New Rules for AAAS–Newcomb Cleveland Prize

The AAAS–Newcomb Cleveland Prize, which previously honored research papers presented at AAAS annual meetings, will henceforth be awarded annually to the author of an outstanding paper published from September through August in the Reports section of *Science*. The first competition year under the new rules starts with the 3 September 1976 issue of *Science* and ends with that of 26 August 1977. The value of the prize has been raised from \$2000 to \$5000; the winner also receives a bronze medal.

To be eligible, a paper must be a first-time presentation (other than to a departmental seminar or colloquium) of previously unpublished results of the author's own research. Reference to pertinent earlier work by the author may be included to give perspective.

Throughout the year, readers are invited to nominate papers appearing in the Reports section. Nominations must be typed, and the following information provided: the title of the paper, issue in which it is published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to the AAAS–Newcomb Cleveland Prize, AAAS, 1515 Massachusetts Avenue, NW, Washington, D.C. 20005. Final selection will rest with a panel of scientists appointed by the Board of Directors.

The award will be presented at a session of the annual meeting at which the winner will be invited to present a scientific paper reviewing the field related to the prize-winning research. The review paper will subsequently be published in *Science*. In cases of multiple authorship, the prize will be divided equally between or among the authors; the senior author will be invited to speak at the annual meeting.

Reports

Pluto: Evidence for Methane Frost

Abstract. *Infrared photometry (1.2 to 2.2 micrometers) of Pluto provides evidence for frozen methane on the surface of the planet. This appears to be the first observational indication of this ice in the solar system. Its presence on Pluto suggests that the planet's albedo (reflectance) may be ≥ 0.4 and that its diameter may be less than that of the moon.*

Pluto's faintness, resulting from its small size and great distance from the sun and the earth, has greatly limited physical studies of its surface. However, newly developed detectors used with large-aperture telescopes have made it possible to begin spectrophotometric studies in the near infrared (1 to 4 μm) where simple frozen volatiles and mineral assemblages have diagnostic spectral features.

Previous studies of the composition of Pluto have been limited to the visible and photoelectric infrared regions of the spectrum. Spectroscopic (*1*) and spectrophotometric (*2*) measurements have failed to reveal absorption features due to gaseous methane, the most likely spectroscopically active atmospheric constituent. Hart (*3*) has conjectured that neon, the only inert gas that would not escape or condense at Pluto's expected temperature of about 43°K, might form a fairly extensive atmosphere around the planet, but there is no direct evidence for any atmosphere on Pluto. The planet's spectrum (*4*) does not show the 0.95-μm absorption that is characteristic of Fe^{2+}-bearing silicates, but the presence of these materials in particulate form on Pluto's surface cannot be ruled out on this basis.

Chemical condensation models for the formation of the solar system suggest that the most significant low-temperature condensates, and hence the most likely constituents of the surfaces of solid bodies in the outer solar system, are ices or frosts of water, ammonia, and methane (*5*). Water ice has already been identified in the rings of Saturn (*6*), on the Jovian satellites Europa and Ganymede (*7*), and on four satellites of Saturn (*8–10*). However, ammonia and methane, which condense at lower temperatures than water, have not been detected.

For a reconnaissance study of the surfaces of Pluto and the satellites of Saturn, Uranus, and Neptune, we designed a simple observational test to distinguish these three frosts. The presence of frost on a planetary surface is strongly indicated by a generally decreasing reflectance with increasing wavelength between 1 and 4 μm. This was first pointed out by Kuiper (*11*) for the case of two of Jupiter's Galilean satellites, and has been discussed more recently in the context of other solar system bodies by Johnson *et al.* (*10*) and Morrison *et al.* (*9*). This general decrease in reflectance is illustrated in Fig. 1, which shows laboratory spectra (*12*) of frosts of H_2O, NH_3, and CH_4 at 77°K. We note that reflectance measurements between 1.4 and 1.9 μm can distinguish CH_4 from either H_2O or NH_3. Methane exhibits a deep absorption at 1.7 μm, while the other two frosts show reflectance maxima near this wavelength and absorptions instead at 1.5 μm. Water and ammonia can in turn be distinguished by reflectance measurements between 3.2 and 3.6 μm, where H_2O is virtually black and NH_3 is highly reflective, contrary to the general trend of decreasing reflectance described above. Some mineral assemblages in rocks found in the inner solar system (Mercury, the moon, the earth, Mars, meteorites, and asteroids) also have absorption bands between 1 and 4 μm, but these are usually accompanied by strong absorption features shortward of 1 μm (*13*) that are absent in the spectrum of Pluto (*4*). Further, since the infrared features in rocks are generally broader and shallower than the features seen in frosts (*13, 14*), they do not confuse the identification.

