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Obsidian Dating in West Mexican Archeology

A regional application of obsidian dating provides a precise chronology for archeological remains.

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In a recent article (*1*), Michels has summarized the present status of obsidian hydration analysis as an archeological dating tool. The benefits to be derived from obsidian dating remain more potential than actual, however, since in fact there have been very few cases in which this method has been applied to archeological data. Only five "application" studies are cited by Michels, and a small number of others remain in the form of papers read at meetings, or unpublished manuscripts. Michels indicates that 7500 obsidian determinations have been made to date (by all the known laboratories) but most of these are exploratory and are concerned with the method itself rather than with its application to immediate problems in archeology. Further, many investigators are unconvinced of the reliability of obsidian dating and few institutions include this technique in their laboratory training of archeologists. It may be of general value, therefore, to present an actual case study in which hydration analysis has been used as an operational tool in developing the archeology of a region. This discussion will have a twofold purpose: first, to bring out the methods for solving the practical problems which face the archeologist in applying obsidian dating to new regions; and second, to reinforce the optimistic appraisal of the obsidian method given by Michels, an optimism which is fully shared by us on the basis of our experience in utilizing this dating technique.

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We here present an application of obsidian dating to a region in western Mexico (Fig. 1) where the method has gone beyond the experimental stage and may be considered operational. We consider obsidian dating to be fully operational when it is possible to determine the age of obsidian artifacts not dated by other means and to have a high degree of confidence in the results. To reach this point, it is necessary first to know that archeological obsidians within a given study area have similar hydration potential in terms of their chemical composition and response to environmental conditions and, second, to determine with some precision the rate at which the process of hydration takes place. While some kinds of dating questions can be resolved without knowing these answers [for example, the serial arrangement of artifacts in a single site (*2*)], regional application of obsidian dating depends upon the ability to interpret the hydration thickness of specimens in terms of calendar years. Once this can be done, all of the other applications of obsidian dating become possible with a high degree of accuracy. On the other hand, in the absence of an obsidian chronology measurable in years, neither the reliability of the method (± factor) nor its sensitivity (discrimination of centuries versus millennia) can be estimated.

In our case example, obsidian dating was done for a series of West Mexican sites studied by the University of California, Los Angeles, since 1956. It soon became evident for several reasons that this region is nearly ideal for application of the hydration method, because of the abundance of obsidian flaking waste and artifacts in the sites, a relatively fast rate of hydration, and sufficient uniformity in environmental factors so that anomalous results are rare. Accordingly, we calculated correlations of hydration and age for a number of sites in order to apply the method to "unknowns," or sites which had not been dated by other means. We find in such regional application of the technique that anomalies or errors appear to be no more frequent than with other dating methods such as radiocarbon and, as a result, we now use hydration analysis as a first step in planning further study and excavation.

From surface samples of worked obsidian, a chronology of unstudied sites can be developed so that their general age is known before excavation begins. Such a chronology is of immense aid in problem-oriented archeology primarily because investigators attempt, whenever possible, to have some preknowledge of the age of archeological deposits before committing the time and cost of excavation to them. Traditionally, such prior knowledge of chronology has come from temporal placement of certain artifact styles (usually pottery types) found on the surface of sites, or from test excavations. For West Mexico, however, using obsidian dating as the first step has major advantages over ceramic analysis for a number of reasons: (i) Obsidian dating is cheaper and less difficult. It is easier to find worked pieces of obsidian on the surface of many sites than it is to recover diagnostic shards of pottery. Further, the analysis of pottery is much more time-

Table 1. Correlation of obsidian and radiocarbon dates from the Morret site, Colima.

Pit	Level (cm)	No. of carbon-14 dates	Carbon-14 (years ago)	No. of obsidian readings	Average hydration (microns)	Rate (years per micron)*
2	120–160	1	1950	2	6.1	320
3	100–120	4	1500	8	5.8	260
3	140–160	1	1600	11	5.8	260
4	160–200	1	2025	3	6.5	310
7	220–280	3	2180	1	8.0	270

* To the nearest 10 years; the average hydration rate, to the nearest year, is 284 years per micron.

consuming; a chronological determination from obsidian dating can be obtained in only a few minutes. (ii) Obsidian dating is more precise. Present knowledge of artifact types in western Mexico does not permit accurate time placement within a century or so; hydration analysis does. (iii) Obsidian dating can be applied to sites and areas where nothing is known of the age of the artifact assemblages. Our analysis has permitted us to determine the age of several fairly large collections of West Mexican archeological specimens, none of which could be assigned to a time period on the basis of our present knowledge of artifact style.

