ca-rich carbonate detections in soils of the Northern Plains, Mars: Evaluation of unpublished data interpretations from the Mars Phoenix Scout's, Thermal Evolved Gas Analyzer (TEGA). *J. Geophys. Res., Planets*, 129, e2024JE008335. <https://doi.org/10.1029/2024JE008335>.