curately than absolute abundances. This capability is fully utilized for the Chryse suite of samples. In Table 1, note that the differences between S1, S2, and S3 are trivially small for many elements. The best-established difference is in S content, which increases by nearly one-half from S1 to S3. Sympathetic variation of other elements with the S increase is obviously difficult to establish, but the most likely candidate (excluding Na) seems to be Mg. Magnesium sulfate, or a hydrate thereof, could be an excellent cementing agent (*15*), and the fragments analyzed in S2 and S3 may therefore simply be fragments of a duricrust (*4*).

Utopia sample (U1). Within hours after the landing of the Viking 2 spacecraft, a calibration sequence of the XRFS unit was initiated. The data showed extra counts in some of the low channels. As a countermeasure, the gains of the detectors have been commanded high enough to place all peaks required for analyses above channel 24. Data reduction becomes more complex in this mode of operation, particularly for PC1, but should not greatly affect ultimate accuracies (*16*). Sample U1 was of fines taken from an area known as Bonneville, and was delivered on sol 29 (*4*). As is evident in Fig. 8, this sample at Utopia Planitia is strikingly similar to those taken at Chryse Planitia, and the preliminary elemental analysis (Table 1) and the bulk-density determination bear out this generalization. The implications of this finding and the mineralogic and petrologic interpretations of our results are discussed elsewhere (*4*).

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15. Laboratory preparation of geochemical analog materials has shown that silt-sized rock particles can be firmly cemented together by evaporation of water from samples which have been soaked in aqueous solutions of $MgSO_4$ to produce a sample containing about 3 percent S by weight. The resultant coarse aggregrates are sufficiently coherent to withstand the acquisition, sieve, and delivery operations by Viking surface sampler.
16. All XRFS spectra obtained on Viking 2 since it landed have shown spurious pulses in the lowest 24 of the 128 channels into which each spectrum is analyzed. The noise is present in all four detectors but is more pronounced for PC1 and PC4 than for the other two. Special test sequences on sols 10, 14, 16, 17, and 27 included the operation of the detectors at essentially zero gain so that only electronic noise bursts were detected, and the results showed clearly that the noise detected by the XRFS was directly correlated with activity of the on-board guidance, control, and sequencing computer (GCSC). Because the noise is restricted to the lower part of each spectrum, the most seriously affected determinations are those of Mg, Al, and Si. The noise occurs in the same channels, independent of detector gain, however, and the peaks corresponding to these elements can be shifted to noise-free parts of the spectrum by suitably increasing detector gain. This causes the backscatter peak to fall off scale, requiring indirect procedures for normalization and gain and offset calibration by comparison of data taken at high and at nominal gains.
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Mineralogic and Petrologic Implications of Viking Geochemical Results From Mars: Interim Report

Abstract. *Chemical results from four samples of martian fines delivered to Viking landers 1 and 2 are remarkably similar in that they all have high iron; moderate magnesium, calcium, and sulfur; low aluminum; and apparently very low alkalies and trace elements. This composition is best interpreted as representing the weathering products of mafic igneous rocks. A mineralogic model, derived from computer mixing studies and laboratory analog preparations, suggests that Mars fines could be an intimate mixture of about 80 percent iron-rich clay, about 10 percent magnesium sulfate (kieserite?), about 5 percent carbonate (calcite), and about 5 percent iron oxides (hematite, magnetite, maghemite, goethite?). The mafic nature of the present fines (distributed globally) and their probable source rocks seems to preclude large-scale planetary differentiation of a terrestrial nature.*

Both Viking landers (VL) are in relatively low, basinal areas of Mars (VL1 at Chryse Planitia and VL2 at Utopia Planitia) characterized by abundant red-colored fine material and scattered blocks of generally angular rocks. At the site of VL1 there is more geologic diversity than at the VL2 site: pitted and relatively unpitted rocks, both light and dark colored; abundant dunelike deposits; and outcrops of apparent bed rock, crudely layered and perhaps intruded by a dike (*1*). The VL2 site, by contrast, is a flat plain more densely covered with angular blocks of uniformly dark-colored, pitted, fine-grained rocks. At both sites, but more prominently at VL2, the uppermost surface of fine material appears to be cemented into a crust 1 to 2 cm thick, which seems to range widely in mechanical strength. As of this report, four samples (three at VL1 and one at