As noted above, there have been few attempts to apply obsidian dating to chronological problems for *regions* (as opposed to application of the method to the chronologies of individual sites). Clark established a chronology for central California (*3*) and his study has been used to evaluate numerous sites over this broad temperate region. Regular application of Clark's work by California archeologists has lagged, however, because of some apparent inconsistencies and problematical results pointed out by him in his study. Although this has tended to undermine confidence in application of the method to California studies, the value of obsidian analysis in the region has been considerably reinforced by the work of Michels (*2*), who dated 500 obsidian artifacts from a single site.

Few other regional applications of obsidian dating have been published, although several scholars are working on such regional studies. Published examples include the work of Evans and Meggers in Equador and Evans on Easter Island (*4*). These studies showed the obsidian method to be consistent and valuable, but obsidian dating was not used as a guide to selection of sites for further study. The Easter Island study demonstrates several of the points made in this article, including the value of obsidiàn dating as an independent check on dating evidence.

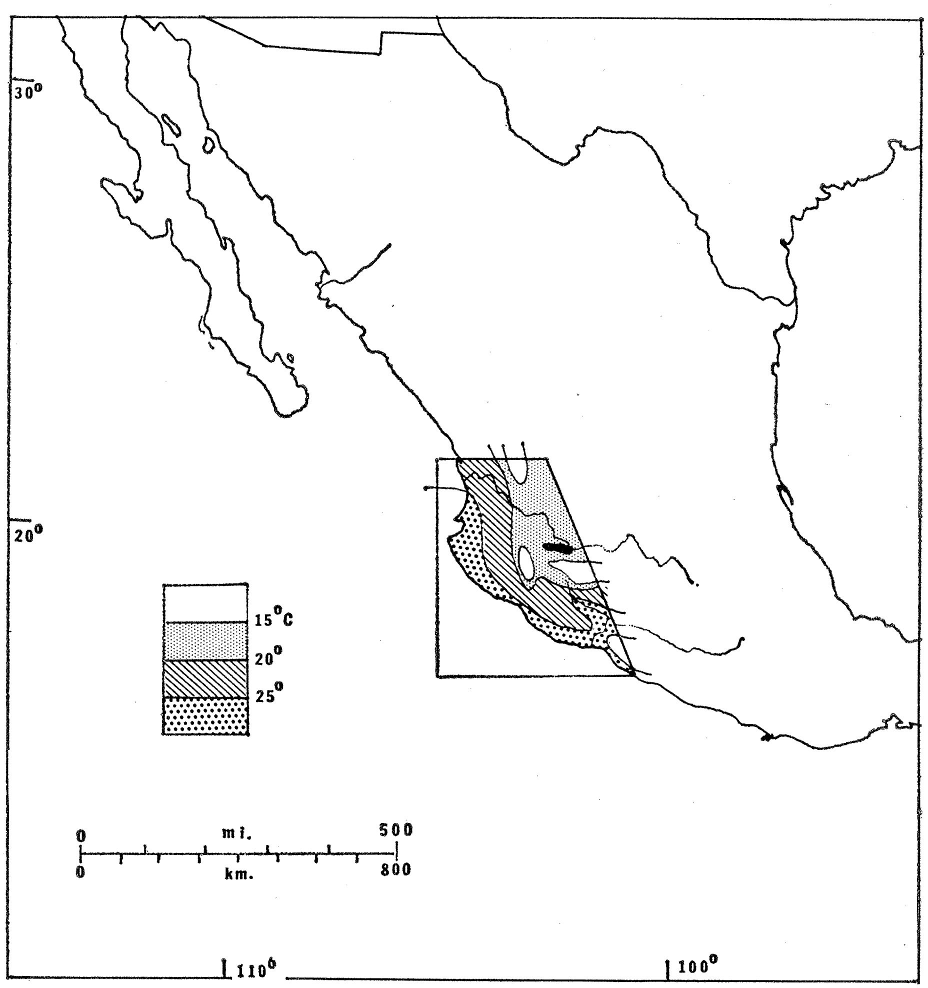

Fig. 1. Climatic zone of West Mexico to which obsidian chronology of this article applies. Simplified after Vivó-Escoto (*6*).

Delimitation of Region

It has been known from the beginning that obsidian hydration is dependent on temperature and that any attempt to use obsidian specimens for dating purposes must take into account the climatic zone from which they come. In their original study, Friedman and Smith (*5*) suggested seven different rates of hydration for regions from the Arctic to Egypt. In establishing a rate for western Mexico, therefore, we considered it essential to have a fairly specific understanding of climatic conditions within the region. As shown in Fig. 1, which is adapted from the climatological map of Vivó-Escoto (*6*), most of West Mexico lies within a zone where the mean annual air temperature is between 15° and 25°C. However, it should be noted that on the coastal plain annual temperatures may be somewhat higher than 25°C, and in some highland areas the yearly mean is slightly cooler than the 15°C figure cited above. While a temperature range of 5° to 10°C may prove to have little significance from a practical standpoint in West Mexican obsidian studies, we discuss below preliminary evidence that such temperature differences may be reflected by slight but detectable variations in the relative thickness of hydration from contemporaneous highland and lowland components.

