Obsidian Hydration Rate for the Klamath Basin of California and Oregon

Abstract. *A hydration rate for obsidian of 3.5_4 microns squared per 1000 radiocarbon years has been established at the Nightfire Island archeological site in northern California and provides a means to date other prehistoric Klamath Basin sites. The new rate follows the form of the hydration equation formulated by Friedman and helps to refute claims made for other hydration equations.*

A hydration rate for obsidian of 3.5_4 μ^2 per 1000 radiocarbon years has been established for the Klamath Basin of California and Oregon. The study was conducted as a part of the Nightfire Island Project (*1*) of the University of Oregon's Museum of Natural History. The new rate provides a means to date prehistoric Klamath Basin obsidian-chipping and habitation sites in terms of their radiocarbon age.

The history of obsidian dating has been reviewed by Michels (*2*), and detailed explanations of the technique have been presented by Friedman and Smith (*3*) and Friedman *et al.* (*4*). In order to calculate local rates of hydration for obsidians of different chemical compositions occurring in different climatic regions, correlations are made by regression analysis between a large number of obsidian measurements and contextually associated C^{14} age determinations in each area. The time span of the C^{14} dates must be large because the regression line is curvilinear. If the span of the C^{14} dates is short, the otherwise curvilinear relation will tend to appear linear.

The Klamath Basin rate was calculated from data acquired during the 1967 excavation season at the Nightfire Island archeological site (4SK4) in Siskiyou County, northern California. The site is on the margin of the dry lake bed of Lower Klamath Lake, near the original western shore. It is 3.2 km south of the Oregon-California border at 41°58′N, 121°48′W. Sometime after the climactic eruption of Mount Mazama, Oregon (*5*), now dated at 7000 radiocarbon years B.P. (*6*), much of Lower Klamath Lake either drained or dried, and the forebears of the historic Modoc Indians moved onto the margins of the dry lake bed and began using the Nightfire Island site as a habitation, fishing, and duck-hunting station. This occupation dates from about 6000 to 500 radiocarbon years B.P.

A given hydration rate is applicable only to the climatic zone where it was established. The present hydration rate applies only to the Klamath Basin which includes Upper Klamath Lake, the Lost River drainage, Lower Klamath Lake, and Tule Lake. The mean annual temperature of the basin is 8°C, with a January average of −2°C and a July mean of 21°C. High temperatures of over 15°C are maintained for a 4-month period from June through the first part of October (*7*). It would be unwise to attempt to use the Klamath Basin rate in any precise way outside this local region. The Great Basin proper, to the east, has higher temperatures. The Cascade Mountains, to the west, and the mountainous California highlands, to the south, are colder.

Nightfire Island was excavated by an interval sampling method, in pits (2 by 2 m) situated approximately 10 m apart. The deepest, best stratified excavation pit (N100-E86) was selected for the rate determination. I attempted to get C^{14} dates from each level and measured and correlated only obsidian flakes from the levels of that pit (*8*). It is better to limit the size of the obsidian sample in this way to preserve an intimate stratigraphic association between obsidian and datable charcoal, rather than to increase the size of the obsidian sample by the use of additional flakes from other pits presumed to be correlated with C^{14} dates from the original control pit. A single C^{14} assay and associated obsidian from a second pit (N72-E100) were included in the study to represent the latest period of occupation not present in the control pit.

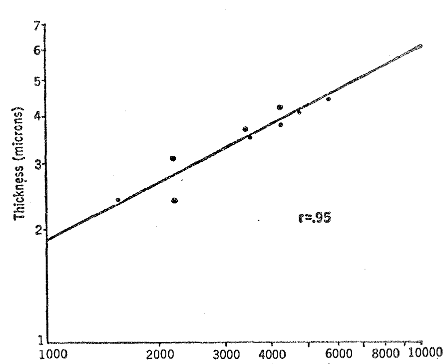

Fig. 1. Least-squares regression line for C^{14} dates (x-axis) and means of hydration-layer measurements (y-axis), Nightfire Island site; r is the product-moment correlation coefficient.

Eleven C^{14} age determinations were made at Gakushuin University, Japan. Each level of the site was represented by one C^{14} date with a single exception where two dates were obtained and their activities averaged. There is an average of 11 measured obsidian specimens for each of the ten dated site levels (Table 1).

