

## Abstract

This research investigates aggregate sources in South Dakota to simulate Martian aggregate for use in future Martian concrete infrastructure. This effort supports the Moon to Mars Planetary Autonomous Construction Technology (MMPACT) project lead by the National Aeronautics and Space Administration (NASA). Currently, Martian simulants are not produced in large quantities or from many geologic sources. Previous work has primarily focused on tholeiitic basalt even though the Martian surface has diverse geology especially in crater locations. Various landing sites were selected to explore Martian regolith compositions and textural characteristics. From these results, it was determined that locations with basaltic andesite would best match geological sources in South Dakota (SD). These local regolith sources will be collected and characterized. Ultimately, this work will contribute to binder production for Additive Construction using In-Situ Resource Utilization (ISRU) processing for surface construction.

## Gale Crater

The team is focusing on finding SD aggregate sources that simulate the aggregates found in Gale Crater on Mars which can be seen in Figure 1. The Gale Crater is home to the Curiosity Rover, which has been exploring the crater since August 2012. Consisting of an alluvial fan and various clays and sulfates, Gale Crater is of great interest as a landing site for humans and it has characteristics that indicate a previous presence of water on Mars. Figure 2 shows a view of Mount Sharp which resides in the center of Gale Crater. This figure is highlighting the main stratigraphy of the sulfate-bearing buttes and the Curiosity rover exploration paths. Figure 3 shows where the crater is in reference to other known Martian landmarks and potential exploration zones for human missions to Mars.

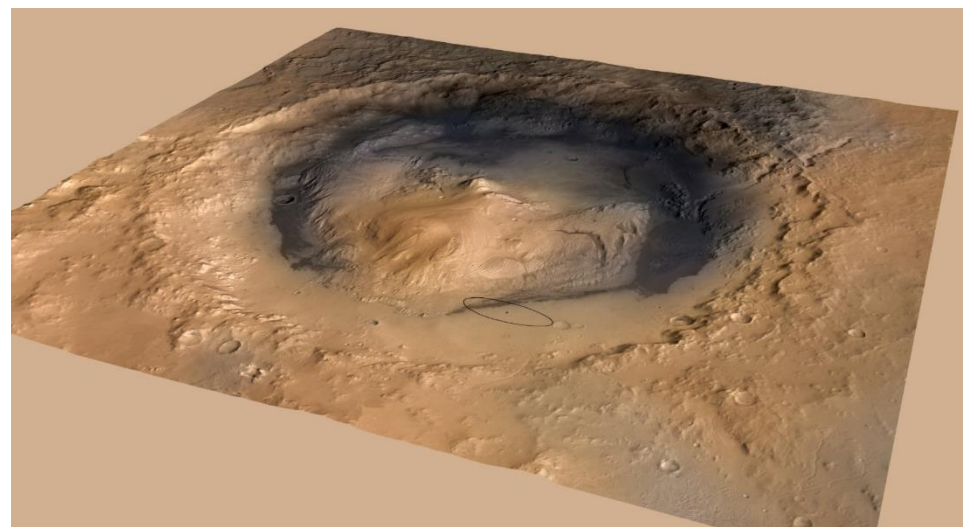


Figure 1: NASA Generated Image of Gale Crater [1]

