At a radio wavelength where we are "seeing" to some depth below the surface we can estimate the temperature by use of the Piddington and Minnett lunar theory (*10*). A simplifying assumption for what follows that is quite valid for Callisto is that the subsolar and subearth points are the same and lie on Callisto's rotational equator. To apply the theory we need a crude approximation for the surface temperature (and for Eq. 1) of the form:

$$T_s(l,b) = \cos^{1/4}b\ (T_0 + T_v \cos l) \quad (2)$$

where l is the longitude from the subsolar point, b is the latitude, and $(T_0 + T_v) = T_{ss}$ (T_0 is a constant temperature and T_v is the amplitude of the part of the temperature that varies with longitude). The theory essentially solves the heat transfer problem, where Eq. 2 is used as the boundary condition to yield the brightness temperature:

$$T_B(l,b,\lambda) = E(l,b,\lambda) \times \cos^{1/4}b\{T_0 + \left[\frac{T_v}{(1 + 2\delta + 2\delta^2)^{1/2}}\right] \times \cos(l - \psi)\} \quad (3)$$

with

$$\psi = \tan^{-1}\,[\delta/(1 + \delta)]$$

and

$$\delta = (\omega\rho c/2k)^{1/2}\lambda/2\pi\sqrt{\epsilon}\tan\Delta$$

where $E(l,b,\lambda)$ is the emissivity at wavelength λ, ω is the rotation rate with respect to the sun, ρ is the density, c is the specific heat, k is the thermal conductivity, ε is the dielectric constant, and tan Δ is the loss tangent.

For the moon δ (ratio of electrical skin depth to thermal skin depth) $\approx 2.4\ \lambda$ with λ in centimeters (*11*). If we assume that the soil parameters for Callisto are the same as those for the moon, this result can be scaled by $(\omega/\omega_{\mathbb{C}})^{1/2}$ to give $\delta \approx 3.19\ \lambda$ for Callisto. By coincidence, this value of δ is approximately the same value that we would expect for a solid ice surface. The value of T_B from Eq. 3 then becomes at 3.71 cm:

$$T_B(l,b,3.71\text{ cm}) = E(l,b,3.71\text{ cm}) \times \cos^{1/4}b[T_0 + (T_v/17.5)\cos(l - 43°)] \quad (4)$$

As expected, the variation of physical temperature with longitude is now greatly attenuated and shows that at our wavelength of 3.71 cm we have essentially reached the isothermal layers of Callisto.

The quantity $E(l,b,\lambda)$ can be determined from ε using the Fresnel reflection coefficients, and T_D can be found from:

$$T_D = \int_{\text{disk}} T_B(l,b,3.71\text{ cm})\ d\Omega/\Omega \quad (5)$$

where Ω is the solid angle of Callisto. With different guesses for T_v we find the values of T_D shown in Table 1. Although the model temperatures tend to be slightly higher than our measured result, the agreement is good considering the uncertainties both in the model and in the measurement. If we simply scale directly from the moon using only the factor $(R/R_{\mathbb{C}})^{-1/2}$, we also find good agreement. The linear polarization to be expected because of the departure of our model from circular symmetry is well below 1 percent and could not have been detected in the observations.

The model is, of course, oversimplified. Not only is there the crude approximation for T_s (Eq. 2), the uncertainty in estimating T_v, and the approximate theory, but we have also not considered the effects of surface roughness. However, we have shown that the measurement is consistent with what would be expected for a dielectric sphere: our measurements do not permit us to distinguish between a lunar-type soil and a solid ice surface. The measurement is in agreement with the observations of Pauliny-Toth *et al.* (*6*) at $\lambda = 2.8$ cm which yield $T_D = 88° \pm 18°$K for Callisto, although their result is in somewhat worse agreement than ours with the model calculations. The results are in considerable disagreement with those of Gorgolewski (*1*) and Kuz'min and Losovsky (*5*), despite the slightly higher temperature to be expected at the shorter wavelengths.