The thickness of the hydration layer for each thin section represents the mean of a number of measurements made at several loci. The average number of measured loci per specimen is three; the average number of measurements per specimen is eight. The mean of each level (Table 1) is an average of the individual specimen means of that level.

The specimen measurements have a pooled standard deviation of 0.2 μ. This figure includes at least three components of variance: (i) variation in thickness of the hydration rim, (ii) instrumental variance, and (iii) observer error.

The mean thicknesses of the hydration layers for each level and their associated C^{14} dates appear in Table 1. Also listed are standard deviations for each level which reflect the distribution of specimen measurements around the level mean. Some standard deviations are large, and those for levels in close proximity tend to overlap. It appears that the large standard deviations for each level reflect a degree of mixing of noncontemporaneous specimens, rather than variation in the chemical composition of the specimens. I will return to this point.

Figure 1 presents the distribution of the mean thicknesses of the hydration layers for the ten levels and associated C^{14} dates (which are also means). I chose time as the independent variable (*9*) since the hydration rate is to be determined from the C^{14} age determinations. Analysis by the least-squares method was used to determine regression coefficients, expressed in terms of the line intercept and slope. Since the hydration layer grows at an ever-decreasing rate, the regression line is curvilinear.

An equation of the form

$$y = a \cdot x^b$$

where both a and b are coefficients, will provide a good fit for a regression curve of the type indicated by obsidian hydration. This is a power function which in logarithmic form becomes the linear regression equation

$$\log y = \log a + b (\log x)$$

If we carry out the necessary calculations, $\log a = -1.2679$ and $b = 0.512$. The power function can now be written

$$y = 0.054x^{0.512}$$

However, before the hydration rate can be determined, the values of both a and b must be altered.

The hydration equation, as expressed by Friedman *et al.* (*4*), is

$$H^2 = kt$$

or

$$H = k^{1/2}t^{1/2}$$

where H is the thickness of the hydrated layer, k is the environmental-petrologic constant, and t is the time in radiocarbon years. The equation used by Friedman is related to the power function in this way: $H = y$, $k = a^2$, $t = x$, and 0.5 (the exponent of t) $= b$.

Friedman's b-value (0.5) was established in a rigorous experiment with freshly chipped obsidian from Tres Piedras, New Mexico (*4*), and should be valid universally. The Klamath Basin value of b, however, is 0.512. To test whether it is significantly different from 0.5, I used a statistic based on the t-distribution, for two regression lines having the same intercept (*10*). The null hypothesis that $b = 0.5$ is accepted at the .10 level.

Since Friedman's b-value was established rigorously, it will be substituted for $b = 0.512$. If $\log a$, which is dependent upon b, is recalculated, the new value is $\log a = -1.2249$. The power function is therefore rewritten

$$y = 0.059x^{1/2}$$

and the hydration equation can be solved for k to give a value of 0.00354. The hydration rate for Klamath Basin obsidian, therefore, is 3.5_4 μ^2 per 1000 radiocarbon years.

The purpose for which the hydration rate is determined is to enable one to predict age in radiocarbon years from given obsidian measurements; that is, the archeological application of obsidian dating makes possible the prediction of a chronometric age from measured obsidian flakes or artifacts.

Table 1. Carbon-14 dates and hydration-layer measurements for obsidian samples from ten levels of the Nightfire Island site (4SK4), California.

Years (B.P.)	Sample No.	No. of specimens	Level mean (μ)	Level S.D. (μ)
1540 ± 100	GaK-1841	5	2.4	0.3
2180 ± 80	GaK-1831	5	2.4	.7
2340 ± 100	GaK-1832	8	2.7	.6
2180 ± 90	GaK-1833	5	3.1	.7
3470 ± 80	GaK-1834	11	3.5	.8
3450 ± 90	GaK-1835	15	3.7	.8
4260 ± 100	GaK-1836	18	3.8	.7
4750 ± 110	GaK-1837	14	4.1	.4
4030 ± 90, 4500 ± 110 *	GaK-1838, GaK-1839	16	4.2	.9
5750 ± 130	GaK-1840	10	4.4	.6

* $\overline{X}_{\text{activity}} = 4265$ years (B.P.).

