eolian or volcanic materials, forming younger intercrater plains. If mantles are absent in these areas, however, valleys are observed.

The distribution of the valleys has an obvious bearing on the question of their age. Valley systems have not been detected on plains material younger than Lunae Planum (7, 15). This has been corroborated in recent mapping by Carr (17). By implication, the martian valley systems must be older than both Lunae Planum and the intercrater plains.

Another way of determining relative age is by counting the number of impact craters in the valleys and comparing the size-frequency distribution to that of both the immediately surrounding terrain and other types of terrain (Fig. 4). There are two main observations. First, the valleys have high densities of superimposed craters, implying very long exposure. Second, there is no significant difference between the density of craters in the valleys and in the surrounding terrain, implying that the valleys are roughly as old as the ancient surrounding terrain. Thus, several lines of evidence suggest that the valley networks were formed early in the history of Mars.

Martian valley systems are diverse and can be classified by network pattern and morphology. The diversity is most likely the result of several processes acting in variable structural and lithologic regimes. Dendritic patterns, prevalent on the earth, are absent on Mars; diffuse patterns, inefficient at filling space, predominate. Valley interiors display steep, clifflike walls, flat floors (without direct evidence for erosive fluid flow), and amphitheater terminations, suggesting basal sapping. Networks of these valleys are widely distributed in heavily cratered terrain, including south polar areas, although the visibility of valleys may vary due to widespread superposition of eolian debris mantles and ubiquitous younger intercrater lava flows. Size-frequency distributions of craters in the valleys indicate that there is no significant difference between the age of the valleys and that of the surrounding ancient terrain. This, combined with the lack of valleys in terrain younger than Lunae Planum and their partially obliterated appearance, suggests that valley formation processes have not been active on Mars for billions of years. It is concluded that valleys were formed on Mars during an ancient epoch by erosional processes involving not rainfall but the movement of groundwater and its participation as a liquid or a solid in the undermining of less competent strata, causing progressive headward collapse (18). These processes, combined with modification by impact and eolian processes, have produced the degraded valleys seen on Mars today.

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Solar Neutrino Production of Long-Lived Isotopes and Secular Variations in the Sun

Abstract. *Long-lived isotopes produced in the earth's crust by solar neutrinos may provide a method of probing secular variations in the rate of energy production in the sun's core. Only one isotope, calcium-41, appears to be suitable from the dual standpoints of reliable nuclear physics and manageable backgrounds. The proposed measurement also may be interesting in view of recent evidence for neutrino oscillations.*

Solar neutrinos provide a unique opportunity for probing the fusion reactions that occur deep in the solar core (1) and for testing properties of the neutrino over distance scales not attainable in terrestrial laboratories. To date, we have only a single measurement of a portion of that neutrino flux, from the ^{37}Cl experiment of Davis and co-workers (2). The result, 2.2 ± 0.4 SNU (3) [1 solar neutrino unit (SNU) = 10^{-36} capture per target atom per second], is quite surprising in view of the most recent prediction for the standard solar and weak interaction models, 7.0 SNU (4). It is not clear whether this discrepancy is due to a misunderstanding of solar physics, of the neutrino, or, less likely, of the chemistry of the ^{37}Cl detector.

The standard solar model predicts that approximately 70 percent of the expected ^{37}Cl rate is due to capture of the high-energy neutrinos produced in the β decay of ^{8}B (see Table 1). The production of these neutrinos depends critically on the central temperature of the sun. Davis's results have thus stimulated the development of a number of nonstandard models in which this temperature, and consequently the ^{8}B neutrino flux, are reduced (5). Probably the most popular such models have been those with a low heavy-element abundance, and correspondingly diminished opacity, in the solar core. However, the fine structure recently observed in the 5-minute solar oscillation (6) has been attributed to a higher velocity of sound than would occur in such models.

Another class of nonstandard solar

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Table 1. Solar neutrino sources. The principal solar neutrino-producing reactions are given along with the maximum neutrino energies. As the state in ^8Be populated by the β decay of ^8B is a broad resonance, the end point given for reaction 2 is with respect to the midpoint of that resonance.