GLENN L. BERGE
DUANE O. MUHLEMAN
Owens Valley Radio Observatory and *Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91109*

References and Notes

1. S. Gorgolewski, *Astrophys. Lett.* **7**, 37 (1970).
2. A. D. Kuz'min and B. Ya. Losovsky, *Icarus* **18**, 222 (1973).
3. J. S. Lewis, *ibid.* **14**, 174 (1971).
4. C. B. Pilcher, S. T. Ridgway, T. B. McCord, *Science* **178**, 1087 (1972); U. Fink, N. H. Dekkers, H. P. Larson, *Astrophys. J.* **179**, L155 (1973).
5. A. D. Kuz'min and B. Ya. Losovsky, *Sov. Phys. Dokl.* **18**, 511 (1974).
6. I. I. K. Pauliny-Toth, A. Witzel, S. Gorgolewski, *Astron. Astrophys.* **34**, 129 (1974).
7. One jansky $= 10^{-26}$ watt m^{-2} hertz^{-1}; 1 millijansky $= 10^{-29}$ watt m^{-2} hertz^{-1}.
8. *The American Ephemeris and Nautical Almanac* (for 1973) (Government Printing Office, Washington, D.C., 1971), p. 403.
9. A. Dollfus, in *Surfaces and Interiors of Planets and Satellites*, A. Dollfus, Ed. (Academic Press, New York, 1970), pp. 45–139.
10. J. H. Piddington and H. C. Minnett, *Aust. J. Sci. Res. Ser. A* **2**, 63 (1949).
11. D. O. Muhleman, in *Thermal Characteristics of the Moon*, J. W. Lucas, Ed. (MIT Press, Cambridge, Mass., 1972), pp. 51–81.
12. We thank J. Lieske for the ephemeris calculations, B. Schupler for help with the observations, W. Russell for assistance with the data reduction, and I. Pauliny-Toth *et al.* for communicating their results to us in advance of publication. This research was carried out under NASA grant NGR-005-002-114, Office of Naval Research contract N00014-67-A-0094-0019, and National Science Foundation grant GP30400-X.

9 September 1974

Morphine-Dependent Rats: Blockade of Precipitated Abstinence by Tetrahydrocannabinol

Abstract. *Male rats were implanted subcutaneously with a pellet containing 75 milligrams of morphine base or placebo, and naloxone hydrochloride (4 milligrams per kilogram of body weight) was administered 72 hours later. Treatment with Δ^9-tetrahydrocannabinol (2, 5, or 10 milligrams per kilogram) 1 hour before naloxone administration significantly reduced the intensity of abstinence; the two higher doses blocked the appearance of wet shakes and escapes, diarrhea, and increased defecation. Δ^9-Tetrahydrocannabinol did not induce abstinence itself, and prior treatment with cannabidiol was ineffective in reducing naloxone-precipitated abstinence in animals with morphine pellets. These data suggest that Δ^9-tetrahydrocannabinol may be of value in facilitating narcotic detoxification.*

Many compounds classified as narcotic antagonists possess some properties characteristic of narcotic agents themselves, and are thus termed "partial narcotic (opioid) agonists" (*1*). Many of these pharmacological properties, such as analgesia, hypothermia, and respiratory depression, are also exhibited by Δ^9-*trans*-tetrahydrocannabinol (THC), a major psychoactive constituent of marihuana (*2*). Despite a lack of more definitive evidence relating narcotics and the cannabinoids, we attempted to determine whether THC could act antagonistically to the effects of morphine in rats. We report that a single administration of THC produced a dose-related blockade of

naloxone-induced abstinence signs in morphine-dependent rats, whereas cannabidiol (CBD), a constituent of marihuana with relatively little effect on the central nervous system (*3*), did not modify abstinence.

Subjects were male Sprague-Dawley rats (Charles River CD strain; Wilmington, Mass.), 170 to 190 g at the time of surgery. Before and after surgery, animals had free access to food and water and were housed two to three per cage. A single pellet 9 mm in diameter containing 75 mg of morphine base or placebo (*4*) was implanted subcutaneously in the lower abdominal wall of each animal under light ether anesthesia.

Abstinence was induced by intraperitoneal injection of naloxone hydrochloride (4 mg/kg) 72 hours after surgery; at this time dependence, as reflected in intensity of abstinence for a fixed dose of naloxone, is maximal in rats with implanted morphine pellets (*5, 6*). One hour before induction of abstinence, animals were weighed and injected intraperitoneally with either a constant volume of the vehicle (a suspension of propylene glycol in saline and 1 percent Tween 80), THC (1, 2, 5, or 10 mg/kg), or CBD (10 mg/kg) for rats with morphine pellets, and with either THC (10 mg/kg) or a constant volume of the vehicle for rats with placebo pellets. The animals were then returned to their home cages.

