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Some Practical Applications of Obsidian Hydration Dating in the Subarctic

D.W. CLARK[1]

ABSTRACT. Eight case studies of obsidian hydration dating in the Koyukuk River region of northwestern interior Alaska are discussed. Historiographic conclusions include recognition of late and early microblade industries, apparent verification of the hypothesis that northern fluted points date within a Paleo-Indian time frame, and validation of a Tuktu-like first millennium A.D. Northern Archaic phase. However, variance in the data and lack of firm hydration rates render the results less precise than is desired.

Methodological conclusions have ramifications that should apply throughout the subarctic region and well beyond. These are: 1) Hydration measurements may be unreliable for dating individual specimens; 2) Lack of closely controlled hydration rates or dependence on 14-C dates with large errors for calibration can be crippling; 3) The average of a series of specimens can be used to date components which were formed during a brief period of occupation, though high variance of the data may be disconcerting; 4) Variance was low in one case for specimens all derived from the same piece of raw material, but for dating it may be necessary to find, through induced hydration or other means, the precise hydration rate applicable to each different piece of raw material (from a single component); and 5) Many variables may be responsible for results which render some sample sets unreliable or unusable, especially those from surface sites. Some of these variables require further technical investigation — loss of the hydration layer and recommencement of hydration after exposure to forest and tundra fires, for instance. Other factors are reasonably well understood by researchers, but it would be desirable to have computer simulations of site contexts in order to assess the magnitude, correlations, and cumulative results of their effects.

Key words: archaeology, western Subarctic, Alaska, dating, obsidian, obsidian hydration

RÉSUMÉ. Il y est question de huit études individuelles de datation d'après l'hydration de l'obsidienne, portant sur des spécimens mis au jour dans la région de la rivière Koyukuk, à l'intérieur des terres du nord-ouest de l'Alaska. Les études historiographiques ont révélé la présence d'industries à microlames anciennes et récentes, confirmé l'hypothèse selon laquelle les pointes cannelées du nord datent de l'époque paléo-indienne et renforcé l'hypothèse d'une culture archaïque du nord de type tuktu qui remonterait au premier millénaire apr. J.-C. Cependant, la fluctuation des données et l'incertitude des chiffres relatifs à la vitesse d'hydratation compromettent l'exactitude des résultats.

Par leurs ramifications, les conclusions méthodologiques devraient s'appliquer à l'ensemble du territoire subarctique et bien au-delà. Voice quelles sont ces conclusions: 1) On ne peut se fier aux mesures d'hydratation pour dater des spécimens isolés; 2) L'absence de valeurs d'hydratation rigoureusement contrôlées ou la dépendance vis-à-vis des dates obtenues par la méthode du carbone 14 avec une grande marge d'erreur dans l'étalonnage risque d'entraver les recherches; 3) La moyenne des données prélevées sur une série de spécimens peut servir à dater des éléments qui se sont formés rapidment, mais les écarts prononcés entre les données peuvent être déconcertants; 4) La fluctuation des données a été modeste dans le cas d'une séries de spécimens qui proviennent d'une seule pièce de matière première. Mais pour la datation, il peut être nécessaire de trouver le chiffre precis relatif à la vitesse d'hydratation. Celle-ci s'applique à chaque pièce de matière première différente (qui provient d'un seul site constituant) par moyen d'hydratation induite ou par d'autres méthodes; et 5) De nombreuses variables peuvent être à l'origine de résultats qui rendent incertaines ou inutilisables certaines séries d'échantillons, en particulier celles qui proviennent des sites de surface. Certaines de ces variables exigent des études technique plus poussées. Mentionnons à titre d'exemple l'évaporation de l'eau dans la couche hydratée et la réhydratation de cette couche à la suite d'un incendie de forêt ou de toundra. D'autres facteurs sont raisonnablement bien compris des chercheurs, mais il serait bon de procéder à des simulations sur ordinateur des caractéristiques du site pour mesurer l'ampleur et la corrélation de leurs effects.

Mots clés: archéologie, subarctique de l'ouest, Alaska, datation, obsidienne, l'hydratation de obsidienne

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INTRODUCTION

Obsidian hydration dating has been used for the archaeology of the western Subarctic for two decades. Most of the results have not been especially useful, except when optimistically interpreted, but there have been enough partial successes to encourage further work with this method of dating. This is especially the case today in view of increased sophistication in techniques for determining obsidian hydration rates which are crucial for assigning calendrical age, for ascertaining the causes of variation, and in the experimental verification of the theoretical basis for hydration dating (cf. Friedman and Long, 1976; Friedman and Trembour, 1983; Michels, 1973; Michels and Tsong, 1980; Michels *et al.*, 1983, 1983a).

It is not always possible or practical to control all the variables that may affect obsidian samples, even when they are from a single site context. Nevertheless, with due allowance for such exigencies, and especially recognizing that results may be unsatisfactory if the natural site context has been subject to certain disturbances, I had operated under the belief that obsidian hydration dating was an accomplished fact. However, Michels and Tsong (1980:435) clearly indicate that the method has not passed out of its developmental stage when they write that "over the next several years a concerted effort will be made to bring obsidian dating 'on line' as an intrinsic chronometric technique...Their [archaeologists'] critical evaluation of our dating efforts will ultimately decide whether the technique has truly 'come of age'...". It appears that only recently have both laboratory scientists and field archaeologists become fully aware of all of the variables that affect hydration.

Therefore, this may be an appropriate time to reiterate practical field problems and to discuss the requirements for successful application of the technique. Physicists and chemists have warned archaeologists of the requirements and sources of error in the method (see Friedman and Trembour, 1983; Michels and Bebrich, 1971), but I believe that archaeologists have not responded with discussion of their problems. It is

[1]National Museum of Man, Ottawa, Ontario, Canada K1A 0M8

hoped that a dialogue will further the development of means for correcting, circumventing and coping with the problems encountered in applied hydration dating. Three papers which deal specifically with hydration dating in the north (Davis, 1977; Holmes, 1978; Smith, 1977) have come to my attention. Each of these, however, differs in emphasis or approach from the present paper. For regions farther south, especially in the United States, Mexico, Central America, and South America, there is an extensive literature describing applied hydration dating. Results found there are in many cases similar to the Alaskan examples: that although hydration dating is imprecise and not free of problems it has been helpful in the absence of acceptable radiocarbon dates (cf. Aikens and Minor, 1978; Bell, 1977; Meighan, 1983). In this paper I will discuss a number of case applications based on my field work in Alaska, done in the vicinity of the Indian River geological source, known as Batza Téna.

The theoretical basis and applied procedures for obsidian hydration dating have been outlined and discussed recently in several articles (Fleming, 1976; Michels, 1973; Michels and Bebrich, 1971; Michels and Tsong, 1980), and will not be described here. The basic premise of hydration dating is that natural volcanic glass (obsidian) absorbs water, e.g. hydrates. Hydration progresses inward from a fresh surface, exposed for instance when an implement is flaked, at a rate (which may be exponential) primarily dependent upon the temperature of the environment in which the specimen is lodged and upon certain other variables, especially the composition of the glass. A number of hydration rate formulae have been applied (see Friedman and Trembour, 1983:546; Meighan, 1983). For northern material most researchers use Friedman and Smith's (1960) formula according to which, as the hydration layer thickens hydration slows down so that thickness equals a constant factor, that takes into account the variables noted above, multiplied by the square root of time, e.g. time = constant × (Thickness)^2. This formula is the basis for the calculations in the present paper. A hydration rim measurement (or the average of a series of measurements for material of coeval age) is squared and then is divided by the appropriate rate to obtain age in thousands of years. Hydration normally does not affect the glassy appearance of a specimen but it can be observed in thin sections. Thus, hydration layer thickness for a particular obsidian type from a particular climatic environment (temperature regime) is a function of age which can be determined through application of the appropriate hydration rate. Hydration rates may be determined experimentally (Michels, 1981; Michels *et al.*, 1983a), hypothetically on the basis of composition (Friedman and Long, 1976), or practically through calibration of measured obsidian specimens with dated archaeological sequences to obtain "natural" rates.

HISTORY OF OBSIDIAN HYDRATION STUDIES IN THE WESTERN SUBARCTIC

The cordillera and other mountainous regions of western North America, extending into the Aleutian Islands, contain numerous obsidian outcrops that were utilized by indigenous peoples seeking an easily flaked raw material from which points, knives, and scrapers were fashioned. Few northwestern sources are fully described (but see Fladmark, 1982; Nelson *et al.*, 1975; Patton and Miller, 1970; Souther, 1970; Stevenson, 1982; Wheeler and Clark, 1977 for partial descriptions), and many additional sources are inferred on the basis of trace element studies that indicate a range of archaeologically-utilized obsidians not documented by known geologic outcrops (Griffin *et al.*, 1969; Haskin and Cook, n.d.; unpublished neutron activation analyses by Atomic Energy of Canada Ltd. Commercial Products for the National Museum of Man, Ottawa; Simon Fraser University Department of Archaeology unpublished X-ray fluorescence identification of samples submitted by National Museum of Man). The chemical characterization of archaeological obsidian, to identify sources or the distribution of each source type in trade networks, and obsidian hydration dating are independent activities. They, nevertheless, draw their impetus together from the occurrence of obsidian in western archaeological sites, most commonly in sites located near the limited number of natural sources. In addition, it may become necessary in the far northwest, as is the case elsewhere, to identify the source group (e.g. composition) for precision in determining hydration rates. With increased attention to the archaeology of northwestern interior regions, a number of attempts have been made to employ obsidian hydration dating for chronology, especially where material suitable for radiocarbon dating has not been recovered.

In their initial exposition on hydration dating Friedman and Smith (1960) utilized specimens from the Yukon Territory to derive a subarctic hydration rate of 0.82 microns squared per 1000 years. This was based on a small sample (Friedman and Smith, 1960: Table 1) from poorly dated contexts, but the rate is within the range of a number of trial subarctic rates obtained recently.

MacNeish then obtained through Donovan Clark nearly 100 obsidian hydration measurements from 21 sites or levels in the southwest Yukon Territory. The results did not fit well with his chronological expectations (MacNeish, 1964:305-308), but they are closer to the realignment of chronology proposed by Workman (1978). This appears to be the first non-experimental use of obsidian hydration dating for the arctic and subarctic regions.