VL2) have been delivered to the x-ray fluorescence spectrometers (XRFS) aboard the landers. We believe all four are martian fines, ranging in physical character from a loose, powdery consistency to more or less indurated or cemented duricrust. Deliveries of pebble-sized fractions of rock material were attempted during the second and third sequences on both VL1 and VL2; an attempt was also made to deliver coarse material residual in the sampler after an acquisition for the VL2 biology investigation. On VL2 no coarse samples were received, while on VL1, the chemical similarities to previously analyzed fines and the low bulk density of the material, suggest delivery of cemented fines only. Further attempts will be made to acquire the geochemically important rock material, but this report is confined to a discussion of the possible mineralogic and petrologic implications that can be derived from the analyses of martian fines from the two Viking landing sites, approximately 6500 km apart.

Samples of Mars surface materials were delivered to the Viking 1 XRFS on sols (*2*) 8, 34, and 40 and to the Viking 2 XRFS on sols 29 and 30 (Table 1). Photographs of the sample sites have been published (*3, 4*).

As with the other Viking lander soil analysis experiments (biology and molecular analysis), samples for the XRFS instruments were obtained from sites located approximately 1.5 to 2.5 m from the spacecraft and from maximum depths of 6 cm below the surface. Two different modes of surface sampler operation, one for fines and the other for pebble-sized grains, were used in acquiring samples. In the "fines" mode, the surface sampler sifts the bulk sample through its 2-mm sieve directly into the XRFS funnel. In the "pebble" mode, the surface sampler was first positioned away from the lander and the inverted collector head was vibrated for 60 to 90 seconds in order to sieve fine particles (< 2 mm) from the bulk sample. The coarse fraction retained in the collector head was then delivered to the XRFS funnel through a 12-mm screen built into the funnel. Simulations performed with the Viking science test lander were used to verify the effectiveness of this technique in removing the fines from mixtures of pebbles and silt-sized rock powder.

At the VL1 site, the first sample (designated S1) was obtained from a drift deposit of windblown material composed predominantly of silt-sized particles (*3*). Two successive acquisitions (the nominal sampling sequence for the XRFS) were taken from the headwall of a trench excavated approximately 3 hours earlier, during sample collection for the biology and molecular analysis experiments. It is likely that S1 was composed largely of material from below the interface of the martian surface and atmosphere.

The second and third VL1 samples, S2 and S3, were obtained in the "pebble" mode from an area of surface concentration of pebble-sized material (*3, 5*). Sample S2 was obtained from alongside the near end of a trench that had been excavated on sol 31 during sampling for the molecular analysis experiment. The S2 acquisitions uncovered several small rocks or soil clods, the average size of which indicates that sampling may have included material from a depth of 4 cm. The S3 sample was obtained 6 sols later by two acquisitions in which the surface sampler penetrated the headwall of the adjacent sol 31 trench.

The first XRFS sample (U1) at the second Viking landing site was obtained (sol 29) from a surface exposure of duricrust that had been sampled on sol 21 for the molecular analysis experiment. The sample probably included material from the immediate surface and from as deep as 4 cm below the surface. The sample was delivered to the XRFS by fines-mode operation of the surface sampler.

The XRFS instruments on Viking require long, repeated analyses of each sample in order to accumulate adequate data for quantitative results (*6*). Before enough data can be pooled for quantitative calculations, however, it is possible to treat the received spectra as qualitative "signatures" of rock or mineral classes by visual comparison with a library of standard spectra. This library of over 1000 spectra of terrestrial and meteoritic materials was accumulated before the landed operations with the use of flightlike x-ray spectrometers (*7*). Although the library includes spectra from a diverse array of minerals and rocks, it is strongly weighted toward potential Mars analogs, such as basaltic volcanic products, soils derived from basaltic volcanics, various evaporite-rich soils, clays and clay soils, samples from

Table 1. Description of Mars surface samples analyzed by the Viking landers 1 and 2 XRFS instruments. Abbreviation: Acq, acquisition.

