heat balance and the direction of the change in obliquity. It has been
argued [2] that variations in the obliquity of Mars cause substantial
departures from the current climatological values of the surface
pressure and the amount of CO₂ stored in both the planetary regolith
and polar caps.

Haberle et al. [3] have constructed a heat balance model based
on the work of Gierasch and Toon [4] that simulates the evolution
of CO₂ on Mars from the end of the heavy bombardment to the
current time. The model partitions CO₂ between its various reser-
voirs based upon predictions for polar, equatorial, and global-mean
surface temperatures. The exchangeable reservoirs are atmosphere,
planetary regolith, and polar caps. The model also loses CO₂
irretrievably to a carbonate rock reservoir via aqueous chemical
weathering according to the method of Pollack et al. [5]. The solar
insolation is affected in time, however, only by varying solar lumi-
osity; the relative distribution between equatorial and polar re-

gions is invariant. Obliquity variation was avoided within the model
by assuming that, throughout the 7.6-m.y. timestep, the current
obliquity, θ = 25.2°, sufficiently represents an average obliquity. It
may be important, however, to explicitly study the climatological
effects of obliquity variation since the size of the CO₂ reservoirs can
be significantly changed, drastically affecting the temperature struc-
ture through feedbacks from the greenhouse effect and the dynamic
transfer of equatorial heat into polar regions.

In this new work we have modified the Haberle et al. model [3]
to incorporate variable obliquity by allowing the polar and equa-

torial insolation to become functions of obliquity, which we assume
to vary sinusoidally in time. As obliquity varies in the model, there

can be discontinuities in the time evolution of the model equilibrium
values for surface pressure, regolith, and polar cap storage. The time
constant, τ, for the regolith to find equilibrium with the climate is
estimated [6], depending on the depth, thermal conductivity, and
porosity of the regolith, between 10⁴ and 10⁶ yr. Thus, using 2000-
year timesteps to move smoothly through the 0.125-m.y. obliquity
cycles, we have an atmosphere/regolith system that cannot be as-
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Model integration begins with the exchangeable reservoirs in
equilibrium at mean obliquity. Starting at 3.5 G.y. ago with 1.0 bar
of total available CO₂, τ = 10⁴ yr and 10⁶ < θ < 50°, the model
initializes without polar caps. When obliquity decreases in a cycle,
the annual polar insolation decreases causing the polar surface
temperature to fall. This trend continues until θ = 23° and the polar
surface temperature reaches the frost point of the 180-mbar atmos-
phere, causing atmospheric collapse [3]. Such a collapse is esti-

ated [6] to take 10³ yr, well within our model timestep; thus, model
pressure drops discontinuously to 0.5 mbar and reaches a minimum
of 1.2 μbar when θ = 10°. The regolith responds, governed by τᵦ,
freeing CO₂, which adds to the polar caps since atmospheric press-
ure is now buffered by the frost point relationship. When obliquity
increases, model pressure and polar surface temperature increase
until thermodynamic equilibrium can only be maintained at the
polar surface after complete sublimation of the polar caps at θ = 42°.
Sublimation leaves a 500-mbar atmosphere, vs. 180 mbar at mean
obliquity, causing 10 K and 20 K increases in respective global and

polar surface temperatures. Increased weathering is significant but
short lived as the regolith finds equilibrium by quickly reducing
atmospheric pressure. The obliquity peaks as the regolith nears
equilibrium and the cycle repeats as obliquity begins to fall.

We find that including variable obliquity can cause our model to
predict CO₂ losses to carbonate formation of less than half that lost
when obliquity is held constant at the mean. This is the case with
the scenario described above, but preliminary experiments with dif-
terent values of τ, have indicated that there is a complicated rela-
tionship between this parameter and the amount of CO₂ lost to
carbonates through an obliquity cycle. This relationship and the
effect of a variable polar cap albedo are being studied.

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DIELECTRIC PROPERTIES OF MARS' SURFACE: PRO-
POSED MEASUREMENT ON A MARS LANDER. S.
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Recent studies of missions to Mars (MESUR by NASA and
Marsnet by ESA) have suggested the development of semihard
landers, also of considerably different designs. One type was to be
extremely basic, consisting mainly of a meteorological package, but
with the possibility of other small, low-mass, low-power instru-
ments. In particular, this type of lander was also considered for the
exploration of the polar regions.

Two methods to investigate the surface material at the landing
site are discussed. Both measure the dielectric constant ε of the
ground material. This information can then be used to elucidate the
surface composition and structure, and especially in the case of a
landing on the polar ice, the determination of the permittivity
would be of high scientific value.

