Rock Varnish Dating, Surface Features and Archaeological Controversies in the North American Desert West

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Article

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Abstract

Archaeological surface features on desert pavements, including geoglyphs, are notoriously difficult to assess. Absent temporally diagnostic artifacts they may be impossible to place chronologically, limiting their inferential utility. Whether they are cultural or natural in origin itself may sometimes be uncertain, not only again crippling their interpretative value but potentially creating problems for heritage management. Not surprisingly, a series of controversies have developed in the North American desert west over certain of these features. We describe methods for chronometrically constraining the ages of desert pavement features using three approaches to rock varnish dating: varnish lamination (VML) and lead-profile dating, as well as cation-ratio (CR) as an additional tool. Each of these techniques may be applied to rock varnished cobbles that have been upthrust into areas that have been previously cleared of the original pavement through cultural or natural processes. We apply these methods to three unresolved archaeological issues: the age of the intaglios (geoglyphs) along the lower Colorado River corridor; whether the Topock (or 'Mystic') Maze is the product of Precontact Indigenous or late nineteenth century railroad construction; and if commonly occurring cleared circles are natural features likely associated with now-missing vegetation and/or bioturbation, or were cultural products.

Keywords: rock varnish; chronometric dating; intaglios; geoglyphs; historical linguistics; Yuman speakers

1. Introduction

Surface archaeological features and sites are common if not ubiquitous in the North American Desert West. Despite their pervasiveness, these types of archaeological remains—lithic scatters, petroglyphs, rock alignments and cairns, and geoglyphs, cleared circles and trails in desert pavements—are problematic in the sense that their chronological placement is often unknown, limiting their inferential value. Indeed, in certain cases it is unclear whether specific features are human or natural in origin, complicating cultural heritage management (McDonald et al. 2011; Bullard et al. 2012). In select cases these features can be chronometrically dated, however, using rock varnish dating techniques. We describe and discuss these techniques and two issues in their application in the following. We then demonstrate the use of three techniques, and the inferential implications of the resulting chronometric ages, for three empirical case studies that help resolve long-existing archaeological controversies: the age of the intaglios (geoglyphs) along the Colorado River and thus the antiquity of the Yuman cultural pattern in this region; whether the so-called Topock ("Mystic") Maze is a Precontact era Indigenous sacred site or instead a by-product of late nineteenth century railroad construction; and the age and origin of many cleared circles in desert pavements.

We start with a brief discussion of rock varnish itself before turning to the approaches and issues involved in its dating, concluding with our empirical studies and results and their implications.

1.1. Rock Varnish

Rock varnish is a paper-thin deposit that accumulates naturally on rock surfaces. It is composed of more than half clay minerals, about one-third Mn and Fe oxides, and minor and major trace elements (Dorn, 2024). Although it can form in any environment, rock varnish is most commonly recognized in arid regions (hence its non-technical label as 'desert varnish'), where it typically appears in two forms: a chocolate brown to blue black varnish on exposed rock surfaces; and orange varnish found under ground-bands along the base of pavement rocks, as well as in cracks themselves (Dorn, 1998). Rock varnish dating involves the first of these two rock coatings, and is the focus of the following discussion and analyses.

The raw clay minerals that are transfixed to lithic surfaces forming a rock varnish coating are derived from windblown dust and thus vary based on regional geology (Dorn, 2025). Despite this variability, Mn-oxides typically dominate, commonly resulting in varnish's dark appearance. The clay particles, Mn- and Fe-oxides and trace elements that comprise this coating are fixed to rock surfaces by biotic and abiotic processes, including the effects of budding bacteria (Chaddha et al., 2024; Dorn, 2024). Rock varnish is then an accumulated biogeochemical coating, not a patina formed from the chemical alteration of the underlying lithic surface, as it is sometimes incorrectly labeled.

Rock varnish's development and its chemical constituents are also influenced by major paleoclimatic changes. During wetter periods varnish is Mn-enriched; drier periods instead result in a less Mn accumulation such that Fe dominates. Over time, as paleoclimatic conditions alternate, this results in a microstratigraphy of Mn- versus Fe-rich layers that is visible in ultrathin sections (Perry and Adams, 1978; Liu et al., 2025). These changes appear as contrasting color differences using optical microscopy, with black (Mn-rich), orange (Mn-low) and yellow (Mn-very low) layers (Figure 1). Varnish develops first in small pockets or micro-basins on a rock surface which, accordingly, typically preserve the most complete varnish layering sequence. This fact has important implications for rock varnish dating, discussed below.
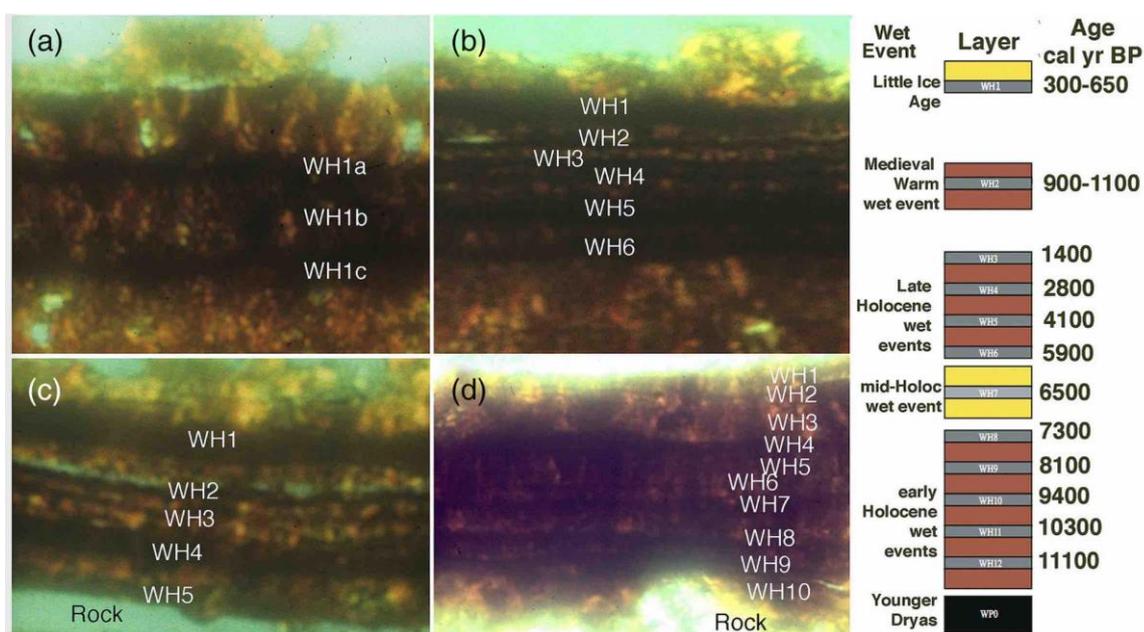
Figure 1. Holocene rock varnishes of varying ages seen in ultrathin sections from the Sonoran Desert. The darker layers are richest in Mn and form during wetter time periods, such as during the Holocene. The orange layers contain much less Mn and form during drier periods. Yellow layers form during the driest periods. We use here Liu and Broecker's (2007) Holocene calibration for varnish microlaminations shown on the right. The calibration

displays wet Holocene (WH = wet Holocene) layers, denoted by WH1 through WH12. Particularly wet microenvironments, such as on the shaded side of a boulder, can have faster rates of varnish accumulation that records greater detail in a wet Holocene period, such as three wet phases of WH1.

It is important to note some additional caveats about varnish formation processes. First, multiple factors can impact or alter these processes and the preservation of complete layering sequences. Acid-producing lithobionts such as fungi (e.g., Burford et al., 2003; Favero et al., 2011; Favero and Viles, 2020), for example, may develop as climatic conditions change, or may be more prevalent in some environmental settings and their acids can dissolve rock varnish (Dorn, 2019, 2024). Second, this (and other factors) may result in an irregular distribution of potential varnish sampling micro-basins useful for archaeological dating, which in turn may impede systematic sampling (Whitley, 2013). Finally, there are other rock coatings that are Mn- and/or Fe-rich, including heavy metal skins, and case-hardened rock surfaces that incorporate varnish components (Dorn, 1998), that may be visually mistaken for rock varnish without technical analysis. All of these circumstances must be considered in archaeological applications of rock varnish dating.

2. Rock Varnish Dating Techniques

A series of different techniques have been developed and applied to rock varnish dating for archaeological purposes (Dorn, 1994, 2001), not all of which have been successful. We discuss three here that have been frequently used in recent archaeological applications: varnish microlamination (VML), cation-ratio (CR), and lead-profile, dating[1].

It is important to emphasize that, regardless of chronometric approach employed, there is a time lag between the first exposure of a rock surface, such as the recently engraved groove of a petroglyph or the exposure of an upthrust cobble in an intaglio, and the initial development of a rock varnish coating. Although we provide new data relevant to this time lag below, here it is adequate to note that prior observations revealed that rock varnish starts to form in millimeter-sized rock-surface depressions, or micro-basins, in hot deserts within a century. We observed this at Fort Paiute in the Mojave Desert (Dorn et al., 1986; Bamforth and Dorn, 1988), on an intaglio made in the 20th century called the "Fisherman" (Dorn, 1998), discussed below, and on a 20th century engraving at South Mountain, Phoenix (Dorn et al., 2012). These prior findings do not indicate that an entire rock surface starts to revarnish within a century; it does not. The process starts in a few micro-basins initially and then slowly begins to cover other parts of a rock surface. As discussed below, this fact has implications for the use and efficacy of different varnish dating techniques and sampling strategies [2].

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[1] An additional experimental technique, AMS-Weathering Rind Organics dating (Dorn et al., 1986), was developed and applied archaeologically in the 1990s (e.g., Whitley and Dorn, 1993). This was predicated on the assumption that rock varnish coatings were closed systems that were not subject to contamination by older or younger organic material, as was repeatedly emphasized in publications where it was employed. This assumption proved invalid and the technique was withdrawn (Dorn, 1996; Dorn 1997). Despite this notification, a subsequent widely-promoted controversy resulted, including accusations of scientific misconduct (Beck et al., 1998). The scientific basis of this controversy, the three separate investigations concluding that no misconduct occurred on the part of the accused, and the legal defamation case that resulted are covered in detail in Whitley (2009, 2013). Here it is adequate to emphasize that the AMS-WRO controversy had no implications for the efficacy or utility of the dating techniques discussed in this paper.

[2] There have also been numerous papers that have attempted to measure the accumulation of Mn in rock varnish, using pXRF, as an indicator of the age of revarnished petroglyphs grooves

2.1. VML Dating

Perry and Adams (1978) first observed alternating Mn- and Fe-rich microstratigraphic layers in rock varnish thin-sections. These micron-scale laminations develop as a result of climatic changes (Liu and Broecker, 2007; Liu et al., 2025). The resulting layered patterning visible in an ultrathin section can be used to determine the age of the sample when compared to a regional sequence developed using independently-dated surfaces as calibration control points. VML dating is then conceptually analogous to tree ring dating, but it does not have the same chronological resolution as dendrochronology. When varnish grows slowly, as is mostly the case in hot deserts (Dorn, 1998), the temporal resolution is low and a sequence only records major climatic signals such as large glacial pulses. Where varnish grows more rapidly, as it does in moister microenvironments (Spilde et al., 2013; Dorn, 2024) such as a north versus south face of some boulders, however, roughly millennial-scale climatic events may be recorded throughout the Holocene (Liu and Broecker, 2007; Liu et al., 2025).

