

THE PETROCHEMISTRY OF JAKE_M: A MARTIAN MUGEARITE. Stolper, E.M.¹, Baker, M.B.¹, Fisk, M.², Gellert, R.³, King, P.L.⁴, McLennan, S.M.⁵, Minitti, M.⁶, Newcombe, M.¹, Schmidt, M.E.⁷, Treiman, A.H.⁸, and the MSL Science Team. ¹Caltech, Pasadena, CA 91125, ²Oregon State Univ., ³Univ. Guelph, ⁴Res. School Earth Sci., ANU, ⁵SUNY, Stony Brook, ⁶Applied Phys. Lab., Johns Hopkins Univ., ⁷Brock Univ., ⁸Lunar & Planet. Inst.

Introduction: Rock “Jake_M” (JM; named for JPL engineer Jake Matijevic) was the first sample analyzed by the Alpha Particle X-ray Spectrometer (APXS) instrument on MSL [1]. Although it is an isolated fragment lacking field context, its dark color and apparently fine-grained texture suggested it was a relatively homogeneous igneous rock and thus an appropriate sample to initiate the APXS analytical program. We report here the preliminary APXS analyses of JM and a plausible interpretation of their significance for petrogenesis.

Results: Three spots on JM were analyzed with the APXS: one analysis during the night and two during the daytime. Complete (but provisional) analyses and errors are given in Table 1 (FeO* = all Fe as FeO). The average of the 3 analyses (each normalized to 100 wt% excluding S and Cl) is listed in Table 2 along with CIPW norms for FeO contents of 100 and 85% of total Fe.

Table 1. APXS chemical analyses of Jake_M; uncertainties reflect precision.

wt%	JM-1	1 σ	JM-2	1 σ	JM-2n	1 σ
SiO ₂	50.70	0.43	49.48	0.53	49.23	0.43
TiO ₂	0.72	0.08	0.92	0.08	1.00	0.03
Al ₂ O ₃	16.44	0.38	14.89	0.28	14.76	0.19
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00
FeO*	10.14	0.06	11.42	0.13	12.11	0.09
MnO	0.13	0.01	0.15	0.03	0.22	0.01
MgO	3.07	0.33	3.80	0.17	3.55	0.08
CaO	6.09	0.07	6.53	0.14	6.90	0.07
Na ₂ O	6.55	0.27	6.08	0.27	5.81	0.11
K ₂ O	2.34	0.06	2.10	0.06	2.00	0.02
P ₂ O ₅	0.41	0.09	0.50	0.11	0.69	0.02
S	1.01	0.05	1.22	0.05	1.10	0.02
Cl	0.76	0.02	0.90	0.05	0.83	0.02
Total	98.35		98.00		98.18	
Temp.	-3 °C		-2 °C		-55 °C	
Time	30 min		12 min		30 min	

Discussion: Bulk composition and classification: JM has a composition consistent with a highly fractionated alkaline basalt: It has > 10% nepheline, albitic plagioclase (~An₂₁), and orthoclase in its norm; molar Mg/(Mg+Fe) ~ 0.36; Ni < 50 ppm; and a position well above the alkaline-subalkaline curve [2] on an alkali-silica diagram (Table 2; Fig. 1). Although classification based solely on chemical composition is not definitive, JM’s composition is consistent with a mugearite (Fig. 1), and there is an excellent oxide-by-oxide correspondence between JM and typical terrestrial mugearites (Table 2). Mugearites are a well-defined and widely distributed (though relatively uncommon) intermediate (i.e., fractionated) member of the alkali-olivine basalt, hawaiite, mugearite, benmoreite, trachyte/phonolite terrestrial magma series found in locations such as ocean islands and continental rifts [3,4].

The surface of JM was not brushed or abraded prior to analysis, so the APXS analyses probably include contributions from surface coatings, including adhering dust, and these are the probable source of the S and Cl in JM. Experience with MER, however, indicates that the characteristics of rock compositions are typically not obscured by surface components, and the levels of S and Cl in JM are lower than virtually all unbrushed analyses from the Spirit rover and lower than many of the brushed analyses, so the level of surface contamination and alteration are likely relatively minor [5].

