that correspond to these ridges probably result from increased disorganization of the structure of daytime additions which increases the intercrystal spaces and causes the deposit to be more opaque. Opaque growth lines are only found in hermatypic corals. They are not formed when specimens are grown in the dark for several days. It follows from the above explanation of growth and structure of the skeleton that growth lines, of the nature and form of those described, would be present in the primary layer of the dissepiment.

The formation of fan systems is not limited to scleractinian corals. Most fossil corals show remnants of fan systems. The sclerosponges, which are apparently modern representatives of the stromatoporoids, have a skeletal structure very similar to that of corals (*11*). Calciferous spicules in many sponges and octocorals have a similar organization. Some recent stereoscan photographs of mollusk shells (*12*) show distinct fan systems. It is probable that the principle of competitive crystal growth may be used to explain the form and microstructure of many types of skeleton which include acicular crystals in their structure.

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13. I thank Dr. L. S. Land for his help in developing the above principle, and Sir Maurice Yonge and Dr. J. W. Wells for their comments on the manuscript. Supported by the Natural Environment Research Council of the United Kingdom as a research studentship and by an NSF grant to Prof. S. K. Runcorn.

17 September 1970

Mars: Detection of Atmospheric Water Vapor during the Southern Hemisphere Spring and Summer Season

Abstract. *Water vapor was found to reappear in the atmosphere of Mars during its southern hemisphere spring and summer season, with a maximum vertical column abundance of 45 to 50 microns of precipitable water averaged over the entire planet. Although the spring-summer seasons for each hemisphere are generally symmetrical with respect to the appearance of water vapor, the data suggest that water vapor may appear later in the season and in slightly larger amounts during the southern hemisphere spring-summer.*

Small amounts of water vapor (up to a few tens of microns of precipitable H_2O in a vertical column) have been reported in the atmosphere of Mars during three of the past four oppositions; in the most recent of these oppositions (1969), the amount and quality of the spectroscopic data were sufficient to establish its presence conclusively. However, all of these previous successful determinations of Martian water vapor have been made when Mars had an orbital longitude L_s of about 60° to 140° (*1*)—that is, during the same spring-summer "wet season" of the Martian northern hemisphere when the north polar cap was receding. Although it is plausible to assume that the situation would be symmetrical with respect to recession of the south polar cap, various factors including the substantial eccentricity of the Martian orbit might produce appreciably different behavior. It is thus of interest that we have recently been able to obtain a number of spectra of the 8200-Å band of H_2O taken at times when Mars had orbital longitudes (L_s) in the range of 250° to 350°, which corresponds to spring-summer in its southern hemisphere.

To set these observations in context, the first true spectroscopic detection of water vapor on Mars was made in 1963 from a single Mount Wilson plate taken at $L_s = 76°$ (*2, 3*). Measurements of spectra obtained at McDonald Observatory and Lick Observatory during the 1964–65 apparition of Mars, which covered $5° < L_s < 122°$, indicated a definite variation in the water vapor abundance with Martian season, and also with areographic position on the disk of Mars (*4*). The search for water vapor was fruitless during the 1966–67 apparition because of limited observing programs and poor terrestrial observing conditions when the Doppler shift was favorable. In several studies (*5*) made at the McDonald Observatory during the first half of the 1969 apparition ($L_s = 80°$ to 150°, spring-summer in the Martian northern hemisphere) with the improved coudé spectrograph of the 82-inch (207-cm) Struve reflector and the newly installed 107-inch (268-cm) reflector with its coudé spectrograph, the date of reappearance of H_2O in the late spring for the northern hemisphere was established and an average abundance for the whole planet of 20 to 35 μ of precipitable water was obtained. Several of the 82- and 107-inch spectra have good enough areographic resolution to show (*5, 6*) that the water vapor varied across the disk of the planet from a maximum in the northern hemisphere, where the polar cap was receding, to a minimum in the southern hemisphere.