VML sampling requires the removal of a complete layering sequence from a rock varnished surface. This may be obtained mechanically, by carefully hand-prying off the varnish layer from a micro-basin using a tungsten needle, or by taking a hollow core sample which preserves the varnish sequence. It is necessary to obtain multiple micro-basin samples from the surface being dated to ensure that the most complete layering sequence is obtained. Sampling petroglyphs requires the removal of intact micro-basins from within the pecked-out area that defines the image whereas, for upthrust cobbles in cleared areas in desert pavements, they may be taken from anywhere on the exposed surface. We note that the area removed is typically a few millimeters in diameter.

Liu and Broecker (1999, 2007, 2008a, 2008b; Broecker and Liu, 2001) identified and calibrated a Late Pleistocene - Holocene Mojave VML sequence (Figure 1). This has been expanded into the lower Sonoran Desert with additional calibration points from radiocarbon-dated landslides (Dorn, 2014) and is used in this paper. Liu and Broecker (2007) further noted and Dorn (2014) verified that when varnish grows fast enough, WH1 is often subdivided into three layers (e.g. Figure 1A) formed in wetter phases of the Little Ice Age, at about 300, 500, and 650 calendar years before present. The chronological implications of this sequence have been described as follows:

> "twelve wet event dark layers and thirteen dry event lighter layers … bracket the period from 300 yrs cal BP to 12,500 yrs cal BP. The lengths of the intervals between wet events vary from 250 to 1800 years, with an average of 970 — roughly 1000 years. The resulting correlated VML ages are certainly not as precise as radiocarbon ages, but they are adequate for age assignment to the broad time periods comprising the regional cultural historical sequence" (Whitley, 2013:4).

VML, notably, has been subjected to, and verified by, blind testing using cosmogenically-dated geomorphic surfaces (Marston, 2003; Liu, 2003). VML has also been used to date artifacts, petroglyphs, constructed surface features, and geomorphic surfaces in Africa, the Middle East, and North and South America (Carbonelli and Collantes, 2019; Cerveny et al., 2006; Liu et al., 2021; Liu et al., 2025; Baied and Somonte, 2013; Whitley et al., 2017), even though its primary use has been in geomorphology (Liu and Broecker, 2008; Liu and Broecker, 2013). VML dating, for example, was used to predict that debris flows could be a major hazard in metropolitan Phoenix (Dorn, 2010), a prediction that was confirmed in 2014 (Dorn, 2016).

(Macholdt et al., 2019; Andreae et al., 2020; Andreae and Andreae, 2022; Andreae et al., 2023; Pingitore and Lytle, 2003; Lytle et al., 2008, 2011; Rogers 2010; Johnson 2018; Guagnin et al. n.d.). We note here simply that Bard (1979) demonstrated decades ago that the accumulation of Mn in rock varnish is not systematically related to sample age, a conclusion that has not been addressed let alone resolved by proponents of the pXRF approach. We discuss the problems with this technique in more detail elsewhere (Dorn and Whitley n.d.).

2.2. Lead-Profile Dating

The industrial revolution caused a significant increase in atmospheric pollutants, including lead (e.g., Candelone et al. 1995). One result is that rock varnish surfaces exhibit an observable increase, or spike, in lead (Pb), beyond the natural background levels in the rock coating. This lead spike occurs only in the very surface-most micrometers of rock varnish that accumulated in the 20th century. We identify the presence of lead in a VML sequence with an electron microprobe, using a focused micron-size beam for 200 seconds, which lowers the detection limit to 0.06% PbO (Dorn, 1998). This 20th century lead spike has subsequently and independently been verified in rock varnish as resulting from manganese and iron scavenging of lead (Fleisher et al., 1999; Hodge et al., 2005; Hoar et al., 2011; Nowinski et al., 2013; Spilde et al., 2013; Sims et al., 2022).

Lead-profile dating was first used to determine if the "Fisherman" intaglio near Quartzsite, Arizona, noted above, was pre-20th century in age or a more recent potential fake. As discussed below, rock varnish coatings from upthrust cobbles within this geoglyph were sampled, all of which were exclusively characterized by the lead spike, indicating a recent/20th century age for the creation of this surface feature (Dorn, 1998). Note that this does not preclude the possibility that this feature may be Indigenous in origin since the ritual practice involved in the use of these geoglyphs has continued into the twenty-first century (Whitley, 2014). That this intaglio is stylistically and thematically dissimilar from other examples, combined with its recent age, however, suggest that it may be Euro-American rather than Native American in origin.

Lead-profile dating has also been used to authenticate historical inscriptions (Dorn et al., 2012). An important use of this technique is the way we have employed it here: as the internal check it provides on the identification of the youngest Holocene rock varnish microlaminations at 300 (WH1a), 500 (WH1b), and 650 (WH1c) cal yr BP, correlated with three wet phases of the Little Ice Age (Liu and Broecker, 2007; Liu et al., 2025), as discussed above. Repeating a point noted previously, rock varnish dating is best conducted using multiple techniques (Dorn, 1994, 2001), as we employ lead-profile dating here.

2.3. CR Dating

The development of CR dating in the early 1980s (Dorn, 1983; Dorn and Oberlander, 1981) yielded the first calendrical age-constraints on petroglyphs (rock engravings), resulting in the first chronometric rock art ages (Dorn and Whitley, 1983, 1984). This technique is based on cation exchange processes in rock varnish that leach out mobile trace elements (K and Ca) more rapidly than stable elements (Ti) through capillary action (Dorn and Krinsley, 1991). The resulting rate of change can be calibrated using independently-dated control surfaces, such as river and lake terraces, and used to provide minimum-limiting age estimates for a rock varnish coating (Dorn et al., 1990).

While CR dating has been independently replicated in a number of regions globally (e.g., Pineda et al., 1990; Zhang et al., 1990; Plakht et al., 2000; Sarmast et al., 2017; Ntokos, 2021) and has been successfully subjected to blind tests in its archaeological use (Loendorf, 1991; Bamforth, 1997), it has certain analytical weaknesses. Varnish growth, as noted above, starts in micro-basins, with initial cation leaching then likewise beginning at discrete points rather than continuously and uniformly across a rock surface. This discontinuity requires the removal (though mechanical abrasion of varnish within the micro-basins) and chemical analysis of a bulk sample in order to obtain an average value for the coating as a whole (Dorn, 1994:24). The resulting age estimates often have large errors margins; and they can underestimate the true age of a varnish surface (see, e.g., Whitley, 2013: Table 1), despite efforts to exclusively sample within micro-basins and thereby minimize contamination from the younger portions of a varnish coating. The most important weakness of the technique, however, is its basis in biogeochemical processes which can potentially reverse over time. Despite these issues, a blind test matching CR to VML dating yielded comparable even if not fully equivalent results, demonstrating its value for broad-spectrum temporal analysis, such as identifying the age range of a corpus of petroglyphs, or a surface artifact assemblage. But like obsidian hydration dating, CR is not appropriate for confident age assignments for individual specimens (Whitley, 2013:7). Given the

considerable advantages of VML discussed above, we employ CR dating below as a secondary check on the age assignment of a VML sequence.

2.4. Dating Surface Features in Desert Pavements

Dating surface features in desert pavements is based on the fact that the wetting and drying of fines and the accumulation of silt push buried cobbles upwards, onto the ground surface, in areas that have been previously cleared of these accumulative ground coverings (Springer, 1958; Haff and Werner, 1996; Adelsberger and Smith 2008; Adelsberger et al. 2013; Haff, 2014; Ugalde et al. 2020). When surface archaeological features involve the disturbance of the desert pavement (e.g., in the creation of a cleared circle, intaglio or trail), VML, CR and lead-profile dating can be used to provide a minimum-limiting age estimate on the subsequently upthrust lithic clasts, and thus on the creation of the archaeological feature. Two technical matters involved in dating desert pavements using such an approach warrant brief discussion here. These are the time lag involved in the upthrust of cobbles onto the surface in a disturbed desert pavement area, and the larger issue of the time lag in the initiation of varnish development on unvarnished rock surfaces of all kinds, noted briefly above.

2.4.1. Time Lag in Desert Pavement Regeneration

A variety of observers have claimed that desert pavement regeneration begins within a few months to a few years (Péwé, 1978; Haff and Werner, 1996; Dietze and Kleber, 2012). We monitored the rate of pavement reformation in meter-scale disturbance plots created by Troy Péwé in the Sonoran Desert outside of Mesa and Quartzsite, Arizona (Péwé, 1978; Bales and Pewe, 1979), to test these estimates, for over four decades. We continued monitoring these pavements with Péwé's permission, even after his passing in 1999.

It was important for our purposes to consider only those cobbles that emerged from the subsurface after Péwé cleared these sample plots, and to ensure that any sampled cobbles were not remnants of the original pavement nor were inherited contaminants, through disturbances of some kind from the surrounding areas. We focused, accordingly, only on those cobbles with inclusions of millimeter-scale fragments of pedogenic carbonate. Such carbonate coatings develop on buried clasts (Springer, 1958; McAuliffe and McDonald, 2006; Haff, 2014), and precipitation would dissolve the carbonate once exposed on the ground surface after a few decades, allowing us to eliminate the possibility that our sampled cobbles were remnants of or derived from the original pavement surface. We found that it took 14 years at the Mesa site and 22 years at the Quartzsite site for previously buried cobbles to emerge and start reforming a new desert pavement. The implication is that desert pavements begin to regenerate within a few decades of disturbances to them, indicating that rock varnish dating of subsequently upthrust clasts can provide an archaeologically-reasonable minimum estimate of the age of manufacture of these types of surface features.

We stress that pavement generation and its regeneration is an ongoing process. The length of time it takes to form a completely intact pavement, measured by radiocarbon and optically stimulated luminescence, can range from about 5000-6000 years in the Mojave Desert to about 12,000 years in Death Valley, California, when cobble sizes are under about 10 centimeters (Seong et al., 2016). The samples we collected are thus from pavements that are still regenerating and tend to have even smaller cobble sizes. We emphasize that the varnish ages presented here are minimum estimates for the age of a pavement disturbing event.

2.4.2. Time Lag in Initiation of Revarnishing

It is also important to emphasize that, regardless of chronometric approach employed, there is a time lag between the first exposure of a rock surface, such as the newly engraved groove of a petroglyph or an upthrust cobble, and the initial development of a rock varnish coating: the start of its revarnishing for petroglyphs and the initiation of varnishing on upthrust cobbles. As noted above, prior observations revealed that rock varnish is present in millimeter-sized rock-surface depressions,

or micro-basins, in hot deserts within about a century, but the varnish only slowly begins to cover other parts of an exposed rock surface. Varnish age across a surface then varies from point to point, a fact which is critical in terms of effective chronometric sampling.