To do this most accurately, one should substitute logarithms of given values of y (microns) into the following formula, making use of the b-value of 0.5 and the best estimate of $\log a$:

$$\log x = 2(\log y + 1.2249)$$

In addition to temperature, chemical composition of obsidian affects the hydration rate. For example, trachytic obsidian will hydrate more rapidly than rhyolitic obsidian (*3*). Since the silica content is systematically related to the abundance of other oxides in igneous rocks, a simple procedure was used to determine the variability in the silica content of the Nightfire Island obsidian. I selected the specimens with the highest and lowest hydration-layer measurements from each of the ten dated levels: two specimens for each level, 20 for the site. I then measured the index of refraction of these flakes by the immersion method with white light. The index ranges from 1.489 to 1.492, and the mean is 1.490. The measured specimens are thus uniform within the precision of the method. To determine the silica content, the glass-bead method (*11, 12*) was used with a flake that had produced a refractive index of 1.490 for natural glass. The resulting fused glass bead has a refractive index of 1.487. The corresponding silica content is 72 ± 2 percent (*12*).

The results of the above measurements indicate that the obsidian is rhyolitic. The refractive indices and, by inference, the silica content of the specimens, are uniform. Therefore, variation in silica content cannot be used to explain the relatively large intralevel standard deviations of the hydration-layer measurements. Mixture of noncontemporaneous items can be posited as one possible explanation.

Meighan *et al.* (*13*) presented a hydration graph for western Mexico which purports to be linear. Clark (*14*) presented data from California described by the equation

$$H = At^{3/4}$$

In both instances the data do not appear to follow the form of Friedman's hydration equation. In a criticism of the article by Meighan *et al.*, Friedman and Evans (*15*) defended the equation used by Friedman; Meighan *et al.* (*16*) replied that a linear equation best fits their data and implied that the nature of the hydration process must be determined in each geographic area.

It is important to underline, for archeologists, the universality of Friedman's equation. It is not restricted to specific geographic areas. It is based on theory and on a controlled laboratory experiment (*4*) which is far more rigorous and exact than any rate determination in the field can be. The correspondence between the Klamath Basin b value and the experimental b value demonstrates that the equation holds for archeologic applications where adequate data are available. The lack of correspondence between data from western Mexico and California and this equation casts doubt on those rate determinations, not upon the equation used by Friedman.

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References and Notes

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6. Two recent assays for a charcoal sample found enclosed in pumice lapillistone on Muir

Creek, Oregon, produced C^{14} dates of 7010 ± 120 (GaK-1124, unpublished data) and 6940 ± 120 [Tx-487, *Radiocarbon* **10**, 389 (1968)]. These are the most reliable dates, so far, for the major eruption of Mount Mazama.
7. The climatological data used here are from *U.S. Weather Bureau-Climatic Summary of the United States* (Supplement for 1931–1952); *Climate and Man* (U.S. Department of Agriculture, Washington, D.C., 1941); R. M. Highsmith, *Atlas of the Pacific Northwest* (Oregon State Univ. Press, Corvallis, 1962).
8. Thin sections were ground to a thickness of 0.05 to 0.10 mm by means of a slurry of size-600 abrasive powder and water. Measurements were made at 600 magnifications under normal light with a Vickers–A.E.I. image-splitting eyepiece. The manufacturer claims that the Vickers eyepiece is accurate to 0.1 μ, which is therefore the theoretical precision limit for any set of measurements made with this particular device. Claims of a better precision cannot be substantiated.
9. The results of the C^{14} age determinations are given as "radiocarbon years" to distinguish them from calendric years, which they are not. Conversion to calendric time is still an uncertain, complex process and for that reason it is not attempted here. Factors which would have to be taken into account are the new C^{14} half-life and the production rate of C^{14} by cosmic rays. See M. Stuiver and H. E. Suess, *Radiocarbon* **8**, 534 (1966); P. E. Damon, A. Long, D. C. Grey, *J. Geophys. Res.* **71**, 1055 (1966).
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17. I am grateful to Dr. L. R. Kittleman, Museum of Natural History, University of Oregon, for valuable advice throughout the entire study and for making the silica determination by the glass-bead method.