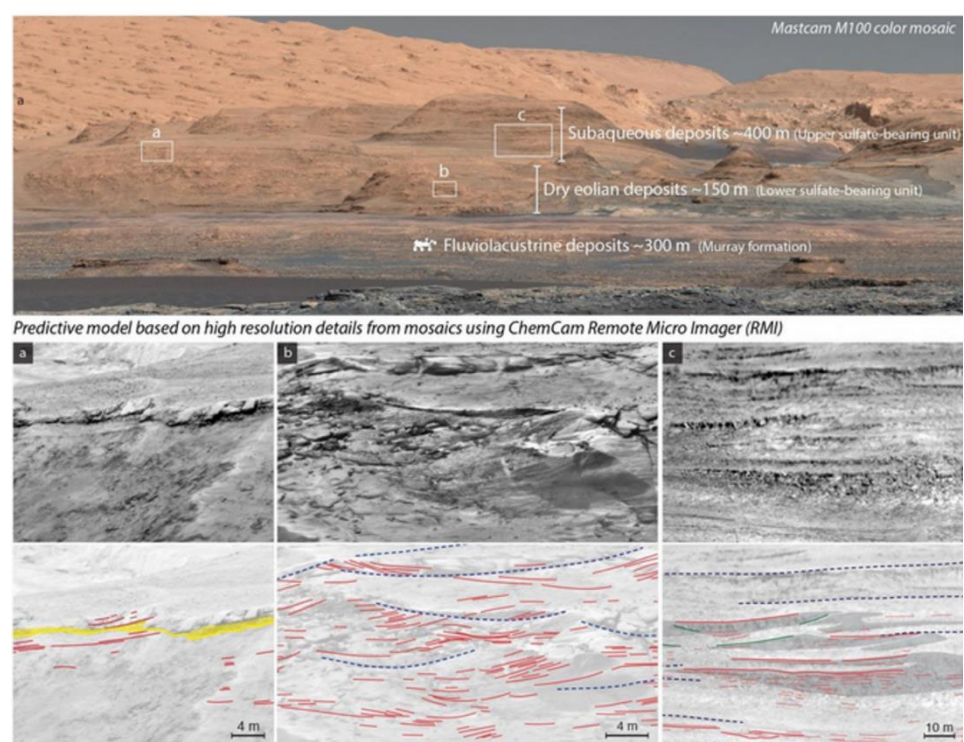


Figure 2: Stratigraphy and Expected Environments to be seen on Mount Sharp within Gale Crater [2]