Reaction[a]	Maximum neutrino energy (MeV)
(1) $p + p \rightarrow {}^2H + e^+ + \nu$	0.42
(2) ${}^8B \rightarrow {}^8Be^* + e^+ + \nu$	14.02
(3) ${}^{13}N \rightarrow {}^{13}C + e^+ + \nu$	1.20
(4) ${}^{15}O \rightarrow {}^{15}N + e^+ + \nu$	1.73
(5) $p + e^- + p \rightarrow {}^2H + \nu$	1.44
(6) ${}^7Be + e^- \rightarrow {}^7Li + \nu$	0.86 (89.6 %)
	0.38 (10.4 %)

[a]Reactions 5 and 6 produce neutrinos with discrete energies, while reactions 1 to 4 yield continuous spectra.

models consists of those in which periodic variations in the sun's energy production could occur. Because of the long response time for the surface luminosity to reflect changes in the solar core, the present luminosity then need not be correlated with the observed neutrino flux. In models in which periodic mixing of ^3He into the solar core occurs, the ^8B neutrino luminosity could turn off suddenly for periods $\geqq 4 \times 10^6$ years (*7*). The possibility that there are secular variations in the sun's energy production on time scales of 10^3 to 10^8 years is now suggested by a variety of circumstantial evidence on global climatic changes, on variations in the solar wind, and on possible changes in the solar radius (*8*).

The solar neutrino production of long-lived isotopes (half-life = 10^5 to $10^{7.5}$ years) in the earth's crust provides one possibility for measuring such variations (*3*) (the upper limit on the lifetime eliminates isotopes for which primordial production is a problem). Since large fluctuations in solar energy production are excluded by the continuity of the earth's biology and geology, a monitor sensitive to subtle changes in the sun's central temperature is needed. We believe that isotope production by the highly temperature-dependent ^8B neutrino flux may be our best tool for probing the sun's past. We have undertaken an investigation of rare isotopes that could be produced by these neutrinos.

There are three principal obstacles to making useful geologic measurements of this type. The first is the difficulty of reliably estimating the neutrino-induced nuclear cross section. Since the ^8B neutrinos range in energy from 0 to 14 MeV, a number of transitions (often including the model-independent Fermi strength) can be important. The second obstacle is the presence of other mechanisms for producing the desired isotope. Background reactions are induced both by cosmic-ray muons and by natural radioactivity. The third is the difficulty of measuring the minute concentrations of the isotope. The chemistry difficulties are exacerbated in the present case by the relatively weak flux of the high-energy neutrinos. Typically, isotope production by ^8B neutrinos may be 100 times slower than that possible with the more plentiful low-energy neutrinos from the proton-proton reaction.

We believe that one isotope, ^{41}Ca, offers the best hope for making a measurement of the past ^8B solar neutrino luminosity. The reaction

$$ {}^{41}K + \nu \rightarrow {}^{41}Ca + e^- \quad (1) $$

has a nominal threshold of 0.42 MeV. However, the weakness of the ground-state transition [$\log ft = 10.7$ (*9*)] and the absence of low-lying excited states in ^{41}Ca yield an effective threshold of 2.36 MeV. Thus reaction 1 is sensitive only to ^8B neutrinos. The natural abundance of ^{41}K is 6.73 percent and the lifetime of ^{41}Ca is $(1.03 \pm 0.04) \times 10^5$ years. Neither of these is particularly attractive in terms of producing favorable concentrations of ^{41}Ca. Moreover, although several solar model calculations have postulated sudden mixing phenomena in the solar core (*7*), a detailed mechanism for turning off the sun's high-energy neutrino production within a period of 10^5 years is lacking. Thus, although we know of no compelling theoretical arguments excluding core variations on this time scale, the motivation for attempting a ^{41}Ca measurement would be strengthened if the results were also of interest within the context of a steady-state sun.