The first report on attempts to detect water vapor subsequent to the blind opposition period (zero Doppler shift) centered on June 1969 was presented in a detailed review of the history of Martian water vapor studies (*7*). Since the 1969 opposition occurred near the start of Martian southern hemisphere spring when the sub-Earth point was going south, the spectra taken after opposition ($L_s = 190°$ to 340°) refer mainly to the spring and summer season in the southern hemisphere. The prediction was made (*4, 7*) that water vapor should reappear when the south polar cap had receded to about the

Table 1. Measured water vapor lines on plates C6670, C6676, and C6743 and the average abundance of water vapor determined for each plate.

Wavelength (Å)	Equivalent width (mÅ)		
	Plate C6670	Plate C6676	Plate C6743
8164.54	7.5	8.5	
8169.995	7.5	6.0	5.5
8189.272	7.5	8.0	8.0
8193.113	7.5	10.0	
8197.704	5.5	6.0	
8226.962	7.0	4.5	
8256.515	13.0	12.5	12.5
8282.024		4.5	6.0
Average	7.9	7.5	8.0
Abundance (μ)	45 ± 11	44 ± 9	50 ± 15

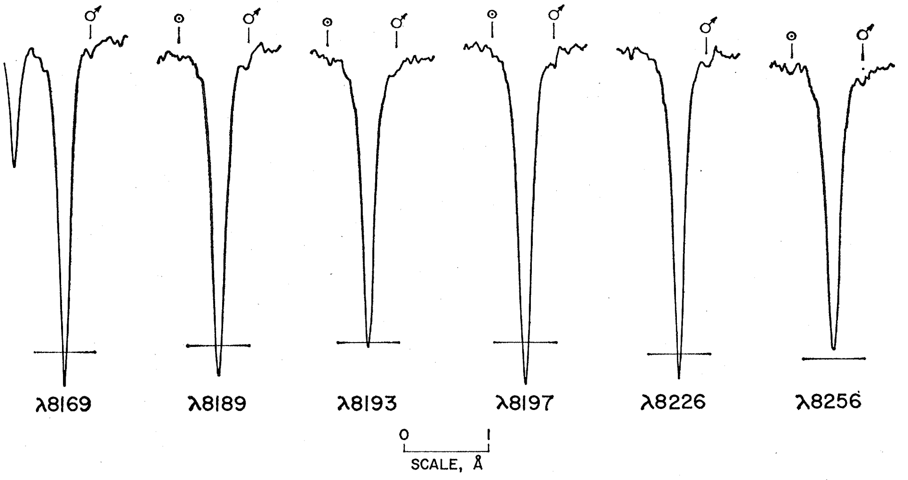

Fig. 1. Density tracings of several water lines on plate C6670 showing positions of the Doppler-shifted Martian water vapor lines (♂) and several solar lines (⊙). The horizontal lines across the bottom of the water lines indicate the density level of the sky background. The feature to the blue (to the left) of the 8169 line is a weaker terrestrial water line at 8169.386 Å.

same size that the north cap has at the phase when water vapor is first observed in the northern hemisphere's late spring. This phase of the Martian season has been difficult to study during the past several oppositions because Mars has been on the far side of the sun, a very small target seen mainly in the daytime sky.

Detailed analysis of all the approximately 30 good spectra of the 8200-Å water vapor band taken after June 1969 will be reported elsewhere (*8*), but in general the reappearance of water vapor occurred as follows. During August–September 1969, no Martian water vapor was observed; the lower limit of about 20 to 25 μ is poor because of small Doppler shift and high terrestrial humidity. By December (L_s of about 290°—the start of Martian southern summer) faint Doppler-shifted lines could be measured; they indicated about 30 μ of water in a vertical column. This amount is generally consistent with that seen in the northern hemisphere around the start of northern summer (*5*).