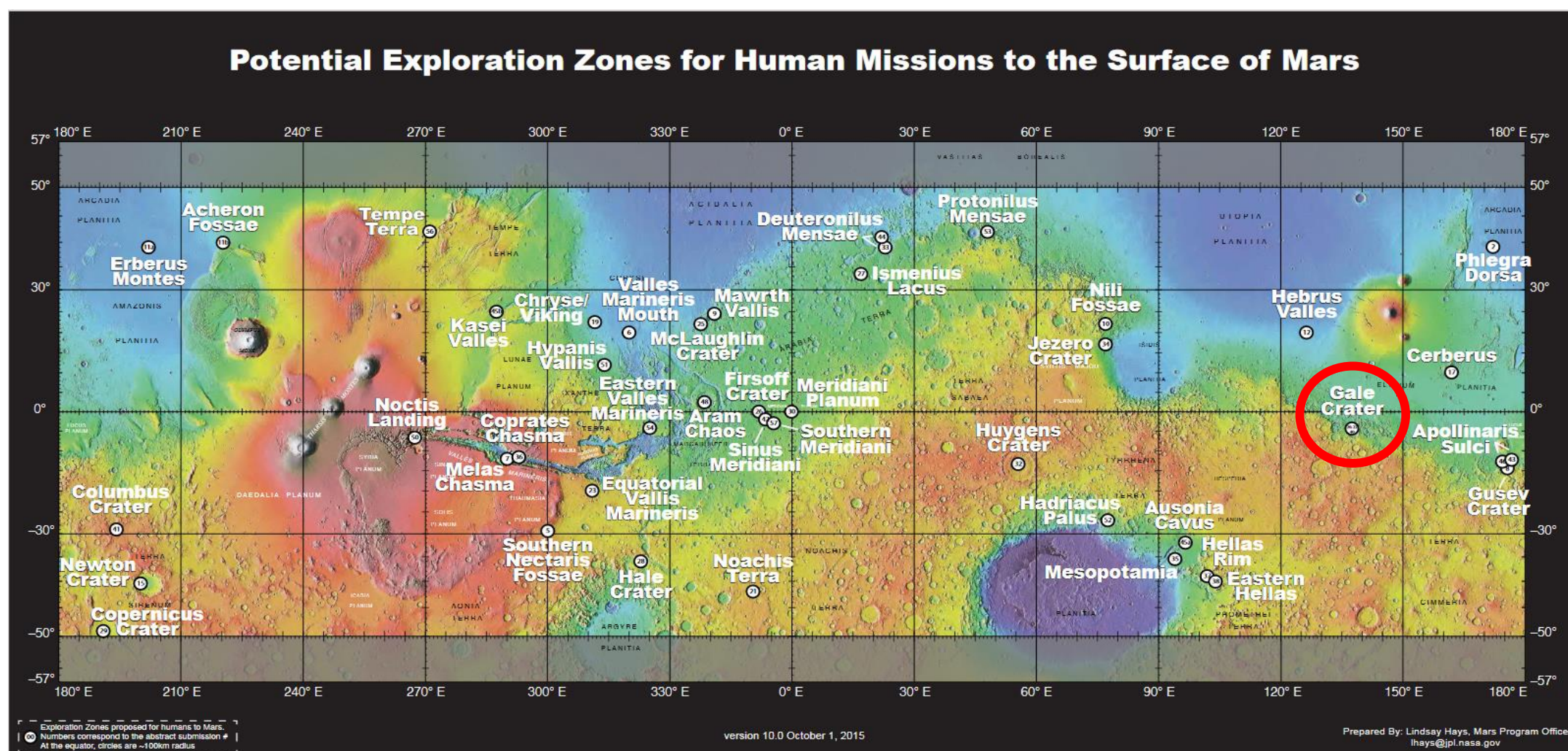


Figure 3: Potential Human Mission Locations with Gale Crater Location Circled in Red [3]

## Current Martian Regoliths

There are currently multiple sources that manufacture simulate regoliths for Mars. Table 1 describes some of the characteristics and shows a sample of Martian simulants available today from Exolith. The cost of the simulants is \$45-55 for 1 kg. NASA needs additional sources of simulant as the quantities here aren't great enough to test in concrete. Further a wider variety of mineralogy would be useful.

Table 1: Examples of Current Martian Regoliths [4]

Simulant	Mineralogy in Simulant (% of Mineralogy)
Mars Global (MGS-1) High-Fidelity Martian Dirt Simulant	Anorthosite (27.1), Glass-rich basalt (22.9), Pyroxene (Bronzite) (20.3), Olivine (13.7), Mg-sulfate (4.0), Ferrihydrite (3.5), Hydrated Silica (3.0), Magnetite (1.9), Anhydrite (1.7), Fe-Carbonate (1.4), Hematite (0.5)
Mars Global Hydrated Clay (MGS-1C) Martian Dirt Simulant	Smectite (40.0), Anorthosite (16.4), Glass-rich basalt (13.7), Pyroxene (Bronzite) (12.2), Olivine (8.2), Mg-sulfate (2.4), Ferrihydrite (2.1), Hydrated silica (1.8), Magnetite (1.1), Anhydrite (1.0), Fe-carbonate (0.8), Hematite (0.3)
Mars Global Polyhydrated Sulfate (MGS-1S) ISRU Martian Dirt Simulant	Gypsum (40.0), Anorthosite (16.4), Glass-rich basalt (13.7), Pyroxene (Bronzite) (12.2), Olivine (8.2), Mg-sulfate (2.4), Ferrihydrite (2.1), Hydrated Silica (1.8), Magnetite (1.1), Anhydrite (1.0), Fe-carbonate (0.8), Hematite (0.3)



## Texture, Shape, and Size

To accurately simulate any Martian aggregate, the texture, shape, and size of the aggregates found in SD should be like the ones found on Mars. Like Earth, Mars's surface contains a wide variety of potential aggregates. Figure 4 shows some of the different soils gathered from the rover Opportunity on a microscopic level.

