CLASSIFICATION SCHEME FOR DIVERSE SEDIMENTARY AND IGNEOUS ROCKS ENCOUNTERED BY MSL IN GALE CRATER.
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Introduction: The Curiosity Rover landed in a lithologically and geochemically diverse region of Mars [e.g., 1, 2]. We present a recommended rock classification framework based on terrestrial schemes, and adapted for the imaging and analytical capabilities of MSL as well as for rock types distinctive to Mars (e.g., high Fe sediments).

Rover Capabilities: Designed as a robotic geologist, the Curiosity rover is outfitted with imaging, geochemical, and mineralogical instruments for rock characterization. MSL cameras acquire grain size and shape information at a range of scales.

Table 1. Imaging grain size capabilities [3, 4]

Image	Min detectable grain size
MAHLI (2 cm stand-off)	45-60 µm (fine silt)
Mastcam M100 (3 m dist)	~500 µm (coarse sand)
ChemCam RMI (3 m dist)	300-500 µm (med sand)[1]

[1]RMI theoretical maximum resolution is 120 µm at 3 m.

Geochemical analytical instruments include the Alpha Particle X-ray Spectrometer (APXS) for bulk compositions [2], which examines 1.8 cm spots on rock surfaces, and the ChemCam, which utilizes Laser Induced Breakdown Spectroscopy (LIBS) to examine 200-300 µm spots and is best for understanding grain compositions and rock heterogeneity. Rock chemical heterogeneity can be estimated with ChemCam by computing the Gini index (G) of the composition distribution, which measures the inequality among values of a frequency distribution [5]. G varies between 0 and 1, where G=0 indicates perfect equality among values.

While mineralogy is fundamental for the classification of terrestrial rocks, the CheMin instrument (X-Ray Diffractometer) was not used frequently during the traverse to Mount Sharp and is applied to in depth studies.

Framework: After interpreting rock origin from textures, i.e., sedimentary (clastic, bedded), igneous (porphyritic, glassy), or unknown, the overall classification procedure (Fig 1) involves: (1) the characterization of rock type according to grain size and texture; (2) the assignment of geochemical modifiers according to Figs 3 and 4; and if applicable, in depth study of (3) mineralogy and (4) geologic/stratigraphic context.

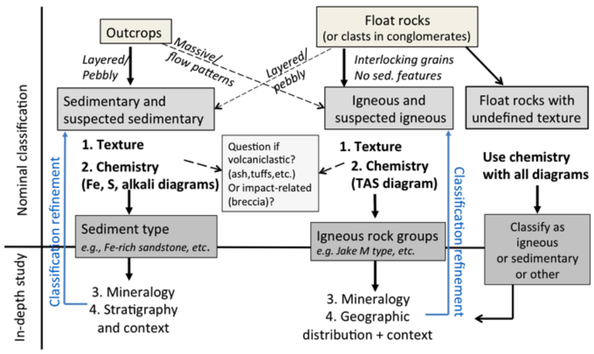

Fig 1. Procedural flow chart for the classification of outcrops and float rocks in Gale Crater.

Textural Classification: Sedimentary rock types are assigned by measuring grains in the best available resolution image (Table 1) and classifying according to the coarsest resolvable grains (as in [6]) as conglomerate/breccia, (coarse, medium, or fine) sandstone, siltstone, or mudstone [7]. If grains are not resolvable in MAHLI images, grains in the rock are assumed to be silt sized or smaller than surface dust particles. Rocks with low color contrast contrast between grains (e.g., Dismal Lakes, sol 304) are classified according to minimum size of apparent grains from surface roughness or shadows outlining apparent grains.

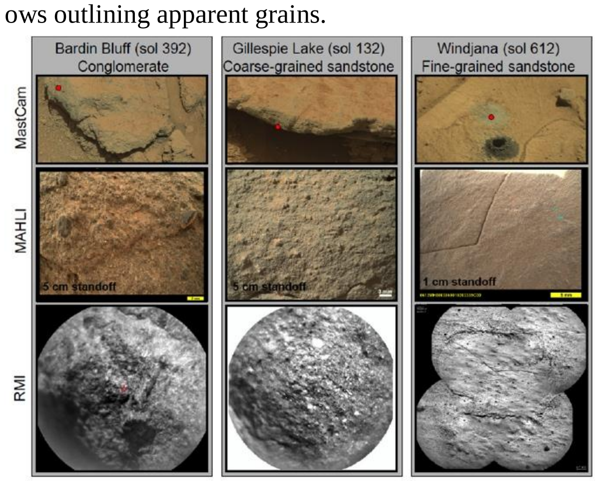

Fig 2. Example sedimentary rocks classified according to images at different resolutions

Igneous rocks are described as intrusive or extrusive depending on crystal size and fabric. Igneous textures may be described as granular, porphyritic, phaneritic, aphyric, or glassy depending on crystal size. Further descriptors may include terms such as vesicular or cumulate textures.

