will be used to do penetration tests, dig a deep trench, and better determine the particle size distribution.

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3. "Soil," as used here, refers to the relatively fine-grained, near-surface materials of Mars that have been deformed as a result of the landing of the spacecraft and which have been acquired by the collector head. Large objects (about 2 cm and larger) that obviously have large cohesion are termed rocks, fragments, and blocks. The word "sample" usually indicates that which was analyzed by the three active soil analysis experiments: biology, GCMS, and XRFS. The word "acquisition" usually refers to the process of obtaining soil.
4. "Sol" is defined as a martian day (24.62 hours). Sol 0 for Viking 1 was 20 July 1976, and sol 0 for Viking 2 was 3 September 1976.
5. L. V. Clark, NASA Langley Research Center, letter to I. W. Ramsey, Jr., Viking Project Office, 12 October 1971. Laboratory tests were carried out at the NASA Langley Research Center, Hampton, Virginia. Full-scale footpads were dropped in different soils which had been prepared with various densities and grain sizes. The velocities at impact were in the range of those encountered on Mars.
6. B. C. Clark, A. K. Baird, H. J. Rose, Jr., P. Toulmin III, K. Keil, A. J. Castro, W. C. Kelliher, C. D. Rowe, P. H. Evans, *Science* **194**, 1283 (1976).
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12. This information was provided by P. Toulmin, team leader of the inorganic chemistry team.
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14. If commands had not been sent to the lander, then on sol 9 the surface sampler would have attempted to sample at the preprogrammed site, ICL rock (rock 1).
15. The normal delivery sequence of the collector head is to vibrate the lid at 8 hertz with the collector head in the inverted position so that the fines pass through a 2-mm screen. The coarse fraction (≥ 2 mm) left in the collector head is then purged from the collector head if the lid is rotated back 180° and vibrated at 4 hertz. Inside the collector head are a series of teeth placed there to disaggregate clods and weakly cohesive material. The purge is usually done on the surface in view of the cameras.
16. The fifth-order harmonic fit was done by J. Mitchell of the meteorology team. The diurnal harmonic (zero and first-order harmonics) curve has its maximum at 154200 L.L.T.
17. The predicted surface temperature curve was furnished by H. H. Kieffer, team leader of the infrared thermal mapping experiment.
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19. We acknowledge the continuing aid and support given to the physical properties investigation team by the surface sampler team. The lander imaging team kindly furnished the pictures (more than 40) used in this report. We also thank P. Duffy for his assistance as the physical properties intern for the month of September. We thank L. Crafton for typing the manuscript several times and for attending to many administrative matters. We thank Dr. D. W. Collinson for his review of the manuscript and discussions of the physics of the soil properties of Mars. Dr. S. Liebes, Jr., provided the mensuration data for the rock pushes and nudges. We thank Dr. R. Goldstein for his support during sol 0 for VL1 and VL2 and throughout the mission. This work was supported by NASA contract NAS1-12705 to the University of Utah Research Institute, NASA order L-9714 to the U.S. Geological Survey, and NASA contract NAS1-10534 to TRW Systems, Inc.

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The Viking Seismic Experiment

Abstract. *A three-axis short-period seismometer is now operating on Mars in the Utopia Planitia region. The noise background correlates well with wind gusts. Although no quakes have been detected in the first 60 days of observation, it is premature to draw any conclusions about the seismicity of Mars. The instrument is expected to return data for at least 2 years.*

A three-axis short-period seismometer was delivered to the surface of Mars by Viking Lander 2 on 3 September 1976 and began to operate at 00:53:01 G.M.T. on 4 September shortly after noon, lander local time (L.L.T.) (*1*).

An important first step in characterizing the seismology of a planet is to determine the level and nature of the background noise. In the case of Earth, the main sources of background noise are the ocean and the atmosphere. These noises, termed microseisms, were studied extensively in the early days of terrestrial seismology but are no longer of much interest since they are now well understood. This "noise" in the case of a first seismic experiment on Mars actually contains useful micrometeorological information and must be well understood before seismic events can be confidently identified.

The ultimate goals of a seismic experiment on a planet are to determine the level of seismic activity and the internal structure. To achieve these requires a long-lived seismic network. Secondary goals are monitoring meteoroid impacts and establishing the nature of the background noise.