We obtained most of the observations with the coudé spectrograph of the 82-inch reflector at a dispersion of 2 Å/mm, with projected slit widths of 0.020 and 0.015 mm. The exposures required 7 to 8 hours, part of which had to precede sunset. [Good plates were also obtained with the 107-inch reflector during this period, but the Martian observing time with this telescope was primarily used for photoelectric spectral scans of selected water vapor lines by means of the new rapid Tull scanner at the coudé focus; detailed reductions of these scans will be reported later (*8*).] Three plates, C6670 ($L_s = 323°$), C6676 ($L_s = 323°$), and C6743 ($L_s = 339°$), taken during extremely high-quality daytime skies in February and March 1970 were chosen for detailed reduction at this time. The spectrograph slit was aligned pole-to-pole along the central meridian by means of an image rotator. Some four to eight Doppler-shifted water vapor lines are detectable on each plate; these are not consistently stronger over any portion of the image of the Martian disk (the angular size of Mars at this time was extremely small—less than 5 seconds of arc—and the image motion due to guiding and seeing effects during the 8-hour exposure makes areographic resolution almost impossible).

The spectra were traced (*9*) in the density mode, and they refer to the entire image (Fig. 1). Equivalent widths of weak solar lines (*10*) in the reflected planetary spectrum near 8200 Å were used to calibrate the tracings, which permitted equivalent widths to be assigned to each Martian water vapor line. A realistic estimate of the systematic errors involved in such measurements of weak lines that fall in the wings of strong lines indicates an overall uncertainty of about 50 percent in the measurement of each line. We used

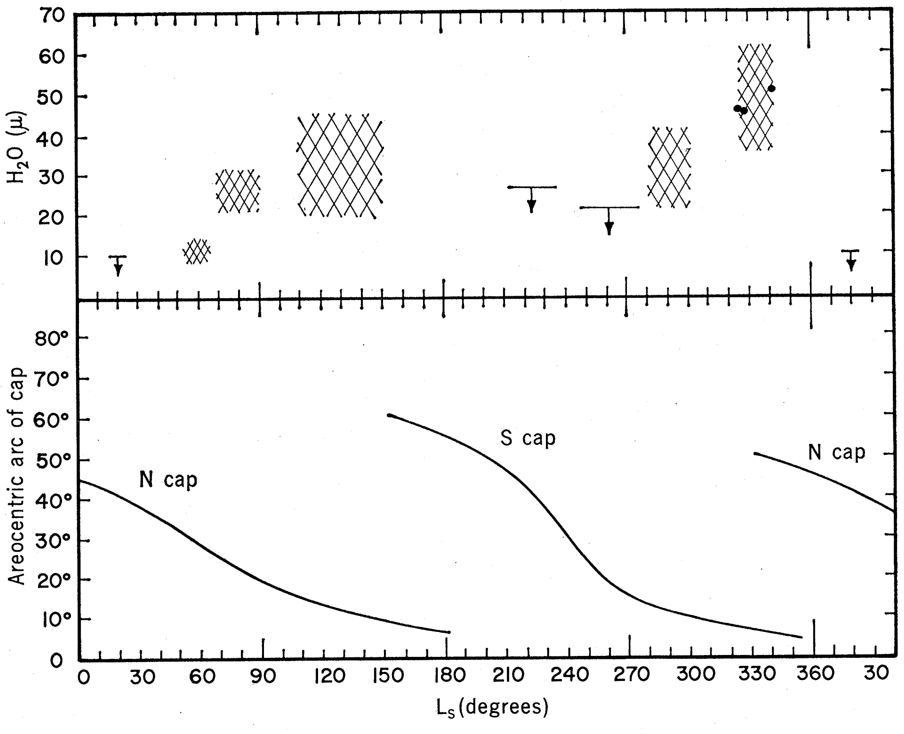

Fig. 2. Abundance determinations of Martian water vapor as a function of L_s. Determinations of several observers (*3–6*) are included in the region of L_s 5° to 180°, and determinations in the region of L_s 190° to 340° are covered in this report. The figure indicates the trend of Martian water vapor abundance; it does not include any error limits, which are substantial in all cases. The vertical arrows point downward from observed upper limits; the cross-hatching represents the range of actual measured amounts. All estimates have been adjusted to utilize Farmer's improved line strengths for 225°K. The mean regression curves for the northern and southern polar caps determined by Antoniadi indicate the relative seasons and sizes of the Martian polar caps.

the new absorption coefficients determined by Farmer (*11*) for the lines listed in Table 1 (except for 8169.995 Å, which has not been measured and for which the mean value of the other lines was used), and we assumed Voigt profiles with a surface pressure of 6 mb and a temperature of 225°K (*5*); we then determined from tables the amount of precipitable water vapor in the total atmospheric path length (*12*). By assuming an effective air mass or atmospheric path length of 3, for a meridional strip of the atmosphere, we derived the amount of precipitable water in a vertical column and its mean error for each plate (Table 1). The apparent abundance values of 45 to 50 μ (0.0045 to 0.0050 g cm^{-2}) of precipitable water are larger than any determination for the whole planet during the northern spring-summer season.