One hour after cannabinoid or vehicle injections, rats were placed singly in clean wire mesh containers. After a 5-minute habituation period, animals were injected intraperitoneally with naloxone; their behavior was observed for 15 minutes while responses were recorded on standardized scoring sheets. Presence or absence of diarrhea was noted 30 minutes after naloxone administration.

The number of rats exhibiting each of several abstinence signs is shown in Table 1. The nine abstinence signs were selected from among those most consistently observed during naloxone-induced abstinence in animals with morphine pellets in our experiments, or were observed less frequently but were included for a comparison of different systems of abstinence scoring (Table 2). Fisher nonparametric statistical tests were used to compare the number of morphine-treated rats receiving THC or CBD that exhibited each sign with the number receiving the vehicle (morphine controls) that exhibited each sign. The data indicate that THC doses of 5 and 10 mg/kg significantly ($P < .05$) reduced the frequency of wet shakes and escapes, frequently used measures of abstinence, whereas CBD treatment did not prevent the appearance of these signs. Heightened gastrointestinal activity, as reflected in increased defecation and in diarrhea, was also significantly reduced after treatment of morphine-dependent animals with THC doses of 5 or 10 mg/kg. Animals with placebo pellets were virtually unaffected by naloxone administration, and a few animals receiving THC exhibited vocalization, a common accompaniment of cannabinoid administration (*7*), and ptosis. In no case did THC alone precipitate withdrawal signs in morphine-pelleted animals.

Mean abstinence scores obtained by two methods for each treatment group are shown in Table 2. Although the proportions of *animals* exhibiting signs 4 to 9 did not differ from those of morphine controls, the total number of *signs* exhibited by animals in the drug treatment groups appeared to decrease with increasing doses of THC. Thus, in the present system, one point is assigned to an animal for each of the nine signs observed; the total is that animal's abstinence score (maximum score of 9). In the Wei system (*6*), scores are assigned on the basis of the presence of key abstinence signs arranged in a hierarchy, with a maximum possible score of 3.

Mann-Whitney nonparametric statistical comparisons between abstinence scores of the morphine control group and the morphine groups given THC or CBD indicate that, regardless of scoring system, a significant reduction in abstinence occurred with a THC dose of 10 mg/kg but not with an equivalent dose of CBD. A decrease in abstinence related to THC dose and significant at 2 mg/kg is shown by scores of the present system, demonstrating the potential sensitivity of assessing abstinence by the use of a variety of measures. Sedation was not apparent at THC doses of 5 mg/kg or below at the end of 1 hour. Scores from the Wei system indicate that abstinence was significantly reduced with a THC

Table 1. Number of animals with morphine or placebo pellets in each drug group ($N = 7$ for each group) exhibiting abstinence signs during naloxone-induced withdrawal.

Abstinence sign	Morphine pellets						Placebo pellets	
	Morphine control (vehicle)	THC, 1.0 mg/kg	THC, 2.0 mg/kg	THC, 5.0 mg/kg	THC, 10.0 mg/kg	CBD, 10.0 mg/kg	THC, 10.0 mg/kg	Vehicle
Three or more wet shakes or escapes	6	2	3	1*	1*	5	0	1
Six or more fecal boluses	7	7	6	0*	1*	5	1	2
Diarrhea	5	2	2	0*	1	4	0	0
Vocalization	6	4	6	6	4	6	4	0
Ear blanching	6	4	3	5	6	7	0	1
Ptosis	6	4	4	7	7	7	5	1
Chewing movements	4	5	6	3	3	2	0	0
Abnormal posture	3	6	1	6	3	2	2	1
Teeth chattering	2	3	2	3	2	2	0	0

* $P < .05$ (Fisher, two-tailed), comparison with morphine control group.

Table 2. Mean abstinence scores for animals with morphine pellets, determined by the present system and that of Wei (*6*). In the present system, each of the seven animals in a group was assigned a score of 0 to 9, reflecting the number of abstinence signs in Table 1 that were exhibited after naloxone administration. In the Wei system, each animal received a score of 0 to 3, depending on the presence of selected signs observed after naloxone administration (*6*). The significance of differences between scores for the morphine control group and THC or CBD groups was assessed by Mann-Whitney tests; chance probabilities (P) for two-tailed comparisons are shown.