In 1965, W. Koch did a small hydration dating project on material from the Onion Portage site of the Kobuk River (briefly noted in Davis, 1977).

Work in the Koyukuk River drainage, which is the source of at least three types of obsidian including the principal high-quality one found north of the Alaska Range, greatly increased the availability of archaeological assemblages with appreciable numbers of obsidian artifacts. This has resulted in several dating projects. Hydration series from various sites proximal to the Indian River obsidian source at Batza Téna have been obtained by the National Museum of Man from 1970 to the present. These are discussed in the present report, with the exception of Norutak Lake (for which see Clark, 1974a:11, 13). C. Holmes (1971, 1973) also has utilized hydration measurements for the Bonanza Creek Island site and further data for sites in the Koyukuk drainage were obtained by the Alyeska Pipeline Archaeology Project (Davis, 1977; Cook, 1977). Holmes (1973:64-66) found that hydration thickness means offered plausible dates for individual sites, but he was unable to verify his results because of lack of radiocarbon dating. Davis's work provides a large series of measurements, divided, however, among many sites. It has led to the presentation of two trial hydration rates which nevertheless leave considerable room for discussion.

Workman obtained a series of measurements from a second millennium A.D. site in the Copper River drainage, south of the Alaska Range. This is of interest because the obsidian is unlike any type from the Koyukuk River and apparently is from an unpublished source located near Nabesna (Workman, 1977, pers. comm. 1981). The archaeological context is not closely dated, and therefore it is not possible to determine how the rate of hydration differs from other obsidian types.

To the south, for the Stikine River drainage in northern British Columbia, hydration measurements are available for specimens made of obsidian apparently from Mt. Edziza (Smith, 1970: Fig. 7; 1971: Fig. 2). The results appear to be clustered in a manner indicative of specific components, but only those pertaining to the microblade industry have been discussed in print. Fladmark (1982), however, rejects the possibility of using hydration dating for upland sites in this area.

Holmes (1978, 1983) has made a serious attempt to apply hydration dating at Lake Minchumina in central Alaska. For comparisons Holmes also has utilized unpublished data made available by J.P. Cook from Healy Lake, Dixthada, and the Campus sites. The data show considerable variance which Holmes suggests may be due to component mixture when the range of measurements is above 0.75 microns. Nevertheless, my own results show that this amount of variance sometimes exists where there is no likely mixture. Holmes did not find a single rate to fit all data but does not discuss whether or not the climatic variation in the region (amounting to approximately 2 °C for his sites but probably 6 °C in the greater region) would lead one to expect that a single rate would suffice.

A relatively large series of hydration measurements is available for later excavations in the southwest Yukon Territory (Workman, 1978). The results are encouraging but are not consistent enough, even for averaged samples, to be regarded as a substitute for radiocarbon dating.

Five series of samples from the Dry Creek Site, located southwest of Fairbanks, were employed in a sophisticated test of Friedman and Long's (1976) formula relating hydration to composition (Smith, 1977). It was found that the data do not fit the formula. Nevertheless, each subset of data, presumably derived from a single nodule of raw material, was internally consistent although there was variance between the subsets which cannot be explained by differences in the environment of deposition. This study then signals an awareness of potential problems, the solutions of which are critical to successful application of hydration dating.

Hydration data continue to be secured by projects in progress in Alaska with, evidently, at least optimistic expectations (P. Bowers, pers. comm. 1981; J.P. Cook, pers. comm. 1983).

CASE STUDIES

We will review several specific applications, each of which illustrates a particular mode of operation, problem encountered, or test. Inasmuch as the initial dating attempts were followed by more controlled tests in which certain potential variables were progressively eliminated, the sequence of examples given here largely follows the history of the project.

Flake Collection Associated with Fluted Point

This example, like several others, comes from the Batza Téna (obsidian trail) locality associated with the Indian River obsidian source of the Koyukuk drainage (Clark, 1972; Patton

TABLE 1. RkIg-10 hydration measurements

Hydration μ
0.72
0.76
0.77
1.38
1.79
1.95
2.15
2.19
2.29
2.35
2.36
2.40
2.40
2.94
2.95
3.33
3.79
3.80
3.85
4.17
4.17
4.75
$\Sigma = 57.26\mu$
n = 22
$\bar{x} = 2.60\mu$ $\bar{x}^2 = 6.78\mu$
Age (R $0.82\mu^2 \cdot 1000$ yr^{-1}) = 8248 B.P.
SD = 1.16μ
CV = 44.56

Σ = sum
n = number in sample
$\bar{x}$ = means
R = rate
CV = Coefficient of Variation (Standard Deviation as a percentage or ratio X 100 of $\bar{x}$)
x = any observation (omitted except where required for clarity)

B.P. age is in years before A.D. 1950. An alternative calculation employing the average of the sum of each squared hydration value is 9807 years.

and Miller, 1970). At the north end of site RkIg-10 there is a frost depression with flakes accumulated on top of one another to a thickness of 10 cm in light-grey clayey soil (a frost sorting phenomenom). Additional flakes occur in the adjacent and partially overlying thin, light-brown soil and in the surficial organic soil and litter mat. A fluted point was found in the brown soil. A sample of flakes from this locality was measured in anticipation that they would date the point. The results are shown in Table 1.

The calculated age of 8248 years (before A.D. 1950) was obtained by squaring the average of the sum of the hydration values and by then dividing that value by the rate indicated. The same procedure is employed elsewhere in this paper. An alternative calculation using the average of the sum of each squared hydration value yields an age of 9807 years, which is a noteworthy increase. Usually the difference between ages calculated by the two procedures is small, and neither this second calculation nor the array of hydration squared values is shown in the simplified version of the tables published here. It should be noted that unless an A.D./B.C. date is specified, age refers to so-called Before Present (B.P.) time before the specimen was dated, but has been restated relative to A.D. 1950 to match customary statement of radiocarbon dates.

For interpreting this set of data there are a number of considerations both peculiar to the site and general to the method. The expected age if the flakes are associated with the fluted point would be either between 10 000 and 12 000 years, closer estimates varying according to details of the reconstruction of Paleo-Indian prehistory utilized, or as recent as 3000 years if hypotheses of independent development, unrelated to Paleo-Indian prehistory, are followed. The question of the age of northern fluted points is discussed in a later example. Moreover, a range of dates is not improbable inasmuch as the site is located at a probable overlook where recurrent use over several thousand years might occur. Although a certain amount of variance is inherent in the dating method, if variance is too high the assemblage could be interpreted as containing mixed components of divergent ages, but exactly what constitutes too high a variance cannot be stated at present.

The precise rate to be used for conversion of hydration measurements to age in years has not been determined. Trial hydration rates, discussed later, suggest that most subarctic material falls within the rate (R) range 0.6-1.2 microns (μ) squared per 1000 years ($\mu^2 \cdot 1000$ yr^{-1}) and here R = $0.82\mu^2 \cdot 1000$ yr^{-1} has been used. This provides a basis for discussion but is too imprecise to provide firm dates.

A small series of implements from the area of RkIg-10 where the fluted point was found was measured separately (three sections each). Because of the select nature of this sample the results have not been incorporated into the series shown in Table 1.

They are:

Fluted point	4.88, 4.88, 4.94 microns (μ)
Biface	2.55, 3.36, 3.85 microns
End scraper	3.30, 3.32, 3.33 microns

These measurements reinforce the interpretation that Paleo-Indians were present.

On the one hand the 45 coefficient of variation (CV) in the RkIg-10 data may indicate component mixture. On the other hand, the age based on the average of all measurements, in the order of 8000-10 000 years, but varying according to the rate and method of calculation employed, is sufficiently great to allow the entire mass of material to be assigned to a late Paleo-Indian occupation, especially if a methodological basis can be found to account for the thinner measurements in the group. The age of the Paleo-Indian component may have been depressed through "contamination" with relatively recent material, and a CV of 45 probably is higher than would be expected for an assemblage representing a brief moment in time (see later examples).

Hahanudan Lake House Floors

Hahanudan Lake is located near Huslia on the east side of the Koyukuk River. Five semi-subterranean houses at two sites were excavated in 1971 (Clark, 1977). Implements from the house floors are identified stylistically with a late Norton culture derivative, most closely with the Ipiutak culture. Aside from the hydration dating problem, Hahanudan is of special interest because it represents an inland Paleo-Eskimo occupation. This typological correlation is in accord with radiocarbon dating of the houses and Ipiutak culture sites. The dated context has provided an opportunity to establish a short-term hydration rate for the area. Localization of specimens in structures each representing little more than a moment in time was also seen as providing an opportunity to determine the variance in hydration layer thickness that could occur within a sample of restricted age.

Three types of obsidian, according to trace element analyses, are present at the Hahanudan Lake sites (Wheeler and Clark, 1977), but the sample from one house consists exclusively of a single type. For the other dated house, it was found that the two types utilized in the analysis hydrated at similar rates (Clark, 1977: Fig. 32, House 2 opaque/non-opaque types). The data and calculation of trial hydration rates are given in Table 2 and Table 3 and the results are discussed below.

Several constructive observations can be made on the basis of this exercise. In calibrating short-time range samples with radiocarbon (14-C) dates, the published one sigma margin of error in the date can introduce considerable latitude in the hydration rate thus determined, 0.90-1.03 and $0.76\text{-}0.86\mu^2 \cdot 1000$ yr^{-1} in the present case. To obtain 95% probability that the true age of the dated sample is within the corrected radiocarbon date bracket, there would be a further increase in the range of bracketing dates (see Klein *et al.*, 1982 for procedure).