Comparison to other martian basalts: The JM composition is distinct from other known martian rocks. Basaltic martian meteorites and most rocks analyzed by the MER rovers are significantly lower in alkalis and alumina and higher in iron [6]. Although some Gusev samples are alkaline (e.g., Backstay), no relatively unaltered samples are as alkaline as JM or similar to it in other critical respects such as elevated K₂O. Models for the origin of previously described alkaline martian magmas have generally called upon melting of a more alkali-rich source (relative to that of shergottites) [7] and/or fractional crystallization [8].

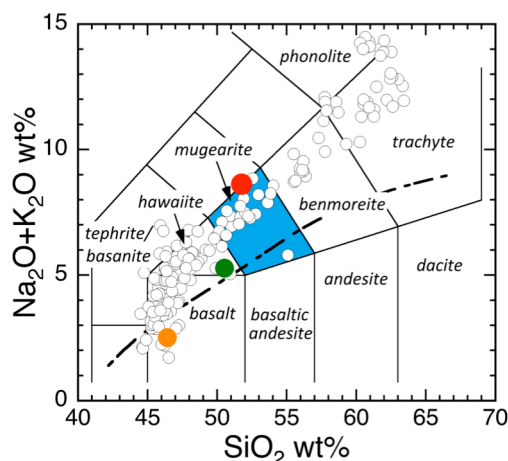


Fig. 1. Alkali-silica diagram [9] showing average JM, red filled circle; orange and green filled circles are Adirondack and Backstay (Table 2); field of mugearite in blue. Igneous rocks from St. Helena [10] in open circles. Dot-dashed line separates alkaline rocks (above) and subalkaline rocks (below) [2].

Petrogenesis: Hypotheses for the origins of igneous rocks rarely rely on chemical compositions alone, but are constrained by field relations, petrography, and compositions of related rocks. We lack these data for JM, but we are able to say with confidence what its compositional features would signify if it formed by processes similar to comparable terrestrial rocks.

Table 2. Comparison of Jake_M composition with typical terrestrial mugearites and other Mars basalts.

wt%	JM avg	JM avg	Mugarite	St. Helena	Backstay	Adirondack
SiO ₂	51.75	51.75	52.0	51.9	50.5	46.4
TiO ₂	0.91	0.91	2.2	2.0	0.95	0.49
Al ₂ O ₃	15.96	15.96	17.2	17.7	13.52	11.04
Cr ₂ O ₃	0.00	0.00	—	—	0.15	0.62
Fe ₂ O ₃	0.00	1.94	1.8	1.8	0.74	1.06
FeO	11.66	9.91	9.0	9.4	12.60	18.14
MnO	0.17	0.17	0.3	0.2	0.24	0.42
MgO	3.61	3.61	3.3	2.6	8.48	11.00
CaO	6.76	6.76	6.3	6.2	6.16	7.87
Na ₂ O	6.39	6.39	4.9	5.2	4.23	2.45
K ₂ O	2.23	2.23	2.5	2.2	1.09	0.07
P ₂ O ₅	0.56	0.56	0.8	0.9	1.42	0.53
Qtz	0	0	0	0	0	0
Plag(An)	37(22)	39(20)	55(30)	59(30)	50(28)	40(46)
Orth	13.2	13.2	14.8	13.0	6.4	0.4
Neph	14.0	12.7	1.9	2.0	0	0
Hypers	0	0	0	0	7.9	11.0
Diop	18.4	18.2	7.1	5.4	5.5	13.9
Oliv	14.9	11.4	12.4	12.4	23.4	30.6
Ilm	1.7	1.7	4.2	3.8	1.8	0.9
Ap	1.3	1.3	1.8	2.1	3.3	1.2
Mt+Chr	0	2.8	2.6	2.7	1.3	2.4

JM avg: average of normalized, volatile-free analyses (Table 1); —: not reported. CIPW norm mineralogy (by wt); 'An' is calculated molar Ca/(Ca+Na) of plag. Average mugearite [11]; average of St. Helena mugearites [10]. Mars basalts Backstay and Adirondack [7] from Gusev Crater.

