RECENT ADVANCES IN PETROGLYPH DATING AND THEIR IMPLICATIONS FOR THE PRE-CLOVIS OCCUPATION OF NORTH AMERICA

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ABSTRACT

Three independent chronometric techniques are used for dating petroglyphs: AMS ^{14}C dating of weathering rind organics encapsulated by natural coatings; analysis of rock varnish microlaminations; and cation-ratio dating. We discuss recent advances in each of these techniques, new empirical data from eastern California and western Wyoming, and the implications of these data for the Pre-Clovis versus Clovis-first debate. Petroglyphs are particularly useful in this debate because they are unequivocally human in origin, and because they were not subject to the radical changes in erosion and deposition that characterized the Late Pleistocene and affected preservation of other aspects of the archaeological record. We also discuss the recent controversy concerning cation-ratio dating, and demonstrate that the controversy derives from a failure to properly follow scientific method in "testing" the technique, not from an inadequacy of the technique itself.

If there has been a central problem in New World prehistory, it is the peopling of the Western Hemisphere. Who the first inhabitants ultimately were, and how they arrived, are intellectual problems that motivated a nascent archaeological discipline in the last century and continue almost into the next century. Questions about the date of first arrival continue to resonate in the profession. The name of Ruth DeEtte Simpson, as should be clear, has been central to this debate: regardless of personal opinions about the verity of her particular claims for an early colonization of the Americas, we all must acknowledge that no California archaeologist has played a larger role in addressing this problem, and few archaeologists anywhere have demonstrated an equivalent commitment and dedication to their respective scientific positions.

We address the peopling of the New World through petroglyph dating. Petroglyphs are an advantaged form of evidence in this controversy for two reasons. First, they are unquestionably cultural in origin, and thus are not subject to the debates of authenticity that pertain to lithics and other archaeological features. Second, they are largely immune to the preservational and visibility problems that affect other types of Late Pleistocene archaeological remains; as is increasingly clear, Late Pleistocene North America was characterized by very dynamic changes in erosion and deposition, thus creating conditions that were unfavorable for the preservation of most surface and subsurface archaeological sites (Butzer 1991; Whitley and Dorn 1993). Petroglyphs, found on basalt and other rock faces, are capable of withstanding geomorphological processes that would destroy or deeply bury other components of the archaeological record, and are easily identifiable in surface surveys.

We use three independent chronometric techniques to constrain the ages petroglyphs. New developments in each of these are discussed below, along with their respective results. We also discuss the implications of these results for the Pre-Clovis versus Clovis-first debate, and conclude with some comments on a current controversy pertaining to one of our three chronometric techniques.

Advances in Petroglyph Dating Techniques

In order to accurately constrain the ages of petroglyphs we employ a multi-tiered approach which involves the application of three independent, but experimental chronometric techniques, each of which themselves may be applied to a single

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petroglyph more than one time (Dorn 1994a). We emphasize this fact because of a widespread misapprehension among archaeologists: namely, that petroglyph dating is limited to or primarily involves cation-ratio (CR) dating. In fact, CR dating is simply used as an adjunct to the more accurate AMS ^{14}C dating of weathering rind organics (WRO) encapsulated by natural coatings, and correlated-age control provided by analysis of rock varnish microlaminations (VML). This three-tiered approach allows us both to check the internal consistency of any single chronometric technique for a given specimen, as well as to confirm the derived chronometric age with two independent dating techniques.

Assigning Numerical Ages with WRO Radiocarbon Dating

When a petroglyph is manufactured and mineral material is exposed to the subaerial environment, epilithic (rock-surface) organisms such as fungi, algae, lichens, algae, and cyanobacteria start to grow. At the same time, biogeochemical weathering processes create pores within the rock material, called the weathering rind (Dorn 1995). As epilithic organisms grow (and die), they leave behind organic remains in the pores of the weathering rind (Bonani et al. 1988; Chaffee et al. 1994; Farr and Adams 1984; Friedmann and Weed 1987; Krumbein and Dyer 1985; Nobbs and Dorn 1993; Weed and Norton 1991). The gradual accumulation of organic remains in the rock weathering rind occurs until the weathering rind is sealed off by the development of rock coatings, often called patina in archaeology. Examples of rock coatings include silica glaze (Dorn and Meek 1995), whewhellite skins (Russ et al. 1995), anthropogenic pigments (Chaffee et al. 1994), and the focus here—manganiferous rock varnish (Dorn 1991).

Prior tests have revealed that manganiferous rock varnish forms a 'closed system' with respect to HF-, HCl- and NaOH-extractable organic carbon (Dorn et al. 1989; Dorn et al. 1992; Nobbs and Dorn 1993). In other words, when the rock varnish forms over the weathering rind, organic carbon within the weathering rind (at least the carbon that is present after chemical pretreatment) does not exchange with atmospheric carbon dioxide.

Because organic matter accumulates after the petroglyph was made, radiocarbon ages on the WRO are best interpreted as minimum ages. We note that WRO ages, encapsulated under rock varnish, are younger than controls in all independent tests thus far conducted—emphasizing that WRO ages are minimums (Dorn et al. 1989; Dorn et al. 1992) for the manufacturing of petroglyphs. This is a particularly important point in our later discussion of the pre-Clovis vs. Clovis debate, because pre-Clovis ^{14}C ages on petroglyphs are best interpreted as *minimum ages* for the rock art.