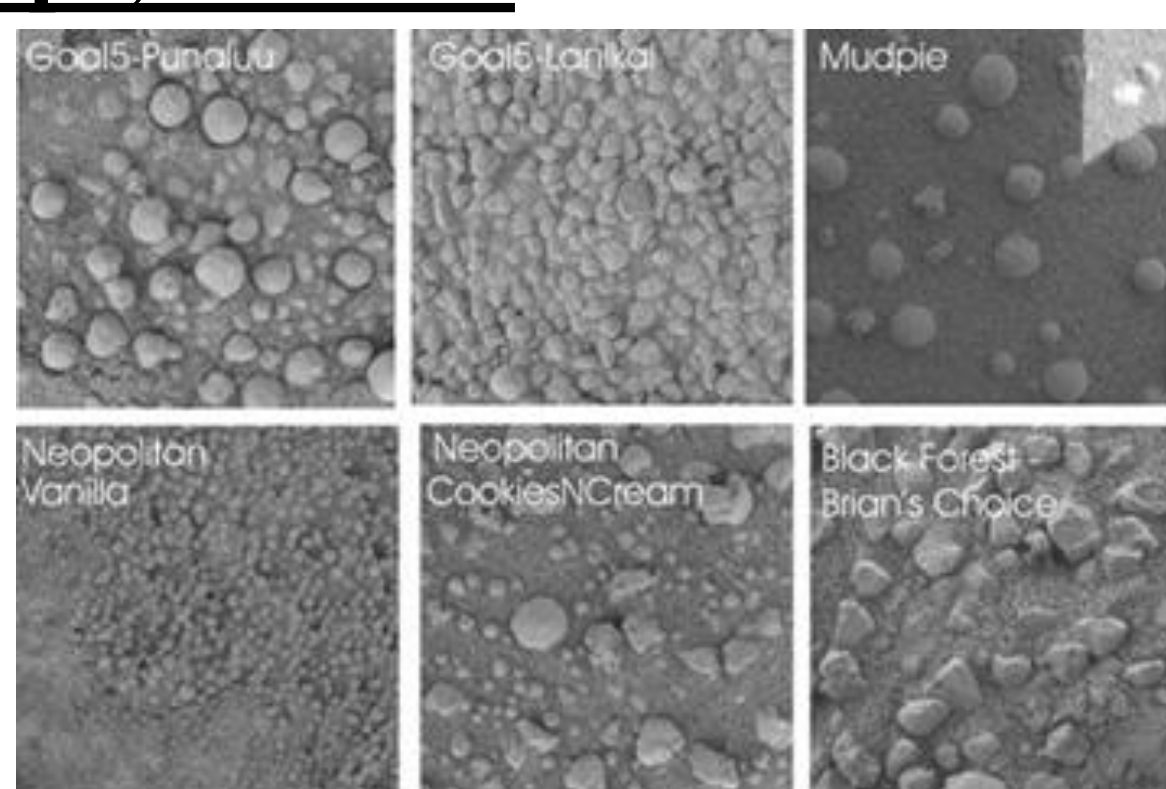


Figure 4: Microscopic Soil Images from Mars Rover Opportunity. Each image is 0.8 in. x 0.8 in. [5]

## Composition

Additionally, the composition of the aggregate must be similar. The Curiosity rover used its Alpha Particle X-Ray Spectrometer (APXS) to divide samples from the Gale Crater into various classes. Figure 5 shows the different classes of rocks and soils in the Gale Crater as a function of their total alkalis versus silica. The Martian rock in the Jake M class are of particular interest due to the similarity to the rock present in the Black Hills (see next section).

