K-Means Clustering and Mapping of All Four Mars Rovers' APXS Oxide and Element Relative Abundance Data *(LPSC 2020: 1262)*

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Purpose: This paper combines spectra from the one spectrometer found on all four Mars rovers, APXS. The goal is to classify all its targets for comparison of all four regions in a single inductively developed framework.

Data and Methods:

1. All 901 APXS readings from all rovers through November 2016 were downloaded from the Planetary Data System (PDS) Geosciences Node and USGS PDS Imaging Node Server.
2. These were integrated into a common Calc spreadsheet.
3. Readings for each oxide and element were standardized with their means and standard deviations for all 901 records.
4. These t-scores were then imported into PAleontological STatistics (PAST 3) software for K-means clustering (K=15).
5. Descriptive statistics were calculated and graphed for oxides and elements by cluster in OpenOffice Calc.
6. Geocoding: Latitudes and longitudes required pre-processing for placement on the same datum (MOLA, r=3396 km).
7. A portion of the database was used for mapping in Google Earth Mars and a downloadable KMZ file was produced: *web.csulb.edu/~rodrigue/mars/apxs//GE/APXS15tscores.kmz*
8. The 15 clusters were grouped into 5 "metaclusters" and tested with Chi-square for differences among the rover sites.

Results:

Metacluster X (many eXogenous)
- Cluster 7 (16 meteorites or, in some cases, hydrothermally altered materials with extremely high Ni, elevated MgO & Zn)

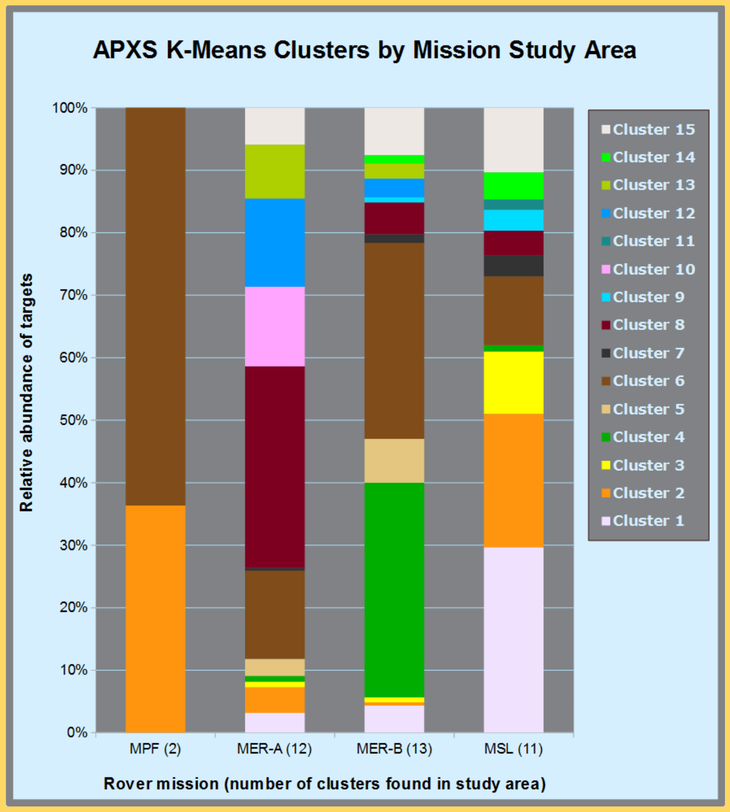
Metacluster B (Basaltic rocks and soils)
- Cluster 6 (187 basaltic rocks and soils, the least divergent material on Mars)
- Cluster 8 (102 pictritic basaltic rocks, some soils)
- Cluster 15 (72 soils, from local basalts mixed with global dust)
- Cluster 5 (32 olivine, some w/ slight Fe sulfates and carbonates)

Metacluster E (possibly from Evolved magmas)
- Cluster 3 (35 alkaline igneous rocks akin to mugearite)
- Cluster 2 (79, elevated silica, andesitic, though these materials can be more altered by neutral water than fractionated)
- Cluster 10 (28, confined to Husband Hill, Wishstone & Champagne class rocks, evolved tephritic, potentially clays)

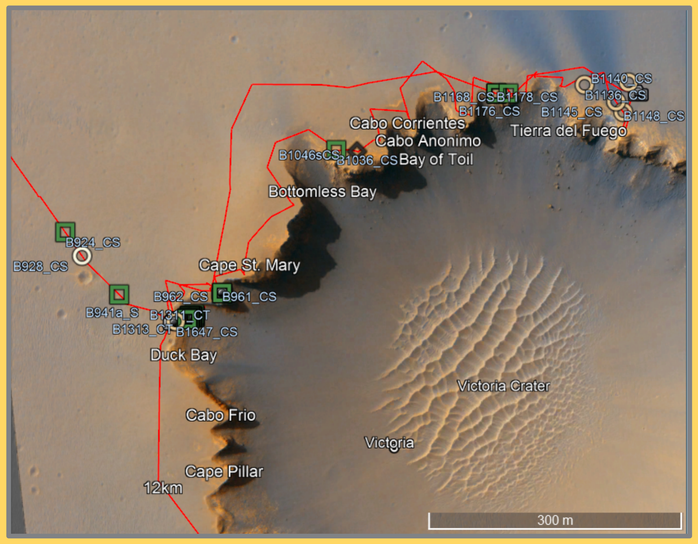
Metacluster N (Neutral to alkaline aqueous alteration)
- Cluster 1 (112 Mars-typical materials showing slight modification by non-acidic waters: somewhat elevated Cl & Br, K_2O & FeO)
- Cluster 12 (42 also Mars-typical basaltic materials enriched in Cl and somewhat elevated in Br & MgO)
- Cluster 9 (13 targets from just 2 rocks in Meridiani & Gale Crater, clastics highly elevated in Zn, Br, & K_2O)
- Cluster 11 (5 targets from the Stephen rock in Gale drastically elevated in MnO, Zn, Br, Cl, MgO, & K_2O)