Geochemical Classification: Geochemistry is commonly applied to the classification of igneous rocks on Earth, but it is much less commonly applied to sedimentary rocks. Although we would like to adhere to conventional practice as much as possible, and have a scheme that is applicable beyond Gale Crater, we are limited to the data in hand. We take a simplified approach in order to be more flexible to the discovery of possible new rock types (e.g., carbonates). Our recommendations for geochemical classification of APXS rock targets are: (1) unless S and Cl are a major component (>10%), all analyses should be volatile-free to compensate for variable surface dust coverage; (2) use the total alkali vs. silica diagram [8] for igneous rocks (Fig. 3); and (3) use elemental enrichment and/or depletion modifiers relative to Mars crust [9] for sedimentary rock names (Table 2, Fig 4)).

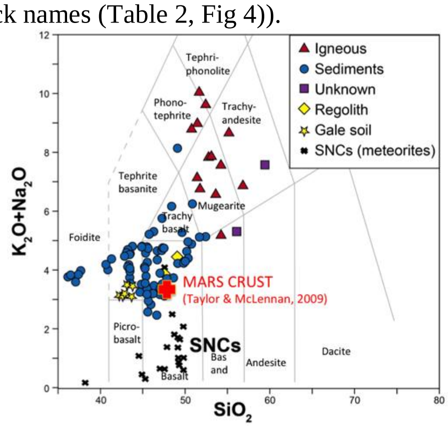

Fig 3. Total alkali vs. silica diagram in weight percent with igneous classification scheme [8]. Gale soils, sedimentary rocks, SNC meteorites, and average Mars crust are for reference.

Table 2. Geochemical Modifiers Relative to Average Mars Crust [9] for Sedimentary Rocks

Oxide	Value[1]	Modifier	Notes
FeO*[1]	>23%	***Fe-rich***	5% above Mars crust
	<13%	***Fe-poor***	5% below Mars crust
SO_3	>10%[3]	***Sulfur-rich***	> very dusty soil
K_2O	>1%	***Potassic***[4]	~2× Mars crust
	<0.2%	***K-poor***[5]	~50% Mars crust
Na_2O	>5%	***Sodic***[4]	natural break in data
	<1.5%	***Na-poor***[5]	~50% Mars crust

[1]In weight percent. [2]Total Fe as FeO. [3]No veins or white blebs obvious in MAHLI images. [4]***Alkaline*** is both sodic and potassic. [5]***Alkali-poor*** if both K- and Na-poor.

In order to maintain flexibility over the course of the mission, the exact values defining "rich" and "poor" could change later if data warranted. We may also add modifiers (e.g., Si-rich) as new rock types are discovered along Curiosity's traverse.

Application: This classification scheme is envisaged for the duration of the MSL mission, but is subject to revision as new rock types are discovered. Note that instrument-specific rock classes (e.g., [10]) are also in use among the science team and this scheme is meant not as a replacement, but as a standardization of general terminology.

References: [1] Grotzinger et al. (2014) Science 343, 1242777. [2] Schmidt et al. (2014) JGR 119, 64-81. [3] Grotzinger et al. (2012) Space Sci. Rev. 170, 5-56. [4] Edgett et al. (2012) Space Sci. Rev. 170, 259-317 [5] Gini, C. (1921) The Economic Journal 31, 124-126. [6] Anderson et al. (2014) Icarus, in press. [7] Wentworth (1922). [8] Irvine & Baragar (1971) Canad. J. Earth Sci. 8, 523-548. [9] Taylor & McLennan (2009) Planetary Crusts: their composition, origin and evolution, Cambridge Univ. Press. [10] Schmidt et al. (2014) LPSC 45, abs. #1504.

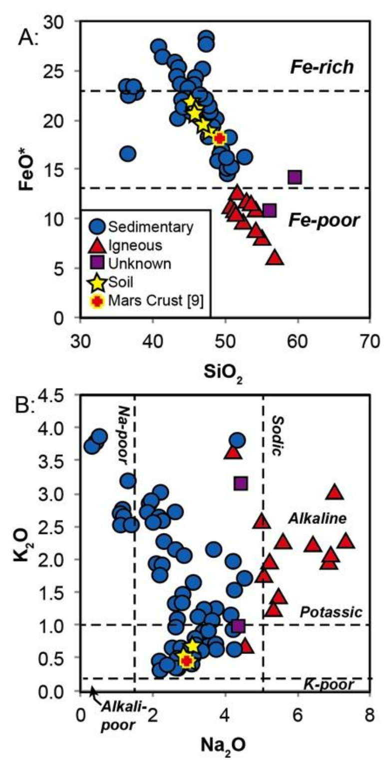

Fig 4. A: FeO vs. SiO_2 and B: K2O vs. Na_2O in weight percent for the determination of elemental enrichment and depletion for geochemical modifiers for sedimentary rocks.*