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The Oxidizable Carbon Ratio (OCR): A Proposed Solution to some of the Problems Encountered with Radiocarbon Data

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Abstract

Since its development as a dating tool, archaeologists have struggled with the interpretation of radiocarbon data due to its limitations in accuracy and precision. These limitations are presented and reviewed in terms of how archaeologists might resolve some of the problems in using this data. A new procedure, the OCR, is introduced as a means of improving the interpretability of radiocarbon data, and as a potential solution to some of the more problematic limits of the radiocarbon procedure. The OCR procedure provides an independent analysis of age for charcoal found in soil. This procedure is based on the chemical analysis of charcoal within definable environmental contexts. As such, it is not restricted by the limits of the nuclear-based radiocarbon procedure. The OCR procedure offers an inexpensive, accurate and precise dating procedure for archaeologists.

Introduction

Since the development of radiocarbon dating in the early 1950s, the establishment of empirically derived date estimates for archaeological sites has been possible. The importance of radiocarbon dating in the field of archaeology is acknowledged by most archaeologists. However, it is also acknowledged by many that erroneous conclusions are often drawn due to the misunderstanding of the nature of radiocarbon data (Levine 1990, Renfrew 1973). These misunderstandings have led not only to erroneous conclusions, but to a growing doubt in the value of radiocarbon dating. Before submitting samples for analysis, the archaeologist must determine whether or not the cost of the procedure is balanced by the acquisition of additional significant information. In those cases where sites contain well-stratified temporally diagnostic artifacts, or research questions are focused on the fine-grained analysis of cultural change, the precision and the accuracy of radiocarbon dating adds little information. In those cases where sites contain few if any temporally diagnostic artifacts, and the condition of the site is questionable, the information provided by the radiocarbon date is of tenuous value. Without corroborating data, the archaeologist must always question the actual relationship between the radiocarbon date and the archaeological site.

Although the situation is not yet critical for many archaeological interpretations, the role of radiocarbon dating in archaeology needs to be reexamined. As a phenomena of nature, C^{14} isotopic decay is real and the principles of measuring the rate of change in this phenomena are valid. The value of applying radiocarbon dating to archaeological studies is the issue to be questioned. Is the potential value of radiocarbon information being realized, or do the limits inherent in this procedure also limit its value to archaeological inquiry?

In a recent review of the use of radiocarbon data in Northeastern North America, Levine discusses the basic misunderstandings and misuses of radiocarbon data. The most basic fallacy is the expectation of the precision of any given radiocarbon date. Insofar as radiocarbon decay is a random process, one cannot expect that the repeated measurements of a sample will yield the same results. Multiple radiocarbon dates will tend to spread, as a normal distribution around a "true" value (Mook and Streurman 1983). Therefore, the radiocarbon date is only an estimate, having a level of probability of being true within the limits expressed by the standard deviation. The standard deviation for a radiocarbon date is determined by the amount of C^{14} in the sample, the age of the sample, and the duration of the measurement (Levine 1990, Mook and Waterbolk 1985). Even with the statistical probability of correctness of the estimate, it is probable that between 10 and 20 percent of radiocarbon dates will not agree with archaeological expectations (Switsur 1990).

Taylor, in his recent book, Radiocarbon Dating, an Archaeological Perspective (1987), presents six basic assumptions which one must accept when conducting or soliciting radiocarbon dates.

1. That the concentration of C^{14} within each carbon reservoir is a constant;
2. That the various carbon reservoirs are homogeneous in their C^{14} concentrations;
3. That the ratio of carbon isotopes will be unaltered except for that due to C^{14} decay;
4. That the half-life of C^{14} is accurately known;
5. That the natural levels of C^{14} can be measured with accuracy and precision; and
6. That there is a known relationship or association between the sample and a specific event.