The only reasonable source of contamination from older carbon comes from WROs that accumulated in the weathering rind before the petroglyph was carved. To assess the potential for 'inherited organics,' control samples are collected in a depth profile adjacent to the petroglyph. This assess the abundance of organic matter in the natural weathering rind. High concentrations of WROs, in control samples of an equivalent depth to the petroglyph sample, usually mean that the sample is not processed further for dating; AMS measurements are simply too expensive to analyze samples that have high levels of potential contamination. For contexts where inherited WROs exist in small amounts, the concentration of WRO in controls can be used to correct the ^{14}C age or add an additional error term (Chaffee et al. 1994; Dorn et al. 1993; von Werlhof et al. 1995).

Assigning Correlated Ages by Stratigraphic Analysis of VMLs

When rock varnish starts to cover an engraving, it leaves behind a time signal in its layering pattern, which was used formerly to provide only a *relative* age signal because more complex layering patterns were recognized as older than simpler patterns (Dorn 1992). However, recent work (Liu and Dorn 1996) has correlated varnish layering patterns to latest Pleistocene climatic changes called Heinrich Events (Heinrich 1988). Heinrich Events are releases of massive icebergs from the North American Laurentide ice sheet into the North Atlantic that coincide with sudden and dramatic climatic changes around the globe (Broecker 1994).

Figure 1 presents the calibration of varnish microlaminations (VMLs) for the Death Valley-Mojave Desert area, where layering patterns are calibrated for the last 24,000 radiocarbon years. In Figure 1, VML Unit 1 is yellow-to-orange varnish (as seen in color ultra-thin cross-section) that formed in the Holocene. Unit 2 is a pattern of two black layers (separated by a thin orange layer) that appear to have formed during the Younger Dryas cold/wet event ~11,000-10,500 ^{14}C years ago and Heinrich Event 1 ~14,000 ^{14}C years ago. Unit 3 formed in a slightly less-humid period characterized by the formation of orange varnish, from ~21,000 to ~14,000 ^{14}C years ago. Unit 4 is characterized by 5 black layers alternating with 4 orange layers that formed between ~55,000 uranium-series years ago and ~21,000 ^{14}C years ago (Heinrich Event 2). Only the uppermost black layer in Unit 4, correlated with Heinrich Event 2, is constrained by ^{14}C ages to be ~21,000 ^{14}C years old.

For the purpose of assigning ages to archaeological features such as petroglyphs, VMLs provide an opportunity to assign 'correlated ages.' In other words, laminations are analogous to finding a volcanic deposit such as the Mazama ash, which correlate with an eruption of known age. For example, if a varnish sequence is only yellow-orange, as viewed in ultra-thin cross-sections, the only thing that can be said is that the varnish is Holocene in age. However, if the layering sequence is yellow-orange on top of a thin black layer, the varnish is correlated with the Younger Dryas climatic event ~11,000 to 10,500 ^{14}C years ago.

We need to point out two important limitations. First, VMLs are only useful for the Pleistocene—and hence only for Paleo-Indian and Pre-Clovis research. Second, the calibration for VMLs is most firm for the Death Valley-Mojave Desert area, and it is experimental beyond this region. However, Tanzhuo Liu and Wallace Broecker of Lamont Doherty Earth Observatory of Columbia University are now engaged in a massive research effort to map and calibrated the extent of these layering patterns throughout western North America.

Assigning Calibrated Ages with Varnish CR Dating

Cation-ratio (CR) dating is a calibrated age-determination method. The ratio (K+Ca)/Ti within bulk samples of rock varnish is calibrated by numerical ages such as radiocarbon. The theory behind CR dating is that water flow through the varnish slowly leaches mobile cations (e.g., potassium-K, calcium, Ca) faster than immobile cations (e.g., Ti)—thus lowering the ratio over time (Dorn and Krinsley 1991). Varnish leaching is the great factor that interferes with the recognition of VMLs, because leaching interrupts the layering patterns (Liu and Dorn 1996). Figure 2 exemplifies a cation-leaching curve, in this case for the Mojave Desert.

The decline in the CR of (K+Ca)/Ti over time has been verified independently by scientists from Russia (Glazovskiy 1985), South Africa (Jacobson et al. 1989; Pineda et al. 1988; Pineda et al. 1990), China (Zhang et al. 1990), Canada (Clarkson 1994), and the United States (Bull 1991; Whitney and Harrington 1993). In spite of this independent confirmation, CR dating has also become controversial due in part to the misrepresentation of data by P. Bierman and A. Gillespie in a supposed 'test' of the method (Cahill 1992), and due in part to legitimate uncertainties that are reviewed elsewhere (Francis et al. 1993; Dorn et al. 1994a).

The basic idea of the method is to collect several different, millimeter-sized samples of rock varnish from different parts of a petroglyph. This sampling strategy mimics the appearance of natural erosional processes and targets places where the varnish starts to grow first—giving the closest-minimum ages. Then, after cleaning the sample of rock contamination, the material is measured for its CR by wavelength dispersive spectrometry. The CR for each separate subsample is then compared with the cation-leaching curve and assigned a separate calibrated age. These ages are then averaged together and a standard deviation determined for the error estimate of the entire sample. The CR dating technique is presented in detail elsewhere (Dorn 1994c; Dorn et al. 1990).

The next section explores the consistency among these different techniques in specific case studies.

Recent Empirical Results

Chronometric results for four recently analyzed petroglyphs from western North America illustrate our three-tiered approach to petroglyph dating, and these results also provide evidence pertinent to the debate over peopling of the Americas. These four petroglyphs are shown in Figure 4. We discuss these in turn.