Samples	Local lander time (sol/hr:min)	Nature of material	Depth (cm)*	Grain size (mm)
VL1, S1		Drift deposit of aeolian sediment	4 to 6	Fines ≤ 2
Acq 1	8/10:46			
Acq 2	8/11:33			
VL1, S2		Surface concentration of pebble-sized fragments; possibly an aeolian lag deposit	0 to 4	2 to 12
Acq 1	34/10:19			
Acq 2	34/11:19			
VL1, S3				
Acq 1	40/10:39	Same deposit as for S2	2 to 5	2 to 12
Acq 2	40/12:19			
VL2, U1				
Acq 1	29/13:42	Duricrust	0 to 4	Fines ≤ 2, partly cemented
Acq 2	30/10:42			

*Sampling depth below the surface. †The dominant grain size of the delivered sample, inferred from imagery and the known mode of surface sampler operation. The silt size for S1 was derived from an estimate by the Viking physical properties team (*3*).

Table 2. Chemical composition of martian samples (as oxides).

Oxide	Composition (percent by weight)					
	S1	S3	U1	Difference S3 minus S1	Difference U1 minus S1	Estimated error*
SiO_2	44.7	43.9	42.8	−0.8	−1.9	± 5.3
Al_2O_3	5.7	5.5	†	−0.3	†	± 1.7
Fe_2O_3‡	18.2	18.7	20.3	+0.4	+2.1	±2.9
MgO	8.3	8.6	†	+0.3	†	± 4.2
CaO	5.6	5.6	5.0	0.0	−0.6	± 1.1
K_2O	0.1	0.1	0.0	0.0	−0.1	±0.1
TiO_2	0.8	0.8	1.0	0.0	+0.2	± 0.3
SO_3	7.7	9.5	6.5	+1.7	−1.2	± 1.3
Cl	0.7	0.9	0.6	+0.2	−0.1	±0.3
Total	91.8	93.6	†			± 7.8

*Applies specifically to S1 but also generally representative of S3 and U1. †Value not yet available. ‡Total Fe as Fe_2O_3.

Antarctic dry valleys, and dune sands.

Three library spectra (proportional counters 1, 2, and 4) per sample cover the light elements (Z = 12–13), the intermediate elements (Z = 14–22) and the heavier elements ($Z \geq 24$). Signature comparisons are particularly sensitive for the latter two groups. In several instances spectra from a particular terrestrial sample proved very similar to first martian results for one or two detectors, but in no case did spectra from all three detectors compare closely with those from the terrestrial sample. However, these signature comparisons yielded clear evidence that the Mars results were indicative of (i) a relatively mafic, iron-rich and aluminum-poor igneous rock, or the degradation products of such a rock type and (ii) at least a binary mixture of materials, such as mafic igneous products and a sulfur compound. These preliminary observations have been described (*6*).

After 22 sols, sufficient spectral data had been accumulated on S1 to permit calculations of numerical values for the elements. Interim conclusions can now be drawn on the quantitative analysis of S1, but these may be subject to change as further improvements are made in our knowledge of the concentrations of the lightest elements (*8*). Our discussion applies directly to the analysis of S1, although the similarities among all samples suggest a common petrogenesis. Table 2 lists the composition of S1, S3, and U1 (as oxides, following petrologic convention) with the oxide differences from S1 for S3 and U1.