Taylor demonstrates that these assumptions are at best “Platonic Forms” to be aspired to but never completely realized. Short term and long term variations in atmospheric C^{14} concentrations exist through time (de Vries 1958). Carbon reservoirs are affected by their environmental context and samples obtained from within the specific context will demonstrate contamination by older or newer carbon. Fractionation, the propensity of different plant species to incorporate differing ratios of the carbon isotopes, improved calculations of the C^{14} half-life, the recent variations in the natural levels of C^{14}, post sixteenth-century de Vries Effect, the burning of fossil fuels which has added old carbon to the sample — Suess Effect (Suess 1955), Nuclear testing — Atomic Bomb Effect (Rafter and Fergusson 1957), which has increased the amount of C^{14} incorporated by recent samples, and the discrepancies between the sample being analyzed and the event being dated (i.e., presample-growth error — Ralph 1971), all conspire to challenge these assumptions.

Although research continues to address these problems, the tenuous nature of these assumptions remains, requiring us to adopt the position that “...the measurements performed in a radiocarbon age determination are essentially those of experimental physics. Consequently, because these measurements inevitably involve some type of error of observation, (either statistical or the product of bias) the exact age of the specimen will be, to that extent, indeterminate” (Switsur 1990).

As archaeologists, our interest in experimental physics is at best only cursory. Our training and expertise are not focused in this area. We know that it is important to recognize the present limits of radiocarbon dating, but there is little that we can do to mitigate the effects of these limitations. While the physicists work on the discrepancies in the fundamental assumptions, we are left to focus on improving the sample collection procedures and interpretations of the results. The literature abounds with suggestions and ideas for improving sample collection. The establishment of rigorous systems to document the stratigraphic integrity of samples (Harris 1989), the excavation of soils by pedogenic rather than arbitrary levels (Frink n.d.), and flotation (Pearsall 1989), are just a few examples of such attempts.

Improving interpretation of radiocarbon dates requires that we find ways to limit the effects of the inherent errors in radiocarbon analysis. Two general approaches have been suggested (Taylor, 1987, Levine 1990). The first is to obtain multiple samples, and the second is to obtain independent correlative data.

Although highly controversial, some scientists have recommended averaging multiple samples to reduce the standard error of the mean (Long and Rippeteau

1974). However, Waterbolk (1983) argues that averaging may often be unwise and unjustifiable due to the high variation in the reliability of any individual reading. Averaging may be considered an option only in cases where samples have been derived from the same object and the archaeologist is confident that all determinations have the same corresponding age. Averaging is unwise in cases where one does not know if all the determinations are estimating the age of the same event or phenomenon, or when samples have been derived from different objects or from different archaeological contexts within a site (Levine 1990).

The development of dendrochronology, tree ring dating, has provided an independent correlation for radiocarbon dates. In those parts of the world where tree ring sequences have been established (Western and Southwestern United States, and Europe), dendrochronological data are used to describe the accuracy and precision of radiocarbon dates (Taylor 1987). Dendrochronology has also been used to describe the variability in atmospheric C^{14} concentrations through time (Renfrew 1973). However, tree ring sequences have not been defined for most regions of the world including Northeastern North America.

Environmental factors in Northeastern North America conspire against the use of either of these approaches for mitigating the errors inherent in radiocarbon dating. Pedoturbations and thermal extremes, particularly during the winter months, pulverize the brittle pieces of carbonized wood, presenting the archaeologist with only a minimal number of pieces large enough for radiocarbon testing. Often archaeological features do not contain sufficient carbon for a singular analysis and seldom contain enough carbon for obtaining multiple samples. Even when fortunate enough to recover these small samples, the archaeologist faces the problem of having to assume a contemporaneous age of the several individual logs represented. It is generally unknown whether the many small pieces of charcoal found in the archaeological feature represent one datable event or several. Compounding these problems, the lack of an established tree ring sequences for the region denies the option for control on the data through the use of correlative data.

