Table 1. Two elemental analyses of organic mat. Oxygen determined by difference; no halogens were detected.

Element (%)				
C	H	N	S	O
58.65	7.45	0.73	8.67	24.50
59.77	7.85	.70	8.60	23.08

and vascular plants do so by 20 to 30 per mille relative to the starting CO_2. Thus, no single-step photosynthetic process could have produced the measured enrichments. Methane bacteria can effect fractionations of $\delta C^{13} = -67.5$ per mille during the degradation of methanol to methane under laboratory conditions (*11*); the carbon dioxide produced during this process was depleted in C^{12} relative to the starting methanol.

Thus it appears that a mat is the end member of a series of transformations in which several fractionation steps have occurred. We consider two possibilities:

1) The release along fissures of methane, from either petroleum or gas reservoirs, or related to thermal activity; oxidation of this methane to carbon dioxide, and its subsequent fixation either photosynthetically by lagoonal algae and bacteria or chemosynthetically by sulfur-oxidizing bacteria.

2) Release of carbon dioxide at the bottom of a lagoon during anaerobic decomposition of algal and terrestrial plant remains; photosynthetic fixation of this CO_2 at the surface, and recycling.

In either case, dilution by dissolved and atmospheric carbon dioxide would occur. The C^{14} ages determined demand that such dilution occurred if step 1 was operating.

Our results point strongly to derivation of both the fractionation and organic material from vital processes *in situ*. It is further suggested (*1*) that these processes are also responsible for the high concentration of elemental sulfur localized in this area. It is obvious, however, that a complex set of conditions may have prevailed. The ability to test such relatively young material points to the dangers of offering interpretations of isotope ratios of old organic matter where single-step fractionations are invoked.

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References and Notes

1. A. Nissenbaum and I. R. Kaplan, in preparation.
2. L. V. Illing, A. J. Wells, J. C. M. Taylor, in *Dolomitization and Limestone Diagenesis*, L. C. Pray and R. C. Murray, Eds. (Soc. Econ. Paleontologists Mineralogists Spec. Paper 13, 1965).
3. With simultaneous-collection mass spectrometers (Nier-McKinney type) by the Institute of Nuclear Sciences, New Zealand; Chevron Research Corp., Calif.; and California Institute of Technology.
4. By S. Epstein, California Inst. of Technology.
5. B. N. Smith, S. Epstein, I. R. Kaplan, unpublished.
6. S. R. Silverman, in *Isotopic and Cosmic Chemistry*, H. Craig *et al.*, Eds. (North-Holland, Amsterdam, 1964), p. 92.
7. By the Institute of Nuclear Science, New Zealand.
8. By the Institute of Geophysics, Univ. of California, Los Angeles.
9. H. Craig, *Geochim. Cosmochim. Acta* **3**, 53 (1953); K. Rankama, *Isotope Geology* (McGraw-Hill, New York, 1954): J. Hulston and W. McCabe, *Geochim. Cosmochim. Acta* **26**, 399 (1962); G. J. Wasserburg, E. Mazor, R. E. Zartman, in *Earth Science and Meteoritics* (North-Holland, Amsterdam, 1963); E. S. Cheney and M. L. Jensen, *Geochim. Cosmochim. Acta* **29**, 1331 (1965).
10. P. H. Abelson and T. C. Hoering, *Proc. Nat. Acad. Sci. U.S.* **47**, 623 (1961); R. Park and S. Epstein, *Geochim. Cosmochim. Acta* **21**, 110 (1961).
11. W. D. Rosenfeld and S. R. Silverman, *Science* **130**, 1658 (1959).
12. We thank T. A. Rafter, S. Epstein, S. R. Silverman, and R. Berger whose laboratories made the stable-isotope and C^{14} measurements. The study was initiated while I.R.K. was Ziskind Visiting Scholar at the Hebrew University, Jerusalem; it was generously assisted by the Israel Geological Survey. Institute of Geophysics and Planetary Physics publication 500.

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Radio Sources: Angular Size from Scintillation Studies

Abstract. *The frequency spectrum of fluctuations caused by interplanetary scintillations may give a sensitive estimate of the diameter of a radio source. Observations of 3C 138, 3C 245, 3C 267, and 3C 273 give diameters of 0.1, ≤ 0.04, ≤ 0.2, and ≤ 0.02 second of arc, respectively. Resolution is at least a factor of 5 higher than that obtained to date by means of either radio interferometers or lunar occulations.*

A radio source may scintillate when observed close to Sun because the rays are diffracted by irregularities in the solar wind. These interplanetary scintillations (*1*) occur only for very narrow sources because a wide source produces overlapping fluctuation patterns on the ground and the net fluctuations are smoothed out (*2*).