Similar hydration rates had been expected for both houses but this identity was not obtained. Nevertheless, the rate ranges only lack 0.04 microns of meeting when calibrated by 14-C dates bracketed at their one sigma level (67%) of probability that the date range contains the true age. This

TABLE 2. Hahanudan site RkIk-3 House C hydration data and hydration rate calculation

Hydration μ
.84
.89
.93
.94
1.04
1.06
1.06
1.08
1.09
1.11
1.18
1.27
1.39
1.43
1.43
1.44
1.47
1.77

$\Sigma = 21.42\mu$
n = 18
$\bar{x} = 1.190\mu$
SD = 0.246μ
CV = 20.7
14-C date S-657: 1500±90 B.P. uncorrected
14-C date × 1.03 to correct half life = 1545±93 B.P.
14-C date range (+93 yr, −93 yr) = 1452-1637 B.P. (B.P. = before A.D. 1950)
14-C date range converted from radiocarbon years to true age according to MASCA tables = A.D. 590/570 − A.D. 393 true age[1]
True age before A.D. 1950 = 1557-1360 yr
True age before A.D. 1972 hydration was measured = 1579-1382 yr
Hydration squared (1.19^2) = $1.4161\mu^2$
Hydration rate brackets (bracketing true age before A.D. 1972 in yr/1000 divided by hydration squared) = $0.897\text{-}1.025\mu^2 \cdot 1000^{-1}$.

[1]Ralph *et al.*, 1973.

discrepancy can be explained in various ways and with recourse to measures of random sampling variance, for the hydration measurements, or to a slightly higher level of significance in the bracketing 14-C date range, it disappears as a statistically valid problem.

For a context better controlled than the previous example (for flakes and a fluted point) the coefficient of variation (CV) is reduced from more than 45 to approximately 20. Comparable data were obtained by Holmes at Lake Minchumina for a Norton-related feature which evidently also represents a brief occupation. There the CV was 27.1 (calculated from data in Holmes, 1978) which, though slightly greater than Hahanudan, is explicable because of the smaller sample of 13 specimens.

If radiocarbon dates had not been available (Clark, 1977:Table IV), attempts to date these sites on the basis of one or two specimens could have produced erroneous ages as recent as 1640 A.D. or as early as 1845 B.C. (at R = $0.82\mu^2 \cdot 1000\ \text{yr}^{-1}$). However, by using the averages of the hydration values and the subarctic $0.82\mu^2 \cdot 1000\ \text{yr}^{-1}$ rate of Friedman and Smith (1960), or even the faster $1.19\mu^2 \cdot 1000\ \text{yr}^{-1}$ Alyeska I rate (Davis, 1977), reasonably close dates would have been provided. *This is one of the more significant results obtained from the program discussed here. It appears to justify attempts to employ obsidian hydration dating.*

Microblade Clusters

The examples from Hahanudan provided a basis for believing that the average hydration of a set of samples could be used to date a relatively discrete event — e.g. a technological event that had taken place within a relatively short time span. Such an event would be the production of microblades from one or a few cores at a particular activity locus of small size. Only three of approximately 80 sites at Batza Téna appear to fit this pat-

TABLE 3. Hahanudan site RkIk-5 House 2 hydration data and hydration rate calculation[1]

Hydration μ
.52
.78
.80
.81
.87
.90
.92
.93
.94
.95
.95
.99
1.00
1.04
1.04
1.07
1.18
1.13
1.19
1.22
1.28
1.29
1.46

$\Sigma = 23.26\mu$
n = 23
$\bar{x} = 1.011\mu$
SD = 0.201μ
CV = 19.9
14-C date S-656: 1285±75 B.P.
14-C date corrected for half life = 1323±77 B.P.
True age date range after MASCA correction = A.D. 620−A.D.780
True age before A.D. 1972 hydration measurement = 1352-1192 yr
Hydration squared = 1.0241μ
Bracketing hydration rates = $0.757\text{-}0.859\mu^2 \cdot 1000^{-1}$

[1]Follows procedure of Table 2.

tern. Two examples are described here; the third, involving cortical flakes from a pebble evidently reduced to a microblade core, is discussed later.

RkIh-37 microblade cluster. This site is in a location lacking outstanding topographic features that might have attracted recurrent use. This factor and its technological homogeneity and small size provide reason to conclude that it represents a single brief occupation. Material was found on ground exposed by burning of the organic mat and forest in 1968 and in the top 15 cm of soil. Evidently some specimens had been within or in contact with the organic mat. Their occurrence there and within the soil poses a pedological problem possibly explained by frost action. Associated with the microblades were flakes from core preparation, core fragments, and the base of a small side-notched point. According to our general knowledge of Alaskan prehistory, an association of side-notched points and microblades could occur in the time range A.D. 500-4000 B.C. (see Clark, 1981; Cook, 1975; Dumond, 1977, 1978), although there has been discussion among archaeologists regarding the correctness of dating microblades to the latest millennium of this time range. The statistical results are presented in Table 4.

TABLE 4. RkIh-37 microblade cluster hydration data

Hydration μ	
1.20	
1.28	b
1.28	
1.28	
1.29	b
1.30	
1.34	
1.34	
1.50	b
1.56	
1.58	
1.64	b
1.73	b
1.78	
1.84	
1.84	
(3.38)[1]	

$\Sigma = 23.78\mu$
$n = 16$
$\bar{x} = 1.486\mu \quad \bar{x}^2 = 2.21\mu$
Age (R $0.82\mu^2 \cdot 1000\ yr^{-1}$) = 2666 B.P.
SD = 0.225μ
CV = 15.1

[1]Excluded from calculations.
b = Showed burning; six additional burned specimens showed no hydration.

In this example we find a clustered set of data which has yielded results in line with expectations. Particular points of information to be drawn are as follows.

The results replicate the Hahanudan Lake examples in that they demonstrate the possibility of dating an assemblage on the basis of averaged hydration measurements. The coefficient of variation, after one aberrant specimen is excluded, is only 15.1 which is less than Hahanudan and accordingly can be considered an improvement.

Proposed trial hydration rates for the region, to be discussed later, range from $0.6\mu^2 \cdot 1000\ yr^{-1}$, or less, to $1.2\mu^2 \cdot 1000\ yr^{-1}$. These rates yield ages of 3623 to 1798 years B.P., or between 1680 B.C. and A.D. 152 respectively. For $R = 0.82\mu^2 \cdot 1000\ yr^{-1}$, used in other examples, the age is 2666 years. The calculations do not take into account a few decades exaggeration caused by faster hydration during six years of warm storage. These dates are within the range of expectation, but, because of the liberal limits set above, to obtain the full advantage of this dating it is necessary to have a reasonably well established hydration rate. Nevertheless, it is apparent that this occurrence of microblades is not especially old.

Although we had anticipated problems in several samples due to recurrent burning in the region, probably since the end of the Pleistocene, this is the only set in which more than the occasional specimen could be identified as burned and had to be rejected for that reason. Fires burn into the organic, peaty mat characteristic of arctic soils leaving exposed mineral soil, except in low areas where the organic mat is saturated with moisture. The fires also destroy any forest and shrub cover and burn off surface litter, as was most often seen to be the effect of the 1968 burn. It appears that in 1968 the fire usually was not hot enough at ground level to affect obsidian hydration layers. This may have been because in most places there was no thick flammable organic mat, an exception being, apparently, site RkIh-37.

Friedman and Smith (1960:484-485) discuss the effects of burning on obsidian and the surface alteration that results from burning. Although such visibly altered specimens have been found in hearths and also are present elsewhere in at least two Batza Téna sites, the burned RkIh-37 specimens with zero hydration retain a glassy appearance and show no surface effects of burning either to the unaided eye or in some cases under magnification. Presumably, these burned specimens have again commenced to hydrate and thus would produce erroneous dates of manufacture in the future (see Freidman and Trembour, 1983:545).

RkIh-28. The second microblade cluster occurred in a soil context at the top of a slight eminence overlooking the Koyukuk River flats. Although multiple use of this locality would be expected, microblades and blades occurred in a localized group of a few metres in extent isolated from the only other cluster of lithic material found on the knoll. As well, the assemblage displays technological homogeneity suggesting that the blades and microblades belong together in a single component. For test purposes this collection is considered to be important because it occurred in a soil context and thus is controlled against the factor of surface exposure. As well, the soil context should have provided insulation against fires. Nevertheless, many specimens (not those sectioned) show the extreme effects of burning as described by Friedman and Smith (1960). The reason for this has not been determined. The burning appears to be have been localized, and in one case a burned unfinished implement fragment was fitted to its unburned half.

The site is of special interest archaeologically because of the presence of prismatic blades — the large counterparts of microblades. Sites with true prismatic blades (in contrast to linear ridged flakes) are uncommon in Alaska, but blades have been found in some Paleo-Arctic or Denali complex sites which date to the period 6000 B.C.-9000 B.C. This then is the age estimate for the site. The data are shown in Table 5.

TABLE 5. RkIh-28 microblade cluster hydration data

Hydration μ
0.87
0.89
0.99
1.07
1.38
1.42
1.69
1.87
1.98
1.98
2.00
2.02
2.04
2.19
2.23
2.23
2.33
2.61[1]
3.31
3.34
4.00
$\Sigma = 42.44\mu$
n = 21
$\bar{x} = 2.021\mu$ $\bar{x}^2 = 4.08$
Age (R $0.82\mu^2 \cdot 1000\ yr^{-1}$) = 4954 B.P. (5729 B.P. if based on mean of squared hydration values)
SD = 0.82μ
CV = 40.4

[1]Biface; all other specimens are microblades.

The results are disappointing. The average of the hydration values provides an age (at the $0.82\mu^2 \cdot 1000\ yr^{-1}$ rate) of only ca. 5000 years, about half that expected. To fall within the expected date range a hydration rate of $0.5\mu^2 \cdot 1000\ yr^{-1}$ or less would be required. Nevertheless, there is no firm basis for rejecting this age calculation. There are indications that for some interior Alaskan sites, hydration rates considerably slower than $R = 0.82\mu^2 \cdot 1000\ yr^{-1}$ apply and, therefore, the assemblage may be significantly older than 5000 years. On the other hand, the prehistory of the region presently is not known in sufficient detail to exclude the possibility of prismatic blade production 5000 or 6000 years ago.

The high coefficient of variation presents a more serious problem relative to the encouraging results obtained in the previous two examples. The expected tight range of data did not materialize and the results are too variable for one to place much faith in the set of hydration measurements for this site. The CV of 40.4 is comparable to that found in the first example, where, unlike the present case, temporal integrity of the assemblage was a very uncertain hypothesis.