Cow Cove, Mojave Desert

Our first petroglyph is a geometric "shield" figure from Cow Cove, Mojave Desert, California. The WRO radiocarbon age on this petroglyph is 4990 ± 70 ^{14}C YBP (ETH-12879). The corresponding CR age is 5400 ± 900 YBP, independently calibrated using the previously established cation-leaching curve for this region (Figure 2). These ages overlap within their one standard deviations.

Although the chronometric ages on this petroglyph are mid-Holocene, not Late Pleistocene, we include this petroglyph for an important illustrative reason. The VML analysis, depicted in Figure 4, is diagnostic of a Holocene age. As is evident in the light microscope picture, the engraved-out portion of the petroglyph consists of rock immediately overlain by a relatively thin layer of orange-yellow (manganese-poor) rock varnish, shown in black and white as a bright band. According to the VML calibration (Figure 1), this pattern is consistent with the mid-Holocene ages derived from WRO radiocarbon and CR dating, and contrasts with the VML patterns discussed below.

Legend Rock, Bighorn Basin, Wyoming

Our second example is from the Legend Rock site in the Bighorn Basin of northwestern Wyoming, and consists of an outline pecked zoomorph of unknown species (probably antelope or horse; Figure 4). The petroglyph has a WRO radiocarbon age of 10,660 ± 50 ^{14}C YBP (Beta-84416) and, at one standard deviation overlap, a CR age of 11,000 ± 2000 YBP, using a cation-leaching curve similar to, but updated from Francis et al. (1993). The micrograph for the varnish on this latest Pleistocene petroglyph shows a relatively thick, bright yellow surficial layer of Unit 1 (Holocene) varnish shown as a thick bright band. This varnish is underlain by a very thin, black varnish layer resting on the rock. This thin black (manganese-rich) microstratigraphic unit corresponds to the Younger Dryas, dated at about 11,000 to 10,500 ^{14}C YBP (Broecker 1994), confirming that varnish formed on the petroglyph at the end of this climatic period.

Black Rock Creek, Green River Basin, Wyoming

Our third dated petroglyph is a fully pecked, solid body anthropomorph from the Green River Basin of southwestern Wyoming. The WRO radiocarbon age on this petroglyph is 11,650 ± 50 ^{14}C YBP (Beta-84418). No CR age has been obtained for this petroglyph because an independent cation-ratio calibration has not yet been established for the Green River Basin region.

Support for the WRO radiocarbon age for this motif is provided by the VML analysis (Figure 4). As in the petroglyph above, the thin-section micrograph shows a thicker Holocene layer (in this photo, thick upper bright band). This is underlain by the upper black layer of Unit 2 (Fig. 1), correlated with the Younger Dryas. This black layer is underlain by a thin unit of bright varnish, which develops in western North America between the end of the Heinrich 1 climatic period at about 14,000 ^{14}C YBP (Broecker 1994) and the Younger Dryas at ~11,000-10,500 ^{14}C YBP, consistent with the minimum radiocarbon age of ~11,650 ^{14}C years.

Little Lake, Coso Range, California

Our final example is from the Coso Range of eastern California, a deeply revarnished spiral located within a talus slope which has partly buried the channel of the Pleistocene Owens River. The WRO radiocarbon age on this motif is 14,760 ± 90 ^{14}C YBP (CAMS-20705), while the CR age is 16,500±1500 YBP—overlapping the WRO ^{14}C age at two-, but not one-standard deviation. Support for both chronometric ages is provided by the VML analysis (Figure 4). In the micrograph, microstratigraphic Unit 1 is the bright Holocene varnish, which is underlain by a black Younger Dryas unit; then by a middle bright layer; another dark unit corresponding to Heinrich 1; and then by again another unit of bright varnish (Unit 3, see Fig. 1) immediately above rock.

There is an additional independent temporal constraint on the age of this petroglyph: the bed of the Pleistocene Owens River, upon which the talus slope rests. The petroglyph could only have been created after this river stopped flowing, but prior to the end of the Heinrich 1 period. Recent ^{3}He studies indicate that the Pleistocene Owens River ceased flowing ~16,200 YBP (Cerling and Craig 1994), thereby independently bracketing the age of the petroglyph between ~16,200 and 14,000 YBP (the termination of the Heinrich 1 microstratigraphic unit present in the VML). The minimum WRO radiocarbon age of ~14,800 ^{14}C years is consistent with these independent age constraints.

Implications of Late Pleistocene Petroglyphs

There are a number of implications of our results which warrant exploration. The first pertains to the general issue of early petroglyph manufacture. The evidence presented here contributes to a growing body of data indicating that rock art manufacture was a very ancient tradition in the New World. This includes two examples of Mazama ash buried rock art panels on the Columbia Plateau, which are necessarily older than 6700 YBP (Randolph and Dahlstrom 1977; Cannon and Ricks 1986); a ~10,000 year old chronometric record for petroglyphs in the Black Hills, South Dakota (Tretabas 1994); and evidence for a number of Pleistocene megafaunal depictions in the rock art of the Colorado Plateau (Agenbroad 1994). When the results of these studies are combined with our latest data, along with our previously reported Late Pleistocene/Early Holocene dated rock art motifs (Whitley and Dorn 1987, 1988, 1993), it is clear that substantial evidence exists for Paleoindian rock art manufacture.

Although this conclusion counters the intuitive petroglyph chronologies suggested by many early authors, such as Heizer and Baumhoff (1962), simple logic supports our empirical evidence. It is now unequivocally established, for example, that rock art was created in western Europe, Australia and southern Africa more than 20,000 years ago. We, therefore, have every reason to assume that Paleoindian or earlier Native Americans may also have made rock art, for there is no justifiable reason to infer that humans in other parts of the world could make rock art while Native Americans somehow could not.