We observed Pluto with the 4-meter Mayall telescope at Kitt Peak National Observatory (*15*) in March 1976, measuring the reflectance of the planet with standard *JHK* filters (*16*) and with two specially made narrow filters centered at 1.55 and 1.73 μm (designated *H1* and *H2*, respectively), the approximate positions of the diagnostic absorptions of H_2O and CH_4 frosts. The measured broadband colors for Pluto, expressed as magnitude differences, were $J - H = 0.2 \pm 0.1$ and $H - K = -0.4 \pm 0.1$. Although the $H - K$ color is that expected for a frost (*8–10*), the $J - H$ value is considerably more positive than that expected for an object covered with water frost. The *H1*/*H2* reflectance ratio for Pluto is also inconsistent with water frost. From laboratory spectra, this ratio should be about 0.5 for a body covered with pure H_2O frost and illuminated by the sun, while pure CH_4 frost should yield $H1/H2 \sim 2.5$. A solar-illuminated surface of neutral reflectance should yield a value of 0.99. The reflectance ratio obtained for Pluto was $H1/H2 = 1.6 \pm 0.1$. Rhea, a satellite of Saturn known to be largely covered with water frost (*8–10*), yielded $H1/H2 = 0.6 \pm 0.1$, the expected result. Two stars, α Leo and α Lyr, which in the absence of stellar absorption or line emission features should have yielded ratios of about 1, in fact gave values of 1.02 ± 0.03 and 1.18 ± 0.03, respectively. The apparent discrepancy in the stellar results is probably due to the fact that the *H2* filter encompasses three atomic hydrogen lines (Brackett ϵ, ζ, and η) present in absorption in the spectra of these stars. It has been shown from visible spectra that Hα absorption is weaker in α Leo than in α Canis Majoris (*17*), a star of the same spectral type as α Lyr. This suggests that all hydrogen absorptions may be weaker in α Leo than in α Lyr. If so, the stellar *H1/H2* ratios may be readily understood, and the ratios are then consistent with the value of 0.99 calculated for a neutral solar reflector.

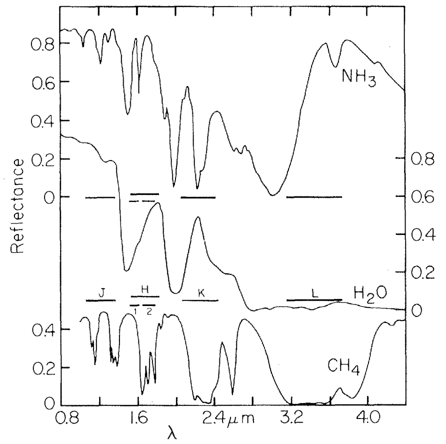

Fig. 1. Reflectances of laboratory samples of frozen NH_3, H_2O, and CH_4 relative to an MgO surface (*12*). The scale for H_2O is given on the right side. The temperature of all the frosts was 77°K. Horizontal bars indicate the passbands of the standard *JHKL* filters (*16*). The two short bars under *H* indicate the passbands of filters *H1* and *H2*, as discussed in the text.

On the basis of Pluto's *H1/H2* ratio, its $J - H$ color, and the restrictions imposed by the other observational and theoretical studies cited above, we conclude that CH_4 frost is probably the dominant reflecting material on Pluto's surface. The fact that the *H1/H2* ratio is less for Pluto than for a pure laboratory sample of CH_4 frost suggests that the frost on Pluto's surface either is mixed with other materials (such as silicates, carbonaceous material, or other frozen volatiles), or has a different grain size distribution than the laboratory sample (*18*). For cosmochemical reasons, it is unlikely that some other material produces the observed *H1/H2* ratio for Pluto. Large quantities of surface H_2O or NH_3 frost are ruled out by our observations, as are large quantities of CH_4 hydrates, because laboratory studies have shown that for even a few tens of percent of H_2O in the hydrate, the spectrum of H_2O dominates that of CH_4 (*19*). We cannot derive from our data any information on the presence of darker material (such as silicate rocks or carbonaceous chondritic material), other than to note that most of the near-infrared sunlight reflected from the surface does not come from a dark component. There is some variation of frost cover, however, as indicated by the brightness variation of about 20 percent in visible light exhibited by Pluto as it rotates (*20*).