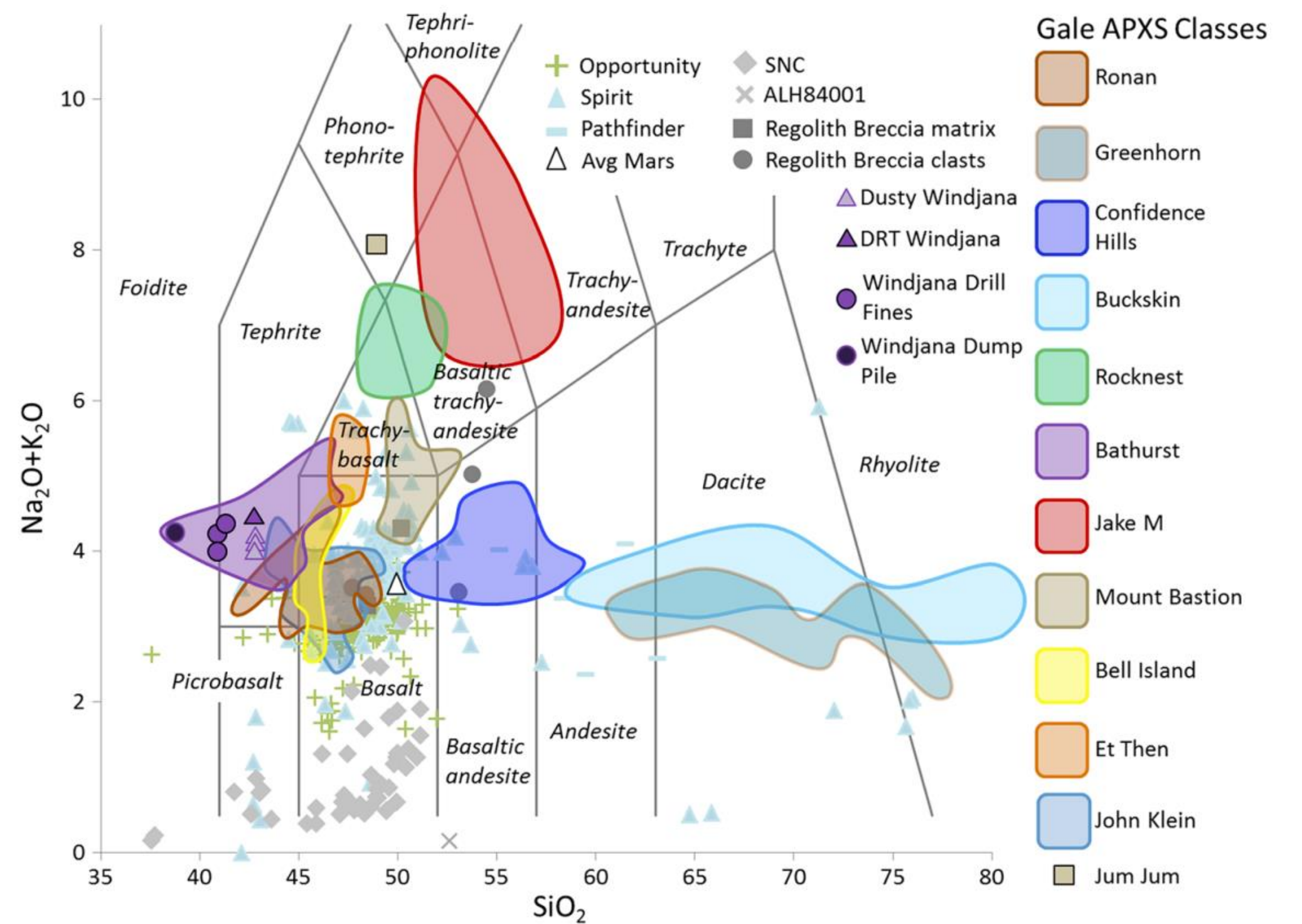


Figure 5: Total Alkalis versus Silica for Classification of Igneous Rock Compositions in Gale Crater [6]