We used the opportunity afforded by the pavement regeneration study, discussed above, to improve the understanding of this time lag in the start of surface revarnishing. Although rock varnish was not detectable on most of the previously buried cobbles we observed on the ground surface at Péwé's Mesa study locale, two had started to develop a varnish coating after 19 years of surface exposure. These coatings, however, were only visible using electron microscopy (Figure 2), not with the light microscopy used for VML and, as expected, were restricted to micro-depressions on the cobble surfaces.
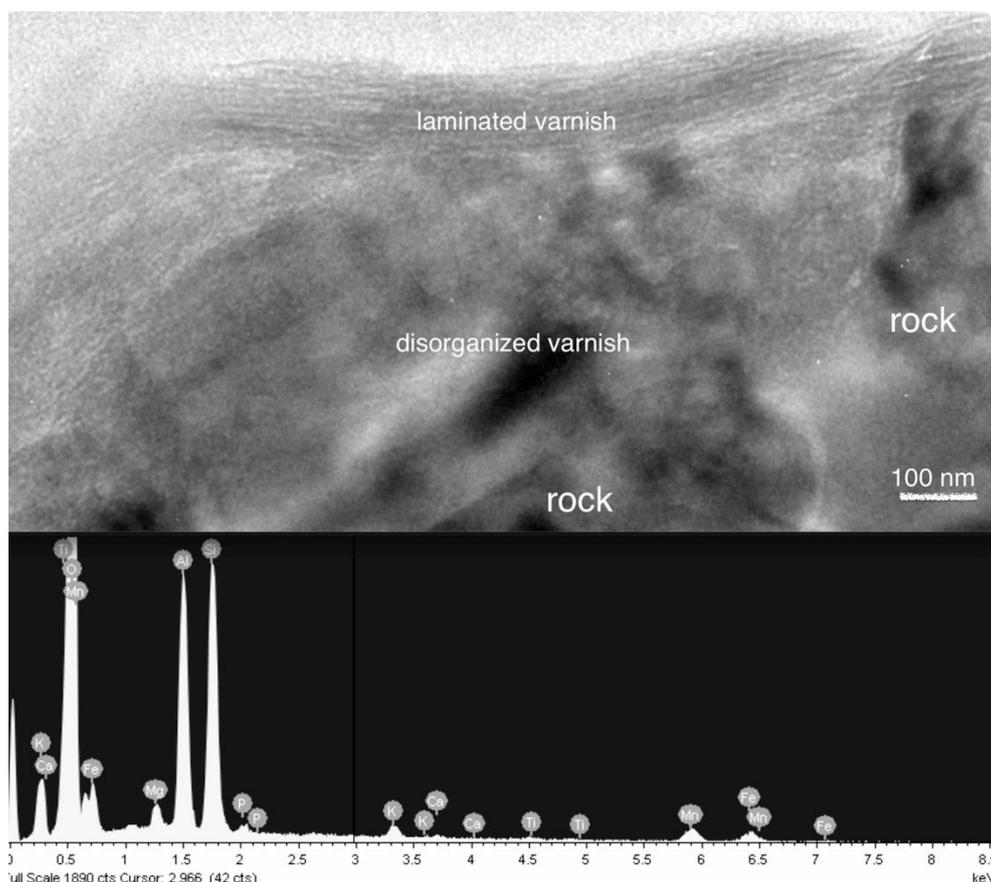

Figure 2. At the Mesa cleared pavement patch, high resolution transmission electron microscopy and energy dispersive spectroscopy reveals varnish formation in small microdepressions after 19 years of exposure. This incipient varnish first accumulated as unlaminated varnish. The energy dispersive spectrometry analysis is that of typical rock varnish, and it is on a spot of disorganized varnish. Then, laminated varnish with a similar chemistry formed on top of the more disorganized material.

We further assessed the revarnishing time lag using a natural petroglyph-like feature — a 0.5 cm-wide scar on a rock surface, created by a landslide in the McDowell Mountains, Scottsdale, Arizona. A radiocarbon age of 1180-1290 cal year BP, obtained on a crushed paloverde tree under the landslide feature (Dorn 2014), provides a useful age constraint on the natural event that created this scar. This allowed us to assess the variability of rock varnish ages in different micro-basins within this feature, using VML dating, along with the rate and degree to which rock varnish spread across this groove, using X-ray mapping (Friel and Lyman, 2006).

Only two of 10 VML cross-sections from micro-basins in the scar had the WH2 microlamination, thereby matching the radiocarbon age. The remainder provided younger estimates: four had the WH1 (Little Ice Age) microlamination at their base, and four were post Little Ice Age (younger than

300 cal yr BP). We accordingly only use the oldest VML sequence for each feature in our age estimates, because the oldest VML provides the smallest time lag between cobble exposure and the onset of varnishing and is likely closest to the true age of the feature. These results emphasize, again, that varnish dating techniques provide minimum-limiting age constraints rather than 'absolute dates,' as well as the need to sample multiple micro-basins to obtain the most accurate age.

3. Age of the Colorado River Intaglios

Substantial popular interest has developed over the last half century in the intaglios (geoglyphs or earth figures) found on the terraces along the lower Colorado River in California and Arizona. These commonly include very large (tens of meters in maximum dimension) stick-like human figures, rarer depictions of animals (mountain lions, lizards, snakes), and geometric patterns like spirals and zigzags, often associated with cleared paths and circles (Figure 3). Like the more famous Nazca Line intaglios of Peru, much of this popular appeal involves spurious claims about putative associations with ancient aliens when, in fact, there is Native American ethnography on the meaning and ritual use of these surface features (Bourke 1889; von Werlhof, 2004; Whitley 2014, 2023). This demonstrates that the sites are specific locations of mythic events for the River Yuman-speaking Quechan and Mojave; that the motifs portray the actors and events that occurred at each location; and that the sites were—and at least until two decades ago continued to be—used for ritual pilgrimages undertaken to re-experience the creation of the world. They are somewhat then akin to the commemorative and ceremonial purposes of the Catholic Stations of the Cross, on a landscape scale.

Figure 3. Air photo of the so-called "Blythe Giant Figures,"California, on a terrace above the Colorado River. One of the two anthropomorphic intaglios (encircled by a fence) is shown here; it is about 52-meters long. The anthropomorphs portray the creator god Mastamho and his twin brother. The quadruped is Hatakulya, one of

two mountain lion spirit-beings who helped in the creation, with a spiral underneath. Minimum varnish ages (Table 1) indicate that these intaglios are at least 1000 – 1100 years old. Other scars in the desert pavement were created by off-road vehicles (Google Earth).

While there is widespread professional archaeological acknowledgement of the Indigenous ritual origin of these surface features, their age has been uncertain, as has the potential antiquity of the associated pilgrimage and ritual belief systems tied to them. This is important in part because the history of Yuman-speaking peoples in this region is uncertain. There is an archaeological consensus that Yuman-speakers were present along the river corridor by at least 700 CE (Schroeder 1979), based on the development of the Hakatayan/Patayan archaeological "culture," but their initial arrival in this region is unresolved. Many archaeologists suggest a relatively late River Yuman arrival (e.g., von Werlhof 1995; Laylander 2001, 2010, 2015). Linguistic evidence, however, alternatively suggests that they may have been present much earlier (Hinton 1991; Field 2018), especially if the Colorado River Delta and/or Colorado Desert area is the homeland for the Proto-Yuman language, as Mixco (2006) and others (Law 1961) have hypothesized.

3.1. VML and CR Ages on Intaglios

Table 1 presents a compilation of rock varnish minimum-limiting ages for intaglios on both sides of the lower Colorado River, along with a trail associated with the Ripley site, including new VML, CR ages and lead-profile ages. Included in the table are calibrated CR ages from a prior study (von Werlhof et al., 1995) [3] in addition to the new chronometric estimates. The VML ages represent the oldest microstratigraphic sequence observed from 10 cobbles analyzed from inside of each of these features. Control cobbles from the unaltered desert pavement surrounding each feature were also analyzed. These "controls" were all Late Pleistocene in age.

Table 1. Minimum rock varnish ages for intaglios (and an associated trail) obtained in this and prior research, as explained in the text, using three different rock methods. The CR ages without matching VML ages have been calibrated from raw data presented in von Werlhof et al. (1995).

Intaglio, Site	VML age cal yr BP	CR age cal yr BP	Lead Profile
Zigzag/Snake, Quien Sabe	650	500 ± 300	Pre-20th century
Stick Figure, Winterhaven	n/a	750 ± 300	n/a
Anthropomorph, Pilot Knob	n/a	850 ± 350	n/a
Anthropomorph 1, Blythe Giant	n/a	1000 ± 350	n/a
Quadruped, Blythe Giant	n/a	1100 ± 400	n/a
Anthropomorph 2, Blythe Giant	n/a	1100 ± 400	n/a
Anthropomorph, Ripley Complex	between 1100-1400	1200 ± 450	Pre-20th century
Cross, Ripley Complex	between 1100-1400	1250 ± 450	Pre-20th century

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[3] The focus of Werlhof et al. (1995) was to present AMS-WRO results that were experimental. The authors at that time cautioned that: "These [AMS-WRO] results must, however, be placed under the cloud of uncertainty that hangs over the entire field of AMS dating of rock art: the untested assumption surrounding contemporaneity of organics in a surface context" (ibid:257). Since Werlhof et a. (1995) also published uncalibrated (K+Ca)/Ti ratios for comparison, these were calibrated for this study providing additional minimum-limiting chronometric ages.

Largest Anthropomorph, Quartszite	n/a	1350 ± 350	n/a
Amorphous Form, Quartszite Airport	n/a	1400 ± 400	n/a
Anthropomorph, Quien Sabe	1400	1500 ± 450	n/a
Trail, Oatman	1400	1500 ± 500	n/a
Lizard Figure, Ripley	n/a	1600 ± 500	n/a
'Snake' Head, Singer Complex	n/a	1900 ± 550	n/a
'Snake', Museum complex near Ocotillo	n/a	2900 ± 750	n/a
Schneider Dance Circle, Yuha Mesa	n/a	3200 ± 750	n/a
Anthropomorph, Quien Sabe	5900	6100 ± 1200	n/a

The minimum-limiting age estimates range from 650 to 5900 cal yr BP, or from the Late Precontact period to the middle Holocene. Figure 4 presents the oldest of the observed VML sequences for two intaglios from the Ripley Complex, Arizona, perhaps the largest intaglio site along the Colorado River. An orange layer underneath the black WH2 layer is shown in Figure 4A, indicating that its varnish began to develop between WH2 and WH3, or from 1100 to 1400 cal yr BP. Figure 4B displays only a very small section of the orange laminae, with the black WH2 layer as its basal layer. Since varnishing always post-dates exposure of a pavement clast, and since upthrust cobble exposure itself takes time, an appropriate minimum age assignment would be 1100 to 1400 cal yr BP for both intaglios.

Note that an area labeled "bacteria cast" in Figure 4A is a cluster of budding bacteria with their cellular casts encrusted in Mn and Fe. These casts are normally dissolved and remobilized as varnish grows (cf. Dorn, 2024), but some preserved areas may occur where varnish is particularly fast growing. This is consistent with preservation of the three Little Ice Age wet events, present in both profiles and indicative of relatively quick varnish development. Lead-profile dating is also consistent with these analyses, as are the CR ages.

That both Ripley intaglio VML ages fall within the same time range suggests that the two geoglyphs may have been created in the same event, or at least during the same general time period. This possibility is enhanced by the CR ages from the famous Blythe Giants site, all three of which are internally consistent with average dates of 1000 - 1100 cal yr BP. This perhaps indicates that at least some of these sites were planned compositions rather than accretions of motifs added over time. Note further that there seems to be a cluster of dates roughly occurring in the first millennium of the Common Era, when the CR dates on samples without accompanying VML ages are included. This may represent a period of intensified ritual activity.
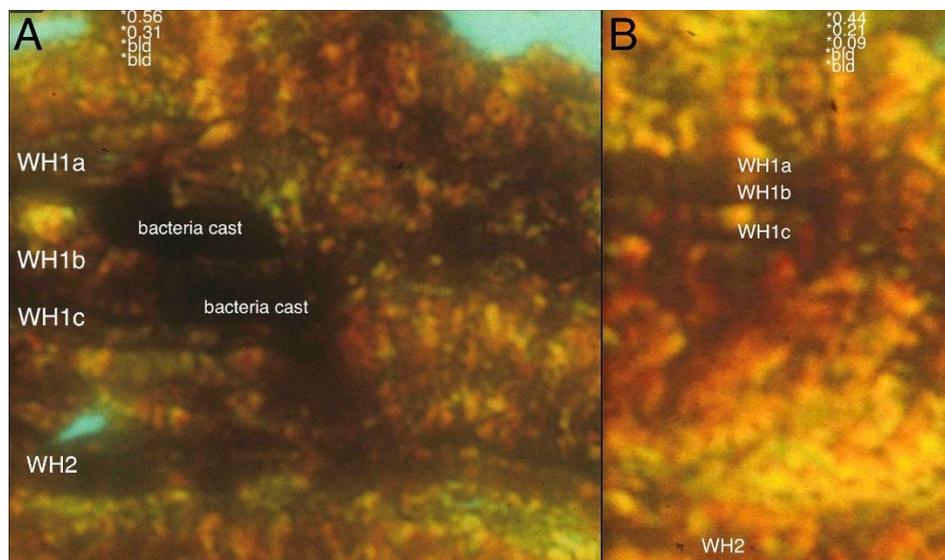
Figure 4. VML sequences on Ripley Complex intaglios: (A) cross and (B) large anthropomorph. The orange basal layer of the cross VML puts its age between 1100 and 1400 cal yr BP, and the black WH2 basal layer is 1400 cal yr BP. CR ages in Table 1 and lead-profile analyses indicated on the VML sequences are particularly useful here, because they provide additional confidence that the three Little Ice Age wet periods (WH1a, WH1b, WH1c) are correctly identified in this VML sequence. Each of these sections has a thickness of ~12 μm.