Although Mars has such well-developed tectonic features as fractures, grabens, and youthful-appearing volcanoes, there is no evidence for the kind of plate tectonics that is responsible for most of the seismic activity on Earth. On the other hand, large areas of Mars appear to be grossly out of hydrostatic equilibrium, as evidenced by gravity anomalies which are much more pronounced than those on Earth or the moon (*2*). Substantial stresses must exist in the interior in order to support the nonhydrostatic shape and, in particular, the young volcanic terrains. Although the level of seismic activity on the moon is much less than that on Earth, thousands of small quakes are recorded there each year by the Apollo seismic network. We would therefore expect that seismic events also occur on Mars, although their magnitude and frequency cannot be estimated.

Description of the Viking seismometer. The Viking seismometer package includes sensors, amplifiers, filters, automatic event detectors, data compactors, and temporary data storage. The instrument package, measuring 12 by 15 by 12 cm and weighing 2.2 kg, is located on the top of the lander's equipment bay near the attachment of leg 1. The nominal power consumption is 3.5 watts. The useful frequency range is 0.1 to 10 hertz with a minimum ground amplitude resolution of 2 nm at 3 hertz and 10 nm at 1 hertz. The maximum magnification is 218,000 at 3 hertz when the received signal is plotted at a scale of 0.436 mm per digital unit of seismometer output. The Viking instrument thus has a maximum sensitivity equivalent to that usable at a relatively quiet site on Earth (Fig. 1).

The sensors are three matched, orthogonally mounted (one vertical and two horizontal), inertial velocity transducers. In each sensor a mass-coil assembly is supported on two booms by two elastic hinges (Bendix Free-Flex) in such a way that the flat transducer coil is poised between the facing poles of two channel magnets arranged in series. Motion of the frame causes the transducer coil to move relative to the field of the magnets and generates a signal that is proportional to the relative velocity between the coil and magnets. The undamped natural frequency of each instrument is 4 hertz, the coefficient of damping is 0.6, and the generator constant is 177 volt m^{-1} sec^{-1}.

Each sensor is equipped with a calibration mechanism by which the mass may be magnetically deflected approximately

4 μm. The deflection and release of the mass in each direction produces a pair of doublets (Fig. 2d), from which the operation and characteristics of the instrument may be ascertained and which may also be used to determine the tilt of the seismometer package. A comparison of the Viking 2 seismometer calibration doublet with prelaunch calibration data gives a tilt of 9.5° ± 2.8° down at an azimuth of 278° ± 17° from north. This agrees with the tilt of the lander of 8.2° determined from the lander's inertial reference system.

Each sensor has an amplifier with an amplification selectable by Earth command within the range of 76 to 112 db in six increments. After amplification and analog multiplexing, the seismic signals are digitized at the rate of 121 samples per second per axis. Subsequent digital processing of the data includes filtering, averaging, compression, event detection, and buffer memory storage. These functions, as well as digital multiplexing, command decoding, timing, and control are implemented in custom, large-scale integrated (LSI) circuitry.

Modes of operation. To maximize the information return within a limited data telemetering capacity, a data compaction scheme with three data processing modes was built into the seismometer. The three modes of operation—high-data-rate, event, and normal modes—are controlled by a command sequence that is issued and updated from Earth. The high-data-rate mode samples each sensor at 20.2 samples per second. Before sampling, data is digitally filtered with a low-pass filter with cutoff frequencies of 0.5, 1.0, 2.0, and 4.0 hertz that can be selected by commands from Earth. Each data word consists of seven bits plus a sign bit. Although this mode gives full characterization of seismic signals, it has been used for an average of less than 1 hour per day because of the limitations of total data bits allotted to the seismic experiment.

The event mode is the most commonly used mode of operation. The envelope of the seismic signal, rather than the signal itself, is sampled at the rate of 1.01 samples per second per axis. To produce the envelope, the absolute value of the seismic signal is smoothed by passing it through the digital filter operating at the 0.5-hertz cutoff frequency. Simultaneously, a count of the positive axis crossings (a measure of the dominant frequency) is sampled at the same rate. This combination of sampling the envelope (7-bit word) and axis crossing (5-bit word) results in a 12.3 to 1 reduction in the data required to encode the original signal. This mode may be initiated either by command or automatically by an event detector in the seismometer electronic package. The trigger level of the event detector is a multiple of the long-term (1081 seconds) averaged microseism level that can be selected by commands from Earth.