Metacluster S (Sulfur, acidic aqueous alteration)
- Cluster 4 (132 Mars-typical rock, mudstone, or soil somewhat elevated in SO_3)
- Cluster 13 (28 acidic water altered materials, with significant elevation in SO_3, some in MnO, and depletion in felsic oxides
- Cluster 14 (18 highly elevated in SO_3, and CaO, depleted in felsic oxides, and interpreted as calcium sulfates [1])

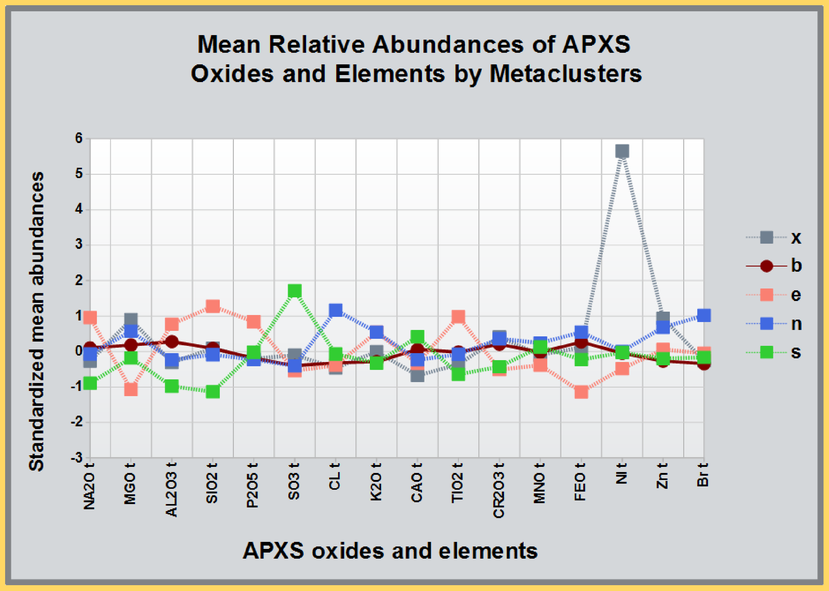
Regional Contrasts in the 15 APXS Clusters



Mapping of 15 Clusters in Google Earth Mars



Average Standardized Scores by 5 Metaclusters



Discussion:

The 15 clusters and 5 metaclusters seem to fall into **3 starting points**: basaltic, possibly evolved magmatic materials, and meteorites or materials resembling them.

The basaltic starting point in some cases then diverged into **2 aqueous alteration pathways**, one neutral-alkaline and the other acidic, themselves linked to changes in the martian atmosphere ([2]'s Phyllocian and Theiikian).

Starting Point	Little to no contact with water	▼ Aqueous Alteration Pathways ▼	
		9 11 12 1	Neutral-alkaline: Elevated halogens
Basalt	6 8 15 5		Little to no contact with water
		4 13 14	Acidic: Elevated sulfur trioxide
Evolved magma?	3 2 10	?	*Note: neutral water can concentrate silica (2?) or produce clays (10?)*
Meteoritic?	7	?	*Note: hydrothermal processes can concentrate nickel*

Conclusion:

The allocation of the 15 clusters contrasts visibly and often sharply among the 4 rover study areas. Testing the 3 rover sites with enough statistical power (MER-A, MER-B, and MSL) for the significance of the differences among them in metacluster allocation, X^2 was 304.022 at 8 df, with $p<0.001$ and an effect size of 0.413: highly significant and moderately strong differences among the study areas. Gusev Crater is basalt dominated and somewhat acidic aqueous impoverished; Meridiani Planum is dominated by acidic aqueous signals and basalt, but short on evolved magma-derived and neutral aqueous altered materials; and Gale Crater is enhanced in evolved magma-derived and neutral-aqueous altered materials and deficient in unaltered basaltic materials.

Context for Purpose:

[3] ran correlations among the 3 spectrometers on the MER rovers and found virtually none. [4] integrated 6 cameras and the LIBS and APXS spectrometers on MSL to mimic geologists' field and lab processes for rock identification. Other ensemble approaches have triangulated orbiter and rover sensors. [5] brought together MRO's CRISM with MER-B's Mini-TES, Mössbauer, and APXS spectrometers to analyze the deposition and alteration histories of sulfate minerals, while [6] integrated 4 spectrometers on 3 orbiters and HiRISE with spectrometers on 3 rovers to work out alkaline and subalkaline magmatic series in Noachian rocks along the crustal dichotomy.

References: [1] Nachon, M. et al. (2014) *JGR: Planets* 119, 1991-2006. [2] Bibring, J.-P. et al. (2006) *Science*, 312, 400-404. [3] Anderson, R.B. and Bell, J.F., III (2013) *Icarus*, 223, 157-180. [4] Mangold, N. et al. (2017) *Icarus*, 284, 1-17. [5] Arvidson, R.E. et al. (2015) *JGR: Planets*, 120, 429-451. [6] Sautter, V. et al. (2016) *Lithos*, 254/255, 36-52.