This point impinges on a second implication of our rock art dates: the question of the stylistic evolution of art. The traditional position is that North American rock art "evolves" over time from simple to complex (e.g., Heizer and Baumhoff 1962). In eastern California and the Great Basin this evolution was posited to begin with crude pit and groove marks, followed by the development of curvilinear geometric forms. As regularization improved, curvilinear forms were joined by rectilinear geometrics and then, at some point in the relatively recent prehistoric past, "iconicity" was thought to have been discovered or invented.

The chronometric data published previously and the new evidence presented here do not support an evolutionary chronology at site specific, regional, and western North American-wide scales. In fact, substantial data indicate that geometric and representational motifs were used simultaneously, throughout the entirety of the rock art making tradition. Certainly, styles may have changed over time, but the contention that this was evolutionary (in the sense of directed or teological) change has yet to be demonstrated, and finds no support in the emerging chronometrically based rock art chronologies elsewhere in the world (cf. Clottes et al. 1995). Moreover, the implicit assumption of such evolutionary style sequences—that artistic capabilities only evolved as cognitive capabilities became more sophisticated—is not only biological nonsense, but is based on patently false and racist doctrines.

Our results are also clearly significant for the peopling of the New World controversy. A key point, however, must be noted in this regard. This pertains to the accepted age of Clovis sites, and thus the earliest possible initial occupation of North America that may be allowed within the parameters of the Clovis-first hypothesis. It is important to emphasize that the age of Clovis sites has been downward revised recently by Haynes (1987, 1991) to 11,200 ^{14}C YBP. Although it is now widely accepted that a Nenena Complex preceded Clovis in Alaska by a few hundred years (Hoffecker at al 1993), the fact remains that the short chronology for the peopling of the New World is still based on one hard and fast proposition: that Clovis sites represent the initial occupation of the 48 contiguous states.

Given the downward revision in acceptable Clovis-site ages, the implications are straightforward: any accepted site or artifact greater than 11,200 radiocarbon years old serves to falsify the Clovis-first hypothesis. This is contrary to Meltzer's (1989) confused contention that sites or chronometric ages a few hundred or even a thousand years older than Clovis ultimately have minimal significance to the problem—leading one to wonder if Meltzer understands what the empirical debate is actually about. The break point in this empirical issue is now 11,200 ^{14}C YBP: humans either arrived in the 48 states at that time, and no earlier, or they colonized the continent at some earlier point.

The important issue here is that our minimum age of 11,650±50 YBP for Green River Basin petroglyph represents a Pre-Clovis rock engraving, as does, of course, the 14,760±90 YBP Coso example. And these petroglyphs simply augment a growing corpus of dated Pre-Clovis petroglyphs, which consists of the following:

- CM-8 (Coso Range, bighorn sheep)—WRO radiocarbon age 14,930 ± 190 YBP, CR age 14,200 ± 1700 YBP;
- PEFO-7 (Petrified Forest, AZ, geometric "shield")—WRO radiocarbon age 18,180 ± 190 RYBP, CR age 19,000 ± 1500 and 20,000 ± 1800 YBP;
- CM-12 (Coso Range, bighorn)—CR age 19,000 ± 1100 YBP;
- CM-5 (Coso Range, geometric)—CR age 17,300 ± 1900 YBP;
- BSS-3 (Coso Range, geometric)—CR age 14,900 ± 1900 YBP;
- CM-15 (Coso Range, geometric)—CR age 13,500 ± 700 YBP;
- CM-7 (Coso Range, zoomorph[?])—CR age 12,600 ± 1500 YBP; and
- C2-5 (Cima volcanic field, geometric)—CR age 10,700 ± 1000 YBP.

Our current evidence, in other words, includes eight petroglyphs with chronometric ages that, at one standard deviation, exceed the 11,200 YBP maximum age for Clovis, four of which are based on WRO radiocarbon dating, but confirmed by the other two independent chronometric techniques.

Two brief points then need be made with respect to these Pre-Clovis petroglyphs. First, and as indicated above, there is growing evidence of depictions of extinct megafauna in North American rock art (Agenbroad 1994). In this regard, although it is impossible to speciate that our Legend Rock, WY, petroglyph with any confidence, it is certainly possible that it is an extinct Equus occidentalis (note that there is a separate V-shaped motif above the head of this engraving; a quick glance at Figure 4 may give the false impression that this zoomorph is horned). Second, bighorn, deer, bison and antelope are all species that were present during the Late Pleistocene and that survived into the Holocene in one form or another. Thus it is entirely feasible that Pleistocene faunal depictions are much more common than now recognized, simply because species such as bighorn sheep that did not suffer extinction were also depicted in the art.

Our rock art data may then be combined with the additional Pre-Clovis ages for a series of Manix Lake Lithic Industry surface artifacts (Dorn et al. 1986; Bamforth and Dorn 1988; Whitley and Dorn 1993), indicating that substantial evidence for a Pre-Clovis occupation of eastern California has now been amassed. When these data are viewed in light of the fact that the occupation of a series of widely accepted and non-controversial South American Paleoindian sites, dating between 11,000 and 10,000 YBP, cannot be reconciled with any biologically-feasible model for hunter-gatherer migration and colonization (Whitley and Dorn 1993), only two conclusions may result: either the Clovis-first hypothesis has been effectively falsified; or, if one remains a skeptic about our petroglyph dating techniques, the Clovis-first hypothesis is now what the philosopher of science Imre Lakatos (1969) would term a "degenerating research program." That is, it is a scientific hypothesis that cannot accommodate new empirical evidence, even "internal evidence" presented by its own proponents, and thus can only be supported by continuing, and increasingly dubious, ad hoc modifications to its original propositions.