Overview. Relatively high values of CaO, MgO, and Fe_2O_3 (and low K_2O and Al_2O_3) require that the sample be mafic or mafic-derived. Oxide summation to 92 to 93 percent precludes the presence of very substantial amounts of carbonates, nitrates, or other low atomic number ($Z \leq 11$) elements, such as Na (*9*). Results from gas chromatograph–mass spectrometry (GCMS) analyses (*10*) demonstrate the presence of H_2O, although the total amount is uncertain for several reasons, including the short duration (30 seconds) of heating to a maximum temperature of 500°C. Relatively high S in our results implies the presence of sulfates, but other S compounds cannot be excluded (*8*). The low content of Al_2O_3 and moderately high SiO_2 place strict constraints on any postulated igneous origin.

The admixture problem. Iron is present in more than one compound. Lander color imagery shows that some Fe must be in a highly oxidized form giving the prominent red-to-orange coloration to surface fines (*5*). We have concluded, however, that this oxide coating must be thin or discontinuous (or both) because low-energy x-ray emissions from light elements are detected (*8*). Fe must also be present in a magnetic fraction amounting to at least 3 percent by mass, probably as magnetite or maghemite (*11*). We conclude that the bulk of the Fe is probably present in a silicate phase or phases. Abundant SO_3, if present as sulfate or sulfates, may represent further admixture with a principally silicate sample. Mg, Ca, and possibly Fe and Na are candidate cations; Clark *et al.* (*8*) present arguments suggesting the presence of magnesium sulfate as a cementing agent in the fines. It seems reasonable to suppose that some of the balance unaccounted for in our analysis represents CO_2 bound as carbonate, possibly $CaCO_3$, and Na as NaCl.

Computer modeling. Analytical results have been modeled in three forms: (i) computer searches of best-fit matches to chemical analyses of thousands of samples of terrestrial, lunar, and meteoritic materials; (ii) normative mineral calculations of martian results; and (iii) mixture calculations to give best-fit proportions of selected ingredient rocks and minerals.

Computer searches yield rank-ordered matches of chemical analyses to martian results. By reducing the "fit" requirements, larger and larger lists of "matches" can be generated (with progressively poorer agreement). In general, the best fits include mafic and ultramafic rocks and minerals, some Fe-rich soils and montmorillonitic clays, lunar materials, and carbonaceous meteoritic materials. High Fe, low Al, and low trace element concentrations appear to constrain these fits. Most analyses in the search library are of well-defined mineral phases or single rocks; soils, however, are included. Some matches are computer-selected

Table 3. Normative mineral calculations, by a modification of the standard CIPW procedure.

Mineral	1*	2†	3‡
Quartz (SiO_2)	27	39	21
Feldspar	19	1	20
Or ($KAlSi_3O_8$)	(5)	(100)	(5)
An ($CaAl_2SiO_8$)	(95)		(95)
Pyroxene	30	12	47
Wo ($CaSiO_3$)	(16)		(14)
En ($MgSiO_3$)	(84)	(100)	(53)
Fo ($FeSiO_3$)			(33)
Hematite (Fe_2O_2)	22	15	
Magnetite (Fe_3O_4)		3	2
Ilmenite ($FeTiO_3$)		2	2
Sphene ($CaTiSiO_5$)	2		
Corundum (Al_2O_3)		6	
Kieserite ($MgSO_4$)		13	
Calcite ($CaCO_3$)		9	
Troilite (FeS)			8

*Norm of S1 analysis, assuming all Fe as Fe_2O_3 neglecting SO_3. †Modified norm of S1, assuming all SO_3 as $MgSO_4$, all CaO as $CaCO_3$, 10 percent of Fe as FeO. ‡Modified norm of hypothetical precursor composition for S1, assuming all S as FeS, 90 percent of oxide Fe as FeO.

Table 4. Chemical compositions of computer-modeled mixtures compared to S1.