That motivation is provided in part by the simplicity of the nuclear physics of reaction 1. A measurement of the delayed proton spectrum following the analog β^+ decay of ^{41}Ti (*10*) allows us to make a model-independent calculation of the neutrino capture cross section, σ. Using $\log ft$ values from (*10*), adjusted slightly to reflect newer mass assignments (*9*), we find

$$ \sigma = (1.45 \pm 0.05) \times 10^{-42}\ cm^2 \quad (2) $$

The error reflects some uncertainty in the experimental profile for the ^8Be 2.94-MeV resonance populated in the solar β decay of ^8B and in the energies of the ^{41}Ca states which we associate with the levels in ^{41}Sc. We employed the Coulomb distortion corrections of (*11*). For a ^8B neutrino flux of $5.3 \times 10^{-6}\ cm^{-2}\ sec^{-1}$, we obtain a capture rate for ^{41}K of 7.7 ± 0.3 SNU. The reliability of this

Table 2. Background constraints. A summary is given of the constraints that follow from requiring background production of ^{41}Ca to be below the 10 percent (0.77 SNU) level. Concentrations of natural argon and calcium in parts per million are denoted by Ar and Ca. Concentrations of uranium and thorium in parts per billion are given by U and Th. The fraction of natural potassium in the ore is K.

Reaction	Constraint
(1) ${}^{38}Ar(\alpha,n){}^{41}Ca$	$U \times Ar < 2.1 \times 10^4$ K
	$Th \times Ar < 2.2 \times 10^4$ K
(2) ${}^{40}Ca(n,\gamma){}^{41}Ca$[a]	
KCl	$U \times Ca < 1200$
KClNaCl	$U \times Ca < 740$
$KAl(SiO_3)_2$	$U \times Ca < 15$
(3) (α,p) followed by ${}^{41}K(p,n){}^{41}Ca$	$U < 2.2$[b]
	$Th < 3.5$[c]

[a]Weaker constraint provided by ${}^{42}Ca(n,2n){}^{41}Ca$, mass defect $Q = -11.48$ MeV. [b]Weaker constraints provided by (α,n) followed by (n,p) followed by ${}^{41}K(p,n){}^{41}Ca$; by fission neutron (n,p) followed by ${}^{41}K(p,n){}^{41}Ca$; and by ${}^{39}K(\alpha,d){}^{41}Ca$, $Q = -9.38$ MeV, induced by long-range α groups. [c]Weaker constraints provided by (α,n) followed by (n,p) followed by ${}^{41}K(p,n){}^{41}Ca$, and by ${}^{39}K(\alpha,d){}^{41}Ca$ induced by long-range α groups.

number, coupled with the exclusive sensitivity of reaction 1 to ^8B neutrinos, permits an unambiguous theoretical interpretation of any ^{41}Ca experimental results.

We have completed a careful study of the backgrounds that compete with solar neutrinos in producing ^{41}Ca. (The details of this and of our cross-section calculation will be published elsewhere.) To reduce ^{41}Ca production induced by cosmic-ray muons to the 10 percent level, 0.77 SNU, the potassium source must be shielded by the equivalent of 3660 m of water. At a typical covering density of 2.4 g/cm^3, this corresponds to a depth of 1500 m. Constraints on ^{41}Ca production by fission neutrons and α-particles are given in Table 2. The principal radioactivity backgrounds are due to $^{40}Ca(n,\gamma)$ and to (α,p) followed by $^{41}K(p,n)$. The α-induced backgrounds will fall below the 10 percent level if the uranium and thorium contents of the potassium ore are less than 2.2 and 3.5 ppb, respectively. The thermal neutron capture rate is sensitive to the ore composition, being much lower if a good neutron absorber, such as Cl, is present. Results for selected potassium compounds are given in Table 2 (*12*). We also must require that the potassium source be $\gtrsim 3 \times 10^6$ years old to ensure that the residual concentration of surface-produced (by neutron bombardment) ^{41}Ca is below the 10 percent background level.