There are two plausible sources for CH_4 on Pluto, with different implications for the bulk composition of the planet and for the conditions in the early solar nebula where it formed. The most straightforward explanation is that the temperature in the nebula dropped below about 40°K at Pluto's distance from the sun, leading to condensation of solid CH_4. Standard equilibrium condensation models (*5*) then suggest a bulk density of about 1.2 g cm^{-3} and allow the possibility that Pluto remains an undifferentiated and relatively pristine body. The second possibility is that temperatures dropped only to the point of condensation of the hydrate, $CH_4 \cdot 8H_2O$, near 70°K. Subsequent internal evolution could then have led to dissociation of this hydrate and outgassing of CH_4. Because of its extremely low surface temperature, Pluto could have formed and retained a surface coating of CH_4 ice while satellites nearer the sun, even if they underwent a similar evolution, would have lost the outgassed CH_4 by atmospheric escape. The present data do not allow us to distinguish between these scenarios.

The diameter of Pluto has been inferred in the past from its known visual brightness and an assumed geometric albedo of about 0.1. In part, this assumption has rested on the analogy between Pluto and the terrestrial planets, and in part on suggestions of a measurable disk for the planet as viewed through the largest telescopes. Kuiper (*21*) derived a diameter of 5900 km from visual measurements of the disk with the Hale Observatory 5-m telescope, although such measurements of marginally resolved images are subject to large systematic errors. A near occultation of a star by Pluto in 1965 yielded an upper limit of 6800 km (*22*). However, in light of our new information about the planet's surface, these diameters, with their implication of a dark, rocky surface, require reexamination. A planetary surface covered largely with frost will have a geometric albedo considerably in excess of 0.1; water frost–covered satellites such as Europa, Ganymede, Rhea, Dione, and Tethys have albedos in the range 0.4 to 0.6. The apparent presence of CH_4 frost on the surface of Pluto suggests that its geometric albedo falls in this range as well. However, our data are consistent with a lower geometric albedo for Pluto if, for instance, only a small fraction of the surface is covered by CH_4 frost and the remainder of the surface has a low-infrared reflectance similar to that of carbonaceous chondritic material. If we assume that the average geometric albedo of Pluto is 0.4, then we conclude that its diameter is 3300 km, slightly smaller than that of the moon. An albedo of 0.6 implies a diameter of only 2800 km.

If the mass and diameter of a planet are known, it is possible to calculate the density and thus to obtain information on bulk composition. Values of the mass of Pluto have been derived from observations of irregularities in the motions of Uranus and Neptune. Indeed, these reported irregularities inspired the original search for a trans-Neptunian planet. However, recent independent analyses of the same data (*23*) have given widely different values for Pluto's mass, and Ash *et al.* (*24*) have concluded that the mass is indeterminate from existing data.

Since the surface of Pluto appears to be that expected for a low-temperature condensate in the outer solar nebula, it seems likely that its composition is dominated (as is that of most outer-planet satellites) by frozen volatiles. If so, the mean density is likely to be in the range 1 to 2 g cm^{-3}. This density, together with a lunarlike diameter, yields a mass a few thousandths of that of the earth, much less than would be required to perturb the motions of Uranus or Neptune measurably. If this train of logic is basically correct, it appears that Tombaugh's discovery (*25*) of Pluto in 1930 was the result of the comprehensiveness of the search rather than predictions from planetary dynamics.

D. P. Cruikshank
C. B. Pilcher
D. Morrison

Institute for Astronomy, University of Hawaii, Honolulu 96822

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26. We thank R. Joyce and R. Capps for assistance with the photometric equipment, and G. Consolmagno and I. I. Shapiro for useful conversations. This work was supported in part by grant NGL 12-001-057 from the National Aeronautics and Space Administration.

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Increased Transport of Antarctic Bottom Water in the Vema Channel During the Last Ice Age

Abstract. *Particle size analyses of surface sediments in the Vema Channel reveal a spatial variation related to the present hydrography. Similar analyses of sediment deposited during the last ice age (18,000 years before the present) indicate a maximum shallowing of the upper limit of Antarctic Bottom Water (AABW) of about 100 meters, coupled with an increase in velocity, which resulted in an increase in AABW transport.*

The Vema Channel (Fig. 1) is a narrow gap in the Rio Grande Rise through which Antarctic Bottom Water (AABW) flows northward from the Argentine Basin into the Brazil Basin (*1*). It has been the major path of AABW flow since the Pliocene before which the Hunter Channel to the east (*2*) may have been a more important route (*3*). There is evidence that the Vema Channel is an erosional feature created by the high-velocity northward flow of AABW through the constriction of the gap (*1*). Average bottom current velocities observed in the axis of the channel are 20 to 25 cm/sec (*4*). Flume studies suggest that such bottom current velocities are sufficient to cause scour in deep-sea sediments (*5*), especially if microrelief such as manganese nodules is present (*6*). We attempt here to identify the extent of AABW in the Vema Channel during the last glacial period.

