wind to interfere with the observation, then one would expect to detect between one and three events per month with the Viking seismometer. To date, no seismic events positively identified as quakes have been detected during the 450 hours (19 days on Earth) of operation in the quiet period of the martian day. The probability that such an observation results when an average of one seismic event is expected per month is as high as 50 percent, under the assumption that events are randomly distributed with time. For a nonrandom distribution in time, the probability may be greater. Thus, from the limited amount of seismic data from a relatively short period of time, it is premature to draw any conclusions about the seismicity of Mars relative to that of Earth. A few anomalous events have occurred during the noisier part of the day, but more data must be accumulated.

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References and Notes

1. A complete description of the seismic experiment and instrumentation is given in D. L. Anderson, R. L. Kovach, G. V. Latham, F. Press, M. N. Toksöz, G. Sutton, *Icarus* **16**, 205 (1972). An identical seismometer on the Viking 1 lander was not uncaged because of an interface problem.
2. R. J. Phillips and R. S. Saunders, *J. Geophys. Res.* **80**, 2893 (1975).
3. Numerous engineers and scientists at the Langley Research Center, the Jet Propulsion Laboratory, Bendix Aerospace Systems Division, and Martin Marietta Aerospace contributed to the seismic experiment. Francis Lehner designed the sensor. Ken Anderson, Anton Dainty, and W. Underwood contributed to the planning and collection of data. Financial support was provided by NASA Viking project office. We thank the Viking meteorology team and S. Hess for access to the meteorology data. This is contribution No. 2837 of the Division of Geological and Planetary Sciences, California Institute of Technology.

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The Viking Carbon Assimilation Experiments: Interim Report

Abstract. *A synthesis of organic matter from atmospheric carbon monoxide or carbon dioxide, or both, appears to take place in the surface material of Mars at a low rate. The synthesis appears to be thermolabile and to be inhibited by moisture.*

The carbon assimilation, or pyrolytic release (PR), experiment measures the capacity of the martian surface material to convert atmospheric CO and CO_2, or both, into organic matter. The experiment is performed under conditions that, as far as possible, approximate the actual martian environment in order to ensure the survival of whatever indigenous life may be present. The operation of the experiment was described in a preliminary report on the results of the Viking mission (*1*) and in earlier papers (*2*).

Essentially, martian "soil" is exposed to martian atmosphere labeled with ^{14}CO and $^{14}CO_2$ and, simultaneously, to a light source that simulates the martian solar flux longwards of 320 nm. After 120 hours of exposure, the atmosphere is removed from the chamber and the temperature of the "soil" is brought to 625°C in order to pyrolyze any organic matter present. The volatile products of pyrolysis, together with unreacted ^{14}CO and $^{14}CO_2$ desorbed from the soil grains and chamber walls, are transferred to a column which separates them into two fractions: peak 1, containing CO, CO_2, and CH_4, if any; and peak 2, containing organic fragments larger than methane. The radioactivity of each peak is counted. The radioactivity of peak 2 represents organic matter synthesized from the labeled gases. Peak 2 also contains a small residue of $^{14}CO_2$ not eluted with peak 1. The size of this residue is known from laboratory tests made on flight-configured columns with either sterilized soils or empty chambers (Fig. 1).

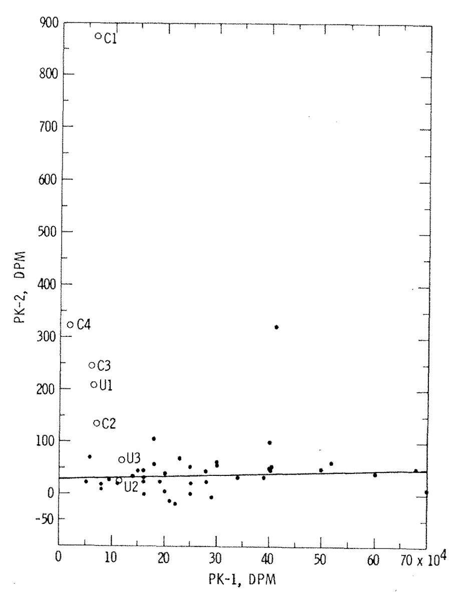

Fig. 1. Peak 2 plotted against peak 1 from laboratory tests with sterilized soils or no soils (closed circles), compared with the Mars results (open circles). The laboratory data are fitted by the regression line peak 2 = 28.8 + 2.84 × 10^{-5} peak 1, with peak heights in disintegrations per minute (DPM). The standard deviation of peak 2 is 27 DPM and that of the regression coefficient is 2.6 × 10^{-5}. The high peak 2 value at peak 1 = 41 × 10^5 DPM was not used in computing the regression line. For comparison with Table 1, DPM × 0.11 = count/min, and the symbols C1 to C4 correspond to Chryse 1 to 4, and U1 to U3 to Utopia 1 to 3.