Lacking the means and opportunity to mitigate or control the extent of errors inherent in the procedures has resulted in a large body of highly questionable data. Archaeological studies describing cultural processes on a regional scale are thwarted by inconsistent radiocarbon dates (James Pendergast, personal communication, 1992, Engelbrecht 1992). It is reasonable to assume that most of the radiocarbon dates are reliable estimates of age, but it is currently impossible to determine which samples are the correct ones. What is needed in the Northeastern region is an independent procedure for dating archaeological carbon samples that will provide a cross-check on the radiocarbon data.

The OCR (Oxidizable Carbon Ratio) as an Independent Procedure for Estimating the Age of Carbon in a Soil Context

Recent studies have demonstrated that carbonized organic matter, or charcoal, within a soil context undergoes chemical changes over time (Frink 1992). These changes are directly related to the age of the sample within the environmental contexts of climate, biota, relief, and the soil chemical and textural matrix. Results from this study determined that charcoal undergoes biochemical alterations over time which are detectable through simple, inexpensive chemical procedures. Variability in the chemical analysis was found to be directly dependent on specific environmental factors such as rain fall and temperature, and contextual factors such as soil texture, pH, and the depth of the sample below the surface.

The two chemical analyses used in this procedure determine the total percentage of carbon and the percentage of readily oxidizable carbon in the sample. The results are converted to a ratio of total carbon to the readily oxidizable carbon in each sample, the Oxidizable Carbon Ratio ("OCR"). The OCR value is then factored into an environmentally based contextual formula and an estimate of age results.

The data for climatic regimes and soil textures were given values based on an arbitrary scale for statistical analyses in the initial study. Climatic regimes are theoretical constructs derived from the combined influence of precipitation and temperature on soil development. Rainfall and temperature affect soil development in several ways. With increased rainfall, carbonates and clay are leached from the soil and organic decomposition increases. For every 10o centigrade rise in temperature, the speed of chemical reaction increases by a factor of two to three times. Soil texture, the description of the size and percentage of individual soil particles, affects soil development by regulating the diffusion of moisture and atmospheric gases. The preliminary study revealed that the variability in the OCR was the result of the interdependent dynamics of several environmental variables. However, the climatic regime and soil texture heavily influenced the variability in the OCR reading.

As rainfall and temperature strongly influence the OCR variability, the calculation of these influences must be precise. In this current study the environmentally based context formula for the OCR uses the mean annual temperatures and rainfall obtained for each sample location (Ruffner 1978) rather than an arbitrary scale. The mean annual rainfall is expressed in centimeters per year, and the mean annual temperature is expressed in degrees (Fahrenheit). Fahrenheit is used to accommodate the more northern regions where the mean temperature expressed in degree centigrade might require negative numbers, needlessly complicating computations.

Depth and texture affect the rate of oxygen diffusion through the soil (Stolzy et al. 1961). Biochemical activity is oxygen dependent. As sample depth increases, the oxygen concentration decreases, and coarse-textured soils show a higher degree of oxygen diffusion through the soil profile. The variability in the OCR values were found to be lower in samples from near the surface and higher as the depth increases. Also, the degree of variability due to depth was found to be less for coarse-textured soils and greater for fine-textured soils.

The oxygen diffusion rate in any given soil is dependent on the available air space, or soil porosity, and soil porosity is primarily influenced by soil texture. Although fine-textured soils contain a greater percentage of pore space, the small pore size impedes oxygen diffusion. Coarse-textured soils have fewer but larger pores, facilitating oxygen diffusion. The current study determines the percent of texture fraction of each soil sample, and the effect of soil texture on the OCR value is expressed as a mean of the particle size fractions by weight. The particle size fractions are defined as very coarse sand, coarse sand, medium sand, fine sand, very fine sand, coarse silt, fine silt and clay.

In addition to the fifty samples obtained from sites in Connecticut, Maine and Vermont, used in the earlier study to establish the initial OCR formula, sixteen new samples were obtained from archaeological sites in New Hampshire (4) and Vermont (12). Eight of the features have associated radiocarbon dates, and eight contained temporally diagnostic cultural artifacts.