The Age of Fluted Points

For several decades Paleo-Indian fluted points, of which the Clovis type is the best known, have been the principal "index fossils" of early man in the New World. The sparseness of documented occupation preceding Clovis (ca. 9500 B.C.) suggests that Clovis culture represents a technological and demographic florescence and possibly migration from the north. With fluted points verifying the presence of Paleo-Indians in the New World, south of Alaska and the Yukon Territory, and given the generally accepted hypothesis of Paleo-Indian migration from Asia through Alaska, discoveries of fluted points in Alaska from the late 1940s onward fulfilled expectations of a northern fluted point distribution (Haynes, 1966, 1969, 1982; Humphrey, 1966; Thompson, 1948).

However, initial finds of fluted points in Alaska were neither numerous nor well dated nor, in many instances, as distinctive technologically as Clovis. The opposite situation held for the mid-continent region in the United States (for dates see Haynes, 1971). Thus, it was more reasonable to adhere to the hypothesis that fluted points had developed in the south, although evidence for this development has eluded discovery. Then as the last continental glaciation waned, the hunters of the northern Plains followed the periglacial fringe northward, recolonizing the land from within (Wormington, 1957:109). Eventually, in small numbers, these people with fluted points reached western Alaska. Other views hold that fluted points are a relatively late development in Alaska, 6000 to 3000 years ago, which occurred independently of the similar technology found earlier elsewhere. Obviously the dating of these points is critical. If they are early they are likely to be Paleo-Indian, and if at least some of them can be shown to be slightly earlier than Clovis, to date to 10 000 B.C., this dating would provide time slope to a dissemination model favoring origin in the north.

The first fluted point to come from a dated context in Alaska was found in the Cape Denbigh Iyatayet site, in the Denbigh Flint complex, and radiocarbon-dated to approximately 4000 years ago (Giddings, 1964). To many people, however, this dating and placement was unacceptable. The few additional finds made up to 1969 did not provide a secure basis for dating. Then, in 1969, 1970, and 1971 many specimens of obsidian were found at Batza Téna and elsewhere on the Koyukuk River (Clark, 1972; Clark and Clark, 1975, 1980; Holmes, 1971, 1973; Reger and Reger, 1972). A basally-thinned point was found in the Chindadn complex of the Healy Lake Village site (Cook and McKennan, 1970, without specific reference to point), and several fluted points came from the Putu site on the north slope of the Brooks Range during preliminary surveys and excavations along the Alyeska Pipeline route (Alexander, 1974). During subsequent years additional specimens have been recovered. All this has increased the information regarding the distribution of these points, but only three new sites have yielded radiocarbon dates: Healy Lake Village, Putu, and one on the Koyukuk River called "Girls' Hill" (Gal, 1976). Variant dates ranging from ca. 6000 to 11 500 years come from the Putu site (see discussion in Clark, n.d.; Dumond, 1980; Morlan and Cinq-Mars, 1982:373); the Girls' Hill date of approximately 4400 years does not fit expectations of the Paleo-Indian hypothesis; and many persons are reluctant to group among fluted points the Chindadn specimen from a component dating between 10 000 years and 11 000 years old. Consequently, further dating of these points is required.

Several hydration measurements are available for fluted points and associated artifacts. Initially, all specimens were sectioned in three places, but the results were sufficiently uniform that multiple sectioning now is considered to have been unnecessary. Nevertheless, multiple sectioning assures one that the measurements are representative of the whole specimen and are not for localized thick areas encountered by chance. According to their magnitude, there are three groups of measurements: a single specimen just under 5 microns, six specimens in the 3-micron range, and five specimens in the 1-micron range. Squared, these measurements amount to approximately 24, 10 and 1.5 microns squared. Further description of the sample is given in Table 6.

Chronometric ages calculated for a number of plausible hydration rates ranging from 0.82 to $1.1\mu^2 \cdot 1000\ yr^{-1}$ are shown in Table 6. The $.82\mu^2$ rate is the so-called subarctic rate which has been applied to numerous previous analyses (Friedman and Smith, 1960); the short-term rates derived from Hahanudan, presented earlier, are in the $0.82\text{-}1.0\mu^2$ range; and Davis (1977) has found that an Alyeska I rate of $1.19\mu^2 \cdot 1000\ yr^{-1}$ is appropriate in some instances. It is seen (this paper) that rates in the order of 0.7 and $0.6\mu^2$ also might occur, but these slower rates would make the specimens in Group B too old to articulate with any plausible Paleo-Indian hypothesis, whether it is one that advocates northern origins or one that proposes derivation from the south.

There is no technological basis for dividing the fluted points into three groups of widely differing age, and we assume that all date to a single period of many centuries or longer during which fluting was a characteristic technique. The date of specimen A, exceeding 20 000 years, is not acceptable under any hypothesis accounting for northern prehistory or relating northern and southern fluted points. The specimen involved is excellently fluted, and presumably an explanation applies that makes this case an exception (see later discussion of causes of variance).

The Group B dates are the most acceptable. Unfortunately, only one of the six Group B "dates" comes directly from a fluted point, but other, unfluted points also enter this group. Although this situation makes the group untidy, it is in accord with hypothetical expectations of there being unfluted prototypes or variants in the north.

The Group B dates in Table 6 can be fitted to either of the following Paleo-Indian hypotheses.

1. Northern origin. The earliest fluted points in the north would date 500-1000 years before the beginning of Clovis culture in the southwestern United States. Northern fluted points thus should date from ca. 12 000 years ago to 10 500 years ago (a 1500-year durance is assumed), or, less stringently interpreted, 12 500 to 10 000 years before present.

2. Southern origin with spread to the north. The earliest points in the north would date at least 500 years later than the beginning of Clovis culture in the contiguous United States. Their duration in the north probably would be only 1000 years or less because the early part of the temporal range of the point type occurs elsewhere. A plausible date range would be from 11 000 B.P. to 10 000 B.P. at the earliest and 10 500 years B.P. to 9000 B.P. at the latest.

The "B" age brackets presented in Table 6 represent the range of multiple measurements. This range would be tightened only slightly by using the average value of the three sections each for the specimens. It may be noted, however, that five specimens cluster closely when a sixth specimen, which is

TABLE 6. Hydration and age estimates of fluted points and associated implements

			Age according to specified hydration rate			
			Hydration rate microns²·1000⁻¹			
Group	Description	Hydration μ	0.82	0.90	1.0	1.1
A	Fluted point RkIg-10:36	4.88-4.94	28 483 B.P.	25 950 B.P.	23 352 B.P.	21 628 B.P.
B	6 specimens (fluted pt., 2 non-fluted pt., end scraper, rudimentary biface from RkIg-10, utilized flake)[1] Range	3.18-3.61[2]	12 308–[3] 15 871 B.P.	11 214– 14 458 B.P.	10 090 13 010 B.P.	9171– 11 825 B.P.
C	5 fluted points (1 from Bonanza Cr.; see Holmes, 1973)	0.92-1.43	1020– 2472 B.P.	918– 2250 B.P.	824– 2023 B.P.	747– 1837 B.P.

[1]Specimens, when not fluted points, are associated with fluted points.

[2]The 3.18-3.61 values exclude a vague 3.71 micron reading and the upper and lower limits of a highly variable biface. If three sections on each specimen are averaged to give a single hydration value the range is reduced to 3.25-3.55 microns.

[3]Minimum B ages are increased between 550 yr (at R 0.82) and 400 yr (at R 1.1) when calculations are based on the mean value 3.25 microns (footnote 2). Exclusion of one apparently utilized flake reduces the B Group maximum age by 1300-1000 years according to the hydration rate selected.

a utilized flake, is excluded (Table 6, footnote 2). These data have been examined in terms of the two options outlined above. Accordingly, at the $0.82\mu^2 \cdot 1000\ yr^{-1}$ rate, Group B is slightly too old for either hypothesis. At $R = 0.9\mu^2$ the set is suitably dated to figure in the northern origin of Clovis culture, but is too old to fit limited early dating evidence from the north which indicates co-occurrence of fluted points and microblades — with the apparent exception of the Bluefish Caves where there is a very early microblade industry (J. Cinq-Mars, pers. comm. 1983). The $1.0\mu^2$ rate accounts for the co-occurrence of fluted points and microblades and appears to be in excellent accord with Hypothesis 1. Actually, a more conservative examination of the $1.0\mu^2$ Group B data shows that when the sixth specimen is excluded (as noted above and in footnote 2 to Table 6), the older age limit of the group is 11 470 years which is too late for Hypothesis 1 and too early for Hypothesis 2. A slower rate then favors the northern hypothesis and a faster rate the southern hypothesis (No. 2). This is essentially the case with the $1.1\mu^2$ rate, although an intermediate rate of ca. $1.06\mu^2$ provides the best fit with Hypothesis 2.

Two conclusions, one historiographic and the other methodological, can be drawn from this part of the exercise. The first is that northern fluted points actually belong in a Paleo-Indian time frame. The second is that if diffusion or distribution, either southward or northward, occurred during a period of no more than 500 years it would require application of a hydration rate accurate to $0.05\mu^2 \cdot 1000\ yr^{-1}$ to work at the requisite level of discrimination. If, however, fluted points had been present in one area for 1000 years before dissemination to another area, it should be possible to demonstrate this age differential using hydration rates accurate to approximately $0.1\mu^2 \cdot 1000\ yr^{-1}$. At the present time, as is discussed in this paper, it is doubtful if even the latter precision is available. Hydration dating then gives a general indication of the antiquity of northern fluted points but is the wrong tool for selecting an origin hypothesis.

Thus far our conclusions have pertained only to the B group of measurements. Were they not so patently unacceptable the Group C data, which include more fluted points, would be an embarrassment to the Paleo-Indian hypothesis. The five late dates, all within or close to the first millennium A.D. when derived on the basis of $0.82\mu^2 \cdot 1000\ yr^{-1}$ to $1.1\mu^2 \cdot 1000\ yr^{-1}$ rates, cannot be taken to indicate affiliation with the 1000-2200 B.C. Denbigh Flint complex, or components of the Northern Archaic tradition of comparable age, as has been suggested by some authors (cf. Gal, 1966), unless an extremely slow hydration rate of $0.4\mu^2$ or less is applied (and the Group B data are rejected). Evidence independent of hydration dating shows that this is unlikely (Clark, n.d.). A hydration rate which would make the Group C measurements equivalent to a Paleo-Indian age is completely out of the question.