The normal mode is the lowest data-rate mode, operating at 4.04 samples per minute per channel. Its purpose is to monitor the average level and spectral content of the microseismic background. A form of "comb filtering" takes place, in which the digital low-pass filter is used in conjunction with the frequency response of the inertial sensor. The absolute values of the data are then passed through a low-pass filter to obtain the 12.67-second running average of the microseismic level. The digital low-pass filter may be fixed or automatically stepped through each cutoff frequency, at the rate of 2 minutes for each frequency.

The instrument produces 6.17×10^3 bit/hour in the normal (or background monitoring) mode, 1.47×10^5 bit/hour in the event mode, and 1.77×10^6 bit/hour when operating in the high-data-rate mode. Examples of seismic data obtained under the three different modes of operation are shown in Fig. 2.

Summary of operations. Before the landing, the computer aboard the lander was loaded with a seismometer sequence that had been designed to survey the ambient seismic environment. After landing and uncaging the seismometer, this sequence was initiated.

The ambient seismic background was lower than expected. Consequently, the seismometer was commanded to maximum gain on day 4, and the operational sequence was updated to provide long-term seismic monitoring. Initially, the seismometer was commanded into the normal mode at times when mechanical activity was scheduled on the lander. On days 9, 19, and 29, the commands for selected activities were changed to provide event-mode data in order to acquire signatures and lander vibrational characteristics as well as to provide diagnostic information on lander operation.

The operation in the event and high-data-rate modes has been maximized since day 10, and normal-mode operations have only been used to fill in when necessary. The periods of high-data-rate operations have been moved throughout the day, including during the windy periods, in order to examine in detail some selected seismic signatures.

As of 1 November 1976, the following total recording times were compiled: event mode, 982 hours and high-data-rate mode, 39 hours; 99 percent of these times were accumulated at maximum gain. Approximately 450 hours of data

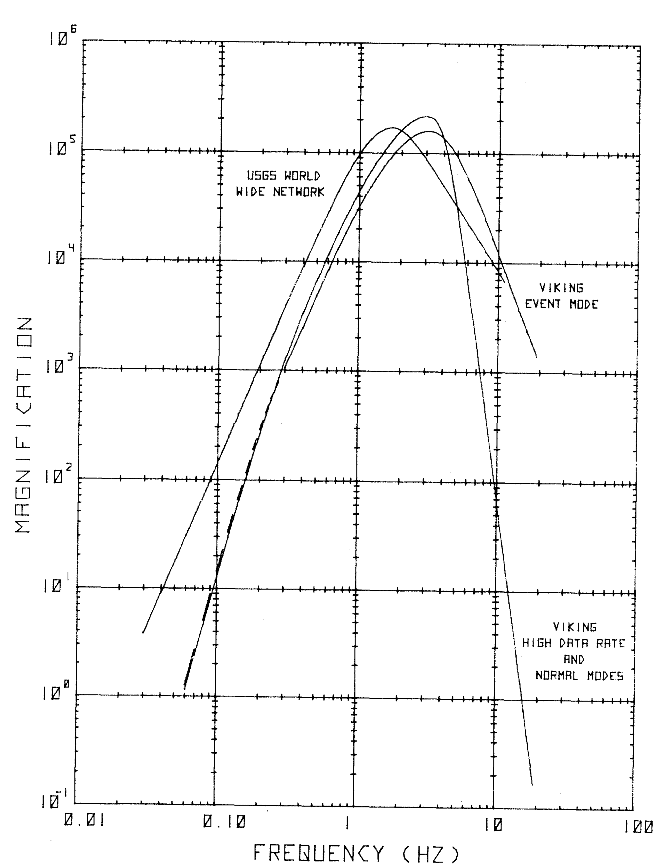

Fig. 1. Magnification of the Viking seismograph in each of the operating modes. The magnifications are based on assumption that the digitized data are plotted at scales of 0.44, 0.51, and 0.76 mm/DU for high-data-rate, event, and normal modes, respectively. A typical U.S. Geological Survey short-period instrument used in the worldwide seismic network is shown as a comparison.