The Quien Sabe Point site, however, presents a very different picture. Figure 5 shows three previously undated geoglyphs from this locale. Ages indicated by the oldest VML sequence from each of the sampled intaglios are presented in Figure 6. These range from 650 to 5900 cal yr BP, which are corroborated by the CR estimates, suggesting that new intaglios were added to this site over a very long period. This demonstrates both the long-term continuity in the use of a specific location for rituals, as has been documented in other Native American cases (e.g., Sundstrom 1996; Whitley et al. 1999), as well as change over time in the sense that new motifs were successively added to the markers signaling this location as sacred. This last fact counters any claim that the intaglio ritual tradition was somehow ahistorical—that is, unchanging—given that it involved the addition of new symbolic elements and, as indicated by the results from the Blythe Giants and Ripley sites, additional sites/ritual locations, over time.

We emphasize, again, that the oldest VML and associated CR ages for each intaglio are the most appropriate estimates, because all varnish dates are minimum-limiting dates. This is due to time lags in pavement reformation and in varnishing. The 5900 cal yr BP age for one of the Quien Sabe anthropomorphs relative to the other two dates, however, raises an obvious question of reliability. This early date is supported by the VML age distribution of the other nine sampled cobbles from this specific intaglio. Two of these have the same WH6 sequence (5900 cal yr BP) age; five have the WH3 sequence (1400 cal yr BP); and two have WH1c at their base (650 cal yr BP). The VML age distribution for these ten sampled cobbles from a single intaglio could reflect ongoing pavement reformation processes, ongoing lag in varnishing, or some combination of these processes. The age distribution might also reflect imperfect "upkeep" (that is, periodic clearing of newly upthrust cobbles in the intaglio), since we know that, in a relevant parallel case, ritual initiates were required to maintain the Trail of Dreams by tamping down this trail used in their puberty rites with logs (Whitley 2014). Since the VML age of the adjacent pavement control cobbles is at least 36 ka, we are confident that WH6 (5900 cal yr BP) is an accurate minimum age assignment for the oldest of the intaglios, and not an result of contamination from the surrounding pavement.

Figure 5. Air photo of the Quien Sabe Point site, showing the estimated VML ages for three motifs: a long zigzag at the bottom and middle, and two anthropomorphs at the top with their legs extending to the cliff edge along the Colorado River. (Photo courtesy of Harry Casey; large creosote bushes, approximately 2 meters in diameter, for scale).
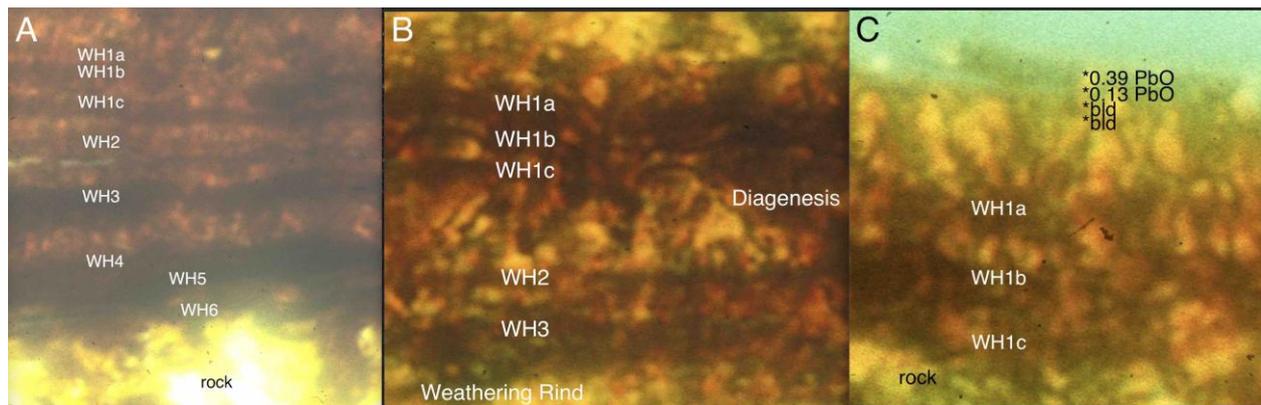
Figure 6. The oldest VML sequences for each of the three sampled intaglios at the Quien Sabe Point site (see Figure 5). A) Oldest VML age of ten cobbles sampled from the older anthropomorph is WH6; section thickness is 45 μm. B) Oldest VML age of ten cobbles sampled from the younger anthropomorph is WH3; section thickness is 25 μm. C) Oldest VML age of ten cobbles sampled from a zigzag/'snake' figure; section thickness is 17 μm. Note the lead-profile dating measurements and the spike of lead in the upper few microns, consistent with the assignment of the Little Ice Age WH 1 wet periods in all three profiles.

The results from the Singer Complex (Figure 7) warrant brief discussion. This site is located in an area where armored infantry troops trained during World War II, west of the river corridor, and pavement disturbance from tanks is visible in the immediate site area. This has led to questions about the authenticity of this site: are the geoglyphs Indigenous in origin or instead the result of military activities of some kind (cf. Casey 1992)? This last possibility might seem supported by the site's location, some distance from where most other intaglio sites occur, and due to the relatively unique nature of its intaglios: very long, snake-like forms. The 1900 cal yr BP resolves that question, demonstrating that these intaglios long pre-date Euro-American arrival in North America.

Figure 7. Air photo of the Singer Complex site showing two long snake-like intaglios, a graded dirt road and fainter tank tracks resulting from World War II armored infantry training exercises. (Photo courtesy of Harry Casey; double-lane dirt bisecting photo for scale).

We also include in these data a VML age for a trail associated with the Oatman site, on the Gila River, Arizona, because of both its substantive and methodological implications. The archaeological significance is that the trail leads to several intaglios, and its age is likely therefore related to ritual activities at these geoglyphs. Sampling, however, specifically involved a cluster of broken crystalline quartz in the reforming trail pavement. The bottom VML layer for the sampled quartz is WH3, indicating an age of 1400 cal yr BP (Figure 8A). As described elsewhere (Whitley et al. 1999), quartz was broken up by shamans during vision quests to release, and therefore acquire, its inherent supernatural power, which was visibly manifest in the triboluminescent glow that resulted. This suggests that this practice may have at least sometimes occurred during visits to the intaglios.

The methodological issue relates to lag times of varnishing on surfaces. While the best minimum age for the trail is 1400 cal yr BP, eight other cobbles were younger than the Little Ice Age, or younger than 300 cal year BP. The back-scattered electron micrograph shown in Figure 8B illustrates why there are so many "younger" ages: the small bright spots are locations of varnishing in microdepressions. This image is a typical example of common Holocene varnish development. The tiny micron-scale pockets are where varnishing first starts to develop, and it is in these pockets where sampling and images are obtained and the oldest varnishing can be visually identified for VML dating. CR dating samples these pockets separately and integrates all the varnish in a sample for the cobble and this integration is one reason why the error term is so high.
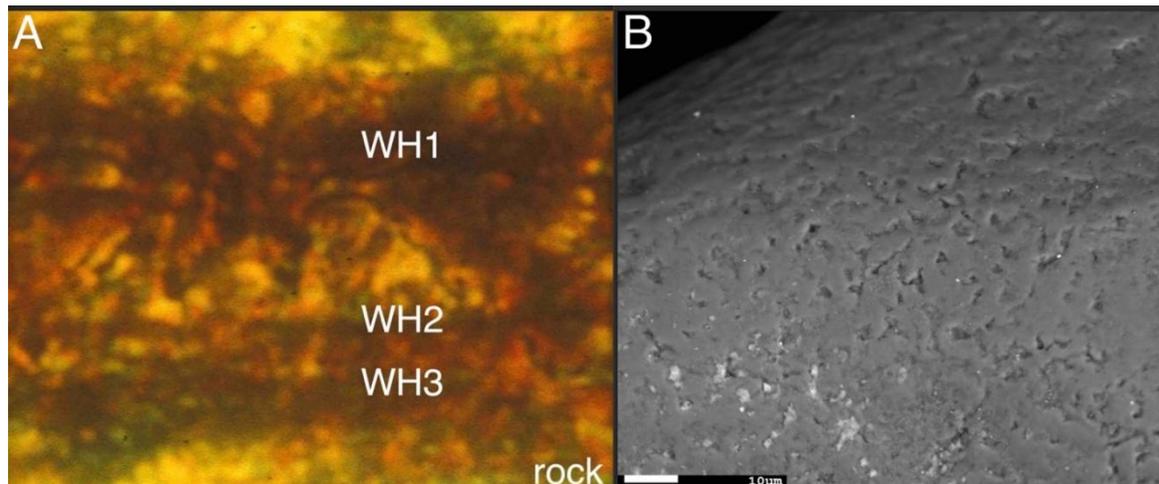
Figure 8. Oldest VML sequence for Oatman trail (A, thickness ~18 μm) with back-scattered electron image of an Oatman trail cobble showing pockets of post-Little Ice Age varnishing for context (B, scale bar 10 μm). In this image, these pockets are much brighter, because of the presence of Mn and Fe, as compared to the quartz mineralogy of the cobble.

3.2. Implications of the Intaglio Ages

There are two issues concerning our intaglio rock varnish ages, ranging from 650 to almost 6000 years ago, that warrant discussion. The first is methodological. It concerns the fact that dating desert pavements is predicated on the processes which re-generate these surfaces over time, as new cobbles are upthrust into a cleared surface. The important question then is how an intaglio can persist for as long as 6,000 years, given that much younger archaeological features may be buried under desert pavements as they re-form (e.g., Ahlstrom and Roberts 2001)? The likely explanation, as noted above, is that these geoglyphs were actively even if not perfectly maintained, keeping them (mostly) clear of newly upthrust cobbles over the millennia. Ethnographic evidence indicates that the cleared surface of so-called Trail of Dreams, which runs through desert pavement and was used for the Quechan boys' puberty initiation run, was tamped down periodically by the boys, using logs, so it would be cobble free (Whitley 2014). It is likely that a similar practice existed for the intaglios themselves and that this accounts for their persistence.

The second issue is substantive and it involves the relationship of the intaglio tradition to the origins of River Yuman-speaking peoples (Mohave, Quechan and, historically, Halchidoma) along the lower Colorado River corridor (von Werlhof 1995). It is important to emphasize at the outset that there is no perfect correlation between language, culture and physical-biological ("racial") type, as the first half-century of Boasian anthropological research demonstrated conclusively (Whitley 2019, 2021). But the parallel fact is that we cannot reduce a culture to an adaptive system or artifact assemblage. Cultures instead are defined in contemporary anthropological terms as cognitive systems of shared symbols and meanings, often tied to common ritual and belief systems, not sets of norms, artifact assemblages or types, nor adaptive strategies, as many archaeologists still assume (Whitley 1992, 2020, 2024). As Sahlins (1985) has emphasized, furthermore, different aspects of human social life change at different rates, with technological and economic factors shifting quickly while belief and ideological systems—which is to say cultures—are much slower to change. Indeed, as Steward noted, a half-century of acculturation among nearby Numic speakers:

> "has not wiped out all Indian practices. Acculturation has consisted primarily of modifications of those patterns necessary to adjust to rural white culture … The Shoshoni retain, however, many practices and beliefs pertaining to kinship relations, child-rearing, shamanism, supernatural power and magic" (1955:58).