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Polar Temperature of Venus

Abstract. *The presence of substantial polar cooling of Venus, as derived from microwave interferometry at 10.6 cm wavelength, is shown to be open to doubt. Other microwave measurements give little evidence for significant poleward variation in temperature on the planet.*

Earth-based microwave measurements of the polar temperature of Venus at 10.6 cm (*1*) have been thought to show the presence of substantial polar cooling on Venus, with the poles approximately 25 percent cooler than the equator. Such cooling would be very significant in consideration of Venus's meteorology and biogenic capability, and the measurements have been used to support the hypothesis of ice caps on the planet (*2*).

However, reexamination of the interferometric data at 10.6 cm, from which the cooling was primarily deduced, indicates that a systematic error was present. Polarization measurements at the same frequency show some evidence for polar cooling, with magnitude 23 percent (*3*), but the measurement is uncertain.

A recent interferometric study at 3.12 cm (*4*) has shown no significant departure from a circularly symmetrical distribution for the observed disk brightness. The high atmospheric opacity at this wavelength implies, however, that the surface temperature was not directly measured.

The 10.6-cm interferometric study of Venus's polar cooling was made during the period of the inferior conjunction of 1964. The technique has been described (*5*), and we need note here only that at each instant a microwave interferometer gives an output, termed the fringe visibility, which is the instantaneous sample of the Fourier transform of the source brightness. The sampling point is determined by the length and orientation of the interferometer base line, the line joining the two telescopes which comprise the interferometer, as viewed foreshortened from the source. Figure 1 shows how the projected base line varies as the earth rotates during the day, with time measured by the hour angle of the source. We have chosen the latitude of the interferometer (37°) and the declination of the source (20°) as those which obtained during the 10.6-cm observations of Venus.

For a planet with polar cooling, in contrast to circularly symmetric brightness distribution, the fringe visibility is dependent on the base line orientation. The magnitude of the cooling may be derived from the difference in fringe visibilities for base lines with the same projected length, but with differing position angles with respect to the pole. For base lines with the same inclination with respect to the pole, and with the same projected length, there will be no difference in fringe visibility, regardless of the form or amount of polar cooling.

The observations of Clark and Kuz'min extended from 25 May to 18 July 1964. During the period 4 to 10 June, the position angle γ of the Venus pole was less than 1°, as now known from radar measurements of the pole position (*6*). The projected east-west base line was then equally inclined to the pole of Venus for the two times at equal hours before and after meridian transit. This can be seen by reference to Fig. 1, which shows base lines for $+4^h$ and -4^h. Since the lengths of the projected base lines were equal for these two times, the visibilities measured—$F_<$ for the time before meridian transit and $F_>$ for the time after meridian transit—should have been the same, as discussed above.

Figure 2 shows the results obtained by Clark and Kuz'min, together with the curve predicted with the use of a model (*7*) with no polar cooling. It can be seen from Fig. 2 that from 4 to 10 June, the measured $F_<$ (filled circles) was consistently smaller than $F_>$ (open circles). For $\beta = 0.438$ this difference was five times the random error from noise.

If the effect is real, it would indicate an extraordinarily large temperature gradient across the planet with the cold points strongly displaced from the poles of Venus. With a displacement of 45° in position angle, giving the smallest gradient for a given difference in $F_> - F_<$, the cold point would have to be at a temperature some 500°K cooler than the average temperature. Such an asymmetric cooling is unlikely on physical grounds, because it is known from the radar results that for Venus the orbital plane and the equator are inclined by only 1.2°, while the dense atmosphere of Venus is unlikely to sustain the large thermal gradients described.

It is more probable that the difference was due to a systematic error. The error may possibly be explained as arising from an error in telescope pointing for easterly hour angles $H < 0$, greatest when the source had just appeared above the horizon (*8*).

From the differences $F_> - F_<$ the data of 27 to 30 June and 10 to 13 July indicate some polar cooling, but a similar systematic error cannot be excluded. We therefore conclude that the 10.6-cm measurements give no reliable interferometric evidence for polar cooling on Venus.

Observations at 3.12 cm have been made by Berge and Greisen (*4*). Their measurements were made at base lines such that the projected length was constant, while their inclinations from Venus's north pole were either 20° or 70°. The difference in fringe visibilities ΔF under these conditions was