Friedman and Smith (*5*) showed that in addition to temperature, variations in the chemical composition of obsidians have an effect on their hydration rates. It was necessary for them to propose two separate rates of hydration in Egypt, one for the trachytic variety of obsidian and another for the rhyolitic type. Within the zone of our study all of the archeological obsidian appears to be chemically uniform and is of the rhyolitic type; however, in the present absence of obsidian data for many areas of West Mexico, we cannot propose to extend our findings to a larger region than we indicate in Fig. 1.

Determination of Hydration Rate

The hydration rate for western Mexico is based on a correlation of obsidian readings and radiocarbon dates from the Morret site on the coast of Colima. This site was chosen because there is both a relatively large number of radiocarbon determinations and a substantial body of obsidian hydration data from it.

Correlation of hydration data with radiocarbon dates is a difficult problem involving numerous judgments concerning the relative value of different pieces of information. It is necessary to take into account inherent problems both in radiocarbon dating and obsidian analysis and, in addition, to know intimately the archeological context and circumstances under which the different samples were taken. Evaluation of the available information results in a hypothetical hydration rate which can be considered valid insofar as it can be supported by relevant data. In our present study we checked our hypothetical rate for the Morret site against known facts from a series of other West Mexican sites and found this rate to be remarkably consistent with field and laboratory data for each of the other locations. In spite of the fact that our proposed rate is derived from observation of data rather than application of theory, it appears to be correct and can be considered applicable to West Mexican dating problems until such time as further refinement is indicated.

For the Morret site, three methods of calculating the correlation between obsidian and radiocarbon dates were employed:

1) Hydration readings for obsidian specimens found in the same levels from which samples were recovered for radiocarbon dating were averaged and divided into the average radiocarbon age (see Table 1). While this is the most obvious method of combining obsidian and radiocarbon data, for several reasons such a direct correlation can be questionable. Aside from the inherent margin of error in both the obsidian determinations and the radiocarbon dates, a principal difficulty lies in the assumption that there has been no disturbance of soil levels and that the obsidian specimens and the radiocarbon sample materials are in fact contemporaneous. The field archeology shows this assumption to be so uncertain for the Morret site that individual correlations—a single radiocarbon date with one or two obsidian readings—cannot be taken too seriously (calculations based on this method indicate a hydration rate at Morret of between 260 and 320 years per micron, with an average from all the determinations of 284 years per micron). However, the largest sample from a single level of the site (four radiocarbon dates and eight obsidian determinations) yielded an average rate of 260 years per micron, which is in close agreement with the results of other methods of combining our obsidian and carbon-14 data.

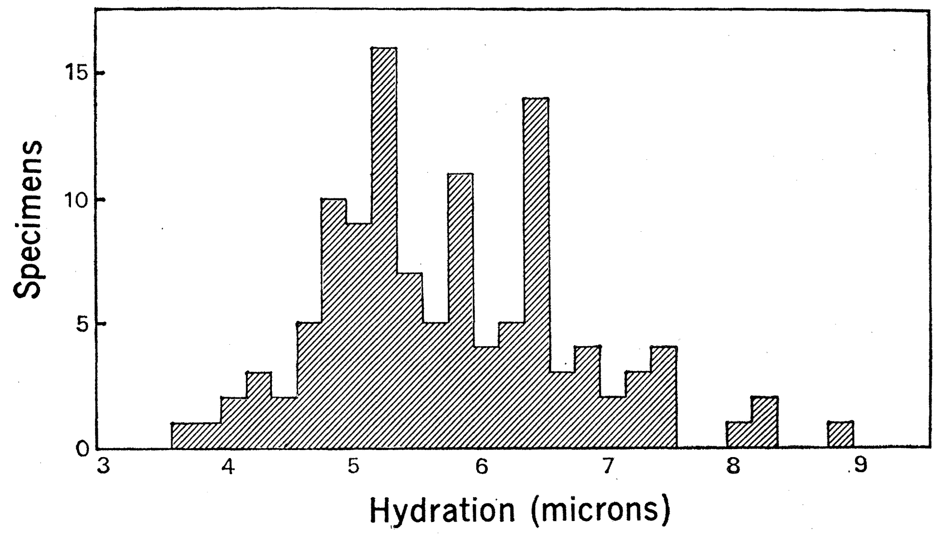

Fig. 2. Histogram showing distribution of 115 obsidian hydration determinations from Morret site, Colima.