Mugearites [12] on Earth are generally produced by extensive crystal fractionation of mildly to strongly alkaline magmas. Although this fractionation commonly occurs in shallow magma chambers beneath a volcanic edifice [3], in some cases it appears to occur in the upper mantle based on the presence of peridotite xenoliths [13]. A crucial constraint on the fractionation required to explain JM is its high Al₂O₃ content. If fractionation from an alkali-olivine-basaltic melt occurs at 1 atm with no dissolved H₂O in the melt, plagioclase saturation is reached long before sufficient fractionation occurs to produce a residual liquid with ~3 wt% MgO, with the result that such a residual liquid has only 12–13 wt% Al₂O₃ (i.e., << the 16–19 wt% Al₂O₃ in JM and terrestrial mugearites) (Fig. 2). In order to produce residual melts with the required Al₂O₃ contents, plagioclase crystallization must be suppressed, e.g., via non-negligible H₂O contents and/or fractionation at elevated pressures. For example, fractionation of a parental melt with 1.3 wt% H₂O at 2 kbar (~15 km depth on Mars) successfully reproduces the elevated Al₂O₃ content of JM (Fig. 2; for this calculation, the JM-like melt produced after ~50% crystallization of olivine and pyroxenes contains ~2.5 wt% H₂O). Pits (vesicles?) observed on the surface of JM are consistent with hydrous fractionation. The importance of hydrous fractionation for some terrestrial mugearites is confirmed by the presence of phases such as amphibole and analcite.

Significance of alkaline magmas: We have no constraints on conditions required to produce the transitional or alkaline liquids from which JM is presumed to

have evolved by extensive fractionation under hydrous conditions and/or elevated pressures. On Earth, such magmas have been attributed to a variety of conditions and processes, including melting of lherzolites at elevated pressure; melting of lherzolite with H₂O ± CO₂; melting of metasomatized lithospheric mantle; and melting of pyroxenites and amphibolites [e.g., 14,15].

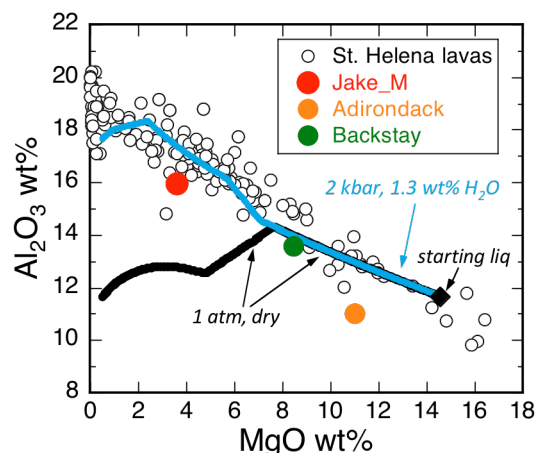


Fig. 2. Al₂O₃ vs. MgO. Black and blue lines are 1 atm, dry and 2 kbar, wet (initial H₂O = 1.3 wt%) fractionation paths calculated with MELTS [16]. Starting liquid (black diamond) from [17].

Implications: We are aware of the dangers of over-interpreting the composition of a single, out-of-place rock, but the characteristics of JM suggest several possibilities: (1) The mineralogy of JM-like rocks may be distinctive, including amphibole, analcite, albitic plagioclase, K-feldspar, and anorthoclase. (2) Felsic igneous rocks (e.g., trachytes and phonolites) are sometimes associated with fractionated alkaline rocks on Earth and may be encountered on Mars if this is not an isolated occurrence. Such rocks may already have been analyzed by ChemCam [e.g., 18]. (3) Given the possibly hydrous nature of the fractionation required to produce mugearites, explosive volcanism may be associated with such magmas.

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