Group	Dose (mg/kg)	Present system		Wei system	
		Abstinence score (mean)	P	Abstinence score (mean)	P
Control		6.3		2.7	
THC	1	5.6	.42	1.8	.19
THC	2	4.6	.05	1.9	.21
THC	5	4.4	.01	2.0	.13
THC	10	4.0	.02	1.3	.03
CBD	10	6.0	.62	2.9	.99

dose of 10 mg/kg. The intermediate position of teeth chattering in Wei's hierarchy, even though it occurred infrequently in our study, combined with the more frequent occurrence of abnormal postures and ear blanching, may be responsible for the lack of a significant reduction in Wei abstinence scores at a 5 mg/kg dose of THC.

These results suggest that further exploration of the therapeutic utility of the tetrahydrocannabinols in narcotic detoxification is warranted. The possibility that such compounds may offer advantages over the widely used methadone substitution technique (*8*) or the proposed use of neuroleptics such as haloperidol (*9*) deserves further study. Methadone, for example, produces physical dependence, and haloperidol produces extrapyramidal side effects as well as morphine-like abstinence signs in animals after repeated administration is terminated (*10*). On the other hand, physical dependence has not been associated with the use of cannabinoids in humans (*11*); toxic effects appear minimal (*12*) when these compounds are used for relatively short periods, as might be required during narcotic detoxification.

B. HINE
E. FRIEDMAN
M. TORRELIO
S. GERSHON

Neuropsychopharmacology Research Unit, Department of Psychiatry, New York University School of Medicine, New York 10016

References and Notes

1. W. R. Martin, *Pharmacol. Rev.* **19**, 463 (1967).
2. P. Lomax, *Proc. West. Pharmacol. Soc.* **14**, 10 (1971).
3. R. Adams, D. C. Pease, J. H. Clark, *J. Am. Chem. Soc.* **62**, 2194 (1940); R. Mechoulam, A. Shani, H. Edery, Y. Grunfeld, *Science* **169**, 611 (1970).
4. Formulated according to the method of R. D. Gibson and J. E. Tingstad [*J. Pharm. Sci.* **59**, 426 (1970)].
5. T. J. Cicero and E. R. Meyer, *J. Pharmacol. Exp. Ther.* **184**, 404 (1973).
6. E. Wei, *Psychopharmacologia* **28**, 35 (1973).
7. B. G. Henriksson and T. Jarbe, *J. Pharm. Pharmacol.* **23**, 457 (1971).
8. J. H. Jaffe, in *The Pharmacological Basis of Therapeutics*, L. S. Goodman and A. Gilman, Eds. (Macmillan, New York, ed. 3, 1965), pp. 285–311.
9. J. Karkalas and H. Lal, *Int. Pharmacopsychiat.* **8**, 248 (1973).
10. G. Granutsos, R. B. Drawbaugh, M. D. Hynes, H. Lal, *Life Sci.* **14**, 887 (1974).
11. W. Bromberg, *Am. J. Psychiat.* **91**, 303 (1934); E. G. Williams, C. K. Himmelsbach, A. Wikler, D. C. Ruble, B. N. Lloyd, *Public Health Rep.* **61**, 1059 (1946).
12. M. Perez-Reves, M. C. Timmons, M. E. Wall, *Arch. Gen. Psychiat.* **31**, 89 (1974).
13. Supported in part by NIMH grant MH-04669. We gratefully acknowledge supplies of THC furnished by the Drug Abuse Research Advisory Committee of the Food and Drug Administration and National Institute of Drug Abuse.