After all, how can it plausibly be suggested that the entire 48 contiguous states were colonized by Pleistocene hunter-gatherers in the 200 year period between 11,200 and 11,000 YBP, as the Clovis-first hypothesis now requires? This point is particularly problematic for Clovis-first proponents inasmuch as this 200 year period represents only 40% of the time that Vance Haynes (1966) originally argued was adequate for the colonization of North America, using plausible models of hunter-gatherer population migration and growth rates as models for mobile Clovis hunting bands. And it is even more problematic given the fact that many of the earlier Clovis site radiocarbon ages within this range derive from the southeastern, not the northwestern states.

Recent Controversy over Varnish Dating

Recently, a controversy has developed in the archaeological literature concerning varnish dating. This is a claim by Karen Harry (1995) that CR dating is unreliable for constraining the ages of surface artifacts. Although her contentions strictly do not concern petroglyph dating, they are relevant to this discussion inasmuch as they attempt to impugn the reliability of CR dating generally, due to the fact that they have been presented at SCA meetings, and because her criticisms have caused confusion within the California archaeological community. A few brief clarifying comments, therefore, are in order.

First, it must be emphasized that Harry's criticisms are restricted to CR dating; they do not address, and have no bearing on, the efficacy and reliability of WRO radiocarbon and VML dating. That is, they concern simply one of the three techniques we employ for dating petroglyphs and surface artifacts; therefore, they do not constitute any general criticism of varnish dating as a whole. Furthermore, they have little relevance to our arguments about the peopling of the Americas, because our empirical contentions primarily concern radiocarbon and not CR dating results (see Whitley and Dorn 1993).

Second, Harry's critique is based on a series of egregious violations of scientific method. The most basic of these is a failure to address the fundamental issue in chronometric dating: whether or not the dating technique being tested provides results that are comparable to those independently obtained using other established chronometric techniques. If Harry's contention that CR dating is unreliable for surface artifact dating were correct, there could be little if any positive correlation between CR dates and WRO radiocarbon ages on the same specimens.

In order to assess the reliability of CR dating in Harry's (1995) examination of varnished specimens from desert pavements, we calculated a regression analysis of radiocarbon ages versus CR dates for varnished specimens collected from desert pavements. The results of this regression (Figure 3) are straightforward: $R = 0.96$; $R^2 = 0.92$; $p = <0.001$. In the context of Harry's (1995) study, CR dating provides results that are comparable to those obtained with radiocarbon dating. Of course, our results are from samples that were collected from well-developed and relatively undisturbed desert pavements—whereas Harry's samples would have been inappropriate for CR dating—using available sampling criteria (Dorn et al. 1990; Dorn 1994b, Dorn 1994c, Dorn n.d.).

Her only age control that is valid in only a relative sense supports the application of CR dating in archaeology. Please look carefully at her Figure 2B, results for the "scraping" method of extracting varnish; this is the approach used in dating artifacts and petroglyphs. [The other data in her diagram are from the "SEM" method that has not been used in archaeology, for reasons detailed by Dorn et al. (1990).] The "cultural" artifacts do have higher cation ratios than noncultural "cortical" positions—as predicted by the CR method! Similarly, the cortical CR values should center around a similar value, as they do in her data, if the varnishes started to grow after the geomorphic event that exposed the cortex. The cultural artifact values should not cluster, if the site was used as a quarry over a period of time.

With the exception of this relative age control, and lacking any independent radiocarbon ages to evaluate CR dating, Harry's (1995) approach instead involved an attempt to correlate the degree of revarnishing on surface samples with their textural characteristics, and with the ground surface sub-strate upon which they were collected. The intent here was to show that varnish development is affected by factors other than time, and thus that it cannot be used for dating purposes. Although there are numerous problems with her test of this proposition (see Bamforth, n.d.; Dorn n.d.; Whitley n.d.), one of them alone renders the testing effort completely meaningless. This is the failure to control the one variable that she was attempting to evaluate: the effect of time on varnish development. That is, to determine whether varnish development is a function of rock texture and/or the nature of the ground surface the specimen is resting upon (soil versus bedrock, etc.) rather than time, it is obvious that the time at which each specimen began to be revarnished must be controlled. The alternative, which is required for her "tests" to have any methodological efficacy at all, is the assumption that all surface lithic specimens began to develop varnish coatings at the same moment. Given the nature of Mojave Desert surface lithic quarries, such as the one at which Harry conducted her "test", this is a preposterous assumption.

In summary, Harry's (1995) putative critical evaluation of CR dating failed to meet the minimal requirements of experimental design and control of the study variables, and therefore can make no claim whatsoever about the efficacy of the dating technique. And, as our regression analysis shows, there continues to be very good empirical evidence supporting our contention that, properly conducted, CR dating is a useful adjunct to our other two petroglyph and surface artifact dating techniques.