Item	Composition (percent by weight)			
	Mixture 1	Mixture 2	Mixture 3	S1
		Oxide		
SiO_2	55.1	46.0	43.6	44.7
Al_2O_3	8.3	8.0	6.9	5.7
Fe_2O_3	19.5	19.0	18.4	18.2
MgO	10.1	9.6	9.0	8.3
CaO	2.4	2.0	5.6	5.6
K_2O	0.0	0.0	0.0	0.1
TiO_2	0.0	0.0	0.9	0.8
SO_3	0.0	9.4	7.3	7.7
		Mineral		
Nontronite	51	52	47	
Montmorillonite	19	21	17	
Saponite	30	13	15	
Kieserite		16	13	
Calcite			7	
Rutile			1	

because of particular features of the Mars analysis (for example, abundant S and low trace elements), and the remaining elemental correlations are poor. Other matches are close for all major elements except one or two. This is especially true for correlations with Fe-bearing montmorillonite clays, if one excludes the S in the Mars analysis. The search results reinforce our belief that the Mars sample should be considered a mixture.

The apparent compositional uniformity of the martian fines from such widely separated localities gives rise to a number of questions and interpretations. Does the bulk chemical composition (with suitable allowances for oxidation, carbonation, and hydration) of the fines represent the overall composition of the primary bedrock materials exposed over a similarly planet-scale area? One way to study this problem is to examine calculated norms to see whether they are compatible with plausible models for the composition of surface rocks on Mars. The detailed results of the norm calculations depend to a considerable degree on assumptions as to the roles of S, Na, and CO_2, and to the degree of Fe oxidation postulated for the primary rocks; but, in every case, the result is significantly quartz-normative and pyroxene-rich (Table 3).

The norm in the first column (Table 3) does not include the S in the analysis, and therefore represents only the silicate or oxide fraction of the material. All the Fe is assumed to be trivalent, in accordance with the apparently highly oxidized character of the surface materials. In the second column (Table 3) we show a norm modified by the assumptions (i) that all the S is present as $MgSO_4$ (or a hydrate such as kieserite, $MgSO_4 \cdot H_2O$), (ii) that all the CaO is present in calcite, and (iii) that a fraction (arbitrarily 10 percent) of the Fe is divalent. The resulting normative assemblage contains a very large proportion of free silica, which results from the removal of the bases CaO and MgO from a silicate fraction already low in bases relative to SiO_2. This depends in part on the plausibility of calculating all CaO as $CaCO_3$. We note that the sum of oxides (and Cl) determined for S1 is about 92 percent; the 8 percent discrepancy from 100 percent could be accounted for by 0.4 percent Na for NaCl, 4.4 percent CO_2 in $CaCO_3$, and about 3.2 percent H_2O as structural water in smectite, in general (although perhaps coincidental) agreement with the analog composition to be discussed below.

The third column (Table 3) shows the norm of a composition derived from S1 on the assumption that 90 percent of the Fe is divalent, and all the S is present as FeS. This would represent the protolith from which S1 might have been derived if the weathering process had been isochemical except with respect to oxidation (and hydration?). This seems somewhat unlikely, as it would be difficult to derive an igneous rock of this composition on a planetary scale by straightforward processes of igneous differentiation. One might imagine that fractional crystallization or partial melting of a parent material extremely low in alkalies and very low in alumina would yield such a product, but most models of planetary accretion would predict that Mars as a whole, as compared to Earth, was enriched in the volatile alkali elements compared. Furthermore, if a large part of the surface is underlain by siliceous, differentiated rocks, the large-scale igneous differentiation required would seem to entail a fairly advanced state of planetary differentiation, that is, a concentration of sialic material near the surface. In fact, the abundances of Ar isotopes in the atmosphere (*12*) suggest extremely limited outgassing from the body of the planet and a quite modest K content in that (presumably shallow) portion that has outgassed. Both inferences are consistent with a poorly differentiated planet. Furthermore, igneous processes on the moon, where alkalies are known to be deficient (at least relative to terrestrial experience), have not led to products like the quartz-anorthite-pyroxene aggregates (Table 3, column 3) that would correspond to the fines of Mars if they had resulted from "isochemical" weathering.

Table 5. Chemical composition (as oxides) of martian analog 6040 compared to range of Mars preferred values.

