Cation Sources for the Sulfate Evaporites in Valles Marineris, Mars. Chaojun Fan, Dirk Schulze-Makuch and John A. Wolff, All at School of Earth and Environmental Sciences at Washington State University, Pullman, WA 99164, USA (cfan@mail.wsu.edu, dirksm@wsu.edu, jawolff@mail.wsu.edu).

Introduction: A huge amount of hydrated Ca and Mg sulfates was identified through the Visible and Infrared Mineralogical Mapping Spectrometer (OMEGA) images [1, 2]. The sulfates were likely formed by evaporation of the standing bodies of acidic water [3]. Where did the huge amount of cations come from? Here, we propose that the cations were derived from alteration of the ancient Martian basaltic crust from a comparison of the chemical compositions of the bedrocks at Gusev Crater and the layered deposits in Meridiani Planum, assuming the layered deposits in Meridiani Planum are derived from weathering of the basaltic crust in the southern highlands.

The bedrocks and chemical compositions at Gusev Crater: The Spirit of Mars Exploration Rover (MER) investigated the soils and bedrocks at Gusev Crater. The bedrocks are volcanic (with phenocrysts [4]) and are dominantly composed of plagioclase, olivine and pyroxene [5]. Fresh rocks exposed by the rock abrasion tool (RAT) are thought to be primitive basaltic rocks, similar to primitive terrestrial basalts [6]. These rocks were subjected to extensive weathering early in Martian history. The abraded bedrocks should represent the unweathered basaltic crust of Mars.

The chemical compositions of the bedrocks were analyzed using the alpha particle x-ray spectrometer (APXS, [6]). We averaged the chemical compositions of the five abraded rock samples, giving them equal weights (Table 1). The sum of Si + Al and the sum of Mg + Ca + Fe are 26.96 wt% and 25.86 wt% respectively. The ratio of ∑Si+Al to ∑Mg+Ca+Fe is 51/49, which is consistent with the composition of basaltic rocks on Earth.

The bedrocks and chemical compositions in Meridiani Planum: The MER Opportunity Rover investigated the soils and bedrocks in Meridiani Planum. The bedrock outcrops display clear sedimentary characteristics and are composed of fine-grained siliciclastic materials (~50%), sulfate minerals (~40%) and hematite (~10%) [7]. Squyres et al. (2004) suggested that the fine-grained siliciclastic materials were derived from the weathering of basaltic parent rocks [7]. It has been proposed that the sulfates in Meridiani Planum were transported from sulfate evaporites deposited in Valles Marineris [8].

The chemical compositions of the abraded rocks in Meridiani Planum were analyzed using APXS [9]. We averaged the compositions of four abraded rock samples (Table 2), except for Bounce Rock because its composition is unique at the Meridiani site [10]. The sum of Si+Al is 30.29 wt% and the sum of Mg+Ca+Fe is 21.27 wt%. A large proportion Mg+Ca+Fe is in sulfates and hematite.

The sulfates are likely kieserite ($MgSO_4 \cdot H_2O$), gypsum ($CaSO_4 \cdot 2H_2O$) and jarosite ($KFe_3(SO_4)2(OH)_6$). If the same amount of sulfur (0.64 wt%) in Gusev crater is contained in the rocks other than sulfates in Meridiani Planum, there is about 8.8 wt% of sulfur derived from sulfates. This amount of sulfur could combine with Mg, Ca and Fe in amounts ranging from 6.7 wt% (if sulfates are totally kieserite), through 11.0 wt% (totally Ca sulfates) to 23.0 wt% (totally jarosite) in the sedimentary rock. Hematite can contribute 5.4 wt% of iron in the sedimentary rocks. So there is at least about 12.1% of the sum of Mg+Ca+Fe in the rocks derived from sulfates and hematite. Removing this portion of Mg+Ca+Fe, the sum of Si+Al and the sum of Mg+Al+Fe in the siliciclastic materials are 32.29% and 9.2 %, respectively. Thus, the ratio of ∑Si+Al to ∑Mg+Ca+Fe in the siliciclastic materials is 77.8/22.2, which is close to the chemical composition of phyllosilicates such as montmorillonite.