Conclusions

As is common in the history of science, the structure of the Clovis-first versus Pre-Clovis debate has closely followed similar controversies in other "prehistoric" sciences: the K/T boundary (dinosaur extinction) debate in geology; and the origin of anatomically modern humans problem in paleoanthropology. In both cases an interpretive position evolved among sub-disciplinary specialists through the application of then-existing scientific techniques, directed towards then-recognized forms of empirical data. Controversies, however, ensued when "outsider" scientists (geochemists and physicists, as opposed to paleontologists, in the K/T boundary case, and molecular geneticists instead of paleoanthropologists, in the modern human origins controversy) brought entirely new analytical techniques to these problems, which allowed the examination of heretofore unrecognized kinds of data, and which supported new interpretations: trace remnants of a microstratigraphic layer of iridium at the K/T boundary, and a "biological clock" based on mitochondrial DNA in the human origins case.

The comment that was expressed by the traditional specialists concerned with each of these empirical problems, when first confronted with these new techniques and previously unrecognized kinds of data, was essentially the same: "we learn about the prehistoric past through the study of bones, not through the analysis of iridium layers" ("or mtDNA"). This is precisely the same kind of plaint that we have also heard from Clovis-first proponents in reviewing our Pre-Clovis petroglyph and surface artifact dates. "These aren't good enough," they have told us, "because we must have stratigraphy to resolve the problem." That is, and this is an important point, they have not expressed a plausible technical reason to cast doubt on our results, but instead have fallen back on the position that only stratigraphy and standard radiocarbon dating are admissible as evidence in the controversy.

While there is no denying the value of stratigraphic context and radiocarbon dating to archaeology, our VML analyses are a controlled microstratigraphy, and our WRO dating is in fact radiocarbon dating. After all, how does the stratigraphic burying of a hearth or artifact on the ground surface by windblown dust actually differ from the stratigraphic covering of a petroglyph scar by rock varnish, which also originates in windblown dust? The subtext of the Clovis-first position is then the denial of the admission of new technological advances, allowing for the examination of heretofore innovative forms of data. In light of the rapidly evolving technology in all of the sciences (and regardless of which position is empirically correct in the K/T boundary, modern human origins or Clovis versus Pre-Clovis controversies), an intellectual posture that bases the resolution of an empirical problem on pre-existing technology, and long-recognized forms of data, can only be considered intellectually retrograde.

Petroglyph dates are not standard forms of archaeological evidence, but this is simply because we have only been able to date rock art since 1982. Still, and as we have emphasized above, petroglyphs are advantaged over other forms of archaeological evidence pertinent to this debate because they are unequivocally human in origin, and because they were largely unaffected by the extreme conditions affecting site preservation at the Pleistocene–Holocene transition (Butzer 1991). Petroglyphs on stable basalt cliffs, in other words, are more likely to have withstood the extreme erosional and depositional conditions of the Late Pleistocene than many other forms of archaeological remains. Still, it is none the less true that some North American regions are more likely to contain preserved Pre-Clovis remains than others. The primary of these is probably the Great Basin, including the eastern California deserts, which was less affected by eustatic sea level changes and glaciation than other parts of the continent.

We think it likely that systematic efforts to examine stratigraphic contexts of the proper age in the Basin and Range country of the far west will stand a good chance of discovering additional Pre-Clovis sites. We also think that this explains why California has contributed what otherwise seems like more than its fair share of putatively Pre-Clovis claims: simply enough, it is because geomorphological conditions permit the preservation of older remains.

Inasmuch as three independent chronometric techniques indicate that a series of petroglyphs date between 12,000 and 19,000 YBP, we think this sufficient to accept the Pre-Clovis hypothesis for an initial occupation of the continent prior to the beginning of the Clovis period at 11,200 BP. When the first Pre-Clovis colonization of the continent ultimately occurred, of course, remains to be established.

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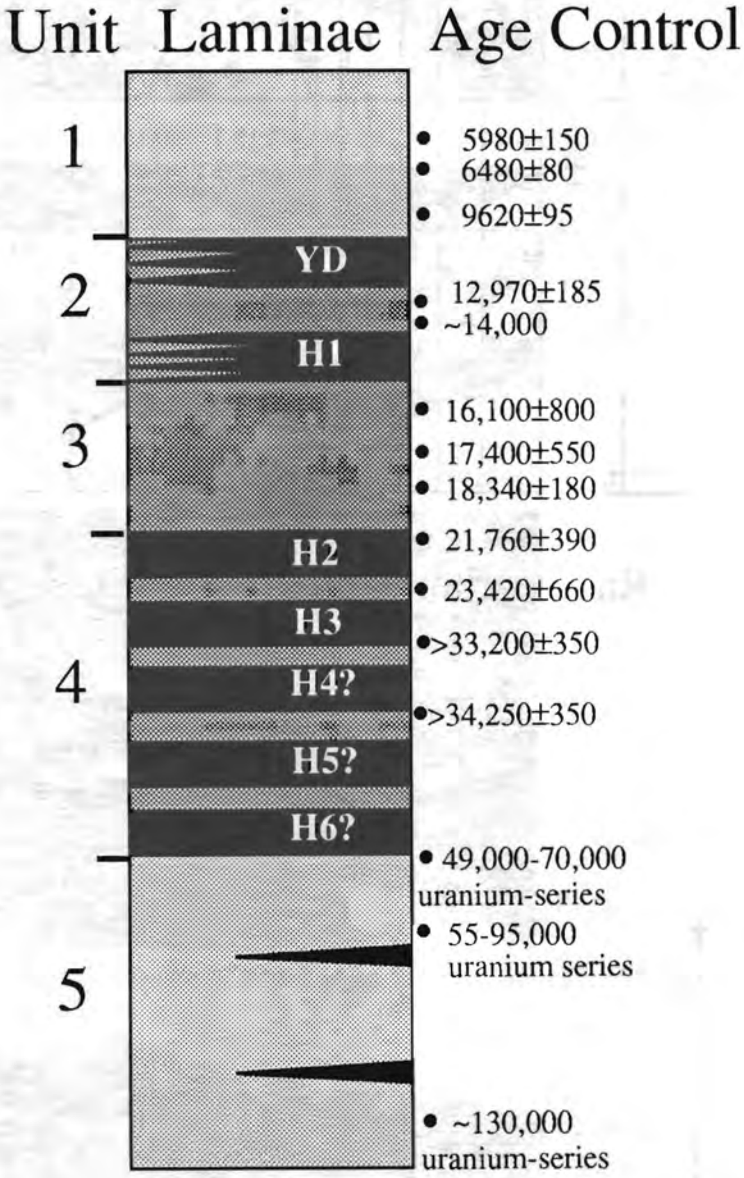