Fig. 1. (a) Possible arrangement of sensor on a Mars lander; (b) side view
of suggested 3/4 antenna.
It would appear that in order to explain the valley networks and other features on Mars, the debate concerning the evolution of CO₂ continues. The presence of 14C in a meteorite sample is to be expected [5, 11]; what is important is the use of the 14C/12C and 34S/32S ratios of the carbonate minerals from the two meteorites to determine whether there has been an input of modern terrestrial carbonates into the meteorites. While some models of atmospheric loss predict that up to 0.4 bar of CO₂ could be removed from the Martian atmosphere [3], this is still not enough to account for the original atmospheric inventory, usually considered to have been in the range of 1–5 bar. Thus, most models of the evolution of the Martian atmosphere require removal of CO₂ from the atmosphere and into carbonate deposits. However, as yet, the evidence for the existence of carbonates on Mars is fairly scant [4]. This is an issue that would have been resolved by results obtained from Mars Observer.

While the existence of carbonates on Mars remains unsubstantiated, their presence in meteorites from Mars is undisputed. Furthermore, their origin as low-temperature secondary minerals, introduced at some point after the rock fabric of the meteorite had crystallized and cooled, has been demonstrated by isotopic measurements [5, 6] and petrographic descriptions [7]. That the carbonate minerals are not simply weathering products produced on Earth has been demonstrated in one case by 14C measurements, which show that there has not been an input of modern terrestrial C to the sample [8]. However, measurements from another sample show the presence of the 14C isotope, interpreted as resulting from terrestrial contamination [9]. These results are somewhat unexpected since the 12C/13C and 16O/18O ratios of the carbonate minerals from the two different samples are similar [5, 10]. At this point the exact significance of the 14C data is unclear, but it would seem that in any particular sample there may be a few components containing 14C that have been added from the terrestrial environment in addition to preterrestrial (i.e., martian) carbonates, characterized by the absence of 14C.

A particularly interesting sample is EET A79001, a meteorite collected from Antarctica. While rocks that experience Antarctic conditions may suffer from the effects of terrestrial inorganic weathering processes (e.g., the build-up on the outer surfaces of magnesium carbonate and bicarbonates, and hydrated magnesium and calcium sulfates), they are relatively free of organic contamination. Thus, it is interesting to note the association, deep within the meteorite, of carbonate minerals and organic compounds [12]. The carbonates are Mg-bearing and also contain P, i.e., there could be magnesium phosphates present [7]. Calcium sulfate, possibly gypsum, is also present [7], and there is also some tenuous evidence for the presence of nitrates [5, 13]. On the basis of N isotope measurements it is clear that the nitrates could not have formed by a mechanism that utilized martian atmospheric N as a source material [5, 13]. Because of the potential ramifications for martian surface evolution, the coexistence of salts and organic compounds in EET A79001, it was perhaps inevitable that a further study of Antarctic weathering processes was necessary in order to constrain the possible extent of such effects. In this regard it is worth noting that EET A79001 has a weathering category “A” (i.e., only minor effects) and a fracturing category “A” (i.e., minor cracks). Since the meteorite is a single stone of mass 7.9 kg, measuring about 20 cm across, it is clear that samples from the center of the specimen ought to be predominantly free of the effects of terrestrial weathering. In contrast, a recently discovered martian meteorite from Antarctica, LEW 88516 (weathering A/B; fracturing A), weighs only 13.2 g and is less than 2 cm in size. Since the terrestrial ages of both Antarctic meteorites are similar, i.e., <50,000 yr. [14, 15] it may be anticipated that the effects of weathering in LEW 88516 would be more severe than in EET A79001. However, LEW 88516 was found to contain the lowest C content of any of the nine known martian meteorites [16], even when material was taken specifically from the surface layers for analysis. This tends to support the notion that terrestrial weathering processes are not necessarily responsible for the components observed in EET A79001. A further consideration here arises from O isotope measurements of water released by heating, which, at face value, seem to demonstrate that EET A79001 has been affected to some degree by terrestrial weathering [17]. However, since it is now considered that the O isotope data should be treated with caution [8], their true significance, for the time being, remains poorly established.

So how do we explain the association of carbonates, sulfates, phosphates, nitrates, and organic materials in EET A79001? It has to be accepted that some of the inorganic minerals could have formed by terrestrial weathering processes. However, it is known for certain that martian meteorites, including EET A79001, contain preterrestrial weathering products [e.g., 7]. Furthermore, the associated organic compounds are present in higher abundances (i.e., by about 2 orders of magnitude) than can reasonably be expected for any contamination episode or handling procedures [12]. It would appear, therefore, that the coexistence of inorganic weathering products and organic materials in EET A79001 was established on Mars. In order to explain this phenomenon, perhaps attention should be turned to recent work that advocates an early CH₄/CO₂ greenhouse on Mars [18], since this might ultimately lead to the formation of nonvolatile surface reservoirs of reduced and oxidized forms of C. An additional consideration, which could be pursued through chemical evolution modeling studies, infrared measurements of the