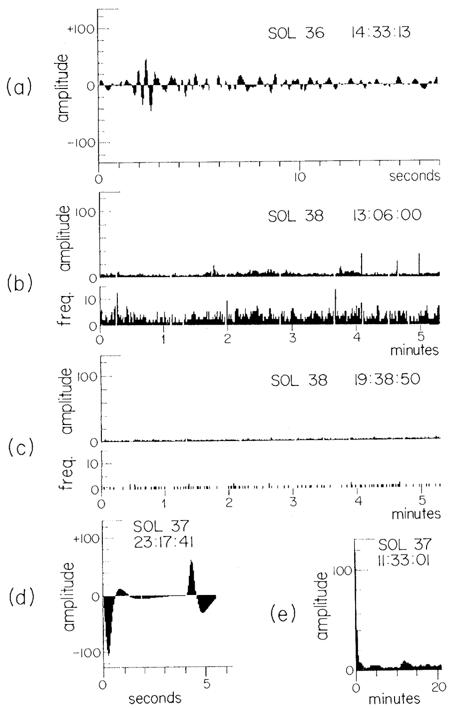

Fig. 2. Representative samples of seismology data. Only the ordinate is shown here. (a) High-data-rate trace, probably wind noise. (b) Event-mode trace of wind noise (daytime). (c) Event mode in late evening. (d) Typical calibration step. (e) Typical normal-mode trace.

have been obtained at high gain during quiet (low wind) periods, when detection of quakes is least ambiguous. The instrument is normally calibrated each day.

Wind-generated "noise." As expected, wind blowing on the lander is the main source of external noise, and there is a high positive correlation of the background noise level recorded by the seismometer with the wind speeds measured by the meteorology instrument.

The quietest recording interval of each day is from about 1800 hours (2 hours before sunset) each afternoon to about 0400 hours (shortly before sunrise) the following morning. During this period of time the wind speed drops to less than 1 to 2 m/sec, and the seismic noise background level falls to between 1 and 2 digital units (DU). (In the event mode at maximum sensitivity, 1 DU corresponds to 2 nm of instrument displacement at 3 hertz.) An increase in background noise level to 2 to 3 DU occurs around martian sunrise.

The "average" wind speed is usually higher in the morning than in the afternoon, but individual wind gusts have higher peak speeds in the afternoon. This is reflected in the seismic signal, which shows relatively steady vibration of the lander in the morning and irregular, high activity in the afternoon. The period of gustiness and highest seismic background (with intermittent peaks ranging from 10 to 40 DU), is between 1300 and 1700 hours. Noise bursts are typically 1 to 3 minutes in duration and separated by 10 to 50 minutes. The seismic background is relatively low between noise bursts, which indicates that little energy is being transferred into the ground by the wind and that the main effect on the seismometer is by direct wind-induced vibrations of the lander.

An example of the correlation between seismic noise activity and a wind gust is shown in Fig. 3. In this case a 100-DU signal was observed on all three components of the seismometer, which was recording in the event mode. This signal, observed on day 36 (12 October 1976), correlates with a 13 m/sec wind speed peak. The amplitude of this signal is 340 nm at an average signal frequency of 5 hertz.

Several distinct seismic signals that do not appear to be particularly correlated with wind speed peaks have been observed during the martian day. These signals could have been generated by wind gusts, which occur between meteorological observations (every 2, 4, or 8 seconds). Such distinct signals have not yet been recorded during the martian night, when background noise is low and no wind gusts occur.

Most of the wind gusts are less than 10 m/sec and generate seismic signals of less than 12 DU in the event mode. An approximately linear correlation exists between peak winds and peak seismic noise; noise is about 2 DU for wind speeds of 4 m/sec and 20 DU for 12 m/sec winds. The threshold of wind detectability of the seismometer appears to be about 3 m/sec. The range of the seismometer is up to 127 DU so that even the larger gusts far from saturate the instrument. In the high-data-rate mode of operation, where no averaging is involved, the correlation is 10 DU at 4 m/sec ranging to 110 DU at 11 m/sec. The total scatter in both correlations is about 2 m/sec in wind speed. A variation with wind direction is also observed.