Oxide	Analog 6040	S1 range*
SiO_2	40.8	39.4 to 50.0
Al_2O_3	6.8	4.0 to 7.4
Fe_2O_3	15.5	15.3 to 21.1
MgO	5.1	4.1 to 12.5
CaO	7.4	4.5 to 6.7
Na_2O	0.5	
K_2O	0.15	0.0 to 0.2
TiO_2	0.84	0.5 to 1.1
CO_2	3.6	
SO_3	7.0	6.4 to 9.0
Cl	0.6	0.4 to 1.0
Total	88.3	

*From Table 2, S1 value ± estimated error.

Computer mixture modeling with the compositions of a number of mineralogic and petrologic ingredients can yield close chemical fits to analyses of the Mars surface. For example, the progressive improvement in fit, beginning with three end-members of the montmorillonite family (montmorillonite, nontronite, and saponite), obtained by adding kieserite ($MgSO_4 \cdot H_2O$), calcite ($CaCO_3$), and rutile (TiO_2) is shown in Table 4. An approximately equal (50 : 50) mixture of type 1 carbonaceous chondrite and average tholeiitic basalt yields a chemical composition which agrees, within error limits, with the S1 results for all oxides including SO_3, except for somewhat higher Al_2O_3. Other mixture models can be made with, for example, basaltic rock compositions with admixed montmorillonite family minerals, plus sulfates. The compositions of these mixes are, however, dominated by mineral assemblages that are characteristic of mafic igneous rocks. It appears that computer mixing of a number of generally mafic or montmorillonitic compositions (or both), plus sulfates and chlorides, will give fairly close fits to the Mars results.

Laboratory analog modeling. On the basis of the results of computer mixtures, an analog chemical material has been developed from nontronite (59.1 percent by weight), montmorillonite (21.7 percent), kieserite (11.8 percent), calcite (5.9 percent), halite (1 percent), and titanium dioxide (0.5 percent). The chemical composition of this mix is shown in Table 5 and spectra for proportional counters (PC) Nos. 1, 2, and 4 (measured in a flightlike laboratory spectrometer) are compared with Mars results in Fig. 1. It must be emphasized that we regard this mix as a *chemical*, but not necessarily a mineralogical, analog to the Mars fines.

Developing a chemical analog has emphasized some problems with respect to mineralogical interpretation of the Mars results. Among iron-rich smectites used as candidate components, Fe_2O_3 is usually in excess of 25 percent by weight and silica about 40 percent. Dilutions to reduce the iron commonly produce unrealistically low silica values compared to Mars results. The principal constituent of the derived mix is a nontronitic montmorillonite (*13*). The addition of bentonitic montmorillonite (*14*) provides the necessary alumina and serves to increase the silica content of the mix. Kieserite, calcite, and halite were selected to provide the magnesium, sulfur, calcium, and chlorine, but other compounds obviously could have been used to achieve the same result (for example, dolomite, gypsum, and antarcticite). The nontronitic montmorillonite contains insufficient titanium; this was supplemented with TiO_2 reagent powder. Terrestrial clay samples contain variable amounts of rutile, ilme-