It may be pertinent to note that one additional fluted point was returned with the notation that there was no hydration but that the specimen showed evidence of burning. In an earlier example forest fires and the effects of burning on hydration were discussed. It was noted that only locally was the 1968 forest fire at Batza Téna hot enough to eradicate the hydration layer. Most of the Batza Téna points which yielded low hydration measurements had lain on the surface, though under litter, and under snow for seven months of the year. The fire in 1968 was not intense enough to affect these specimens, except evidently the one point noted, but conceivably during an early period some points were enveloped in an organic layer which burned with sufficient intensity to destroy any previous hydration layer. Such destruction of the organic mat is a well known feature of modern fires in the north. Presumably, then, hydration began anew — later to produce misleading "dates".

Analysis of Variance to Test the Batza Téna Tuktu Component

Recovery of a notched pebble chopper, 40 end scrapers, side-notched points, microblades, and bifaces at Batza Téna site RkIh-36 is indicative of a Northern Archaic or a Tuktu-related occupation (see Anderson, 1968 for definition of Northern Archaic; Campbell, 1961 for Tuktu complex). The local manifestation was called "Batza Téna Tuktu" and in keeping with the dating of Tuktu at Anaktuvuk Pass and Northern Archaic components at Onion Portage an age of 5000-6000 years was estimated (Clark, 1974). Later, a single radiocarbon date of 1355 ± 260 years (S-976), A.D. 625, was obtained on calcined bone from a hearth deposit that had been reworked in a frost involution.

The date is at variance with expectations and is from a poorly controlled context, but dating of bone does provide the advantage that the results cannot be dismissed as the result of a forest fire or non-cultural activity. Moreover, data obtained during the 1970s in Alaska show that assemblages with microblades and notched points may in some cases be as recent as the beginning of the first millennium A.D. (cf. discussion in Clark, 1977:108-110); thus it was felt that the radiocarbon date is not necessarily inappropriate.

The provenience of the Batza Téna Tuktu assemblage is tied together through the distribution of end scrapers and other implements, but these are localized within a broader subsurface distribution of obsidian flaking detritus. Accordingly, I was concerned that the localized area of the Batza Téna finds contained artifacts from more than one occupation. Moreover, a copper awl recovered among the implements was judged to be too recent to be associated with the microblades and notched points. If, however, the radiocarbon date is correct the awl may belong with the rest of the assemblage.

The problem, then, is twofold: (a) is Batza Téna Tuktu a valid assemblage (representing the occupation of a single culture or period) or is it a mixture of components of widely divergent ages? and (b) what, if any, material belongs to the first millennium A.D. occupation suggested by the radiocarbon date?

The test procedure was to obtain a set of obsidian hydration measurements from each of several classes of artifacts, including ones expected to be of divergent ages if multiple components are present at the site. Unfortunately there are too few obsidian points for a notched point series to be dated, and there were so few microblades that some specimens from adjacent site RkIh-35, which yielded an assemblage similar to that from RkIh-36, were included. Sampling data naturally are somewhat divergent so a statistical requirement is that they be tested to determine whether this variance can be explained as a result of random sampling error.

The only evidence of stratification was that artifacts were found in the bottom of the peaty organic mat, as well as a few inches into the underlying soil, and deeper in frost cracks where there is separation of clayey particles due to frost action. It is evident that at least to a certain extent this "stratification" does not represent a natural order of deposition but may be the result of pedological phenomena. Moreover, artifacts which ought to be early and deep, in particular some of the microblades, were found to be within the vegetal mat.

The combined data and statistical analysis are presented in Table 7.

The analysis of variance shows that the four classes of artifacts examined may have come from the same population, e.g. the same age-equivalent hydration-rind grouping of artifacts. This outcome makes it possible to posit a single date for the assemblage. However, if the assemblage is derived from a long period of site use, such a date, in the case of the radiocarbon date, provides only one point within the span of occupation, or, in the case of the average of all hydration readings, an approximate median or average date for the Batza Téna Tuktu component.

TABLE 7. RkIh-36 Batza Téna Tuktu analysis of variance

Artifact class	Bladelike flakes	End scrapers	Biface *outre-passe* flakes	Microblades and core	
Hydration	0.61	0.59	0.81	0.70	
	0.71	0.66	0.87	0.76	
xμ	0.77	0.72	0.89	0.86	
	0.81	0.74	0.95	0.87	
	0.81	0.92	0.96	1.07	
	0.84	0.94	0.97	1.13	
	0.95	0.95	0.97	1.18	
	0.64	1.02	1.01	1.19	
	1.13	1.03	1.02		Total for
			1.04		all groups
N (number)	9	9	10	8	36
Σx (sum of hydration)	7.27μ	7.57μ	9.49μ	7.76μ	32.09μ
(Σx)² (square of sum)	52.85	57.30	90.06	60.22	260.44
x̄ (mean)	0.8078μ	0.8411μ	0.949μ	0.970μ	0.8914μ
(Σx)²/n	5.872μ	6.367μ	9.006μ	7.572μ	28.773μ
SD (standard deviation)					0.1535μ
CV (coefficient of variation)					17.2
(x̄)² (hydration squared) used for derivation of hydration dates	0.6525μ	0.7074μ	0.9006μ	0.941μ	

Computation of SA² (variance among sample groups)

Using group values

(1) $(\Sigma x)^2/n = 5.8725 + 6.367 + 7.5272 + 9.006 = 28.7727$

Using totals

(2) $(\Sigma x)^2/n = (32.09)^2/36 = 28.6047$

Result subtracted from Step 1 = 0.168

(3) Divide by N Groups-1 = 0.168 /(4-1) = 0.056

Computation of SW² (variance within sample groups)

(1) Sum of square of sums minus SA² = 260.44-28.7727 = 231.67

(2) Step 1 result/N-N of Groups = 231.67 / (36-4) = 7.24

Therefore, the variance among individuals (231.7) is sufficient to account for the variance implied by the difference among the group means (0.056). Accordingly, the data suggest that differences in mean hydration values are not related to differences in age.

Conversion of radiocarbon date to true age in years before 1980 (year when thin sections prepared) for calculation of hydration rates (see Table 2 procedure)

Date (S-976): 1355±260 B.P. uncorrected

Date, half life corrected = 1396±268 B.P. (A.D. 554±268 years)

Range = A.D. 822-A.D. 285

True age with MASCA correction = A.D. 890-A.D. 365

Age in years before 1980 = 1090-1615

The analysis of variance demonstrates that Batza Téna Tuktu is a valid assemblage from a single culture or period. However, there is no definite answer to the question of to which of the recovered artifacts that A.D. 625 radiocarbon date applies. Nevertheless, a reasoned response is possible when the following factors are taken into consideration.

(1) Although technological elements in the assemblage have a long duration, the localization of implements in one small area of the site suggests a camping place used by a single group or family over a relatively brief period. In addition, the coefficient of variation (CV) of 17.2 is similar to that from three other sites which are known to represent brief occupations.

(2) It is doubtful that the large side-notched points are any more recent than the end of the first millennium A.D.

(3) It is doubtful that the microblades are any more recent than the middle of the first millennium A.D. if they are even that recent.

(4) The radiocarbon date should have a plausible counterpart in obsidian hydration dates based on rate information independent of the 14-C date for the site.

The mean of all 36 hydration measurements is 0.8914 microns (Table 7). At the hydration rate $0.82\mu^2 \cdot 1000\ yr^{-1}$, which appears to be satisfactory for some sites in the greater region, the equivalent age is 940 years (before A.D. 1950). This age not only is younger than the radiocarbon date for which the true age is sometime between 1060 and 1585 years, but it also fails to meet expected middle or early first millennium A.D. dating. Allowance of a range of a few decades to take into account the duration of site use under the short-period option provides little improvement.

Inasmuch as the first trial calculation, at $R = 0.82\mu^2 \cdot 1000\ yr^{-1}$, fails to meet expectations on the basis of both typology and radiocarbon dating, use of a slower rate for dating may be justified. The rates obtained when the age value for mean hydration (0.891μ) is calibrated with the 14-C date taken at its one sigma bracketing values converted to true years are $0.72\mu^2$ and $0.49\mu^2 \cdot 1000\ yr^{-1}$ (Table 8). Restated, if the mean hydration is correct, and if it and the 14-C date apply to essentially the same time, the hydration rate at the site under conditions prevailing from approximately 1400 years ago is between 0.72 and $0.49\mu^2 \cdot 1000\ yr^{-1}$. Using the data from the four sample subsets it is possible to calculate a standard deviation of the mean, which when entered into the calculations broadens the bracketing range of hydration rates, but I do not believe that the data are sufficiently controlled to justify carrying this analysis to its possible limits. Trial rates as low as $0.7\mu^2$ and $0.4\mu^2 \cdot 1000\ yr^{-1}$ actually have been obtained for a number of subarctic samples (see Table 10). For instance, the hydration range for Minchumina Lake site MMK-12, which has approximately the same 14-C date as Batza Téna Tuktu, is between 0.61 and $0.73\mu^2 \cdot 1000\ yr^{-1}$. Based on the experimentally derived rate discussed later (see "Causes of Variance and Unsatisfactory Results"), the rate for the Batza Téna site could be as low as $0.38\mu^2 \cdot 1000\ yr^{-1}$. These comparisons show that the 14-C date for Batza Téna Tuktu is acceptable.

TABLE 8. Trial hydration rates, site RkIh-36 (Batza Téna Tuktu)

Calibration date[1]	Rate ($\mu^2 \cdot 1000\ yr^{-1}$)[2]
Without storage correction	
1090 yr	0.729
1615 yr	0.492
With trial correction for storage (0.06μ subtracted from $\bar{x}^2$)	
1090 yr	0.674
1615 yr	0.455

[1]Radiocarbon date S-976 (1355±260 B.P.) MASCA corrected and restated in years before A.D. 1980 when specimens were sectioned and with 260 years subtracted or added to provide the one sigma error range.

[2]Based on the average hydration of all specimens, squared: 0.7945μ.