Religion, a set of beliefs and practices involving supernatural agents, is often but not always a proxy for culture. While this is not the case for large scale societies, like our contemporary western

world with its proselytizing religions (Keane 2003), full concordance often exists between the cultures of small-scale societies, like those in the North American desert west, and their non-proselytizing religions (e.g., Harris 1940:55; Opler 1940:136; Siskin 1983:11; Laird 1976:24). Religious remains, including sacred objects and evidence of ritual practices, are then the most useful category of archaeological remains for studying cultural continuity and change. Even if we cannot, *with complete certainty*, equate culture with language, genetics or phenotypes alone, an assumed equivalence is reasonable in certain cases. A series of matters concerning the linguistic history of the Yuman-Cochimi language family then warrant discussion in light of our chronometric ages and their possible importance as an expression of an early Yuman-speakers' cultural system along the lower Colorado River.

These start with the fact that many linguists hold that the Baja California peninsula was a linguistic dead-end in terms of the initial Late Pleistocene migration and colonization of the west coast, resulting in the development of an isolated speech community in this restricted area that eventually developed into the ancestral Yuman-Cochimi languages. This standard reconstruction posits that this initial colonization was followed by successive migrations northwards, out of this cul-de-sac homeland, creating a kind of linguistic stratigraphy, as it is sometimes described (Shaul 2020; cf. Massey 1961, 1966; Kowta 1984; von Werlhof 1995). But this reconstruction entails at least one confounding empirical problem. This is the 200 kilometers separation between the Pai-speaking branch at the northern extreme of the Yuman languages, with the Iipay and Tiipay ("Diegueño") in the coastal San Diego area and the Yavapai, Walapai and Havasupai ("Upland Yumans") in central- and north- western Arizona. This is typically, though not plausibly, explained by a very late, hypothesized migration and thus split of Pai speakers in one direction or the other (e.g., Laylander 2015).

A more parsimonious reconstruction would suggest instead that there was an extra-peninsular Proto-Yuman heartland in southern California and/or the Colorado River Delta region, as Mixco (2006) argues, based on linguistic borrowing and reconstructed ecological terms. The separation over time into distinct speech communities and, ultimately, individual Yuman languages occurred at least partly in-situ, then, rather than primarily due to migrations. The geographical separation of the Pai, further, resulted again in part or wholly from the later movement of Takic-speakers southwards into former Yuman territory, as Hinton (1991) first suggested, splitting the Pai apart, rather than exclusively due to late-dating Pai migrations. This last possibility accommodates the physical anthropological evidence suggesting that the Cupan branch (Gabrielino, Luiseño, Cupeño and Cahuilla) of Takic-speakers were originally biologically-Yuman or, alternatively, that a substantial proportion of Yuman speakers were absorbed into the in-moving Takic to account for the physical similarities (summarized by Sutton 2009), as well as the equivalences in their mythic corpora (cf. Kroeber 1906; Waterman 1909). It also fits with the genetic evidence (Monroe et al. 2013) and comparative trait studies (Jorgensen 1980) which suggest an earlier split for the Pai languages. Relatively greater antiquity, rather than recent arrival, then is a plausible even if unproven expectation for the Yuman speakers along the lower Colorado River, suggesting that the early dated intaglio in fact may reflect the presence of these peoples 6,000 or more years ago.

The subtexts of this first point are estimates for the various divergences in the Yuman-Cochimi and surrounding language families, the second pertinent issue concerning the linguistic history of this region and its relevance to early intaglio dates. Three general approaches to the history of these languages have been employed in the far west, an understanding of which is necessary for clarifying their value to archaeological interpretation, as well as reconstructing the cultural history of Yuman-speakers along the river corridor. The most common of these approaches involves linguists' guesstimates commonly offered, insofar as we have been able to determine, with little or no detailed analytical basis, but apparently based on very general analogies (e.g., Golla 2007). These guestimates appear tied to the following assumptions:

> "The rule of thumb (derived from the study of languages with hundreds of years of written documentation…) is that after about 2,000 years, language changes tend to have obscured

the clear sorts of correspondences [for grouping language families and detecting borrowing, while] … After 5,000 years there are few [such] correspondences" (Shaul 2014:7).

The implications are that (1) all languages change at approximately the same speed, universally, regardless of population size and density, interaction networks, communication transmission and storage systems, demographic structure or social complexity; and that (2) the written texts of the Indo-European, Egyptian and Semitic language families, the source of these estimates, are appropriate analogical models for the rate of linguistic changes, even to all manner of small-scale oral cultures and societies. Since language divergence and change is at least partly based on (if not heavily influenced by) the social structure of the speech communities using a given tongue, the nature of their interactions with speakers of surrounding languages (cf. Babel et al. 2013), and the differences in the various types of population movement and replacement that may occur (cf. Eshleman et a. 2004; Kemp et al. 2010), these assumptions are empirically implausible from the start (cf. Greenhill et al. 2023:85).

But even more severe, from an archaeological perspective, is the temporal limit that such assumptions necessarily impose on the past, with the observable linguistic differences then required to have developed solely in the last few thousand years. Taken at face value and in aggregate, a synthesis of the far western Precontact past using these guestimates would require numerous and frequent in- and out- migrations of different peoples, as if the far west were little more than a transit corridor for population displacements. Only occasionally is there a logic suggested that (right or wrong) would explain the cause for such movements (Bettinger and Baumhoff 1982, Diamond and Bellwood 2003, and Sutton 2009 are some notable exceptions). Even more rarely is there a plausible description offered concerning where those populations that were forced-out or replaced moved to, and the larger downstream demographic ripple effects of these geographical shifts. The effective result is models of linguistic change without people involved or social interactions considered. The similarities and close relationships between many far western Native American languages, instead, are more likely a reflection of "a normal foraging adaptation in an arid region" (Shaul 2014:66) resulting from a linguistic network rather than a dialectical chain, as opposed to numerous, necessarily recent population movements, as the guestimates require.

A second, superficially more analytical approach to linguistic history has employed glottochronology. This has suggested that the core Yuman languages split up between 3,500 and 1,300 YBP (Shaul and Hill 1998). Note however that Shaul (2014) is no longer willing to assign specific dates to linguistic divergences, tacitly questioning his previously-published estimate. This change in perception reflects a more widespread rejection of glottochronology, the nature and usefulness of which is well-described as follows:

"Glottochronology uses the percentage of shared 'cognates' between languages to calculate divergence times by assuming a constant rate of lexical replacement or 'glottoclock'. Cognates are words inferred to have a common historical origin because of systematic sound correspondences and clear similarities in form and meaning. Despite some initial enthusiasm, the method has been heavily criticised and is now largely discredited. Criticisms of glottochronology, and distance-based [statistical] methods in general, tend to fall into four main categories: first, by summarizing cognate data into percentage scores, much of the information in the discrete character data is lost, greatly reducing the power of the method to reconstruct evolutionary history accurately; second, the clustering methods employed tend to produce inaccurate trees when lineages evolve at different rates, grouping together languages that evolve slowly rather than languages that share a recent common ancestor; third, substantial borrowing of lexical items between languages makes tree-based methods inappropriate; and fourth, the assumption of a strict glottoclock rarely holds, making date estimates unreliable. For these reasons historical linguists have generally abandoned efforts to estimate absolute ages" (Gray and Atkinson 2003:435-436).

The disqualifying problems inherent to glottochronological analysis are further emphasized by the fact that language changes sometimes involve punctuated bursts rather than gradual, progressive evolution (Atkinson et al. 2008), as glottochronology would require.

The third approach to linguistic history is the use of computational phylogenetic models derived from evolutionary biology. These overcome the four main problems with glottochronology and they employ linguistic, genetic and archaeological data to calculate dates for language change, with the archaeological and genetic data calibrating the linguistic rates. Although this approach has not yet been applied to the Yuman-Cochimi languages, to our knowledge, Greenhill et al. (2023) have provided an analysis of the neighboring Uto-Aztecan language family which has implications for the Yuman-Cochimi problem: the temporal relationship of the Yuman speakers to the neighboring Takic branch of Uto-Aztecan speakers and their residence in southern California. There is widespread agreement that the Yuman peoples were in place to the north of the Baja peninsula earlier than the Takic (e.g., Hinton, 1991; Elliot 1994; Sutton 2009; Shaul 2014; Field 2018). Initially the arrival of the Takic in California was widely assumed to be linked to a southern origin, and intrusive migration northwards of Uto-Aztecan speakers out of Mexico, perhaps associated with the spread of maize agriculture (e.g., Hill 2001). This necessarily placed Uto-Aztecan speakers in the region relatively late and, by implication, also then accommodated a relatively younger date for the presence Yuman speakers. The alternative hypothesis was a northern origin for Uto-Aztecan speakers as a whole, including the Takic branch (Fowler 1983). Although this was initially a minority opinion, recent phylogentically-based reevaluations of Proto-Uto-Aztecan linguistic history provide significant support for the northern origin hypothesis, as well as deeper time-depth for these people in the region (Merrill 2012; Greenhill et al. 2023[4]). The Proto-Uto-Aztecan language had differentiated into its own distinctive speech community minimally by about 4,000 years ago, based on these latest reconstructions, in the central Mojave Desert adjacent to the Colorado River corridor. Assuming this reconstruction is correct, Yuman speakers necessarily then would have been in place outside of the Baja peninsula prior to about 4,000 years ago.

[Footnote 4 – The archaeological data that Greenhill et al. used in their analyses

were from reports that partly based their chronologies on the discredited Lamb (1958) glottochronological study of the Numic branch of Uto-Aztecan, potentially biasing the phylogenetic results towards a younger estimated date. This was pointed out in personal correspondence with Simon Greenhill who kindly re-ran his analyses with those data removed. This yielded no appreciable difference in the results and thus his estimated 4,000 YBP date for the development of Proto-Uto-Aztecan in the Mojave Desert (email communication to Whitley, 7/18/2024). Unanswered, however, is a related question: what effect would the inclusion of earlier archaeological ages based on evidence suggesting much longer-term Numic cultural continuity, extending back into the Terminal Pleistocene (Whitley 2013; Whitley et al. 1999), have on the calculated estimate for Proto-Uto-Aztecan in the region?]

There is then a plausible even if not conclusive argument suggesting that the 6,000 years antiquity of the intaglios reflects an early and, ultimately, enduring River Yuman religious and ritual system. This would comprise a third long-lived North American rock art tradition, joining the Great Basin petroglyphs (Whitley 2013, 2019; Whitley et al. 1999) and the Pecos River pictographs (Steelman et al. 2025), each of which also lasted for thousands of years. The three traditions provide a stark contrast to the changes in subsistence strategies and artifact assemblages over the same time periods in these three respective regions. This points on the one hand to the poverty of adaptive patterns and tool-making practices for understanding the cognitive and religious lives in Precontact Native America. But it does not, on the other, imply that these traditions were necessarily timeless and ahistorical, as is sometimes alleged. Such criticisms are based on confusions about the nature of religious change, in that they assume that historical changes necessarily require catastrophic breaks or massive shifts in practice and belief. As Bloch (1986, 1992) has illustrated, religious change over time often instead may involve a persistent core of ritual practice that alternately is elaborated and embellished, followed by a retrenchment to the basic pattern. Just such a pattern of change, in fact, can be cited for the desert west, where the historical Ghost Dance developed out of traditional Paiute and Shoshone beliefs. With the failure of its prophecies, however, Basin religion returned to its core of traditional beliefs and practices (Jorgensen 1986). There is justification in assuming that similar

processes of religious expansion and retraction, in other words, may have occurred along the Colorado River, contributing to persistence yet also variability over time.