RESULTS

In the aforementioned initial study, a basic formula was constructed from those samples having a radiocarbon date estimate or a known date. This formula relates the various factors affecting the biochemical changes in the soil-charcoal sample. Below the initial formula is adjusted to include the new data categories of mean temperature, rainfall, and texture.

$$f = \frac{(\text{OCR} \times \text{DEPTH} \times \text{MEAN TEMPERATURE} \times \text{MEAN RAINFALL})}{(\text{MEAN TEXTURE} \times 2\sqrt{\text{pH}} \times 2\sqrt{\%\text{CARBON}} \times \text{TIME})}$$

From this equation the constant “f “ is recalculated, and found to equal to 14.4888.

Next, the equation is solved for the variable TIME, expressed as OCR_{DATE}.

$$OCR_{DATE} = \frac{(OCR \times DEPTH \times MEAN\ TEMPERATURE \times MEAN\ RAINFALL)}{(MEAN\ TEXTURE \times 2\sqrt{pH} \times 2\sqrt{\%\ CARBON} \times f = 14.4888)}$$

A regression line is plotted to compare the OCR_{DATE} to the radiocarbon date (Figure 1). A total of 58 samples are thus compared. The high degree of correlation (r2= 0.95) and the low standard error (0.03) indicate that the OCR_{DATE} estimate is comparable to the radiocarbon date estimate.

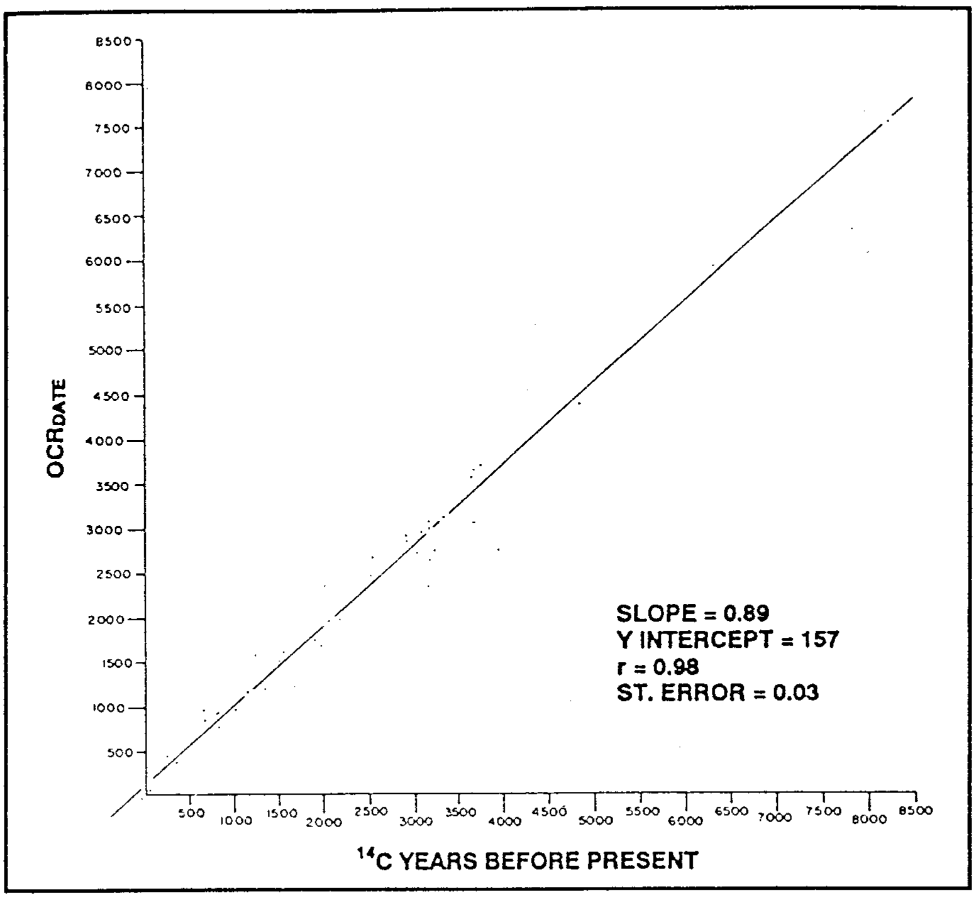

Figure 1. Regression line for calculated OCR_{DATE} and ^{14}C radiometric date (and recent documented events).