## Black Hills Geology

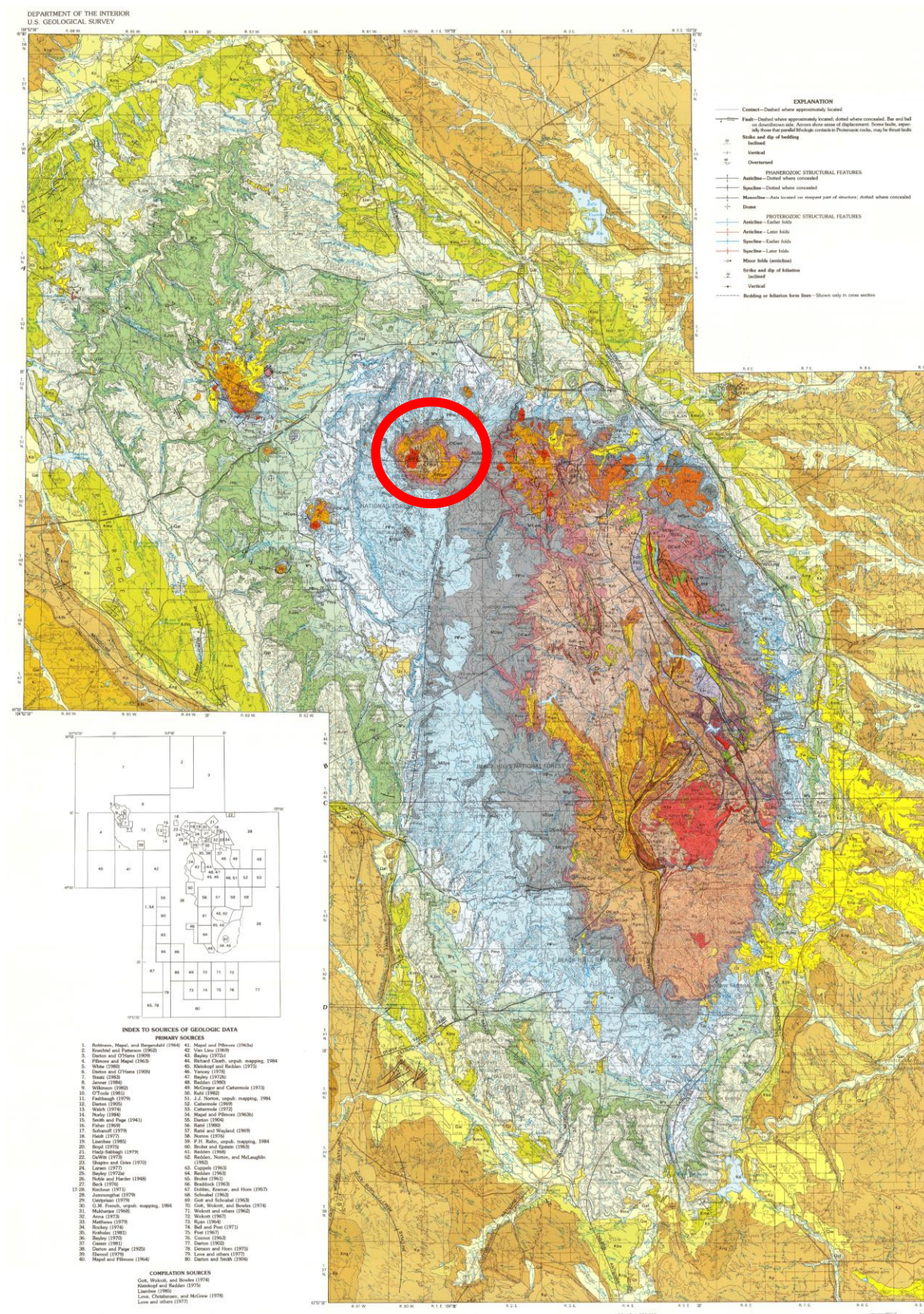


Figure 6: Geologic Map of the Black Hills [8]

Figures 6 and 7 highlight the geologic regions in the Black Hills area. This team is specifically interested in the bright orange color regions labeled Tp which represents phonolitic intrusive rocks (Eocene and Paleocene) including pockets of trachyandesite and alkalic trachyte porphyry [8]. One of the largest deposits of these rocks can be found in the Mineral Hill area circled in red in Figure 6 with a profile view in Figure 7. The next step of this research will be to collect rock samples from these regions and test for similarity to Martian rock.