2) A second way of correlating obsidian dates with radiocarbon results is based on a histogram of the obsidian determinations (Fig. 2). The clusterings of readings were assumed to represent cultural periods corresponding to the average radiocarbon dates for early and late periods. The readings of those obsidian specimens having the thickest hydration bands were averaged and divided into early radiocarbon dates, centering on a carbon-14 age of 2025 years ago. The same was done for the later period, with 1500 years ago being used as the age. The underlying assumption here is the basic assumption of obsidian hydration, that is, that the rate is constant, and that the thickest hydration rims belong to the oldest specimens. This correlation ignores the stratigraphic positions of the individual specimens in the site, and is therefore not affected by the disturbance of site levels through rodent action or other causes. The results suggest a hydration rate of 263 years per micron (sample of 92 hydration readings) for the later period, and 264 years per micron (sample of 13 readings) for the earlier phase. If the assumption of a constant hydration rate is valid, the number of years per micron should remain the same throughout the occupation of the site; the results just given differ by only 1 year in rate and therefore agree with our division of the histogram into early and late groups. The distribution of readings on the histogram may be divided differently but we found that other manipulations of our data showed a relatively wider rate difference (up to 30 years), and are not considered here.

3) A more complicated but probably more reliable calculation begins with the determination of contemporaneous levels of the site, based on frequencies of the various pottery types. Using the three-pole seriation method (*7*), five different orderings were determined for the ceramics from each pit and level, a total of 55 shard lots in all. These orderings were all in close agreement and consequently allowed for arrangement of the shard lots in sequence from most recent to oldest. The most recent lots (17 in number) were then grouped together as the "late" material, and the earliest lots (a total of ten) were likewise grouped as the "early" levels. The middle 28 lots were ignored for these calculations. There were five radiocarbon determinations and 53 obsidian readings from the levels in the late group and five radiocarbon dates and

three hydration readings from those of the early group. Averaging the determinations, the hydration rate for the early group is indicated as 236 years per micron and for the late group the indicated rate is 256 years per micron.

Considering the numerous factors affecting the precision of our calculations, the agreement in correlations between hydration and age in the three methods employed is most encouraging. This is especially so in that our calculations are based on different kinds of assumptions and have different sources of error. Considering our total range of results, we propose that the hydration rate for Morret obsidian is 260 ± 15 years per micron, yielding age determinations as shown in Fig. 3.

Notwithstanding the eventual necessity of some correction to compensate for slightly lower temperatures, hence somewhat slower rates of hydration in the cooler highland areas, the Morret figure can presently be considered applicable to calculations of obsidian age from both highland and lowland sites in West Mexico. This rate, almost 4 microns per millennium, is considerably faster than any of the regional hydration rates proposed by Friedman and Smith (*5*), and it is precisely such relatively rapid hydration that gives obsidian dating its specific value in western Mexico. Rapid hydration rate has two effects beneficial to the archeologist. First, it permits recognition of short periods of time in the occupation of a given site. For example, a West Mexican site occupied over the span of a thousand years will show measurable variation over a 4-micron range in its obsidian hydration, while a deposit covering the same time period in California—a temperate zone—will be represented by a variation of only 1 micron or so. In the Arctic, such a site might show no measurable variation in hydration at all. This means that in regions where hydration progresses at a very slow rate, the obsidian dating method has little or no practical value for the archeologist, whereas in areas where the hydration bands form rapidly, the method may assume the status of a primary dating technique. The second effect has to do with errors in measuring very thin hydration layers; the thicker the hydration band, the less significant are the effects of errors in measurement.

Michels (*1*) claims a "reading error" of only 0.07 micron for his current studies. With the optical equipment and procedures now used, such accuracy of measurement is probably the practical limit and is not attained by most obsidian laboratories. Measurement error is a function of the instruments used, reproducibility of results by different workers reading the same specimens, the number of determinations made on the individual specimen, and whether repeated determinations are made on the same or different parts of the hydration band. For our own results, we allow for a maximum measurement error of ± 0.2 micron; many of our individual errors in measurement are probably somewhat less and we are confident that the mean error is not greater.

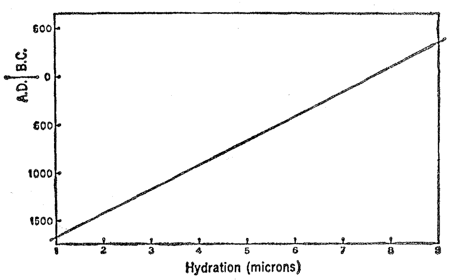

Fig. 3. Hydration of obsidian in western Mexico (1 micron = 260 years).

