first suggestion, but at the moment we cannot give a conclusive interpretation.

Limited comparison of our fossils can be made with the cupules of the Lower Carboniferous seed petrifactions *Stamnostoma huttonense* and *Eurystoma angulare* described by Long (*7*). In the first of these the cupule is formed by the repeated dichotomy of simple cylindrical axes, and in the second the branched structure (a primitive cupule) bearing the seed shows some suggestion of dorsiventrality. Differences exist, however, and in the Devonian seeds the appendages forming the cupule-like structures are distinctly dorsiventral. The specimens also bear a certain resemblance to *Moresnetia zalesskyi* and *Xenotheca bertrandi* of Stockmans (*8*), but our knowledge of these particular fossils is limited to their external appearance.

This discovery not only demonstrates the existence of seed plants in the Devonian, but also further supports the proposal of the origin of gymnosperms in the Upper Devonian progymnosperm (*6, 9*). More detailed discussion and a formal description of the specimens will be published elsewhere.

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Venus: Volcanic Eruptions May Cause Atmospheric Obscuration

Abstract. *High rates of volcanic and tectonic activities are inferred from Venus's high surface temperature. The effects of volcanic effluents, gas and dust, on obscuration in the atmosphere are considered. The optical extinction due to particulate matter is estimated from assumed distributions as to particle size and altitude. As few as ten explosive eruptions per annum would cause significant absorption and scattering of visible light.*

The reports of high surface temperatures on Venus, derived from Mariner II (*1*) and earlier data, have raised much speculation about atmospheric processes, but little effort has yet been expended toward reconciliation of the observations with the theory of planetary interiors. One immediate inference from the observations is that the lower part of the crust may be very warm. The subsurface heat conductivity (0.006 cal/°C cm sec) and surface heat flow (1.1×10^{-6} cal/cm^2 sec) measured on Earth (*2*) would lead to temperature gradients around 19°C/km. A high surface temperature would imply that the surface heat flow on Venus is considerably greater than on Earth, so temperature gradients would be correspondingly increased. A surface temperature of 500°K and a thermal gradient (say) twice that of Earth would result in temperatures of 1300°K at depths less than 25 km, which would be adequate to melt silicate rocks (*3*). Therefore the crust is probably quite thin; it may even float on a layer of molten rock (*4*).

An important result of intense volcanic activity is very high atmospheric concentrations of volcanic gases and suspended particles. Water vapor may be present; if it is, the concentration depends on whether large amounts of steam are generated during volcanic eruptions; sulfur compounds may be present in detectable quantities. Meinel and Meinel (*5*) recently noted that the terrestrial high-atmospheric haze following important volcanic eruptions may be due to a sulfate aerosol resulting from reactions involving SO_2; much of the atmospheric obscuration of Venus may be caused by such a high "smog" layer. Volcanoes may be considered a likely source of the HCl recently discovered in the atmosphere of Venus (*6*).

Particles from terrestrial volcanoes are carried upward by the momentum acquired on ejection and by convective currents (*7*). The most important unknown factor is the height to which particles can rise. A violent volcanic eruption can create a strong thermal column that carries micron-size particles to great heights. Certainly some material ejected by terrestrial volcanoes can go as high as the tropopause. The tropopause on Venus may be at a much greater altitude, but its atmosphere also appears to be subject to stronger convection. Small particles at high altitudes may take years to drift down to the surface. We shall make some estimates of light absorption and scattering by small particles and show that complete blanketing of Venus could result from a modest rate of volcanic activity.

In computations of particle density and optical depth we have assumed that all particles from an eruption rise in the atmosphere of Venus to the tropopause altitude, where they are completely dispersed in latitude and longitude. If $N(r)$ represents the distribution of particle radii and if there are S eruptions per second, the steady-state particle distribution at any altitude (below the tropopause) is

$$n(r,h) = S\ N(r)/Av(r,h)$$

where A is the surface area of the planet and $v(r, h)$ is the terminal descent velocity of a particle of radius r at altitude h.

An empirical distribution of particle sizes

$$N(r) \approx C/r^{1.56}\ (1 + 4.38 \times 10^5 r^2 + 9.33 \times 10^9 r^4 + 1.57 \times 10^{19} r^8)$$

(r in centimeters) was derived from investigations by Miller and Lee (*8*) of fallout from a volcanic eruption. The total amount of material was normalized to 1 km^3, which is consistent with Humphrey's (*9*) estimate of the amount of micron-sized material injected into Earth's atmosphere by the 1912 Katmai explosion. It follows that the total (vertical) optical depth of volcanic dust in a planetary atmosphere is

$$\tau = \int dr \int dr\ n(r,h)\ \sigma(r) \approx \frac{SC}{A} \int_0^{h_T} dh \int_0^{\infty} dr\ (2\pi \mathrm{X}\ r^2) / [v(r,h) r^{1.56} \times (1 + 4.38 \times 10^5 r^2 + 9.33 \times 10^9 r^4 + 1.57 \times 10^{19} r^8)]$$