To determine the independence of the OCR_{DATE} estimate from radiocarbon date, twenty samples obtained from archaeological hearth features containing temporally diagnostic artifacts as well as charcoal were analyzed using the OCR procedures, and the OCR_{DATE} was calculated. The OCR_{DATE} estimates are compared to the expected age range established for the diagnostic artifacts (Figure 2). All twenty OCR_{DATE} estimates fall well within the expected temporal range of the artifacts.

Discussion and Application of the OCR Procedure

The results of this study demonstrate a strong correlation between radiocarbon date estimates and the OCR_{DATE} estimates. This demonstrates that the OCR analysis may be used as an independent check on radiocarbon dates. As such, the OCR procedure can be used to complement and verify the accuracy of the radiocarbon date. In situations where the radiocarbon date estimate differs significantly from the archaeological expectation, interpretation of the data requires that a choice be made as to whether the archaeological data upon which the expectations are based is in error, or the carbon sample was contaminated. All too often archaeologists have been quick to misjudge the condition of the radiocarbon sample without a scientifically rigorous examination of the archaeological data. The OCR procedure may be used as an independent test of both the radiocarbon date and the archaeological assumption, verifying one or the other, or casting doubt on both.

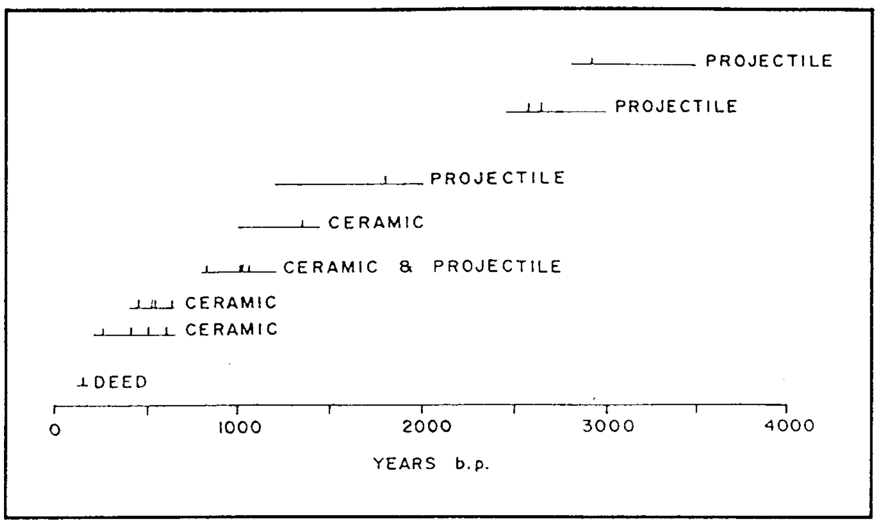

Figure 2. Comparison of expected artifact age and OCR_{DATE} estimate.

Radiocarbon analysis is limited by a wide range of errors inherent in the assumptions that must be made in the process. For this reason, the radiocarbon date is an estimate only. The OCR procedure is also limited. However, unlike radiocarbon analysis where the errors are in the domain of experimental physics, the errors in the OCR procedure are primarily contextual, an area which should be within the expertise of the archaeologist. The spatial and environmental contexts of the charcoal sample are the principle factors effecting the accuracy and precision of the OCR_{DATE} estimate. With tightly controlled statigraphic excavation and rigorous environmental data acquisi- tion, a relatively precise OCR_{DATE} estimate is expected.