Insofar as the duration of occupation is involved, we should at the least be aware of the effects of an erroneous conclusion. It is tempting to deal with this problem in terms of probability sampling theory, especially inasmuch as the data already have been described by means, standard deviation, and coefficient or variation. In my estimation neither statistical methodology, nor the accuracy of the conversion of individual hydration measurements into years when done on the same basis for all members of the sample, nor what is known with certainty regarding the occupation of the site can support such an approach. We can, nevertheless, use some of the values already calculated (particularly the standard deviation) in a model which assumes that the one-sixth of the measurements representing the thinnest hydration and the equivalent representing the thickest hydration are erroneous. The measurements which validly date the occupation then would fall within one standard deviation of the mean. At the trial $0.72\mu^2 \cdot 1000\ yr^{-1}$ rate, which is the faster end of the rate bracket calculated above through calibration with the site's radiocarbon date, the age range for the measurements taken to one standard deviation of either side of the mean is 484 years; at the trial $0.49\mu^2$ rate, which is the slower end of the rate bracket, the age range is 711 years. In my estimation, therefore, even if Batza Téna Tuktu is interpreted as representing long-term use of the site, there is little reason to expect the principal occupations to have extended over a period longer than 500-700 years. A duration of this length would require some adjustment or restatement of the trial calculations given above (e.g. the 14-C date would best fit late in the time range), but this would not change to any very significant extent the interpretations of prehistory based on the site and the hydration dating program. The example further illustrates a potential use of statistical procedures in the practical application of hydration dating.

RkIg-30 Test for Paleo-Indian Occupation

Eight fluted points and fragments were found at RkIg-30, associated with non-fluted point fragments and flaking detritus (Clark and Clark, 1980). The problem is to determine whether any part or a considerable part of the assemblage, in addition to the fluted points, can be assigned to a Paleo-Indian occupation. This problem is similar to the test of flakes from

RkIg-10, but is presented here to follow the chronological development of the Batza Téna hydration dating program. The measured RkIg-30 sample differs from RkIg-10 in the following respects. Artifacts typologically assignable to presumed Paleo-Indians are more numerous at RkIg-30, some specimens were exposed on the surface, and the sample measured was limited to bifaces and hinged biface roughout edges. Thus, the hydration should date a particular technology — the preparation of bifaces or biface reduction. This is pertinent to dating fluted points at RkIg-30 inasmuch as these points were produced through bifacial techniques, and the presence of unfinished specimens there suggests that this took place in the same site area from which the sample for hydration measurement was taken. The results are given in Table 9.

TABLE 9. RkIg-30 hydration data

Hydration μ	
Cluster I	Cluster II
1.50	2.71
1.25	2.66
1.23	2.62
1.40	2.79
1.11	2.77
0.97	2.75
1.41	2.78
1.51	2.74
1.56	$\Sigma = 21.82\mu$
1.17	n = 8
1.37	$\bar{x} = 2.73\mu$
1.29	SD = 0.06μ
1.34	CV = 2.2
1.34	$\bar{x}^2 = 7.439\mu$
$\Sigma = 18.45\mu$	Age (R $0.82\mu^2 \cdot 1000$ yr^{-1}) = 9040 yr
n = 14	
$\bar{x} = 1.32\mu$	
SD = 0.16μ	
CV = 12.9	
$\bar{x}^2 = 1.737\mu$	
Age (R $0.82\mu^2 \cdot 1000$ yr^{-1}) = 2087 yr	

The measurements fall into two discrete clusters for which separate parameters are calculated. The first cluster shows a relatively low to moderate coefficient of variation (12.9) and relatively low hydration (range 0.97 to $1.56\mu^2 \cdot 1000$ yr^{-1}; mean $1.32\mu^2$). This cluster may be derived from one occupation of modest antiquity, in the order of two millennia, or from a series of closely spaced occupations, still of only moderate age. However, site RkIg-30 is located in an area where fluted point hydration layers are anomalously thin. Points used in an earlier case example (see "The Age of Fluted Points", Group C) include, from RkIg-30, one fluted point found on the surface with no hydration but which had been burned, another fluted point with hydration ranging from only .92 microns to 1.08 microns, and a third excavated specimen for which the single section measures 1.43 microns. If the suggestion that hydration of these points has been affected by forest fires is correct, the same effect should be present in at least some of the first sample cluster reported here. If surface exposure had resulted in solar heating, it would be the thick measurements, not the thin ones which should be in error (cf. Fleming, 1976:195). But solar heating cannot reasonably account for the uniformity of the second cluster of readings.

The second cluster forms a very tightly defined group (coefficient of variation 2.2) isolated from the first cluster by an interval of one micron. The standard deviation of this cluster (supplied by the dating laboratory) is essentially equivalent to the intrinsic measurement variance (J.W. Michels, pers. comm. 1983) and therefore it is evident that this subset represents essentially a single moment in time expressed in the hydration of presumably homogeneous obsidian (see succeeding section). The mean hydration value of $2.73\mu^2$ is approximately equivalent to an age between 7000 and 10 000 years.

The results from this example are somewhat problematical. Discrete early and late occupations seem to be indicated. Supplementary evidence ties fluted points from the site to the late occupation, but I am not confident that this occupation is correctly dated or that it is in fact late. If the fluted points date to the earlier occupation they may be no older than 10 000 years. This age is not wholly out of line with the results of two previous examples in which the age of fluted points was examined, but in no case can we be assured that these points have been accurately dated.

Test for Homogeneity (Low Variance) Among a Set of Refitted Flakes

Certain series examined up to this point consist of specimens produced essentially at one moment in time. Accordingly, time is not a variable to contend with in assessing the causes of variance within these groups. However, one potentially major variable remains to be controlled. This is the difference in hydration rates that may occur between the various cores or pieces of raw material used to produce the several specimens within each series. Ostensibly, such variance is due to differences in composition.

Site RkIg-47 consists of several clusters of flakes and associated microblade core fragments plus scattered flakes, most of them exposed at the surface in a lightly forested area. The cores are of a non-formalized, flat to curved-face, Tuktu-like type that is tentatively dated as old as 6000 years ago at some Alaskan sites. From among one of the flake clusters (B) a number of refitted flakes of a distinctive grey obsidian was recovered. These formed the greater part of the cortical surface of a pebble, the interior portion of which was used to produce a microblade core, judging from the recovery of core fragments of similar obsidian.

Thin sections were taken from 17 flakes of this group. The hydration measurements for this set form a very tight statistical cluster and, accordingly, only the following summary description is given here.

N = 17

Range = 1.95μ-2.12μ

Mean = 2.03μ
Standard deviation = 0.05μ
Coefficient of Variation = 2.5
Age (before A.D. 1950) R $0.82\mu^2 \cdot 1000\ yr^{-1}$ = 4994 yr

This exercise was not undertaken to date the microblade technology at RkIg-47 (for which, nevertheless, an age in the 4000-6000 year range appears to be indicated), but to test whether or not specimens all from a single core or piece of raw material would produce results with a low variance in hydration. The results overwhelmingly conform to expectations — even more so than one might expect, considering the surficial provenience of the sample. The coefficient of variation is by far the lowest of any of the series reported in this paper.

This example is similar to a series of flake clusters from Dry Creek Component II, insofar as the results for a series believed to be derived from a single nodule of raw material are very uniform (Smith, 1977). Between flake clusters at Dry Creek there is, however, considerable variance even though all are of approximately the same age. At RkIg-47, as well, additional samples produced results dissimilar to those in the series reported here.

The tentative conclusion to be drawn from this example is that very good results can be obtained through hydration measurements applied to a series of specimens known to come from a single core of material. Similarly, it should be possible to obtain comparable results through multiple sectioning of a large artifact. This does not by itself provide an adequate basis for dating, because if nodules of raw material vary in hydration characteristics, particular hydration rates would have to be determined in each case.

It is possible to take the analysis one necessary step further by determining through induced hydration an action energy factor for the particular obsidian used (Michels, 1981). Because the cost of obtaining a series of hydration measurements together with an induced hydration determination would be a deterrent to routine use of such a procedure, one probably would resort to this means of dating only where it is impossible to achieve radiocarbon dating. The less expensive possibility of determining appropriate hydration rates on the basis of bulk composition also is being considered (J. Michels, pers. comm. 1983).

REVIEW AND DISCUSSION

Review

Several attempts to apply hydration dating have been discussed. In some cases hydration measurements were utilized to examine the archaeological context for age or homogeneity; in other cases archaeological information from dated or controlled contexts was used to examine the hydration data for variance, for the usefulness of their means for dating, and for hydration rates. The following examples were presented.

1. Two collections of flakes and implements associated with fluted points were examined to determine whether they were from single component sites or mixed sites. The flake lot from RkIg-10 was found to have generally thick hydration profile, but because of uncertainty regarding the meaning of variance in hydration measurements and whether thin readings identify specimens from later use of the area, it cannot be stated with certainty that the entire collection from the site is Paleo-Indian.

For RkIg-30 the data are divided into two discrete groups, one with an average hydration similar to that for RkIg-10. However, associated fluted points also have yielded thin hydration measurements which do not represent the true age of the points if their Paleo-Indian attribution is correct.

2. Two collections of flakes from dated house floors were utilized to establish hydration rates and to examine the distribution of hydration data of fixed age.

The collections from the house floors also provide some indication of the coefficient of variation that might be expected from a single-period collection in a buried but not too deep context.

3. Two collections of microblades from short-term technological events were measured to date the events. One set from RkIh-37 produced a relatively tight (low CV) set of thin hydration measurements, which indicates an age late in the history of microblade technology in Alaska. The other set of measurements, from RkIh-28, has a high degree of variance which reduces the confidence that I would place in using the mean as an indicator or age, although the relative dating in relation to RkIh-37 is acceptable.

4. The dating of northern fluted points was a complex exercise in which the data were interpreted in terms of hypothetical models controlled by radiocarbon dating. It was concluded, though not proved, that thin hydration of certain fluted points could be dismissed for reason of burning or other undetermined factors, and that other points and associated implements are of an age commensurate with the late Paleo-Indian stage of New World prehistory. However, hydration dating probably never will be precise enough to determine whether fluted points originated in the north or in the south. Slight differences in hydration rates are shown to be critical.