Figure 1. Idealized sequence of varnish layering units from Death Valley and vicinity (modified from Liu and Dorn 1996), where ages are placed stratigraphically underneath the layering sequence for that varnish. The ages less than 35,000 are from radiocarbon, and the older measurements are from uranium-series measurements; data are presented in Liu and Dorn (1996). We emphasize that the radiocarbon measurements represent maximum ages for the overlying varnish sequence.

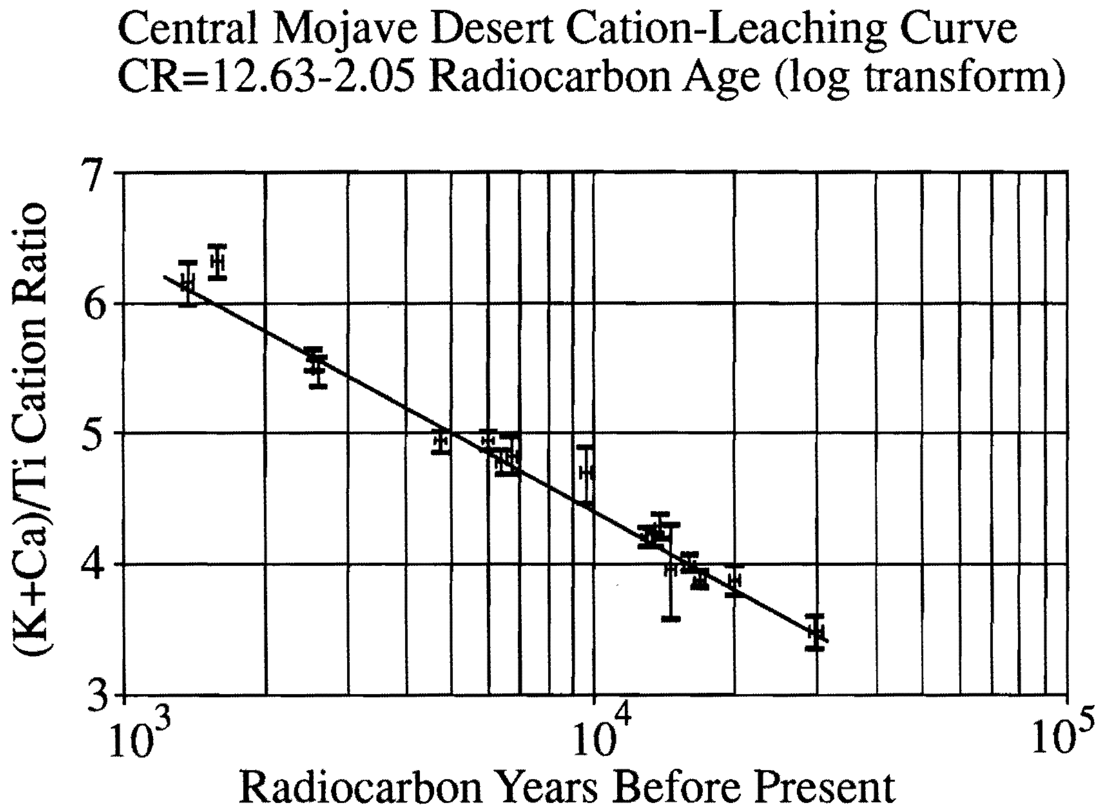

Figure 2. Cation-leaching curve for the central Mojave Desert calibrated by radiocarbon ages.