The relative accuracy and precision of radiocarbon date estimates are the product of a number of identified effects: long term fluctuations in the strength of the earth's geomagnetic dipole field, carbon reservoir effect, de Vries Effect, Suess Effect, and the Atomic Bomb Effect. Dendrochronological studies have shown that these effects are not constant through time and exhibit varying degrees of influence on the C^{14} concentration through time. The Suess and Atomic Bomb effects are recent phenomena. These effects, in combination with de Vries Effect, which has been particularly pronounced since the mid-seventeenth century, have rendered recent radiocarbon date estimates virtually meaningless. Statistically, radiocarbon date estimates during this time period are generally reported simply as modern (Taylor 1987).

The relative precision of the OCR_{DATE} estimate is statically linear. The estimated error for the OCR_{DATE} estimate is roughly 3%. For a recent sample from a fire 100 years ago, the expected precision of the OCR_{DATE} estimate is + three years, whereas the precision for a sample 10,000 years old is + 300 years. The greater precision afforded by the OCR_{DATE} estimate on recent samples makes the OCR procedure a more appropriate dating technique for use on late Native and early European American sites.

Like radiocarbon, the OCR procedure requires several basic assumptions which one must accept when conducting or soliciting dates. By and large, the assumptions for these two procedures are similar in that they focus on the context of the sample and the behavior of the underlying phenomena being measured. The sixth assumption posited by Taylor has always been troublesome for archaeologists using radiocarbon analysis: that there is a known relationship or association between the sample and a specific event (Taylor 1987). Radiocarbon analysis measures the date of C^{14} absorption by a living organism. For charcoal samples obtained from archaeological features, the specific event which the archaeologist seeks to date is the carbonization of the wood, which occured during its use in a cooking hearth. The average life span of tree species used as fuel in the hearth range from less than 100 years to over 400 years. Depending on how recently the wood used in the hearth fire was in active growth, the "postsample-growth error" (Ralph 1971) could account for several hundred years. In Northeastern North America charcoal containing archaeological features rarely contain single pieces of charcoal large enough for dating. Thermal extremes and pedoturbations tend to pulverize the fragile charcoal samples. Even under "ideal" conditions, the excavated carbon sample is usually composed of many small pieces of charcoal representing several different pieces of wood. The postsample-growth error is not likely to be the same for all of the pieces of wood represented in the sample submitted for radiocarbon analysis.

The OCR procedure measures the change in the readily oxidizable portion of the charcoal from the time of carbonization, or shortly after burning, when soil biochemical processes resume. With the OCR procedure, the relationship between the sample under analysis and the specific event to be dated is clear.

Another common problem faced by archaeologists in the Northeast is the availability of charcoal in sufficient quantities and of sufficient quality within archaeological features. As indicated above, the environment in this area tends to physically destroy charcoal. Recent advances in physics, specifically the development of Accelerator Mass Spectrometry (AMS), have provided a means of obtaining accurate and precise radiocarbon date estimates from vary small samples. However, these procedures are expensive, generally costing more then twice the amount spent for the standard decay counting procedures. The budgets of archaeological society sponsored studies, CRM contracting archaeologists, and, all too often, university grant sponsored research, lack the flexibility to absorb the additional expense of the AMS procedure.

The sample submitted for analysis in the OCR procedure is principally the soil, consisting of mineral and carbon particles, infilling the archaeological feature. The procedures measure the percent total and readily oxidizable carbon contained in the soil sample. The size of the charcoal pieces is inconsequential, as the soil sample is ground to pass through a 2-mm meshed screen or smaller. The OCR procedure has proven accurate and precise with soil samples containing as little as 1 percent total carbon. An effective lower limit for this procedure has not yet been discerned, although it is likely that samples containing as little as 0.1 percent total carbon can provide meaningful information. Unlike the AMS radiocarbon dating procedure, the cost of OCR analysis will not require major adjustments in research budgets. The cost per sample for the OCR procedure is roughly one-fifth that of the standard decay counting procedure and one-eleventh the cost of the AMS procedure.