Two water masses are present in the Vema Channel, the deeper northward-flowing AABW and the shallower North Atlantic Deep Water (NADW) which flows south with a lower velocity (*1*). The transition zone between the two water masses is marked by sharp gradients in water properties and in the concentration of suspended particulates (*4*), and by pronounced changes in the characteristics of the underlying sediments (*7*). The identification of the level of no motion (LNM) within this transition zone is somewhat arbitrary in the absence of closely spaced observations of current. Hydrographic considerations (*4*) suggest that the LNM may correspond approximately with the 1.2°C potential temperature isotherm, a surface which in turn corresponds to the foraminiferal lysocline at approximately 4000 m on the east flank of the channel (*7, 8*). An alternative interpretation, more consistent with data presented here, is that the LNM corresponds to the maximum gradient in the benthic thermocline, which slopes from about 3900 to 4000 m on the western side of the channel to about 4200 to 4250 m on the eastern side (*4*).

Where the LNM intersects the sea floor one would expect to find a stagnation zone produced by the effect of opposing currents (*9*). Although this zone may be characterized by turbulent conditions, the net advective component should be approximately zero so that bottom current transport of sediment should be minimal. This effect should result in a

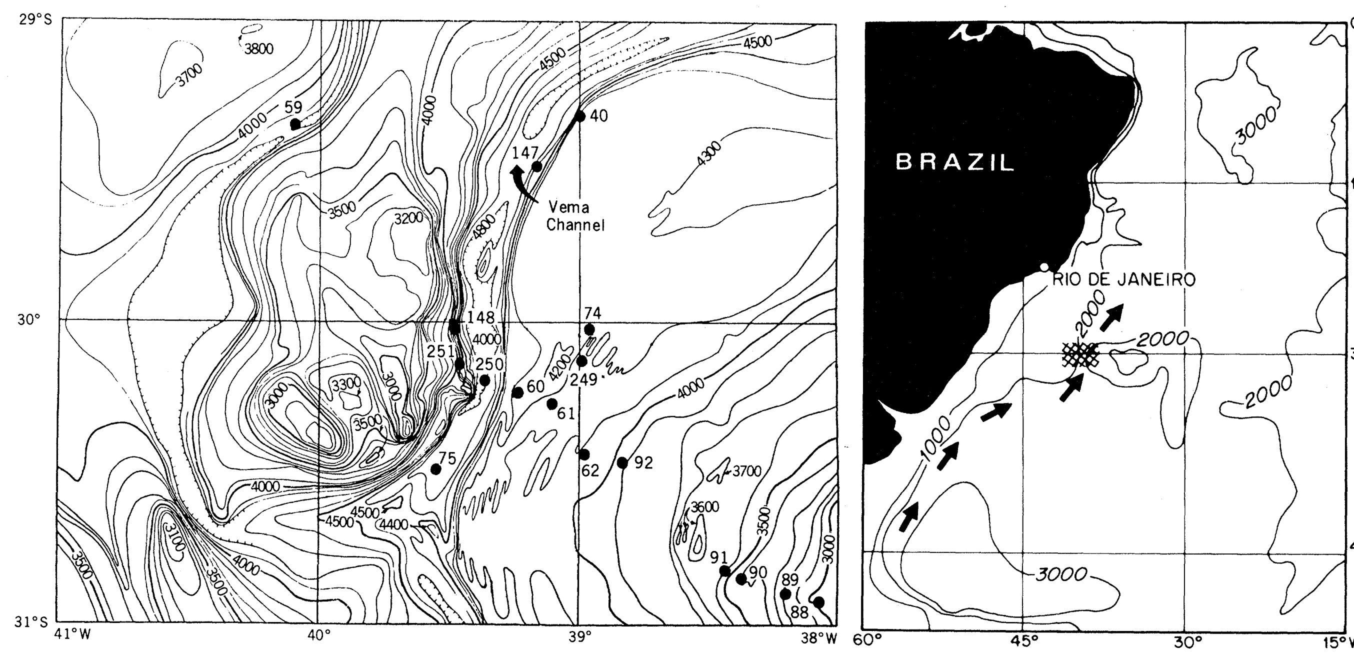

Fig. 1. (Left) Map showing the location of cores (*Chain* 115-60, 61, 62, 88, 89, 90, 91, 92; *Vema* 22-74, 75; *Vema* 24-249, 250, 251; *Robert Conrad* 11-40; *Robert Conrad* 15-147, 148) in the Vema Channel. Bathymetry (in meters, corrected for the density of the water) is from (*4*). (Right) Regional setting of the Vema Channel in the southwestern Atlantic.