4. Age and Origin of the Topock Maze

Few surface rock features are visually more impressive, and more controversial, than the Topock (or 'Mystic') Maze geoglyph site (CA-SBR-219). Located on adjacent Colorado River terraces near Needles, California, the site consists of an extensive series of low, linear gravel rows that have been scraped into the desert pavement, creating numerous parallel cleared paths, each about 1.3-meters wide (Figures 9 and 10; despite the name, these cleared paths do not form an actual maze). The site area has been heavily impacted by over a century of development, starting with the Atlantic and Pacific Railroad right-of-way through the site in 1893. The subsequent construction of Interstate-40 and the railroad grade now divide the locality into northern and southern areas. The southern section is bounded by a PG&E pipeline compression station and county waste-water treatment plant on the east and west, respectfully, with steep terrain to the south; while the northern portion has been impacted by a variety of projects, including the construction of a marina along the river. Extant sections of the gravel alignments today cover about 13 hectares (34 acres), while the remnants suggest that it may have originally been very roughly 100+ hectares (247 acres) in size. The site was listed on the National Register of Historic Places (NRHP) in 1978, signaling its importance as a heritage resource.

Figure 9. Air photo of a portion of the southern section of the Topock Maze. (Google Earth; single-lane dirt road, lower left, for scale).

Figure 10. Ground view of SW area of Topock Maze showing intact desert pavement in foreground, parallel "maze" rows in center, and disturbed pipeline corridor towards middle right. (David S. Whitley; 3-ft high fence posts for scale at end of row).

Controversy over the origin and function of the site has long existed (see Haenszel 1978; Musser-Lopez 2011), however, despite its NRHP listing, with some contending that the site resulted from the collection of gravel for railroad track ballast. This argument has been putatively supported by an early article describing construction techniques for the 1893 Red Rock Bridge, which crosses the Colorado River at this location. This states in part that, for construction purposes:

> The process of gathering [gravel] was to rake these fragments of [surface] stone into windrows and haul them by wagon to a pile where convenient to load into a car when needed...Indian labor was used very successfully for this as well as for labor about the caisson (American Society of Civil Engineers 1891:692-693).

Ethnographic and archaeological evidence, in contrast, supports an Indigenous religious origin and use of the site that pre-dates the railroad and bridge. Edward S. Curtis, writing at the turn of the century for example, published an ethnographic account of the Topock Maze stating the following:

> The Mohave Indians near-by have utilized the area so marked, in recent years, as a maze into which to lure and escape evil spirits, for it is believed that by running in and out through one of the immense labyrinths one haunted with a dread may bewilder the spirits occasioning it, and thus elude them (1908:55).

It has been further reported that this ritual was specifically followed by warriors returning from travel outside of Mohave territory who were concerned with ensuring that they would not be contaminated by their exposure to foreign dangers manifest in ghostly spirits (Haenszel 1978).

The unpublished ethnographic notes of John Peabody Harrington (n.d.), also written early in the twentieth century, further support a Mohave origin for the site. Harrington's notes include an account of a discussion he had with Arthur Woodward, an early California archaeologist, about the site. According to Harrington, Woodward was aware that bridge construction had resulted in the creation of a gravel windrows on the Arizona side of the Colorado River, but Woodward was certain that the

much larger "maze" on the California side was Indigenous. Supporting this conclusion, Woodward noted that it originally included a large anthropomorphic intaglio, similar to the giant earth figures that are documented in numerous places along the river. What may be a small segment of this motif is still present at the site (Haenszel 1978). The intaglios depict mythic actors, were placed at the locations of mythic events, and were used in a ritual pilgrimage that celebrated the creation of the world (Whitley 2014), as described above.

Malcolm Rogers (1939) was the first archaeologist to publish information on the site, although his written discussion was brief. But his unpublished notes, written prior to 1939, concur with and elaborate on Woodward's observations to Harrington. Rogers states in part that:

> Early settlers claim that when the Santa Fe R.R. [originally the Atlantic and Pacific] was built (1893) several acres of the lower end were gathered up for ballast for the RR tracks and that a large shrine at the lower [i.e., northern] end on the River Trail was at the same time destroyed. This shrine contained potsherds and artifacts. In the assemblage was [sic] stone axes and some turquoise jewelry. The informant F.M. Kelley of Needles said that near the base toward the river there was previous to this a large intaglio human figure similar to those at [another site]. Mohaves in early days disclaim having built the maze and that it had always been there but that in the old days they used it for ceremonial purposes occasionally (Rogers n.d.).

Rogers' unpublished account suggests that, while the site is in fact Indigenous in origin, it was created in Precontact times, was used ritually, and a portion of it was destroyed for railroad track ballast. This reconciles the contrasting non-Indigenous versus Indigenous accounts of its origin.

Widespread public perception also has acknowledged the Indigenous origin of the Topock Maze from the turn of the century onward, pointing to its ritual importance. A Fred Harvey Company postcard (Figure 11) dating from the early 1900s, for example, is a painting of the site showing the gravel rows, a rock shrine, and two Native Americans with horses. These postcards were sold at restaurants ("Harvey Houses") at rail stations and thus were widely distributed across the west. Popular accounts, similarly, have associated it with the land of the dead and/or the Mohave mourning ceremony, though somewhat ambiguously (Haenszel 1978; Meloy 2003).
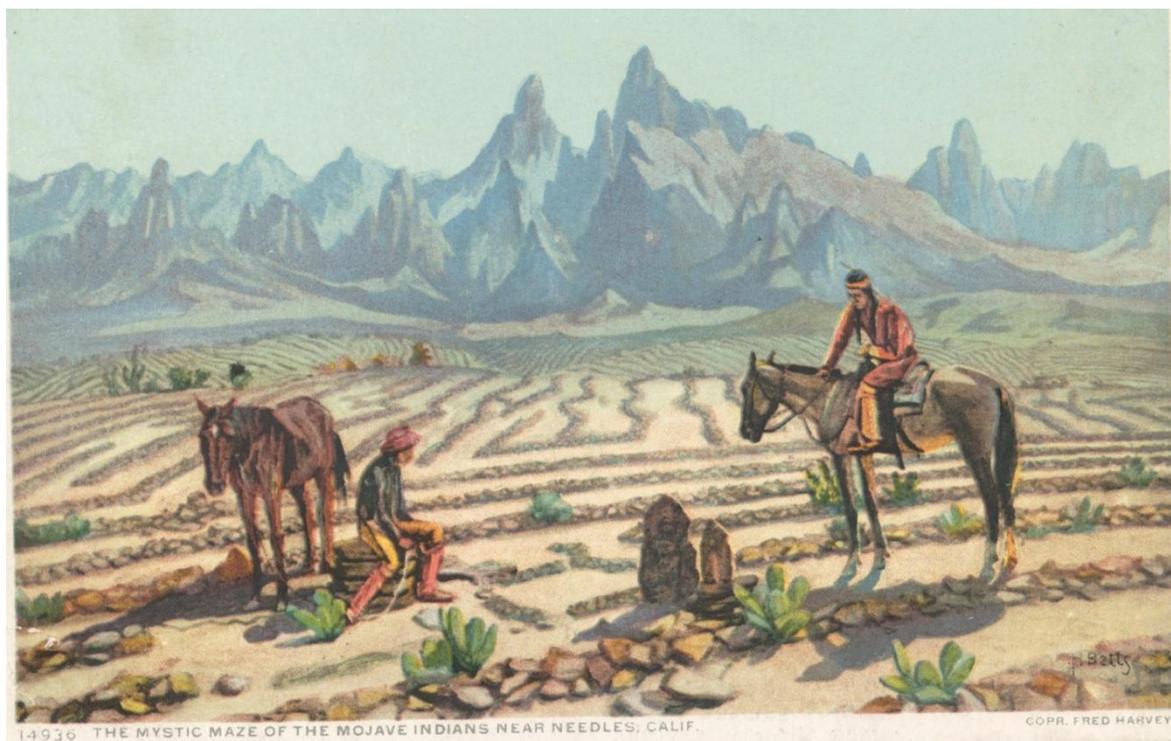

14936 THE MYSTIC MAZE OF THE MOJAVE INDIANS NEAR NEEDLES, CALIF.   COPR. FRED HARVEY.

Figure 11. Turn-of-the-century Fred Harvey Company picture postcard painting of Topock Maze showing shrine originally associated with this site.

A third interpretation of the origin of the Topock Maze developed during the 1970s when Robert F. Heizer and C. William Clewlow, Jr., mapped and sampled the site to test the hypothesis that it resulted from Indigenous farming practices (personal communication from Clewlow to Whitley, 1977). They took soil samples for pollen analysis and, finding none that could be the result of Indigenous farming practices, concluded that the site instead resulted from railroad gravel operations. Although they did not publish their study, Clewlow provided a useful summary included in Musser-Lopez's (2011) discussion of the site.

More recently, Musser-Lopez (2013) has revived the railroad track ballast hypothesis, in part by arguing that the gravel rows were created partly using horse-drawn Fresno or Buck scrapers. As is clear, this would require a recent—less than 150 years—age for the site. It would further discount the Indigenous knowledge that has supported a ritual use for the locale, including the rationale for recent tribal efforts to protect the site.

4.1. VML and Lead-Profile Dating of the Topock Maze

Ten cobbles were collected from within the cleared pathways between the cobble rows from the extant southern section of the Topock Maze, along with 3 control cobbles from an adjacent, unaltered desert pavement area. Four cobbles had varnish coatings with a VML sequence that started to form when microlamination WH2 (Wet Holocene 2) was deposited, about ~900-1100 cal yr BP, providing the oldest age estimate for the surface feature. The corresponding CR ages for these for cobbles are 1200±400; 1150±400; 950±400; and 850±350 cal yr BP.

The other six cobbles had younger VML and CR ages. It is instructive to provide here the range of younger ages for the Topock Maze, because they are all consistent with the finding that this feature is prehistoric. The microlamination sequence for five other cobbles started at the WH1c (Wet Holocene 1c) layer, deposited about 650 cal yr BP (Figure 12), while one cobble had a microlamination sequence falling between 650 and 900 cal yr BP. CR ages for the six other cobbles are: 700±350; 700±350; 700±350; 600±250; 550±250; and 400±250 cal yr BP.