where h_T is the height of the tropopause and X is a correction to the total cross section $\sigma(r)$ when particle diameters are comparable with wavelengths of light. For consideration of the extinction of visible light, it is reasonable to let X equal $r/(2 \times 10^{-4})$ for $r < 2 \times 10^{-4}$ cm; otherwise X equals 1 (*10*). Earlier computations (*11*) for $v(r, h)$ on Mars were adapted to the atmosphere of Venus. An atmospheric model (*12*) was used, with surface temperatures of 620° to 720°K and surface atmospheric densities of 0.0174 to 0.150 g/cm³. Typical values of $v(r, h)$ at 50 km were 0.0074 cm/sec for particles 1 μ in diameter, 0.66 cm/sec for 10-μ diameter, and 5.1 cm/sec for 100-μ diameter. The velocity of descent of very small particles is roughly proportional to the diameter squared. The particles were assumed to ascend to a tropopause altitude (h_T) of 60 km. The calculation of $v(r, h)$ is not valid for extremely small particles, so the integration of τ was cut off at $r \leqslant 2 \times 10^{-5}$ cm = 0.2 μ. Numerical integration of the optical depth yields the result $\tau \approx 2.7 \times 10^6 \cdot S$ for a mean atmosphere; this result is quite insensitive to the choice of atmospheric parameters.

It is apparent that τ is of the order unity for $S \approx 3 \times 10^{-7}$ sec^{-1}, about ten explosive eruptions per annum or 10 km³ of material annually injected into the atmosphere. This rate of volcanic activity is considerably higher than the current rate on Earth if only the most violent eruptions carry large amounts of material as high as the tropopause. Nonetheless it does not seem unreasonable to us that Venus should sustain a rate of volcanic activity sufficient to keep the optical depth of suspended dust greater than unity. Our conjectural atmosphere would therefore contain high clouds of H_2O vapor and ice, and other volcanic gases, surmounting an optically thick suspension of fine dust particles. The dust particles might not be readily detectable from above, but would have profound effects on the dynamics of the lower atmosphere.

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Radio Reflection by Free Radicals in Earth's Atmosphere

Abstract. *Reflections of megacycle-per-second radio signals by free radicals in Earth's ionosphere are observed having about the intensity predicted for induced magnetic-dipole transitions. It seems that magnetic atoms, ions, and molecules in planetary atmospheres may be detected by this method. These observations were made with the topside ionosonder of the Canadian satellite Alouette II.*

We report probable observation of the reflection by free radicals in Earth's upper Antarctic atmosphere of megacycle-per-second radiation. The measurements were obtained with the topside ionosonde satellite Alouette II; records from the south polar station were used because they were exceptionally clear. The satellite (*1*), lofted into a nearly polar orbit with apogee at 3000 km and perigee at 500 km, remains well above the main part of the ionosphere.

Basically our point is that such radiofrequency sounding is an important technique for analysis of the upper atmosphere. The probability of spontaneous emission of magnetic-dipole emission at megacycle frequencies is very low, so that only absorption and induced emission are important. We calculate that by using the Alouette ionosonde one should be able to detect induced magnetic-dipole radiation from free radicals at concentrations as low as approximately $10^4/\text{cm}^3$ (see *2*).

The signals we report, of frequencies lower than the electron gyrofrequency, have not been previously identified; we suggest that they are from magnetic-dipole transitions induced by the topside sounder pulse—transitions within a Zeeman multiplet split by Earth's magnetic field.

Our investigation stemmed from previous studies of the strange triggering action of the Jovian moon Io on the decameter radiation from Jupiter. Recently two of us suggested (*3*) that Io, orbiting in a Van Allen belt, produces energetic hydromagnetic disturbances in the Jovian magnetic field, which propagate by Alfven-wave transport into the Jovian ionosphere below. Free radicals, expected to be abundant in Jupiter's reducing atmosphere, transduce this perturbing energy in a manner similar to reflection, the energy being emitted as the decameter radio signal.

The ionosonder in Alouette II is a transmitter and receiver which simultaneously sweeps from 0.2 to 14.5 Mc/sec during each 30-second interval. At the beginning of each interval the transmitter emits a 100-μsec pulse at a frequency of 0.2 Mc/sec and an average power of 300 watts. After a 2-μsec delay, there follows a receiving period of 33 msec; then the transmitter emits a second pulse of higher frequency, followed by another listening period, and so on.

This sequence is repeated 900 times during the 30-second interval as the frequency increases from 0.2 to 14.5 Mc/sec, the pulse length and power and the receiving period remaining constant. For each interval an ionogram displays the frequency of any detected signal, its time of arrival, its intensity, and the real time. For the ionogram records now reported, the signal intensities were not available.

Figure 1 shows a series of consecutive 30-second ionograms, with examples of signals that we attribute to induced magnetic-dipole radiation from free radicals. Figure 2 shows a distribution of Landé g values calculated from some 500 signals found by examination of more than 100 ionograms; the values were computed from the frequency of each signal divided by the local geomagnetic field ($g = 0.714\ \nu/B$). The field at the satellite was computed from a polynomial expansion of the geomagnetic field; values so computed