Suppose the scintillations are produced in a layer of thickness $L << z$, where z is the distance from Earth (Fig. 1). A source consisting of two points separated by θ produces patterns separated laterally by θz. A source spread continuously through the angle θ produces a smearing over distances θz. If the scale S of the diffraction pattern caused by the irregularities themselves (the point-source pattern) is much greater than θz ($S/\theta z >> 1$), the source behaves as a point source. If $S/\theta z << 1$, there are no scintillations.

In intermediate cases, the pattern is the convolution of the point-source pattern with the brightness distribution of the source. If S is known, limits can be placed on the diameter of a source according to whether or not it scintillates (*1, 2*). A much more sensitive estimate, however, can be obtained by measuring the scintillation spectrum.

Figure 1 shows that all Fourier components with wavelength shorter than about $2\theta z$ are smoothed out. If the screen is moving parallel with itself with velocity u, the diffraction pattern also moves with velocity u. An observer at a fixed station sees the pattern as a function of time, and the frequency spectrum is cut off at $f_c \approx u/(2\theta z)$. If the cutoff frequency can be measured,

Table 1. Details of four radio sources (see text). Int, interferometer; occ, occulation; ct, component(s).

Source	Diameter (sec)	Relative strength	Posn. angle (deg)	$\Delta\lambda/\lambda_o$	Linear diameter (parsec)	Remarks
3C 138	~0.1	0.8 (195)	015			Int: ~ 0″.5 (*11*)
3C 138		.7 (430)				
3C 245	< .04	> .3 (430)	145	1.029 (*5*)	<145	Int: > 12″ (*6*); occ: ct < 0″.5 (12)
3C 267	< .2	> .3 (430)	037			Int: ~ 47″ (*13*); < 0′.7 (*14*)
3C 273	< .02	.2 (195)	160	0.158 (*10*)	< 34	Int: ct < 0″.1 (*6*); occ: ct < 1″ (*15*); ct < 0″.15 (*7*)
3C 273		.3 (430)				
3C 273		> .3 (611)				

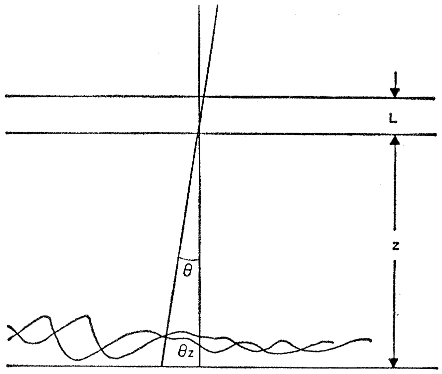

Fig. 1. Diffracting screen of thickness L and height z. Components of source separated by θ produce diffraction patterns identical but separated by θz.

then the angular size of the source can be estimated from $\theta \approx u/(2f_c z)$. A more detailed analysis, if one assumes a gaussian source, gives the value of the half-power angular width ψ as 0.266 $u/f_o z$, where f_o is the standard deviation of the (gaussian) frequency spectrum.

We have observed (*3*) interplanetary scintillations at three frequencies: 195, 430, and 611 MHz. Intensity at each frequency is recorded digitally, and the fluctuation spectrum (*4*) is calculated. We have observed the three quasi-stellar sources (quasars) 3C 138, 3C 245, and 3C 273 when they were close to Sun (within 7°). At this elongation the root-mean-square phase deviation $\phi_o >$ 1 (at 195 and 430 MHz); S is reduced below a, the scale of the phase-fluctuation spectrum on the screen (*1*); and there is increased opportunity to measure a cutoff frequency. We have seen a cutoff at $f \approx 1.5$ cy/sec for 3C 138 (at 195 and 430 MHz) and no sign of a cutoff for 3C 245 for $f \leqq 5$ cy/sec (at 430 MHz); nor for 3C 273 for $f \leqq$ 10 cy/sec (at 195 and 430 MHz). (The 611-MHz data always give a weaker limit, and we have no 195-MHz data for 3C 245.) An angular diameter ψ may be inferred from these observations by use of $u = 350$ km/sec and $z = 1$ A.U. (astronomical unit) (see Table 1, column 2).

Column 3 of Table 1 gives a rough estimate of the relative strength of the narrow component of the source; this is made by measuring the minima of the scintillation pattern and by assuming that the radiation from the narrow component can go to zero in the strong scattering regime. In some instances we are not certain of the regime and indicate only a lower limit to the relative strength; frequency in megahertz appears in parentheses.