Discussion: Two types of rocks were recognized in the Martian crust, basalt in the southern highlands and basaltic andesite in the northern lowlands by the Mars Global Surveyor Thermal Emission Spectrometer [11]. The outcrops with high concentrations of olivine and pyroxene were identified in the southern ancient terrains or crater floors [12], while alteration products and phyllosilicates were identified in broad areas of the northern lowlands by the OMEGA images [13]. Incorporating the sedimentary characteristics of the bedrock outcrops, the siliciclastic materials in Meridiani Planum are most likely dominated by the clay minerals (mixed with a portion of basaltic fragments). This is consistent with the value of ∑Si+Al /∑Mg+Ca+Fe of the portion of siliciclastics materials removing sulfates and hematite.

These clay minerals were probably derived from weathering of the basaltic crust in the neighboring areas of the southern highlands, which had similar chemical compositions to the bedrocks analyzed in Gusev Crater. Based on the above discussion, the ratio of ∑Si+Al/∑Mg+Ca+Fe changed from 51.0/49.0 to 77.8/22.2 when the basaltic crust was altered to the phyllosilicate minerals. The calculation indicates that more than 50 wt% of ∑Mg+Ca+Fe in the basaltic rocks was released by this process. These released cations were likely dominated by magnesium and calcium (sodium and potassium are not considered here), because they have much higher solubility than iron. The released Mg and Ca were dissolved in acidic water and accumulated in standing bodies of water in the depression areas along the ancient dichotomy boundary of Mars. They precipitated to form sulfate evaporites in the area of Valles Marineris in Noachian before the uplift of the Tharsis rise combining with sulfur derived from elsewhere [8].

Table 1 The chemical composition of the bedrock abraded by RAT at Gusev Crater*

Oxide	Adirondack	Humphrey		Mazatzal		Average (wt%)	
		Sample1	Sample2	Sample1	Sample2	Oxide	Element
Na_2O	2.70	3.10	2.80	3.10	3.10	2.97	2.20
MgO	11.90	10.40	11.50	9.90	10.70	10.92	6.56
Al_2O_3	10.90	10.90	10.60	10.00	10.80	10.68	5.63
SiO_2	45.40	46.10	45.70	45.40	45.50	45.80	21.33
P_2O_5	0.54	0.60	0.59	0.86	0.67	0.65	0.28
SO_3	1.15	1.02	1.20	3.20	1.39	1.60	0.64
Cl	0.13	0.21	0.17	0.36	0.15	0.20	0.20
K_2O	0.06	0.12	0.08	0.27	0.15	0.14	0.11
CaO	7.42	7.84	7.53	7.22	7.68	7.57	5.39
TiO_2	0.45	0.54	0.53	0.65	0.56	0.55	0.33
Cr_2O_3	0.59	0.66	0.59	0.44	0.53	0.56	0.38
MnO	0.38	0.38	0.38	0.37	0.39	0.38	0.29
FeO	18.00	17.80	18.00	17.70	18.00	17.97	13.91
Total	99.62	99.67	99.67	99.47	99.66	100.00	57.25
∑Si+Al	56.30	57.00	56.30	55.40	56.30	56.48	26.96
∑Mg+Ca+Fe	37.30	36.00	37.00	34.80	36.30	36.46	25.86

* Data derived from [6].

Table 2 The chemical composition of the bedrock abraded by RAT in Meridiani Planum*

Oxide	Mckittrick	Guadalupe	Flat rock	Pilbara	Average (wt%)	
					Oxide	Element
Na_2O	1.10	1.00	1.20	1.10	1.11	0.82
MgO	7.40	7.80	7.80	8.00	7.82	4.71
Al_2O_3	6.00	5.70	6.00	5.60	5.87	3.11
SiO_2	38.10	36.30	36.20	34.70	36.63	27.18
P_2O_5	1.00	0.99	1.03	0.98	1.01	0.44
SO_3	21.00	24.60	23.30	24.70	23.60	9.45
Cl	0.39	0.33	0.36	0.44	0.38	0.38
K_2O	0.56	0.54	0.59	0.50	0.55	0.46
CaO	4.49	5.02	5.28	4.9	4.96	3.55
TiO_2	0.85	0.67	0.77	0.78	0.77	0.46
Cr_2O_3	0.22	0.19	0.23	0.23	0.22	0.15
MnO	0.32	0.32	0.27	0.37	0.32	0.25
FeO	17.6	15.8	16.3	16.7	16.74	13.01
Total	99.03	99.26	99.33	99.00	100.00	63.98
∑Si+Al	44.1	42.00	42.20	40.30	42.51	30.29
∑Mg+Ca+Fe	29.49	28.62	29.38	29.60	29.52	21.27

* Data derived from [9].

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