29 July 1974; revised 17 September 1974

Primitively Columellaless Pollen: A New Concept in the Evolutionary Morphology of Angiosperms

Abstract. *Comparative study of pollen of the ranalean complex has revealed a remarkable, hitherto unrecognized characteristic of primitive angiosperm pollen, namely, its complete lack of columellae. Pollen with such exine has been designated* atectate *and taxa in the Magnoliaceae, Degeneriaceae, Eupomatiaceae, Annonaceae, and possibly Himantandraceae and Nymphaeaceae have pollen which is considered to be primitively columellaless.*

The pollen wall of most angiosperm pollen grains consists of two fundamentally different layers: an inner, more or less uniform cellulosic layer known as the intine, which is usually destroyed on acetolysis (*1*), and an outer, generally much more complicated and taxonomically useful acetolysis-resistant layer, the exine, which is composed of oxidative polymers of carotenoids or carotenoid esters, or both, known as sporopollenin (*2*). Recently, Van Campo (*3*) pointed out that the presence of distinct, well-defined, internal, upright, rodlike elements known as columellae, covered by a rooflike layer or tectum (tectate-columellate pollen, Fig. 1A) rather than a honeycomb-like network or an irregular spongy layer (alveolate pollen, Fig. 1B), is one of the main features in which the exine of angiosperm pollen grains differs in general from that of gymnosperms.

However, comparative study of pollen of the ranalean complex has revealed that the pollen exine in some of the most primitive families of angiosperms is structurally amorphous and devoid of any trace of either a columellate or alveolate structure (Fig. 1, C and D). Moreover, study of character correlation within the ranalean complex of primitive angiosperms strongly favors recognition of a major evolutionary trend; this goes from pollen with

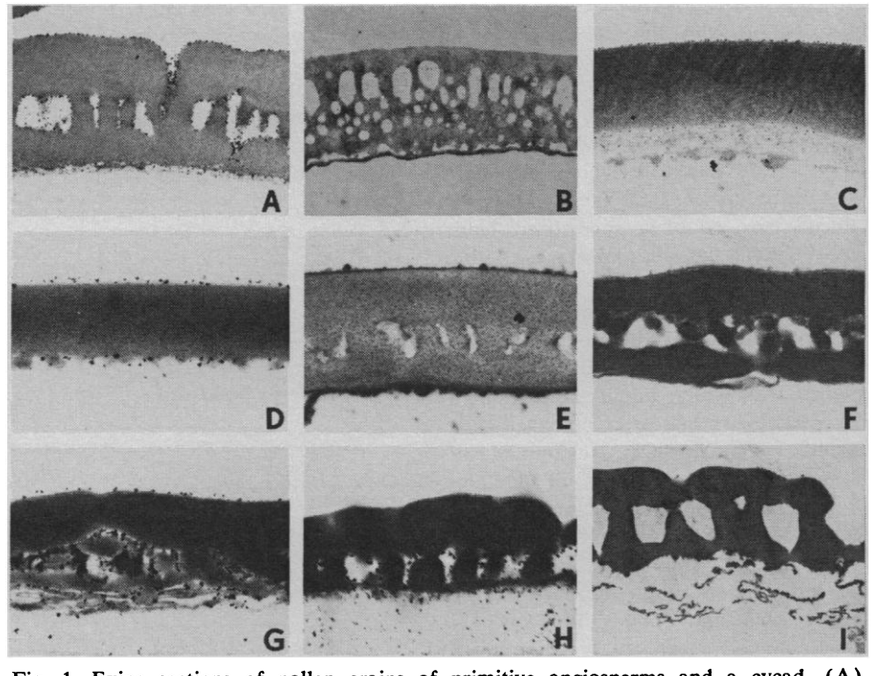

Fig. 1. Exine sections of pollen grains of primitive angiosperms and a cycad. (A) *Calycanthus floridus* L. (Calycanthaceae), with tectate-columellate pollen with well-developed columellae (× 9,425). (B) *Cycas revoluta* Thunb. (Cycadaceae), with aleveolate pollen (× 7,000). (C) *Degeneria vitensis* I. W. Bailey & A. C. Smith (Degeneriaceae), with atectate pollen (× 13,000). (D) *Eupomatia laurina* R. Br. (Eupomatiaceae), with atectate pollen (× 24,375). (E) *Aromadendron elegans* Blume (Magnoliaceae), with granular pollen with presumed incipient columellae (× 18,200). (F) *Magnolia fraseri* Walt. (Magnoliaceae), with granular pollen with presumed incipient columellae (× 14,950). (G) *Uvariastrum zenkeri* Engler & Diels (Annonaceae), with granular pollen (× 13,300). (H) *Desmopsis bibracteata* (Robinson) Saff. (Annonaceae), with granular pollen with presumed incipient columellae (× 19,475). (I) *Asimina pygmaea* (Bartr.) Dunal (Annonaceae), with pollen with well-developed columellae (× 3,795).