We also list in Table 1 source 3C 267 as an example of a source not previously known to have a small diameter component; the diameter limit is higher than the others because the observations were made farther from the sun (~12°) where $\phi_o < 1$ (at 430 MHz, the only frequency used) and $S \approx a$.

Column 4 of Table 1 gives the position angle for the observations, assuming a radial motion for the irregularities. Column 5 gives the redshift $\Delta\lambda/\lambda_o$, where it is known. Column 6 gives the linear diameter, obtained by assuming: the redshift to have a cosmological origin, $H = 100$ km sec^{-1} Mpc^{-1} (megaparsec), and $q_o = +1$ (*5*). Column 7 gives other diameter information, obtained from interferometer and occultation observations.

This interpretation of the scintillation observations is consistent with the occultation observations, but is partially inconsistent with the interferometer observations. In the case of 3C 245 and 3C 267, the discrepancy may be explained by the weak relative strength of the narrow component and the resulting poor visibility. We are able to establish diameter limits a factor of at least 5 smaller than limits set by either interferometer (*6*) or lunar occultations (*7*).

The upper limit to the linear dimension of the component of 3C 273, 34 parsecs, is the smallest dimension yet measured in an extragalactic radio source. The observed temporal variations of the source (*8*) suggest that the dimensions are much smaller yet: possibly a few light years for the radio source and only light weeks for the optical source. Our measured limits are also consistent with the theory of synchrotron self-absorption, which predicts diameters of 10^{-2} to 10^{-4} seconds of arc for sources with curved spectra (*9*).

A full account of these observations, with a detailed theory of the interplanetary scintillations, is being published elsewhere.

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References and Notes

1. A. Hewish, P. F. Scott, D. Wills, *Nature* **203**, 1214 (1964).
2. B. H. Briggs, *Geophys. J.* **5**, 306 (1961).
3. At Arecibo Ionospheric Observatory (operated by Cornell Univ. with the support of ARPA under a contract with AFOSR).
4. M. H. Cohen, *Nature* **208**, 277 (1965).
5. M. Schmidt, *Astrophys. J.* **141**, 1295 (1965).
6. R. L. Adgie, H. Gent, O. B. Slee, A. D. Frost, H. P. Palmer, B. Rowson, *Nature* **208**, 275 (1965).
7. C. Hazard, S. Gulkis, A. Bray, *ibid.*, in press.
8. H. J. Smith and D. Hoffleit, *ibid.* **198**, 650 (1963); W. A. Dent, *Science* **148**, 1458 (1965); E. Epstein, *Astrophys. J.* **142**, 1285 (1965); F. J. Low, *ibid.*, p. 1287; W. A. Dent, *ibid.* **144**, 843 (1966).
9. V. I. Slish, *Nature* **199**, 682 (1963); P. J. S. Williams, *ibid.* **200**, 56 (1963).
10. M. Schmidt, *ibid.* **197**, 1040 (1963).
11. B. Anderson, W. Donaldson, H. P. Palmer, B. Rowson, *ibid.* **205**, 375 (1965).
12. C. Hazard, M. B. Mackey, W. Nicholson, *ibid.* **202**, 227 (1964).
13. L. R. Allen, B. Anderson, R. G. Conway, H. P. Palmer, V. C. Reddish, B. Rowson, *Monthly Notices Roy. Astron. Soc.* **124**, 477 (1962).
14. P. Maltby and A. T. Moffet, *Astrophys. J. Suppl.* **7**, 141 (1962).
15. S. von Hoerner, *Astrophys. J.* **144**, 483 (1966).

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Movement Directions in Late Paleozoic Glacial Rocks of the Horlick and Pensacola Mountains, Antarctica

Abstract. *Striae and associated structures beneath and within the Buckeye Tillite in the Ohio Range of the Horlick Mountains show that Permian(?) glaciers moved toward the west-southwest. Striae in the Wisconsin Range of the Horlicks display similar orientation, but the sense of movement could not be determined. Paleoglaciers in the Neptune Range and the Cordiner Peaks of the Pensacola Mountains moved toward the south-southwest with some dispersion. Paleocurrents flowed parallel to ice motion in the Ohio Range and in the Pensacolas, but they also flowed toward the north-northeast in the Pensacolas.*

Glacial deposits of late Paleozoic age were discovered in 1960 (*1*) in the Ohio Range of the Horlick Mountains (Fig. 1). Similar rocks were subsequently found in the Wisconsin Range of the Horlick Mountains (*2*) and in the Pensacola Mountains (*3*). During the austral field season of 1965–66, the Ohio Range glacial deposits and those of the Wisconsin Range and the Pensacola Mountains were studied (*4*). We now report the paleoglacial and associated paleocurrent directions for three areas in Antarctica for which there has been a paucity of such information.