The results of all experiments conducted on Mars from the start of operations until the beginning of the solar conjunction period are summarized in Fig. 1 and Table 1. (Counts per minute are convertible to disintegrations per minute by dividing by 0.11, the efficiency of the counters. All counts are corrected for background.) The first two experiments (Chryse 1 and Chryse 2) were described previously (*1*). Chryse 3 was intended to repeat Chryse 1 with a fresh sample from the same site. The result, 245 disintegrations per minute (27 count/min), is weakly positive. In seeking an explanation for the difference between Chryse 1 and Chryse 3, it was found that the two samples had different temperature histories. Chryse 3 was acquired at 1120 hours, Mars local time, when the surface temperature was some 60°C higher than at 0700 hours, when the Chryse 1 sample was acquired. Perhaps more important is the temperature increase (to 26°C) that occurred during the Chryse 3 incubation because of a programming error which deactivated the thermoelectric coolers.

Chryse 4 was another attempt to duplicate Chryse 1. Since the three incubation cells provided with the instrument had now been used, Chryse 4 was incubated in the chamber that had been used for Chryse 2; fresh surface material was added to that already in the chamber. The thermal control was satisfactory in this experiment, but the unusually low first peak indicates either an incomplete delivery of soil or of radioactive gases, or a leak from the incubation chamber. Peak 2 is, nevertheless, clearly positive; in fact, the ratio of peak 2 to peak 1 is higher for Chryse 4 than for any other sample.

The first Utopia sample was incubated in the dark. The result, weakly positive, suggests that illumination is beneficial but not essential for the reaction. Of par-

Table 1. Summary of carbon assimilation data from Mars. Column 2 indicates whether the lamp was on or off, whether or not water vapor was injected, and whether the soil sample was heat-sterilized (control) or not. Counting rates are given with their standard errors. See text for further details.

Experiment No.	Conditions	Incubation temperature (°C)	Peak 1 (count/min)	Peak 2 (count/min)
Chryse 1	Light, dry, active	17 ± 1	7,421 ± 59	96 ± 1.15
Chryse 2	Light, dry, control	15 ± 1	7,649 ± 60	15 ± 1.29
Chryse 3	Light, dry, active	13 to 26	6,713 ± 58	27 ± 0.98
Chryse 4	Light, dry, active	16 ± 2	2,040 ± 42	35 ± 1.6
Utopia 1	Dark, dry, active	15 ± 3	7,133 ± 58	23 ± 1.7
Utopia 2	Light, wet, active	18 ± 1.5	12,523 ± 76	2.8 ± 0.92
Utopia 3	Dark, dry, active	10 ± 2	13,014 ± 44	7.5 ± 2.5

ticular interest is the similarity between the first peaks of Utopia 1 and the first three Chryse experiments, a finding consistent with other Viking data which show the surface fines at the two landing sites to be very much alike. A slow leak from the radiation counter was detected in the course of this experiment. To forestall a loss of data should the leak worsen in later experiments, the counting program was changed so that peak 2 was read out in both 1-minute and 16-minute segments instead of 16-minute segments only. (Peak 1 is normally counted in 1-minute segments.)

The Utopia 2 sample was acquired from the same spot as Utopia 1. Approximately 80 μg of water vapor was injected at the start of the incubation from a reservoir connected to the incubation chamber through a valve and flow restrictor. The near-doubling of the first peak confirms that the injection was successful. Peak 2 was very low, although the lamp was on, and was the first clearly negative result obtained in these experiments.

The sample for Utopia 3 was acquired from under Notch Rock, and it was incubated in the dark for this reason. No water vapor was injected, but the high first peak suggests a higher water content for this sample than for surface samples. This inference has been confirmed by direct determination of the water content of a different sub-rock sample from the Viking 2 landing site (*3*). Again, a low second peak, indistinguishable from those found in sterile or blank laboratory runs, was obtained.