Lead-profile dating was also employed, yielding findings that are consistent with the VML and CR ages in two ways. First, all ten cobbles had surface lead spikes with background levels of lead underneath, providing confirming that the Topock Maze is Precontact in age. Second, the lead values are measured every micron; this provides overlap in measurements, but it also gives a stratigraphic perspective on where the 20th century (high PbO values in Figure 12) spike ended in relationship to when the Little Ice Age ended, at about 300 cal yr BP (WH1a in Figure 12).
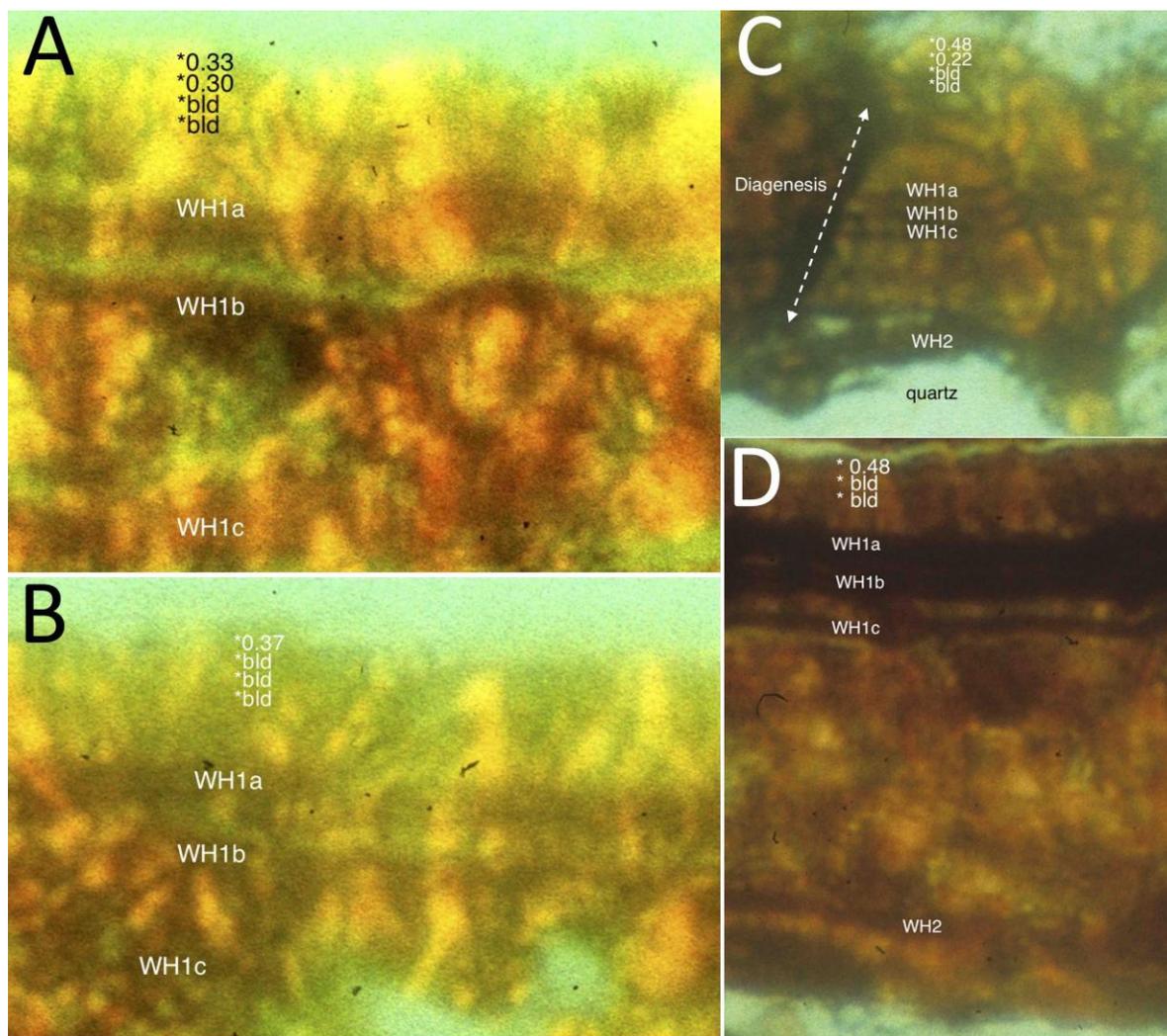
Figure 12. The oldest VML sequences on four cobbles collected from the Topock Maze. The distance between lead-profile analyses (asterisks) is 1 micron. BLD is 'below limit of detection,' demonstrating that Industrial Revolution surface spikes are underlain by background levels of lead. The area of "diagenesis" in image C shows an area of Mn-Fe leaching and reprecipitation. Varnish thicknesses range between 17 μm and 30 μm.

These results likely reflect one or more different possibilities that are not mutually exclusive: the process of upthrusting cobbles into the cleared paths was ongoing; younger results reflect a time lag in the revarnishing process; and/or cleared pathways were imperfectly maintained. This uncertainty demonstrates the importance of multiple samples for age determinations. We conclude, accordingly, that the Topock Maze is minimally about 900 years old.

The control natural pavement cobbles collected outside the Topock Maze had much older VML sequences that were late Pleistocene age. There was once exception (Figure 13). A cobble collected about 0.5 m from the maze showed an angular unconformity produced by varnish erosion followed by a new sequence of VML deposited on top of the eroded surface. The new varnishing started during WH6 (about 5900 cal yr BP). The cause of this unconformity is unknown although it is not due to wind abrasion. We speculate that it may be evidence of a mid-Holocene construction phase at this feature, and include this information partly to emphasize that our varnish ages are minimum-limiting dates.
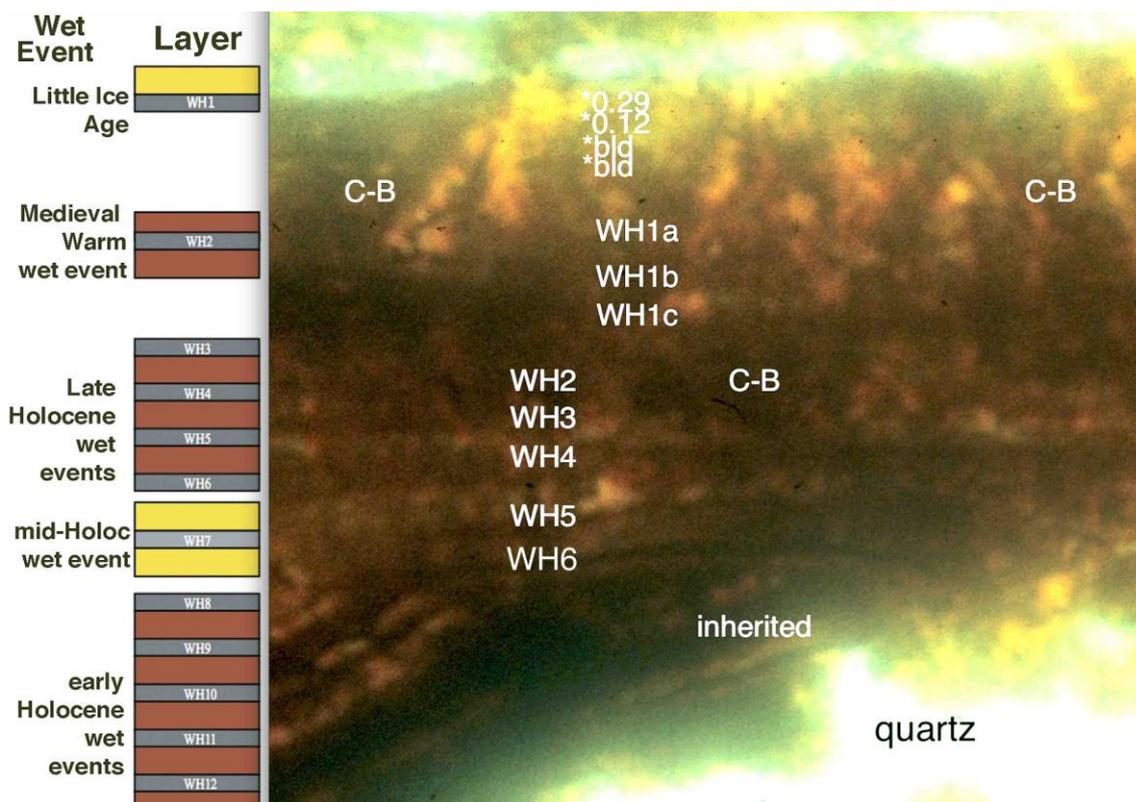
Figure 13. "Control" cobble collected outside the Topock Maze displays an angular unconformity where much older varnish ("inherited") is truncated via erosion. Then, the VML sequence starting with WH5 was deposited on the eroded varnish. C-B indicates the presence of cyanobacteria that dissolved varnish and then resulted in infilling of areas of disturbed laminations. Varnish thickness is 30 μm at the deepest. The Holocene VML calibration of Liu and Broecker (2007) is displayed for reference (WH1 occurs in this section as Little Ice Age Layers WH1a-c, because of the varnish accumulated fast enough to record these climatic events).

4.2. Function, Meaning and Symbolism of the Topock Maze

VML, CR, and lead-profile dating indicates that the Topock Maze is at least 900 years old, and thus represents a Precontact feature, not a recent railroad-related activity. It is important to emphasize, however, that the upthrust sampled cobbles from within the surface feature were exclusively derived from the extant portion of the site: a relatively small area at its southern extreme. The large majority of the site to the north has been destroyed, including an intaglio that was once associated with the gravel rows. As with the intaglios, discussed above, it is possible (if not likely) that this surface feature was ritually maintained over time, to prevent the regeneration of a complete pavement surface. It is also unlikely that the feature was created during a short period of time, given its large size, the labor required to create a construction this massive, and the small-scale society that occupied the river corridor in Precontact times.

We accordingly do not suggest that 900 years necessarily represents the maximum antiquity of this feature but instead that it is simply the currently identifiable minimum age of the southernmost section of the site. It is plausible if not likely that the northern destroyed sections of the feature were built at different times; perhaps much earlier. For example, the unconformity seen in the varnish in Figure 13, dating about 5900 cal yr BP, could potentially reflect construction activity, as noted above. This emphasizes again that our derived chronometric ages are minimum-limiting constraints and not necessarily estimates of the overall antiquity of this feature and its associated ritual practice.

But the Pre-Contact rock varnish age on and the cryptic ethnographic and popular descriptions of the Topock Maze provided above beg an important question: are there additional ethnographic data that support and augment our understanding of its symbolic meaning, ritual function and use?

Perhaps not surprisingly, there is in fact significant but heretofore overlooked evidence important to fully understanding this cultural landscape feature. They start with interviews obtained in the last few decades which support the earlier reported ethnographic accounts. But they also include information from older ethnographic studies about traditional fears of travel outside of Mohave territory and its association with ghosts, and thus the need to conduct rituals to nullify this 'foreign contamination.' And they further provide information, more generally, about the association of Topock with beliefs about the spirits of the dead and thus its symbolic importance as a religious place along the Colorado River.

Recent accounts provided by Mohave tribal members about the Topock Maze, first, have been summarized as follows:

> "interviewees suggested that stories or songs telling of its construction were present in the Mojave culture, but these stories are only told in some family lines and are not known by everyone … Other interviews in the 20th Century suggested that the Mojave would use the Maze to purify themselves by running through the Maze or by navigating through the Maze without walking over a windrow, leaving evil spirits or ghosts in the Maze, or that the purpose of the Maze is to help the deceased atone for their life before fully passing to the afterlife" (AECOM 2010:4.4-34).

This corroborates the earlier accounts claiming that the Topock Maze was used for ritual purification involving the shedding of ghosts obtained while travelling outside of Mohave lands.

According to Devereux (1961:129), second and helping to explain this perceived need, a "'xenophobia of fear' is a major theme in [traditional] Mohave culture," causing them to "refrain from all close contact with other tribes, and even more with intimate connections with alien races." Alien contamination illness, *ahwe : hahnok*, was in fact one of three categories of disease linked to ghosts (ibid: 21), and contact with foreigners was thought the chief cause of insanity (ibid: 32): "the Mohave experience one and the same type of dread in connections with aliens, magical powers, and the ghosts of the deceased" (ibid: 133). Their fear of aliens and thus ghosts was linked to their beliefs that "the soul of the dead person draws them to the land of the shadows" (Devereux 1937a: 411; our translation); that is, the Land of the Dead.