Lander noise. The seismometer is located on top of the lander, and is thus expected to sense most mechanical activity aboard the lander. The following lander activities have been identified: tape-recorder motions, surface sampler activities, camera motions, S-band antenna motions, and x-ray sample dumps. There are also impulsive events, occurring throughout the day but having activity peaks at around 1300 and 2100 hours L.L.T. There are approximately 25 of these events each day, and they are suspected of being thermal or mechanical pops.

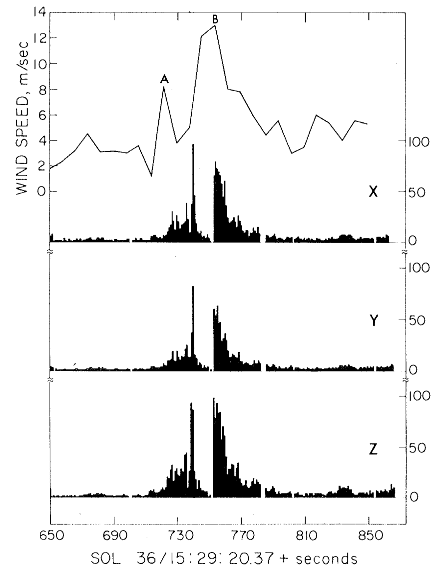

Fig. 3. Representative sample of the correlation between seismic and wind data. The wind data should be displaced by + 9 seconds for correct alignment. Between gusts *A* and *B*, the wind direction changed from southwest to north. The terms *X*, *Y*, and *Z* designate vertical and two horizontal components, respectively. The orientation of the horizontal components are 329° (*Y*) and 239° (*Z*), measured clockwise from north.

There is a lander body resonance identified at 8 ± 1 hertz, which is excited by strong vibrations induced by lander activities. Higher-frequency resonances are known to exist, but they are beyond the range of detectability of the seismometer. There appear to be some minor resonances between 1 and 4 hertz, but their sources have not yet been identified.

Detection capability and results to date. The seismic noise background on Mars has been relatively low except during limited periods of high wind gusts and spacecraft activity. At the present, the seismometer runs at maximum gain at all times. From the instrument sensitivity and results of terrestrial tests, we estimate that the Viking seismometer should detect quakes with body-wave magnitudes of $m_b = 2.5$ at 100 km, $m_b = 3$ at 200 km, $m_b = 5$ at 900 km, and $m_b = 6$ up to a distance of 90° (5300 km), provided that the attenuation characteristics are similar in both planets. At greater distances a possible core may create a shadow zone and detection may become more difficult. It is reasonable to assume, however, that a quake with an equivalent magnitude of about 6.5 to 7.0 can be detected anywhere on the planet.

If the seismicity per unit area of Mars were the same as that of Earth, if quakes were distributed uniformly over the surface of the planet and they occurred randomly with time, and if there were no 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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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).

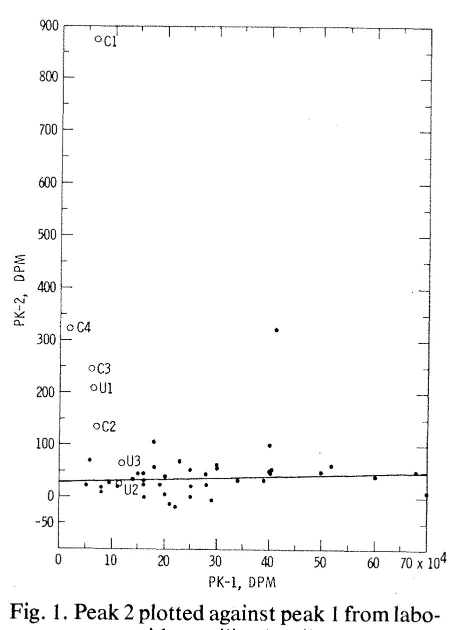

Fig. 1. Peak 2 plotted against peak 1 from laboratory tests with sterilized soils or no soils (closed circles), compared with the Mars results (open circles). The laboratory data are fitted by the regression line peak $2 = 28.8 + 2.84 \times 10^{-5}$ peak 1, with peak heights in disintegrations per minute (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 $1 = 41 \times 10^5$ DPM was not used in computing the regression line. For comparison with Table 1, DPM $\times$ 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-