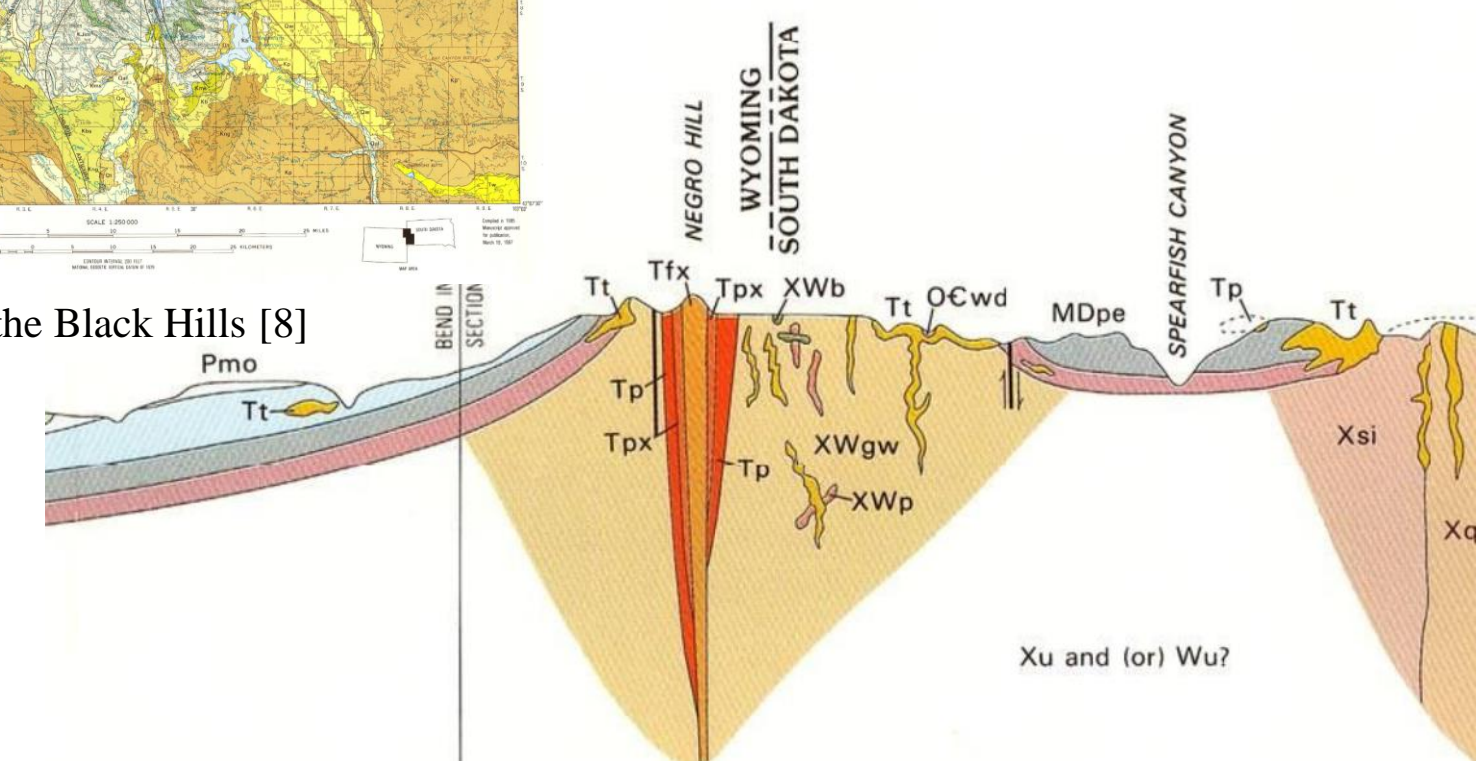


Figure 7: Profile View of Area of Interest Circled in Red [8]

## Acknowledgments

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## References

- NASA. (2019, August 8). *Gale crater*. NASA. <https://mars.nasa.gov/msl/timeline/prelaunch/gale-crater/>
- Rapin, W., & al., et. (2021). *Supplemental Material: Alternating Wet and Dry Depositional Environments Recorded in the Stratigraphy of Mount Sharp at Gale Crater, Mars*. <https://doi.org/10.1130/geol.s.14233550>
- Hays, L. (2015). *Potential Exploration Zones for Human Missions to the Surface of Mars*. Retrieved 2023, from <https://www.nasa.gov/sites/default/files/atoms/files/exploration-zone-map-v10.pdf>.
- Regolith simulants*. Exolith Lab. (n.d.). <https://exolithsimulants.com/collections/regolith-simulants>
- NASA/JPL/Cornell/USGS. (2004). *Catalog page for PIA05651*. NASA. <https://photojournal.jpl.nasa.gov/catalog/PIA05651>
- Thompson, L. M., Schmidt, M. E., Spray, J. G., Berger, J. A., Fairén, A. G., Campbell, J. L., Perrett, G. M., Boyd, N., Gellert, R., Pradler, I., & VanBommel, S. J. (2016). Potassium-rich sandstones within the Gale Impact Crater, Mars: The APXS perspective. *Journal of Geophysical Research: Planets*, 121(10), 1981–2003. <https://doi.org/10.1002/2016je005055>
- Welch, C. M. (1974). A preliminary report on the geology of the Mineral hill area, Crook County, Wyoming: M.S. thesis. South Dakota School of Mines and Technology.
- DeWitt, E., Redden, J. A., Buscher, D., & Wilson, A. B. (1989, January 1). *Explore this publication in the NGMDB*. [ngmdb.usgs.gov/Prodesc/prodesc\\_9999.htm](https://ngmdb.usgs.gov/Prodesc/prodesc_9999.htm)