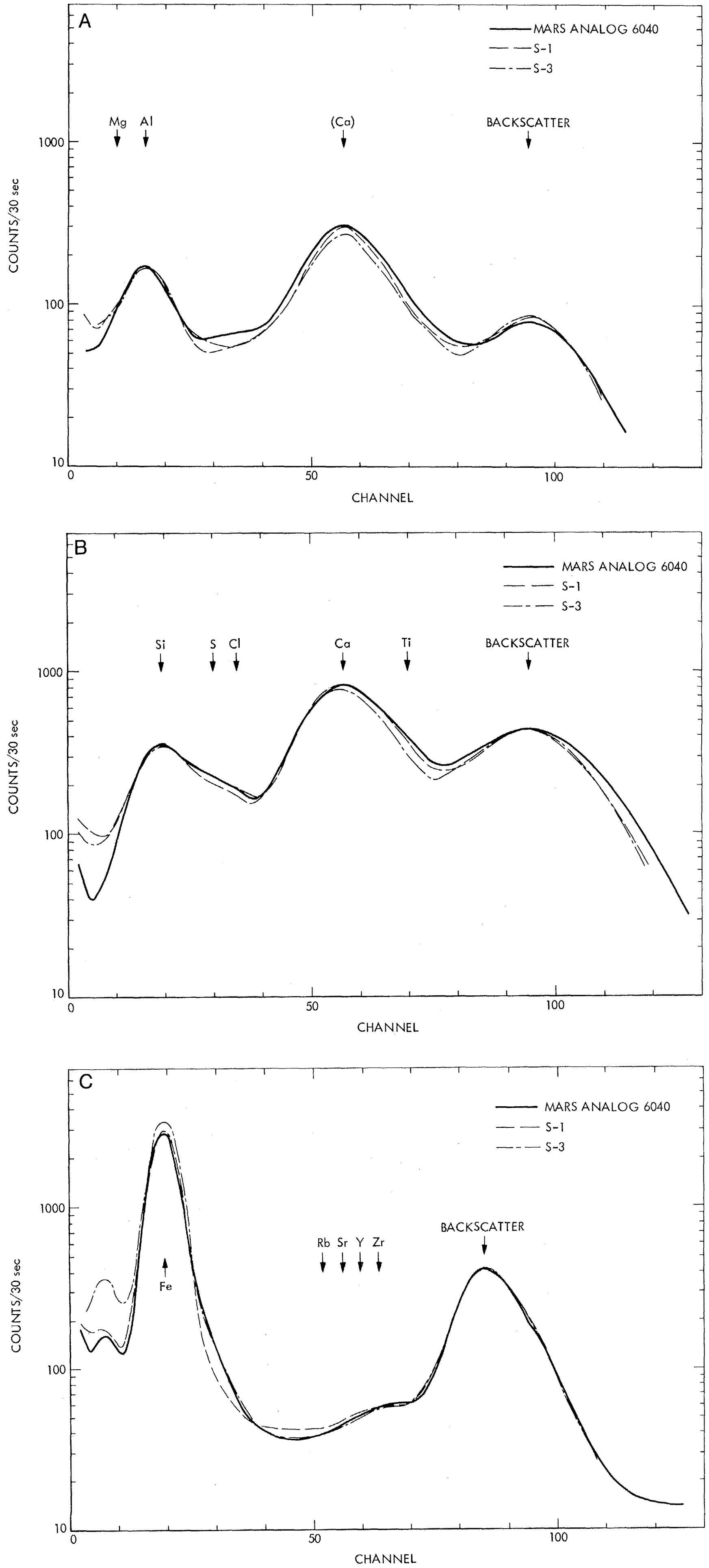

Fig. 1. Spectra of Mars analog material (our ref. 6040) compared to pooled spectra of S1 and S3 from Chryse Planitia. (A) The PC1 spectra for Mg and Al determinations (Ca is determined by PC2); (B) PC2 spectra for Si through Ti determinations; and (C) PC4 spectra for Fe and trace element determinations. Composition of analog is given in Table 5.

nite, anatase, or leucoxene as minor constituents.

A mineralogic-petrologic model. It seems likely that the Mars fines represent not the composition of primary rocks, but the products of some sort of chemical weathering process (*15*). In fact, as we have noted, a very large fraction of the overall major-element composition can be matched quite closely by a mixture of iron-rich clays characteristic of the terrestrial weathering and alteration of mafic igneous rocks. The color, albedo, and texture of certain fresh-appearing rock surfaces at the Viking landing sites (especially at VL1) are consistent with a mafic or ultramafic composition (*16*). While the present mineralogy of the fines obviously also includes "free" iron oxides, very likely sulfates, and probably carbonates and chlorides as well, the uniform composition at the two landing sites suggests that all the phases in the fines may be very intimately associated, quite possibly as extremely fine intergrowths (so that particle-to-particle compositional variation is slight). We might speculate that oxidation-dehydration of an iron-rich clay could lead to destabilization and destruction of the clay mineral structure, giving rise to just such a very fine grained aggregate. As a specific example, oxidation of a ferroan saponite could yield a mixture of nontronite, montmorillonite, and free iron oxides, with excess Mg and Ca (both "structural" and "exchangeable") available for fixation as sulfate (*17*). Ion exchange and absorption characteristics of the material could be significantly different from montmorillonite clays in a terrestrial environment. Derivation of the (relatively) less oxidized clay is even more speculative, but could have resulted from weathering processes in an ancient, more humid climate, or by direct interaction between mafic magma and extensive bodies of ice at or near the surface.