5. Hydration measurements were employed to test the Batza Téna Tuktu assemblage for variance to determine if there was a statistically valid basis for identifying the collection as a single-component assemblage. This test was based on the hypothesis that certain implement classes, particularly microblades, would occur in one occupation but not in others, especially those of the relatively recent age indicated by a radiocarbon date for the site, if more than one component is present. The radiocarbon date also was examined for appropriateness in the light of trial hydration rates. Results of an analysis of variance, supported by low variance of the composite sample, indicate that no more than one temporal group is necessarily represented among the artifacts. The occupation responsible for the microblades is seen to be late in terms of microblade technology in the north. Hydration dating therefore has helped support what some archaeologists may regard as a controversial conclusion.

6. In the final example, all specimens are derived from a single pebble of raw material. The results are excellent in terms of their homogeneity (low variance). It is foreseen, how-

ever, that they will vary from potential data derivable from specimens that originate from other cores from the same context. To take this into account it would be necessary to determine a hydration rate applicable to each piece or core of raw material.

Causes of Variance and Unsatisfactory Results

Major problems centre around the high variance of most sample sets. The importance of establishing hydration rates also has been emphasized. A number of factors may be responsible for high variance. These are only briefly discussed below but have been examined in greater detail by experimental scientists whose work is cited elsewhere in this paper.

1. Surface or very shallow depth provenience. Artifacts lying on the surface may be exposed to solar radiation, but in the north for approximately seven months of the year the surface is mantled with snow. As well, many of the exposed surfaces which exist briefly after forest fires are at other times shielded by shrubs, trees, moss, and other vegetation and organic litter. Nevertheless, surficial contexts may be especially subject to microclimatic variations caused by topography, slope orientation, vegetation, local winds, solar heating in conjunction with the low albedo of obsidian, and other factors. Friedman and Long (1970) stress the effect of diurnal temperature fluctuations on obsidian located at the surface or at depths no greater than 10 cm, and indicate that a modified procedure is required for the determination of the predicted hydration rate under this circumstance. It would be instructive to model reported microclimates and other surface variables to determine the extent to which they affect hydration.

2. Burning. The effects of burning on obsidian hydration were discussed earlier. Light burning of surface litter and the forest cover may not affect hydration. More intense burning does. This can occur without greatly altering the surface of a specimen as it appears to the unaided eye. It is assumed that hydration will recommence once the hydration layer has been lost through heating. This series of events would produce erroneous dates of tool manufacture, and in this manner burning may be a cause of variance. Further complications are that initially, instead of obliterating hydration, heating increases it dramatically (Friedman and Trembour, 1983; Smith, 1977:30, Michels *et al.*, 1983), and fire may expose specimens to solar heating if vegetation cover is removed.

3. Variable previous contexts. Initially, nearly all specimens occupied a surface context regardless of their provenience at the time of recovery. In locations where soils are formed and subsequently removed or where solifluction and frost action occur, an artifact, unless well sealed in a stratified site, may have occupied various contexts over a span of many millennia. It thus may have been subjected to exposure, to fires, and to differing depths of burial and types of vegetational cover with changes in the effective hydration temperature (T_e) of its context.

4. Mixture of components. This is simply a problem of cleaning up the data controlled by the archaeologists, but that may not be possible for some shallow sites. Certain kinds of component mixture might, however, produce interpretable results in the statistical distribution of data. It has been proposed that mixed components can be sorted out by direct dating of individual obsidian artifacts involved. I doubt, however, if hydration dating in the Subarctic is sufficiently precise for that procedure to be applied there.

5. Composition differences and the interrelationship of temperature and composition. Differing types of obsidian are known to hydrate at different rates (see Friedman and Trembour, 1953), but as far as I am aware comparative hydration rate data are not available for the various Alaskan obsidians, including those which may originate in the Yukon Territory and British Columbia. Usually in a sample set there will be a single source type, but multi-component sites may contain several source types (Griffin, *et al.*, 1969) and two types were present in one of the Hahanudan house samples. Differences *within* a source, which usually involve elements like silicon that make up the bulk composition and are not among those utilized to distinguish *between* sources, may also be significant.

In an applied test of the method for determining hydration rates on the basis of composition, adumbrated by Friedman and Long (1976), Smith (1977) obtained tightly clustered hydration measurements (CV 5.4 to 9.3) for which there is a radiocarbon date of 10 690 years (see Powers and Hamilton, 1978). Each set of samples is thought to come from a single nodule of raw material. However, differences between groups were considerably greater than would be expected to occur through random sampling. Smith (1977:44-45) found that the composition (SiO_2, CaO, MgO, H_2O) and the resultant chemical index (CI) was different for each group. By taking into account their chemical indices Smith was able to reduce the differences between the derived age of each group, although a sizable amount of unexplained variation remained.

In one series discussed in the present paper low variance was obtained when all measurements were on specimens derived from a single piece of raw material. The preliminary conclusion reached on the basis of this series is that a major cause of variance in Alaska is difference in bulk composition. Differences of significant magnitude might occur within a single source as well as between source groups. This conclusion needs to be supported by chemical analyses of northern obsidians.

Smith (1977:45, Fig. 3) points out that for low temperatures, 2°C or less, differences in the chemical index affect hydration rates very little unless the CI is above 40; Smith's data range from CI 21.3 to 40.4. At Bettles Field, located 175 km northeast of the Batza Téna sites, at 30.5 cm depth, which is sufficient to account for most sites in the region, the soil temperature exceeds 10°C but is less than 12°C for approximately one month and it exceeds 4°C for slightly longer than three months (data scaled from Fig. 33 in State of Alaska, Alaska Regional Profiles, VI, Yukon Region). By its endothermic nature the hydration reaction, so to speak, gets its "perks" from peaks in the temperature (Michels, 1981:4) — thus the attention given here to temperature highs and their duration instead of to the means. It is evident, therefore, that what is happening in a site in the few warmest months of the year has a disproportionate effect on hydration, but more so for obsidians of certain compositions than for others. This discussion leads to the next factors to be discussed.

6. Temperature. In addition to composition, temperature is probably the primary variable that affects rate of hydration. Thus, it was realized early that slower rates would apply in regions of relatively colder climate (Friedman and Smith, 1960). However, because of the endothermic nature of the hydration reaction, accurate comparison of empirical data or calculation of hydration rates on either an experimental or a theoretical basis requires a factor that takes into account peak temperatures and their durance — the effective hydration temperature (EHT or T_e; see notes to Table 10). Assumed T_e generally is calculated from above-ground air temperatures, but T_e is meant to be the actual temperature of the specimen in place. Friedman and Smith (1960:349) state that T_e can be calculated with reasonable accuracy for tropical climates by use of conventional climate statistics, but imply that this procedure would be less satisfactory in other regions. Two trial calculations by me show that the T_e drops approximately 0.4°C at a relatively average subarctic location and 0.6°C at a colder site 30.5 cm (1 ft) below the surface. At two feet the total decrease amounts to 0.6°C and 1.0°C, respectively.

There has been a growing awareness of the need for precision that has progressed from comparison of data on the basis of mean annual temperature, to using the T_e of the air, and finally to employment of the archaeological site matrix T_e. But for the lack of data, northern archaeologists do not take these factors into account (Smith, 1977 is an exception). Whether or not imprecise procedure actually has introduced significant errors remains to be determined, but this very likely is the case. For example, a difference of 4.32°C T_e among subarctic sites produces a 45% difference in hydration rates according to the constants and factors published by Michels for "Batza Téna" obsidian (1981). Using mean air temperature data as a basis for estimation, a range of 3.35°C T_e can be expected within interior Alaska between Delta Junction in the south and Bettles Field in the north. The difference calculated for these stations changes the hydration rate by 36%. The range is greater if the area considered is extended south of the Alaska Range.

One effect of paying attention to the T_e is that it is seen that the former distribution between "arctic" and "subarctic" sites for major rate differentiation breaks down (cf. Table 10, Denbigh, and compare with subarctic sites).

7. Depth of burial. Depth of burial affects the effective hydration temperature because increases in depth modulate or reduce the magnitude of differences between maximum and minimum seasonal and diurnal soil temperature. Certain details have been discussed in the preceding paragraph. Data necessary for the calculation of the T_e of subsurface contexts have been recorded for a number of Alaskan stations and probably can be extrapolated for other locations. For locations that can be revisited it would be more accurate to record the required information directly with sensing devices, briefly noted by Friedman and Trembour (1983:546), that can be retrieved and read after an appropriate interval. As is the case with other variables, it would be desirable to simulate a number of situations on paper in order to examine the effects of depth of burial. In Hahanudan House C, for instance, between the sides and the centre of the housepit the thickness of the fill covering the floor varied by a factor of two. Could this have been the cause of variance in hydration?

8. Climatic change. When hydration continues over a long time interval, increased accuracy is achieved if changes in mean annual temperature are taken into account (cf. Suzuki, 1973:298). Accurate paleo-temperature data are not always available and it may be desirable to model a range of possibilities — with the assistance of a computer (cf. Smith, 1977). It may be noted, however, that warming of a cold location (Bettles) by 3°C, as might occur during a thermal maximum, would raise the T_e of the air by almost 2.6°C, and lowering of a moderate location (McGrath) by the same amount would lower the T_e by 2.8°C (assuming that the entire temperature pattern as well as the mean is decreased 3°C). This amount of change is sufficient to alter hydration rates significantly.

9. Erroneous hydration rim measurements. Our discussion to this point has approached hydration as if the measurement data constitute fact, and therefore the factors which affect hydration must be determined and explicated in a manner that account for the data. As we have seen, this may become a tortuous and interminable process.

We are cautioned that problems may arise due to thin-section reading error. "The hydration rim is an incredibly complex optical phenomenon that can confuse even the most experienced analysts" (J.W. Michels, pers. comm. 1983). Where the data demand complex modelling, out of line with original expectations, to explain derived dates, it would be advisable to have the thin sections reexamined either by the original dating lab or by another lab. This can be done even after the sections have been stored for several years.

It is tempting to believe that in the case of the present study any changes in the older data sets would improve or tighten the results; would reduce the coefficient of variation; or would allow the recognition of subsets from two or more components within a sample as in fact was done at site RkIg-30 (Table 9) after the slides were remeasured.

10. Limits of accuracy. One often hears reports of dating single specimens or no more than three specimens in a sample. Aside from erroneous measurements, there is an estimated limit of accuracy or so-called error in hydration layer measurements, whether or not this is reported by the dating laboratory, that could be significant in such cases.