Conclusion

In the discussion section above, the OCR procedure is compared and contrasted with the radiocarbon procedure for accuracy, inherent assumptions and cost. Within the framework of the discussion the OCR procedure appears to offer a complete alternative to radiocarbon dating. This is not the case. With the noted exceptions of analyses of samples dating from the past 300 years and samples containing a limited number of small-sized charcoal pieces, the OCR is not an alternative to radiocarbon analysis. The OCR procedure has been developed to analyze only archaeological charcoal within a biochemically active, aerobic soil context. Radiocarbon dating procedures measure the isotopic ratio of a wide range of carbon containing material, regardless of context.

Although the environmental context of a carbon sample may introduce certain errors influencing the interpretability of the radiocarbon date estimate, specific environmental conditions must be met before the results of the OCR procedure can have any meaning. The principal assumption behind the OCR procedure is that the phenomenon being measured is an oxygen dependent biochemical processes in the soil that causes a change in the relative oxidizability of the charcoal. Deep riverine soils which undergo multiple episodes of reduction and oxidation due to fluctuating water table levels have been shown to severely affect the OCR procedure. Environmental barriers to oxygen diffusion in the soil, such as large capping stones or pavement, and barriers to solar radiation and rainfall, such as are found in a rock shelter, have an as yet incalculable effect on the rate of biochemical change on the charcoal (Frink 1992).

Furthermore, while the radiocarbon procedure can currently date carbon samples as old as 50,000 years and has the potential of extending that range (Taylor 1987), the OCR procedure has been tested only on samples spanning the past 8,000 years. As the OCR procedure presumes a biochemical process, major climatic changes, such as those that occurred during the Pleistocene Period may restrict the application of this procedure.

The OCR procedure does offer a much needed independent correlation data base for verifying radiocarbon dates obtained from charcoal found within an archaeological soil context. In this supporting role, the OCR procedure may be used either for verifying the radiocarbon date or as a screening tool to select specific samples for radiocarbon analysis.

The low cost of the OCR procedure allows the archaeologist to test a number of samples, either from within one feature or from a number of different features, providing the preliminary information necessary to select those samples which are most likely to result in interpretable radiocarbon dates. Intrusive root burns on Native American sites, morphologically similar to cultural hearth features, may be separated from the list of cultural feature samples submitted for radiocarbon dating, and compound or perturbated cultural features can be dissected and analyzed for those parts of a given feature having the most archaeological integrity.

As an independent verification of radiocarbon dates, the OCR procedure allows the archaeologist to interpret the accuracy, precision and reliably of both the radiocarbon date and the archaeological conclusions being drawn from associated data. For example, seriation studies of ceramics require a high level of accuracy and precision in the dating of each style of ceramic. Use of the OCR procedure can reaffirm the radiocarbon date estimates, and supply the precision not possible through radiocarbon analysis for the more recent samples.

The problem encountered by archaeologists with radiocarbon dating is not with the procedure, but with the interpretative and relative value of the information it provides. Radiocarbon dates are estimates, and as such have limits. These limits are not insurmountable. By employing independent correlative data, radiocarbon date estimates may be refined, or rejected as imprecise. The OCR procedure provides archaeologists with a means to obtain independent correlative data. OCR_{DATE} estimates can refine temporal analyses by minimizing the number of potentially misleading radiocarbon dates and by strengthening the level of confidence in both the accuracy and precision of the date estimate. In specifically defined situations, such as the limitations of the radiocarbon procedures caused by the de Varies, Suess, and Atomic Bomb effects, the OCR procedure provides an alternative dating tool and scientific basis for rejecting the radiocarbon data. The demonstrated accuracy and precision of the OCR procedure on archaeologically young charcoal provides a viable solution to the problematic dating of late Native American archaeological sites and European American archaeological sites.

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Biographical Note

Douglas Frink received his Masters in Anthropology/Archaeology in 1983, and is currently the owner and Principal Investigating Archaeologist at Archaeology Consulting Team, Inc. His research interest in soils, and in particular soil genesis, as the primary context for most archaeological data has led to new ways of interpreting archaeological sites as well as the OCR phenomena.

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