Discussion. The findings to date from the PR instruments on Mars suggest that an organic synthesis from atmospheric CO or CO_2 occurs in the martian surface material. The synthesis is weak compared to that found in biologically active terrestrial soils (*2*) and, unlike the latter, is inhibited by small amounts of water. It resembles a biological reaction in being thermolabile, although there is room for doubt that the synthesis was completely abolished in the Chryse 2 sample, which had been heated to 180°C for 3 hours. The second peak of Chryse 2 is higher than that expected for an inactive sample by 105 ± 30 disintegrations per minute; that is, the difference is more than three times its standard deviation (Fig. 1). It would seem likely that some synthesis was occurring in Chryse 2, but this is uncertain owing to the fact that no lower peak has as yet been obtained in a Chryse sample. It seems reasonably clear, nevertheless, that the major part of the reaction is thermolabile, even at moderate temperatures. A nonbiological explanation for this thermolability could be the evaporation of traces of H_2O, or possibly H_2O_2, required for the reaction. It is hoped that these and other ambiguities can be resolved by further experimentation on Mars and in the laboratory.

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References and Notes

1. H. P. Klein, N. H. Horowitz, G. V. Levin, V. I. Oyama, J. Lederberg, A. Rich, J. S. Hubbard, G. L. Hobby, P. A. Straat, B. J. Berdahl, G. C. Carle, F. S. Brown, R. D. Johnson, *Science* **194**, 99 (1976).
2. J. S. Hubbard, G. L. Hobby, N. H. Horowitz, P. J. Geiger, P. A. Morelli, *Appl. Microbiol.* **19**, 32 (1970); N. H. Horowitz, J. S. Hubbard, G. L. Hobby, *Icarus* **16**, 147 (1972); J. S. Hubbard, *Origins Life*, in press.
3. K. Biemann, personal communication.
4. We thank P. K. Cartier III and W. Ashley for invaluable assistance and the members of the Viking flight team for helpful discussions. This work was supported by NASA contracts NAS1-12311 (to N.H.H.) and NAS1-13422 (to J.S.H.) and NASA grants NGR-05-002-308 (to N.H.H.) and NSG-7069 (to J.S.H.).

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Viking Labeled Release Biology Experiment: Interim Results

Abstract. *This report summarizes all results of the labeled release life detection experiment conducted on Mars prior to conjunction. Tests at both landing sites provide remarkably similar evolution of radioactive gas upon addition of a radioactive nutrient to the Mars sample. The "active" agent in the Mars sample is stable to 18°C, but is substantially inactivated by heat treatment for 3 hours at 50°C and completely inactivated at 160°C, as would be anticipated if the active response were caused by microorganisms. Results from test and heat-sterilized control Mars samples are compared to those obtained from terrestrial soils and from a lunar sample. Possible nonbiological explanations of the Mars data are reviewed along with plans for resolution of the Mars data. Although such explanations of the labeled release data depend on ultraviolet irradiation, the labeled release response does not appear to depend on recent direct ultraviolet activation of surface material. Available facts do not yet permit a conclusion regarding the existence of life on Mars. Plans for conclusion of the experiment are discussed.*

Prior descriptions of the labeled release (LR) Mars life detection experiment have indicated its scientific concepts (*1, 2*) and instrumentation (*2, 3*) and have presented data obtained from terrestrial soils (*1, 2*). Recently, preliminary data from the first two Mars samples have been reported (*4*). Briefly, the radiorespirometric LR experiment seeks to detect metabolism with or without growth by monitoring the evolution of radioactive gas from a 0.5 cm^3 surface sample after the addition of 0.115 ml of a nutrient (*2, 4*) containing seven organic substrates (formate, glycolate, glycine, DL-alanine, DL-lactate) uniformly labeled with ^{14}C. Total oxidation of any one of the 17 carbon positions would produce gas containing approximately 15,000 counts per minute (cpm) (based on instrument counting efficiency), whereas total utilization of the nutrient would produce gas containing approximately 257,000 cpm if we assume complete conversion of all carbon atoms to gas.

Each of the two Viking LR instruments, one aboard each lander, has now conducted three analyses of Mars surface material ("soil") between the time of touchdown and the communication blackout period, which occurs dur-