Genetic implications of mineralogic model. On Earth the formation of ferroan montmorillonites is associated with a ferromagnesian parent rock interacting with abundant water. Parent materials include basalt, basaltic glasses and palagonites (*18*), diabase (*19*), and ultramafic plutonic rocks (*19*). In the oceans, basaltic extrusions associated with ridge systems interact with oxygenated seawater to form nontronitic clays (*20*). Ferroan clays are a common, if not abundant, result of hydrothermal alteration of mafic rocks (*17*).

Prior to the Viking mission, Huguenin (*21*) advanced theoretical arguments and experimental evidence for photochemical surface reactions with the potential for forming clay minerals from pyrogenic silicates in an environment similar to that on the surface of Mars. His reaction mechanism requires only the very low partial pressure of O_2 and H_2O known to be present in the present atmosphere of Mars. So far as we are aware, however, no clay minerals have yet been produced in the laboratory by such reactions. Furthermore, photochemical processes on mineral surfaces may be effective mostly on the very fine dust grains that are carried to high levels in the atmosphere, in which case some other agency for prior comminution must be sought. The sequential combination of argillization at or near the surface, and photochemical desiccation or oxidation (or both) of the resulting dust in the high atmosphere is one hypothesis consistent with these conditions.

Our mineralogic model has, therefore, two major requirements for petrogenesis on Mars. (i) There must be exposed on the surface of Mars abundant mafic parent materials for clay formation and, conversely, there cannot be large, exposed source areas providing alkali-rich granitic materials. (ii) There must be (or must have been) sufficient water or ice on Mars to interact with mafic rock material to form ferroan clays.

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The Atmosphere of Mars: Detection of Krypton and Xenon

Abstract. *Krypton and xenon have been discovered in the martian atmosphere with the mass spectrometer on the second Viking lander. Krypton is more abundant than xenon. The relative abundances of the krypton isotopes appear normal, but the ratio of xenon-129 to xenon-132 is enhanced on Mars relative to the terrestrial value for this ratio. Some possible implications of these findings are discussed.*

We have previously reported the detection of ^{36}Ar and the establishment of upper limits on Ne, Kr, and Xe in the atmosphere of Mars, using the mass spectrometer on the first Viking lander (*1*). The upper limit on krypton was close to the value that would be predicted if the ^{36}Ar/Kr ratio on Mars were identical to that on Earth. It thus seemed important to try to increase the sensitivity of the experiment with the hope of actually detecting this important element.

The successful deployment of the second Viking lander (VL2) on Mars afforded us the opportunity to conduct this experiment. We had established from tests of the two instruments during the cruise from Earth to Mars that the background in the mass spectrometer on VL2 was much lower than that in the instrument on the first lander, making it a superior instrument for the detection of trace amounts of atmospheric gases. It was also clear from experience gained with the operation of VL1 that the best way to maintain this low instrumental background would be to perform the atmospheric analyses prior to any analyses of the martian soil. A delay in obtaining the first soil sample for our instrument with VL2 provided the opportunity to design an optimized enrichment sequence for detecting trace gases in the atmosphere.

The basic procedure has already been described (*1*). We use a chemical scrubber to remove over 99 percent of the CO and CO_2 in a given sample of martian atmosphere, admit a new sample, again remove CO_2, and repeat this procedure a preselected number of times to build up the concentration of trace constituents. The sample is exposed to a drying agent during each cycle to remove water gener-