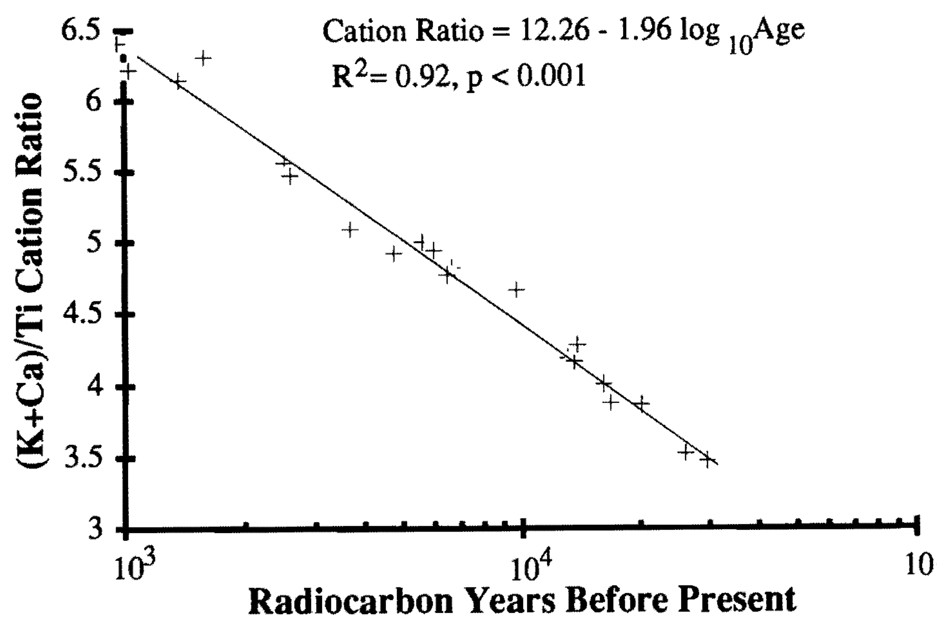

Figure 3. Regression analysis of CR values and AMS ^{14}C ages on Mojave Desert surface specimens (artifacts and cobbles in desert pavements). The regression uses a log transform of the ^{14}C ages, following standard convention in CR dating. The results show a high positive correlation, empirically supporting the contention that CR dates provide reliable minimum-limiting ages for surface artifacts. Data are from Dorn (1994b), Dorn et al. (1992), Laity (1994), McGill (1994) and Meek (1990).

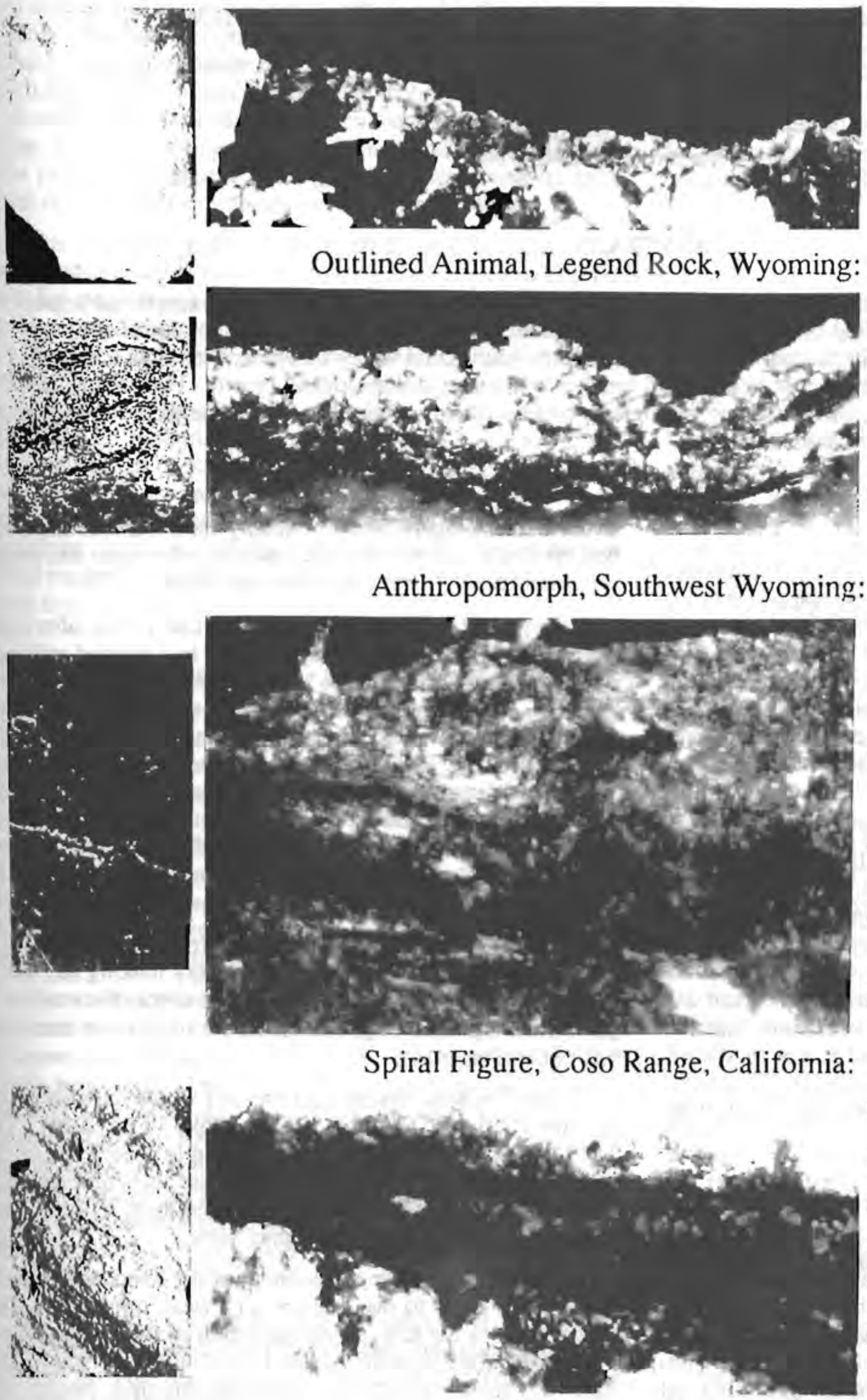

Figure 4. Comparison of how petroglyphs appear in the field and in ultra-thin sections viewed by light microscopy. The width of the petroglyph grooves is about 1 cm, except for the anthropomorph where the body is about 4 cm across. Black layers are enriched in Mn, while bright layers are Mn-poor; the different appearances of the Mn-poor layers is due to polarizer effects. The assignment of the annotated layering units is based on the calibration in Figure 1. Question marks emphasize the still-experimental nature of this calibration, from Liu and Dorn (1996).