Michels (1967:213) noted that this cause of error amounted to a standard deviation of 0.07 micron for the Pennsylvania State University laboratory. Measurements by MOHLAB for two series in the present study carry reported errors in the range 0.03 to 0.12 micron — 0.05 micron would be an approximate average error. It is assumed here that where several observations are averaged the errors cancel one another, but the possibility that there may be accretionary errors should be considered. In the case of a measurement reported as 1 micron

TABLE 10. Trial gross obsidian hydration rates based on exponential formula $\mu^2 \cdot 1000\ yr^{-1}$

Rate	Locality	Mean annual temperature	T_e*	Obsidian type	Details
Koyukuk River Region and Northern Alaska					
0.76-0.85	Hahanudan House 2	ca. −4.6 C	−0.065	1 and 2	Obsidian Type 2 also called "Batza Téna". Climatic data is for Galena south of site, and slightly warmer.
0.90-103	Hahanudan House C	See above	See above	2	See above. Calculation is in this text.
0.55-0.81	Batza Téna Tuktu	−4.8°C	ca. −1°C	2	Assumes 14-C date applies to biface manufacture, sample of 10, corrected for storage; nearly same rate applies to microblades, explicated in text.
0.43-0.63	Batza Téna Tuktu	−4.8°C	ca. −1°C	2	Assumes 14-C date applies to end scrapers, sample of 9 corrected for storage (see Table 8).
0.33	N foothills Brooks Range	−9.2°C	−1.97°C	2 "Batza Téna"	Expected on the basis of induced hydration (Michels, 1981) for T_e −1.97 C.
0.62	Various N & S of Brooks Range	ave. ca. −5.9°C	−2.09°C	Probably 2	Alyeska all-site rate (Davis, 1977:8-9), temp. for Bettles - Wiseman region.
1.19	Same, selected	See above	See above		Alyeska I Rate.
0.32	Same, selected	See above	See above		Alyeska II Rate (Davis, 1977:9).
0.36	Denbigh Flint	−3.0°C Unalakleet	0.27°C		Arctic "G" Rate (Friedman and Smith, 1960). Calibration with assumed 6500 B.P. age of Denbigh erroneous, hence R is in error.
Other Interior Alaska and Southwest Yukon					
0.82	SW Yukon	Approx. same as Big Delta			Subarctic "F" Rate (Friedman and Smith, 1960), calibration frail.
0.66	SW Yukon, Chimi lower peat	See above	See above		Ave. of consistent sample of 4, calibration with 6240 ± 120 yr B.P. uncorrected 14-C date (Workman, 1978:577).
0.58-0.62	As above	See above	See above		With radiocarbon date corrected for 95% probability at sigma 100 yr (procedure of Klein *et al.*, 1982).
0.71-0.78	Healy Lake L. 8	−2.5°C for Big Delta	1.26°C		Single specimen calibrated to 11 000 B.P. and 10 000 B.P. Sample SBD-020 L8 (in Davis, 1977).
1.00-1.12	Healy Lake L. 6	See above	See above		Ave. of 3 of sample of 4 (4th is thin & would produce lower rate, 10 000 B.P. and 9000 B.P. calibration (J.P. Cook data from C.E. Holmes, 1978).
1.06	Minchumina MMK-4 Level 1	−3.4 McGrath	0.75°C	2?	Ave. of series, calibrated with 1140 B.P. corrected 14-C date (data from Holmes, 1978).
1.27	MMK-4 L.2	See above	See above		Ave. calibr. with 2365 corrected 14-C date (data from Holmes, 1978).
0.67	Minchumina MMK-12	See above	See above	2?	Ave. of series from feature related to Hahanudan, calibrated to corrected 1380 B.P. 14-C date. Range for one sigma 14-C date error is $0.61\text{-}0.73\mu^2$.
0.46	Dry Creek II, sample Set I	ca. −0.9°C	—		Calculated from data in Smith (1977), calibrated with 10 690 B.P. 14-C date. Context presently ca. 140 cm below surface.
0.64	Above, Set II	See above	—		
0.31	Above, Set IV				
0.39	Above, Set V				
6.00	Laboratory storage	22°C constant	21.8°C	2?	See text discussion.

*T_e for Hahanudan should be between the atmospheric values of −0.065 at Galena and −1.27 at Hughes (for mean ann. T of −4.6 and −4.9 respectively). Approximate T_e at Galena 1 ft below the surface is −0.492 and 2 ft below the surface −0.688. For Bettles there is a progression: T_e air −2.09, 1 ft below surface −2.76, 2 ft below surface −3.06. Subsurface temperatures are estimated from graphic portrayals in Alaska Regional Profiles, Vol. VI, and though this procedure is not accurate, variation from site to site according to slope, particle size, drainage, and vegetation renders precise figures devoid of a base for meaningful application.

The formula for calculating T_e given by Michels (1981) is (in Celsius):

$$T_e = \frac{(\text{mean ann. air temp} + 1.2316) + (0.1607 \times \text{Jul mean-Dec mean})}{1.0645}$$

This value can be used with certain constants and an experimentally derived activation energy value (E) specific to each obsidian type to obtain the hydration rate for any particular climatic environment (Michels, 1981).

± 0.05 micron, at the $0.82\mu^2$ rate the age would be between 1101 and 1345 years, and for a 3-micron measurement with 0.05-micron error the age, at one sigma probability, would be between 10 612 and 11 345 years. With a 0.1micron error the latter range increases to 10 256-11 720 years. Further complications arise from the presence of "invisible" hydration rims (Michels *et al.*, 1982). Obviously, isolated data or data of undetermined quality should be treated with circumspection.

11. The effect of warm storage. In some cases it may be desirable to take into account the hydration that has occurred, during storage, between the time a specimen was collected and when it was sectioned for dating. This may be significant for material removed from arctic and subarctic contexts and held in heated storage for long periods. The effective hydration temperature (T_e) in storage, at a comfortable room temperature (22°C), is approximately 23 degrees higher than the T_e of some subarctic sites. A difference of this magnitude can increase hydration rates by a factor of six or more.

Michels (1981) has determined experimentally a hydration constant for Batza Téna or Indian River obsidian which allows theoretical determination of its hydration rate under any temperature. Accordingly, the calculated rate for T_e -1.0°C, which is derived from my estimate for air temperature in the area of the Batza Téna Tuktu site, is $0.38\mu^2 \cdot 1000\ yr^{-1}$. For a T_e of 21.8°C, which is that of a constant 22°C environment, the calculated hydration rate becomes $6.00\mu^2$.

At the latter rate, hydration is $1.0\mu^2 \cdot 166\ yr^{-1}$ or $0.01\mu^2 \cdot 1.66\ yr^{-1}$. For a collection which was in storage for 10 years, as were some of those reported here, this should have resulted in $0.6\mu^2$ of hydration. This is equal to the difference which would be obtained, for instance, between samples with hydration layers of 0.97 and 1.0μ (which became 0.941 and 1.0 when squared). To follow through with the Batza Téna Tuktu example, when the square of the average of the sum of the hydration values for the combined sample series, $(\overline{x})^2$, is decreased by 0.06μ (from 0.7945μ to 0.7345μ) the commensurate change in age is a decrease of 158 years if the calculation is based on R $0.38\mu^2 \cdot 1000\ yr^{-1}$ (given above). Accordingly, 10 years of storage has "aged" the specimen 158 years — by a factor of 15.8, which is the ratio of the new $6.0\mu^2$ rate to the original $0.38\mu^2$ rate. (Actual aging may have been somewhat less, inasmuch as I believe that a $0.38\mu^2$ above-ground rate is too slow for the Koyukuk drainage). Aging in storage also has caused calculated hydration rates to be overstated (Table 8) though the amount of error is small.

Hydration Rates

In only one case, the two Hahanudan houses, was it the objective of this paper to calculate an empirical hydration rate. It has been shown, however, that accurate determination of hydration rates is essential if hydration dating is to be used for more than relative chronology. A number of trial exponential hydration rates are available for Alaska and Yukon Territory (Table 10). These range from $0.3\mu^2 \cdot 1000\ yr^{-1}$ to approximately $1.5\mu^2 \cdot 1000\ yr^{-1}$. This range in part reflects differences in the effective hydration temperature at various sites, and possibly in obsidian composition, but may be subject to errors, especially in the reliability of dated benchmarks used for calibration. No single hydration rate suffices for the subarctic region, but the suitability of many of those presently available is uncertain (see Davis, 1977; Holmes, 1978). A further problem is that the exponential mode of calculating rates may not be universally applicable (Meighan, 1983).

Attempts to apply these rates produce some surprising results. For instance, radiocarbon dates for the Mosquito Lake site, on the north slope of the Brooks Range, agree very well with the independently derived Alyeska I (fast) rate (Kunz, 1977), but the radiocarbon dates are themselves considerably younger than expected for the Denbigh Flint complex and their acceptance could force radical rethinking of arctic prehistory. A rate of $0.8\mu^2$ thus would not be unreasonable for the site, but if the experimentally derived rate of $0.33\mu^2$ for the foothills of the Brooks Range (Michels, 1981) is valid this third alternative should be the one to use. It, however, makes the site too old. Apparently, the search for suitable hydration rates in Alaska is still in a groping stage.

CONCLUSIONS

The history of hydration dating for the western subarctic region has presented a story of anticipation, qualified successes, qualified failures, and frustrations. I believe this characterization applies to the experience of others as well as to my own work — and is not confined to the western Subarctic. The facts which should be taken into account in order to secure more accurate hydration dates have been known for several years but have not been fully taken into account by archaeologists. In some cases this has been because of the lack of requisite environmental data or because collections come from contexts that are almost impossible to control for some of the disaffecting factors — exposure and mixture of components, for instance. It is evident that archaeologists will have to secure precise data on the environment of hydration if the technique is to be used effectively. For some contexts it never will be possible to control all the variables, but it may be possible to devise strategies to cope with surficial sites and other less than satisfactory situations. Recognition and rectification of dating-laboratory errors is contributing to the improvement of obsidian hydration dating. Although the substance of this article has been to describe practical applications of hydration dating, the discussion of problems has entailed solutions for which there are as yet few applied examples in the northwestern Subarctic.

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