In addition to the measurement error, present uncertainty in obsidian dating must take into account the ± factor in the hydration rate. The uncertainty factor in our obsidian dates is indicated in Fig. 4, which shows the ± correction to be applied to each age determination. The chart indicates the maximum uncertainty based on whichever of the two error factors is the larger, but it assumes that the two sources of error are not cumulative. Applying these estimates, a determination on a specimen having 8 microns of hydration (about our upper limit at present) could be in error by as much as 120 years because of the uncertainty in the hydration rate, and by 52 years due to the possible reading error. Our date for such a specimen would be 2080 ± 120 years ago, using the larger error factor. On a specimen with only 1 micron of hydration, however, the error would be no more than 15 years due to uncertainty in the hydration rate, but would remain 52 years in the reading error, which is a constant, independent of the thickness of the hydration band. Here our determination would be 260 ± 52 years, again using the larger of the two error factors. Our largest percentage errors (percent of elapsed time) are therefore with very thin hydration layers.

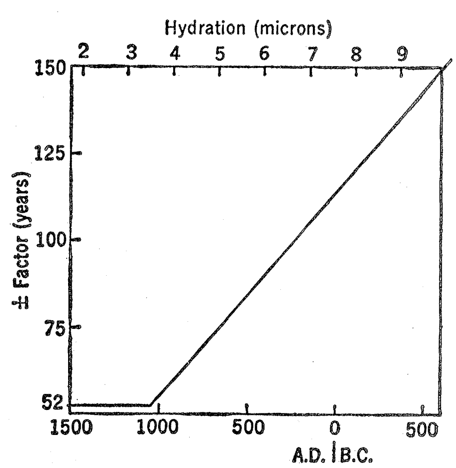

Fig. 4. Uncertainty factor for West Mexican obsidian dates.

The uncertainty factors in our obsidian dates are of about the same magnitude as those for radiocarbon and most other dating methods presently available for archeological application. For remains older than about 2500 years, the uncertainty in our obsidian results is greater than it would be for radiocarbon determinations from the region. The only significant improvement in our obsidian chronology can come from a reduction in the uncertainty in the hydration rate; that is, a better fit of obsidian readings to known chronologies established by radiocarbon or some other means. Reduction of the measurement error is also desirable but has very little effect on the age determinations for this particular region. In practice, we can determine the age of most obsidian artifacts in our region within two centuries; in few areas of the world is it possible to date archeological remains any more precisely than that.

As noted previously, there should in theory be a slight difference in hydration rate between highland and lowland obsidians corresponding to a 5° to 10°C difference in mean annual temperature between the two areas. In preliminary support of that hypothesis, indications of a detectable difference are found in two apparently contemporaneous obsidian samples, one from a lowland site at Amapa, Nayarit (157 determinations), and the other from a highland site at Tizapan el Alto, Jalisco (54 determinations). The ceramic materials in association with analyzed obsidian from the two sites consist in part of elaborate local polychrome wares which are closely related stylistically and can readily be assigned to the post-Classic period on the basis of radiocarbon determinations and cultural cross-ties with the South Central highland region of Mexico. However, despite the rather close ceramic correlation, plus the oc-

Table 2. Dating of West Mexican sites.

Site	No. of carbon-14 dates	Carbon-14 time span (*10*)	No. of obsidian dates	Range of obsidian values (microns)	Obsidian time span (*11*)
Morret, Col.	16	750 B.C. – A.D. 1300	115	3.7 – 8.8	330 B.C. – A.D. 990
Coamiles, Nay.			15	1.1 – 4.2	A.D. 860 – 1660
Amapa, Nay.	2	A.D. 1250 – 1305	157	1.1 – 7.6	30 B.C. – A.D. 1660
Peñitas, Nay.	4	A.D. 180 – 1270	11	1.1 – 4.6	A.D. 754 – 1660
Cojumatlan, Mich.			14	3.0 – 5.0	A.D. 650 – 1170
Tizapan el Alto, Jal.	3	A.D. 1000 – 1220	54	3.2 – 5.2	A.D. 600 – 1120
San Gregorio, Mich.			26	2.6 – 5.4	A.D. 550 – 1270
San Sebastian, Jal.	5	140 B.C. – A.D. 335	9	4.5 –5.5	A.D. 520 – 780 (*12*)
Barra de Navidad, Jal.	2	A.D. 1240 – 1450	47	1.8 – 5.6	A.D. 490 – 1480
Santa Cruz, Nay.			25	1.0 – 5.8	A.D. 440 – 1690
Playa del Tesoro, Col.	1	A.D. 520	12	5.0 – 6.0	A.D. 390 – 650
Huistla, Jal.	1	A.D. 1330 – 1400	9	2.3 – 3.8	A.D. 960 – 1350
Las Cuevas, Jal.	1	A.D. 1225	26	1.8 –6.5	A.D. 210 – 1480