There are several deep marine deposits of potassium that could satisfy these background criteria. One of particular interest, since it is worked commercially, is the KCl deposit near Regina, Saskatchewan. The depth of the deposit is 1600 m and the calcium content is less than 0.1 percent. A significant portion of that calcium is contained in clay seams that can be separated from the KCl. The thorium and uranium contents have not yet been measured, but values on the order of 1 ppb have been found for similar deposits (*13*).

Some aspects of the chemistry are also favorable. Very elegant accelerator mass analysis techniques, in which ^{41}Ca atoms are fully stripped, can be applied. We anticipate that a discrimination of 10^{16} with 1 percent efficiency may be attainable (*14*), although this has not yet been established experimentally. For a marine deposit we may need to deal with up to 1 kg of natural calcium extracted from 1.3 tons of KCl in order to obtain the 10^4 atoms of ^{41}Ca needed for such an analysis. Since optimal sample sizes for accelerator mass analysis are 10 to 15 mg, a preconcentration of ^{41}Ca relative to natural calcium by 10^5 is required, and the initial quantity of calcium must be increased in proportion to the inverse of the efficiency of this preconcentration. This may be the major experimental difficulty. Since the calcium concentration in marine deposits may be far from homogeneous, careful selection of salt samples may be important. We are currently analyzing samples from several layers of the Regina deposit and are also exploring possibilities for designing crude, high-amperage mass separators that might be capable of processing a 1-kg sample. We believe that an order of magnitude improvement in the amperages that can be achieved with present technology is required. Alternatively, suitable non-marine sources of potassium might be found that are significantly more free of calcium, which would simplify the requirements for preconcentration. We would welcome any suggestions on these points.

Although geologic experiments sensitive to other components of the solar neutrino flux have been proposed (*15*), we believe that the experiment discussed here is the first one to be viable from the standpoints of both backgrounds (*3*) and the reliability of the nuclear cross section. We also believe that production of ^{41}Ca may be the only tool nature has provided for probing the long-term ^{8}B solar neutrino luminosity, and thus for probing small variations in the solar core that may have occurred during the past 10^5 years.

Finally, in view of tentative laboratory evidence for neutrino oscillations (*16*) and for a massive electron neutrino (*17*), one other aspect of the proposed experiment should be stressed. Although the reported neutrino mixing is not sufficient to resolve the large discrepancy between theory and Davis's experiment, the possibility that additional mixing mechanisms could operate over larger oscillation lengths is open. Solar neutrinos thus present a unique opportunity for extending present terrestrial experiments. The ^{37}Cl results are ambiguous in that they can be explained by the absence of high-energy ^{8}B neutrinos, predicted by various nonstandard solar models, or by an overall reduction of all components of the solar neutrino flux, which could result from mixing of several neutrino species. Since the ^{41}Ca experiment will test only ^{8}B neutrinos, this measurement, in combination with Davis's results, could help distinguish between these two possibilities. Independent of the question of secular variations in the sun's core, this provides an important motivation for mounting new solar neutrino experiments.

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Anesthetics as Teratogens: Nitrous Oxide Is Fetotoxic, Xenon Is Not

Abstract. *Exposure of pregnant rats to the anesthetic nitrous oxide on the ninth day of gestation causes fetal resorption, skeletal anomalies, and macroscopic lesions including encephalocele, anophthalmia, microphthalmia, and gastroschisis. The inert gas xenon, which has anesthetic properties similar to those of nitrous oxide, does not cause teratogenic effects under the same experimental conditions.*

There has been increasing concern that inhalation anesthetics may cause teratogenic and other harmful effects. Physicians and nurses who work in operating rooms polluted by waste anesthetic gases have a higher incidence of spontaneous abortions and fetal malformations than control groups (*1*). However, other factors, including differences in occupational stress and working conditions, may be implicated (*2*). Such factors may be excluded from studies of dentists and their assistants, because the dental population can readily be divided into groups that differ only in the use of inhalation anesthetics for analgesia. A recent survey of dental health professionals in the United States (*3*) strongly suggests that

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