Figure 2 shows these abundances determined at $L_s = 323°$ and 339° plotted on a modified version of the graph (*7*) which contains all the reliable water vapor abundance determinations as a function of L_s. All abundances have been determined by use of Farmer's improved line strengths (*11*). Also included are Antoniadi's mean regression curves for the north and south polar caps (*13*); 1969 polar regression curves are in preparation (*8*).

Figure 2 is consistent with a correlation between the behavior of the polar caps and the appearance, disappearance, and the amounts of Martian atmospheric H_2O. Although this correlation is suggestive, it does not necessarily imply a cause-and-effect relationship between the two phenomena. The data suggest that the water vapor may appear slightly later in the Martian season when the south cap is receding, rather than when the north cap is receding, and also that a slightly larger amount of H_2O may be present in the southern summer. Such effects could be consistent with expectations based on the ellipticity of the Martian orbit. Thus the south polar cap, which becomes larger than the north polar cap because it is formed during the longer, colder winter at aphelion, may have more water to release but does so at a later seasonal date. Although some water must freeze out on the caps (because the temperature of the caps is low enough and the water vapor is there at times), we feel that several processes—H_2O snow, frost, or adsorption—may well contribute to the observed behavior of the Martian H_2O at the same or at different times during the Martian seasons. One hypothesis assumes that when water disappears from the atmosphere, a substantial part of it is trapped in the frozen carbon dioxide polar caps (*14*). As an alternative explanation (*15*), appreciable amounts of H_2O could be tied up in surface soils, which would allow the warmer southern perihelion summer to release a larger amount at that phase from the soil. Observations during additional Martian years hold out the prospect of being able to distinguish among any yearly, seasonal, or weather-caused differences in the time of appearance and amount of Martian water vapor.

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1. The term L_s is defined as the planetocentric longitude of the sun and is measured in the plane of the orbit of the planet from the ascending node on its equator. At the beginning of spring in the northern hemisphere of Mars, $L_s = 0°$.
2. Detection of a weak nonterrestrial water line is possible because of the planet's relative radial component of orbital velocity with respect to the earth; this causes a Doppler displacement, which shifts the nonterrestrial water vapor line into the outer wings of the terrestrial water vapor line where the planetary line can be detected. Such work requires spectra with high dispersion and resolution, a good Doppler shift ($\geqq$ 0.2 Å), and low terrestrial humidity.

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Molecular Microscopy: Fundamental Limitations

Abstract. *On the basis of estimates of molecular damage caused by the observation process, it is concluded that molecular microscopy of biological molecules in which the individual atoms are resolved is impossible with an electron or x-ray microscope. Microscopes that use low-energy helium atoms or neutrons as illuminants may be capable of serving as ultimate biomolecular microscopes.*

X-ray and neutron diffraction studies have served as the principal means for the determination of molecular structure. The diffraction pattern of a macroscopic crystalline sample of the molecule under investigation is analyzed to obtain information concerning the atomic arrangement in the molecules. For the giant molecules of biological interest unraveling the diffraction pattern to obtain the molecular structure is a difficult task and is sometimes ambiguous because of the phase problem (*1*). Furthermore, many biological molecules cannot be crystallized without serious structural modifications. For these and other reasons it would be very desirable to have a device, a molecular microscope, which could form an image of the individual atoms in a single molecule. With such an instrument, for example, one might be able to observe a molecule while it is undergoing a reaction, or perform an operation on a biological molecule in which a selected small group of atoms could be excised or altered.

Molecular microscopy, however, is subject to a fundamental limitation. To resolve the individual atoms of a molecule, the illuminating radiation must have a wavelength λ less than about 1