currence at both sites of other temporally related features such as distinctive projectile point types (hydration determinations from a number of which are included in the present study), obsidian data from the two sites are at some variance with each other, significantly in a direction and of a magnitude which could be expected if the temperature variable were taken into consideration. An early post-Classic peak of occupational intensity at Amapa appears to be represented by approximately 4.5 to 4.9 $\pm$ 0.2 microns of hydration, while at Tizapan what we interpret as the same climax is represented by 4.0 to 4.4 $\pm$ 0.2 microns. If such hydration differences can ultimately be attributed to the temperature factor rather than simply sampling error or actual temporal differences between the sites, then considerably greater precision will be possible in calculating the ages of samples from adjacent climatic zones within the region.

Applications of the Method

With the hydration rate determined as accurately as possible, the most useful applications of obsidian dating in our region can be outlined as follows:

1) Direct determination of age. Utilizing the hydration rate established for the Morret site, we prepared a comparative table (Table 2), showing the ages of 13 sites for which obsidian determinations were made. This table includes several sites for which there are also confirmatory radiocarbon dates and, in addition, some others for which the only dating evidence previously rested on ceramic comparison and other stylistic cross-ties with dated sites in other areas. The stylistic cross-ties are in all cases in agreement with the obsidian dates, but since the former can only confirm within 300- to 500-year periods in most cases, they cannot verify the exact obsidian dates given. We find no evidence to contradict our age estimates, however, with the exception of specimens from the deeply buried shaft tombs of San Sebastian, Jalisco, as explained in the reference notes to Table 2.

2) In addition to direct determination of age, obsidian dating provides excellent evidence for the time range during which a given site was occupied and also indicates the periods of its most intense occupation. Such information, invaluable to the archeologist in describing the history of a site, comes more readily from hydration analysis because it is generally much easier to obtain a large number of age determinations from obsidian than it is by means of the radiocarbon dating method. This is partly because of the expense of radiocarbon dating but it also stems from the fact that obsidian is both abundant and easily collected in most sites while samples suitable for carbon-14 determinations are not. Obsidian dating can be applied to specimens recovered from the surface of sites; dating of surface specimens should not be done with charcoal or other organic materials for numerous reasons. Adequate samples for radiocarbon dating purposes can generally be obtained only from test excavation in a site, and sometimes even a fairly extensive field operation yields few or none of the desired sample materials. For many of our West Mexican sites, we can readily make 20 to 50 determinations of obsidian age but have *no* sample suitable for radiocarbon or other dating techniques. In any event, the net effect of hydration analysis is to give us a much clearer picture of time range for sites than we should otherwise be able to obtain. For all of our sites but two, the radiocarbon dates provide one or two temporal points, which may fall at the end of the occupation period, or near its beginning—or somewhere in between—providing no real evidence as to the duration of habitation in these areas.

3) Hydration analysis also serves as an excellent independent method for checking the integrity of other dating evidence. For radiocarbon in particular, the check in the past has largely depended upon archeologists' judgments concerning cultural level or inferred rates of cultural change for a site or area. Such judgments are imprecise at best, are often quite erroneous, and have tended in many cases to obscure rather than clarify the situation with regard to unexpected radiocarbon dates. However, once a pattern of correspondence between obsidian and radiocarbon data has been established, obsidian determinations may point up questionable radiocarbon results. Four examples from our region may be mentioned. For the Morret site itself, there is a radiocarbon date of A.D. 1300. Since none of 115 obsidian determinations is later in time than A.D. 990 and the hydration evidence indicates the end of the major occupation of the site as being approximately A.D. 750, we may conclude with some assurance that the late carbon-14 date applies to material which is somehow intrusive in the deposit and does not pertain to the bulk of cultural remains from the site. Until this conclusion was reached, the archeologist writing the site report was confronted with considerable difficulty in trying to extend the observed cultural remains into a time period some 500 years too late for them; elimination of the anomalous radiocarbon date immediately resolved the major chronological problems.

A second example is provided by the site of Tizapan el Alto, Jalisco. One

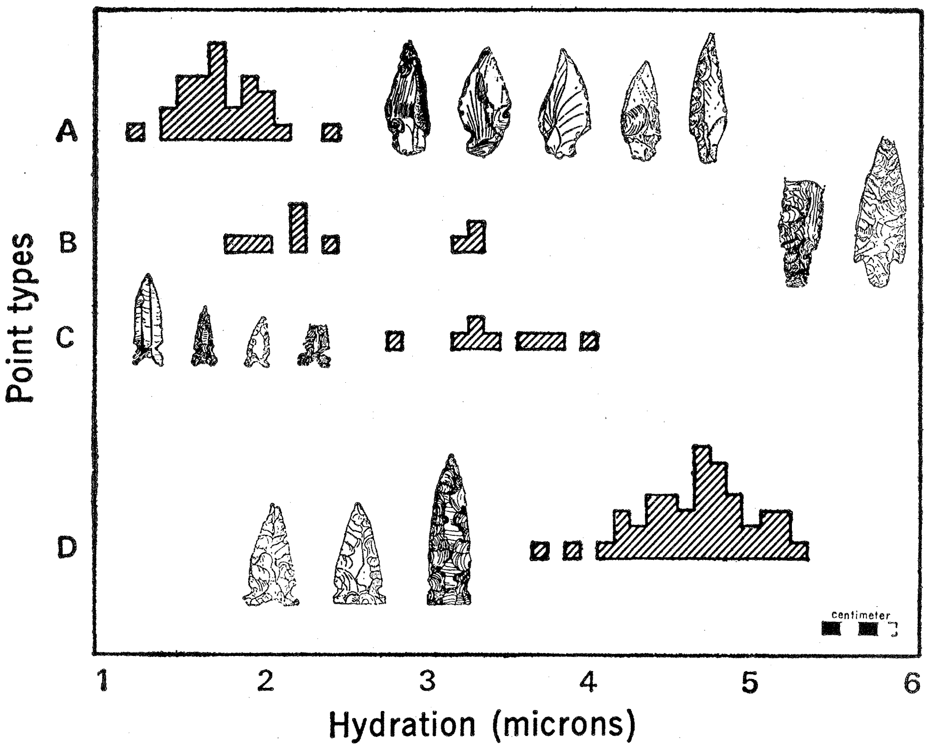

Fig. 5. Combined histogram showing the range and distribution of the Amapa point types. Each square represents one point.

radiocarbon determination indicates an age for the lower levels of approximately 4000 years ago; obsidian determinations and pottery on the same levels indicated an age of about A.D. 800 to 900. We still cannot explain how charcoal of such an age was introduced into the site, but we are able to again eliminate the anomalous date and rely entirely on the other three radiocarbon determinations, which all correspond to our obsidian data.

A third example is the Huistla site, Jalisco. There is only one radiocarbon determination—A.D. 1090—but the nine obsidian determinations indicate that the site should be some 150 years older than this. The conflict cannot be clearly resolved as yet, but the excavator of the site believes, on the basis of pottery and other artifacts, that the obsidian dates are closer to the true age of the deposit than the single carbon-14 determination (*8*).

Finally, there is the site of Barra de Navidad, Jalisco, excavated by Long, who used Morret data to estimate a hydration rate of 232 years per micron (*9*). In that his rate was based on a fraction of the data used in our own calculations, the rate of 260 ± 15 years per micron proposed here is more likely to be correct. In correspondence, Long has indicated no disagreement; the difference in rate represents only a century in his age determinations. However, in his published report he notes some discrepancy between the obsidian and radiocarbon results from Barra de Navidad and comments: "... the radiocarbon dates still do not agree with the rest of the data. Since an acceptance of the obsidian data results in better data fit than the radiocarbon dates, the ceramic and obsidian results were used to establish the site chronology."

For our region of study, it is clear that obsidian hydration studies can provide a valuable cross-check for other kinds of chronological evidence.

4) Since obsidian determinations are made directly on artifacts, it is possible also to determine the time range of individual artifact types, as first demonstrated by Michels in a California site (*2*). In our area of study, we have an excellent example of this application of obsidian dating at the site of Amapa, Nayarit. Four distinct point forms occurred at the site, three of which were manufactured solely from obsidian, while the fourth was represented by both obsidian and other materials. It had been hypothesized that the considerable differences in their forms represented not only the obvious typological distinctiveness, but functional difference as well. One of the types, a small notched point, seemed most likely to have functioned as an arrowpoint, while another, a crudely fashioned form, suggested use as a cutting implement of some sort. The other two forms might have been used for either or both of these functions. A hypothesis utilizing obsidian dating was set up as follows: if, in fact, the forms represented primary functional variability, then the obsidian determinations for all the points of these types (98 in all) should reveal similar time ranges. Plotting of the obsidian hydration readings (Fig. 5) led to a rejection of the hypothesis. Far from having similar time ranges, each type occupies a distinct but somewhat overlapping time period. We were unable to determine this temporal relationship from traditional stratigraphic records made in the field, but obsidian dating shows it clearly. Rather than having four forms with different functions, the point types appear to represent a functional constant changing stylistically through time. This example shows that obsidian dating allows the investigator to measure time directly and independently when working with typological studies utilizing obsidian artifacts. It therefore provides independent evidence upon which conclusions can be based rather than leaving it to comparative data or outright speculation.

Conclusion

In sum, our experience in applying obsidian dating to one delimited region suggests some ways in which the archeologist can establish a hydration rate and estimate correction factors. Once this is done, use of the method provides an immediate guide to practical decisions about the choice of sites for excavation, and in addition contributes directly to several important areas of analysis of collections. Obsidian dating, like other dating methods, is not a universal tool for the resolution of all chronological problems in all areas. As we have discussed, in some regions obsidian dating is of little or no value. Hence, as with other methods, some discrimination in use is needed, and areas of uncertainty remain to be clarified. However, despite its limitations, the obsidian method yields very consistent results in such areas as western Mexico where it can be used effectively. Obsidian dating is a significant addition to archeological techniques and will be widely applied in future archeological programs. It may be of particular value for those sites from which no other direct evidence of age (such as radiocarbon dates) is available.

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9. S. V. Long and M. Wire, *Anthropológica* **18**, 43 (1966).
10. The C^{14} dates have a statistical error which varies with the size of the sample and other factors; for the dates given in the table, the average $\pm$ factor is approximately 100 years. All dates are corrected for tree-ring data, and those dates determined on marine shell are corrected for ocean upwelling. The age as determined by carbon-14 is subtracted from 1950 and is rounded off to the nearest 10 years. See G. J. Fergusson and W. F. Libby, *Radiocarbon* **5**, 1 (1963); R. Berger, G. J. Fergusson, W. F. Libby, *ibid.* **7**, 336 (1965); R. Berger and W. F. Libby, *ibid.* **8**, 467 1967); *ibid.* **9**, 477 (1967); *ibid.*, in press.
11. Hydration dates are figured at 260 years to the micron (to the nearest 1/10 micron). For consistency with the radiocarbon dates, the obsidian ages are subtracted from 1950 and are rounded off to the nearest 10 years.
12. The San Sebastian obsidian readings yield "short" dates, presumably because the specimens had been placed in a deep (5 m), sealed tomb shortly after their manufacture. Deep burial of this type preserves the obsidian in a more constant, somewhat cooler environment than that characteristic of surface sites and, as a result, the hydration rate of tomb obsidian is apparently considerably slower.

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Assay Systems for the Study of Gene Function

Two assay systems, the syntheses of RNA and of protein, are described; their virtues and drawbacks are discussed.

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One of the major goals of developmental biology has been to find out how a cell of a higher organism acquires its structural and functional characteristics as it develops, and how the different cell types of an organism become different from one another during embryonic development. In recent years, the results obtained by molecular geneticists have had a strong impact on the thinking of developmental biologists. "The point of faith is: make the polypeptide sequences at the right time and in the right amounts, and the organization will take care of itself" (*1*).

All cell types do not contain the same array of proteins. Hemoglobin, to choose a well-known example, is present in red blood cells, but not in the cells that produce the black pigment of hair and skin. These pigment-producing cells in turn contain tyrosinase, an enzyme necessary for pigment formation; this enzyme is not found in red blood cells.

The simplest hypothesis to account for cellular specialization at this level of organization is that all genetic information does not effectively reach all cells. This concept of "differential gene function" dates back to Theodor Boveri (*2*). It could be due to at least three mechanisms. First, the different cell types could differ in their genetic constitution. If such differences were qualitative, this would mean that some cells contained some genes that were lacking in others. This is almost certainly not the case, for there are a number of instances where a population of already specialized cells can give rise, in the course of regeneration, to a variety of cell types (*3*). Also, when an individual cell nucleus is removed from a differentiated cell and placed into an egg, this artificial embryo can divide, grow, and develop into a mature organism containing all the cell types typical for a normal sib (*4*). But maybe genetic differences between cell types are quantitative only. In fact, it has been found that amphibian oocytes contain far more copies of the genes coding for ribosomal RNA than differentiated cells of the same organism do (*5*). It remains to be shown whether such quantitative differences also exist among nonribosomal RNA genes. Second, the genetic constitution of all cell types could be identical, but only those genes whose products are needed in a particular cell type would be transcribed. Thus, the various cell types would differ in the quality and quantity of RNA copies of the common DNA templates. Cellular differentiation in this case would result from a mechanism regulating genetic transcription. Third, the RNA copies produced during transcription could be utilized differentially; in this scheme, a given informational RNA copy would be translated in one cell, but not in another. Regulation of translation would therefore account for differentiation.

Probably more different routes of attack have been chosen than there are laboratories trying to unravel these fundamental regulatory processes. In this article we restrict ourselves to describing the experimental systems

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