The paradox is that Mohave were great travelers and warriors, with trading, raiding and scalping all putatively exposing them to this contamination illness. Scalpers were especially subject to the "nefarious influence of scalps, prisoners and aliens," which resulted in fainting, hollering at night and more general aberrant behavior (ibid: 43). According to Fatheur:

> The scalper, being a shaman, has power over this disease and can cure people afflicted with it. The scalps … bring beneficial power to the tribe after they have been tamed. The scalper, then, contributes to tribal welfare by his power to tame the scalps and to cure the "enemy sickness." He also directs one of the most important Mohave ceremonies [the Mourning Ceremony]. Scalper is one of the most important religious statuses (1951b: 275).

A ritual, conducted by the scalper, or "Ghost Doctor," was then required to "tame" the scalps; that is, to nullify the dangerous power they otherwise contain and that results in alien contamination sickness. Subsequently:

> When the scalper returns with the war party he turns the scalps over to the *kwaxot*, or custodian of the scalps, who is the principal Mohave religious leader. The custodian of the scalps prepares a great celebration in honor of the returning warriors … After the feast the custodian of the scalps places them in large pottery ollas for safekeeping (ibid; cf. Kroeber 1925: 752).

The Mohave were also renowned for capturing girls and young women, but not men, on their raids. Because of these females' potential for introducing foreign illness, "a ceremony had to be made over them else they would bring sickness into the land; and even after purification they seem more generally not to have been married" (ibid). Fatheur notes however that:

> The female captives are given by the custodian of the scalps to some of the old men who need wives. Young men are afraid to take these women because of the 'enemy sickness' but the

old men are glad to have them since they have lived a long time and do not have long to live under any circumstances (1951b: 275; cf. Devereux 1961:42).

Mohave ethnography then supports the implications of this limited commentary on the ritual use of the Topock Maze in the sense that the Mohave considered themselves spiritually contaminated, by ghosts, while travelling outside their lands and from interactions with foreigners, despite the fact that this was a relatively common experience, especially for warriors conducting raids and for traders. It also demonstrates that specific rituals were conducted to prevent the ghost sickness that could result from certain of these activities. It follows that a ritual would be necessary to ensure good health after foreign travel more generally, and thus that the Topock Maze may have served that purpose, as suggested by the Curtis (1908) account.

There is, furthermore and third, important ethnographic evidence that explains the logic of the ritual use of the Topock Maze as a place to "lose" a foreign ghost after travelling outside of Mohave territory, based on its association with spirits and the Land of the Dead. Although there is minor variation (or confusion) in the specific geographical details, three different accounts all refer specifically to the Topock area. (Note that the general toponym 'Topock' strictly refers to a small, census-designated community in Arizona, immediately across the Colorado River from the 'maze' in California, possibly explaining the confusion). These start with the Bourke's early publication which stated:

"That other sharp, high mountain, down there near the Needles, in Arizona, was also a spirit mountain; that was where the Mojaves went when they died. (It was the Mojave Elysium)" (1889: 172).

Devereux augmented Bourke's account, despite some degree of uncertainty over the meaning of his informant's comments. He noted that:

The entrance to the "land of the dead" (*cilia'yt*) is somewhere near Needles, California, almost by the Colorado River on the Arizona side. There is something that looks like a big invisible "wash" containing a big invisible shed [i.e., ritual ramada] near a place called *Ahatcku-pi'lyk*, which is but a few feet [sic] from the land of the dead (1937b: 419).

The Mohave in fact held that the afterworld was at or near the confluence of the Colorado River and the Bill Williams Fork. It most likely was in the sandy Chemehuevi Valley on the western, California side of the Colorado across from the confluence of the two rivers, roughly 20 miles southwest of Topock, with its name various transcribed as *cilia'yt* (ibid.), *calya: at* (Devereux 1961: 146), *sil'aid* (Wallace 1947: 256), *salya:yt* (Steward 1973:316); and *saly'at*, "the Happy Hunting Ground," from *selye'aya*, 'sand' (Munro et al. 1992:160; cf. Kroeber 1948), although some instead claimed that it was under the Colorado River or in sand dunes on the Arizona side of the river (see Bourke 1889: 174; Harrington 1910: 333; Kroeber 1902: 280, 1925: 727; Devereux 1935: 114, 1861: 146; Drucker 1941: 148; Laird 1976: 134). Regardless, Fatheur clarified the earlier comments, observing that:

"Following cremation, the soul remained near the site of the [funeral] pyre four days. At the end of this time the soul changed into a ghost which was then able to see the road to the afterworld. *This started at Topock and ran south into the desert in the neighborhood of the Bill Williams River*" (1951a: 605; emphasis added).

Fatheur's account is confirmed by recent ethnographic data which state that "The Topock Maze … is the passageway to the next dimension, to the land of those who have passed on" (BLM 2012: 50). The Topock Maze locale was then a portal comprising the start of the trail to the land of the dead which, following widespread Yuman-speakers' belief, ran to the south. Regardless of the exact location of the afterworld, the Topock Maze was the place from which ghosts departed towards that destination and was, symbolically then, the entrance to the Land of the Dead. It was thus the appropriate location for a ritual intended to send off ghosts to a location where they would be harmless to living people.

But that the maze was the start of the path to the Land of the Dead suggests a potential additional ceremonial use of this locale, beyond its employment by those returning to their home needing ritual purification. This is implied by a comment by Devereux who stated that: "when a man dies his relatives often request a shaman to visit the land of the dead to check up if he reached it" (1937b: 419):

> "When rumors spread that a person has died as a result of evil practices, the members of their family send a bona fide sorcerer to visit the land of the dead to see if the deceased's soul has arrived there. If the messenger does not encounter this soul, it is ipso facto proof that the soul is being held captive somewhere by the sorcerer" (Devereux 1937a: 410).

Sometimes a shaman would even transport an individual to this ghostly realm to visit the deceased:

> The ghost doctor also could take people to the spirit world, although he did not encourage this because it was dangerous. He warned the person who wished to see a dead relative: 'Be careful. If our hands slip apart, I'll have to look for you all night. If I don't find you before morning we will both be stuck here.' The shaman and the person who was to accompany him dressed in their best clothes and painted themselves. About twilight they built a small brush shelter and then lay down to sleep with their hands clasped. In less than an hour they were transported to the afterworld. The ghost doctor knew exactly where the person's family was, so they went directly there (Fatheur 1951a: 605)

It is possible, although far from certain, that these rituals to enter the Land of the Dead occurred at the Topock Maze location.

There is, finally, one other implication of the Topock Maze that warrants brief mention. This concerns the implications of its original size of roughly 250 acres. This surface feature is, by any measure, a monumental construction, a trait not previously thought associated with the small-scale, low population density horticultural societies like the Mohave. It seems unlikely that a surface architectural feature of this size could have been created in a single episode, given these constraints. The most likely scenario would be its construction over multiple generations, perhaps with additions to its size occurring whenever it was used ritually, much as male puberty initiates were tasked with maintaining the Trail of Dreams used in their ritual run noted above. The angular unconformity evident in the varnish coating of a control cobble (**Figure 13)** would be consistent with ongoing construction over a much longer period of time, with the varnish erosion event occurring at WH6 or 5900 cal yr BP.

5. Age and Origin of Cleared Circles in Desert Pavements

Cleared circles in desert pavements have long been reported in the North American desert west (Rogers 1939; Breternitz 1957; Davis and Winslow 1965; Hayden 1976; Shaefer 1994; Ahlstrom and Roberts 2001; Hartmann and Thurtle 2001; Altschul 2005). Despite their prevalence, there has been controversy over their origin (Whallen 1976; Tuohy 1984; Bendimez et al. 1986; Caldwell et al. 2011; McDonald et al. 2011). Early California archaeologist Malcolm Rogers (1939, 1966), for example, claimed that they are cultural in origin. He viewed them as "sleeping circles," an interpretation which has been accepted by many subsequent archaeologists (e.g., Dosh and Marmaduke 1992; Marmaduke and Dosh 1994; Schaeffer 2018). Others, primarily natural scientists, however, have argued that they result from a variety of natural processes (e.g. Stone and Dobbins 1982; McDonald et al. 2004; Caldwell et al. 2011) such as bioturbation (Viles et al. 2021; Walsh et al. 2023) and/or plant die-offs during extended droughts (cf. McDonald et al. 2004b, p. 69; McAuliffe and McDonald 2006). Elephants and other animals produce shallow wallows (Butler, 1995), for example, while ants (Hölldobler and Wilson, 1990) and termites (De Bruyn and Conacher, 1990) also can create bare circles. The Namibian grassland "fairy circles" are argued to result from the self-organization of large-scale vegetation (Tschinkel, 2015), while stony circles in the Namibian Desert may be caused by fossil rodent activity (McAuliffe et al., 2024). The Libyan Plateau of Egypt contains accretionary desert pavements (Adelsberger and Smith, 2009) with circular depressions several meters in diameter that are likely due to bioturbation (Adelsberger et al., 2013). Similar 1.5 – 3.0 meter cleared circles in the lower Sonoran Desert pavements have been interpreted as the product of rodent activity around perennial shrubs (Hayden, 1976), followed by die-offs of these plants, such as creosote bush (*Larrea tridentata*) during long droughts (McAuliffe and Hamerlynck, 2010; McAuliffe, 2019).

It is important here to define what we mean by 'cleared circles', given that there are a variety of circular surface features commonly found in desert pavements. We refer specifically to approximately circular areas that are cleared of all or almost all pebbles and cobbles; are roughly less than five meters in diameter; that lack encompassing 'house rings' or encircling walls that would require obvious human agency to create; and that have very few or, more commonly, no associated artifacts. Our definition thus excludes both obvious humanly-made constructions, such as walled brush hut foundations, and very large cleared areas that may be several hundred feet in diameter and which have been identified ethnographically as dance circles (Bourke 1889; Johnson 1985).

It is also useful here to clarify any potential confusions about the most common characteristics that would result from the creation of a plant scar versus a human origin for cleared circles. Rodents, ants, reptiles and other animals target plants in desert pavements for the locations of their burrows. In combination with rooting structures, this bioturbation contributes to the upward and downward movement of surface rocks in a soil (Caldwell et al. 2011). With the loss of the plant, a surface cleared of varnished clasts would be created by this process, not from plant-brushing caused by the wind (as archaeologists sometimes assume). The surface morphology of the resulting cleared circles then exhibit:

> "time-dependent changes following [the] disappearance of the large plants and eventual cessation of bioturbation. Plant scar mounds represent a geologically recent episode of plant mortality, whereas plant scar depressions represent the disappearance of plants at a considerably earlier time" (McAuliffe and McDonald 2006, p. 204).

We emphasize a few important characteristics of cleared circles resulting from bioturbation. First, no accumulation of clasts along the edge of a cleared circle then would result from a natural origin for the plant scar feature whereas just such concentration would be expected in a human origin, with the surface rocks intentionally swept or moved away from the middle. Second, the bioturbation process brings rocks both up and down; this also brings up lots of fines, both silt and sand, and the rocks that are bioturbated also lose any prior rock varnish and often gain pedogenic carbonate. The resulting appearance of an active bioturbation area is a cleared, circular surface consisting of fines and unvarnished cobbles. It is when the plant dies that the bioturbation ends, the pavement begins to reform, and rock varnish starts to accumulate on exposed cobbles.

Ethnographic evidence indicates that Native Americans use these surface features for prayer and vision quests and they are thus understood as sacred in nature (Forde 1931; Stoffle et al. 2011; Wright and Meren 2016; Whitley et al. 2025); that is, while they may be natural in origin they still are used for cultural purposes (Bullard et al. 2012). As McDonald and McCarthy (1998) note, their occasional association with petroglyph sites further supports such a religious function, while the number and density of cleared circles in different geomorphic settings also suggest a natural origin for at least some of them (Whitley et al. 2025).

The age of these surface features has also been a topic of significant concern. Rogers (1966), favoring a cultural origin, argued that cleared circles date to the San Dieguito complex, during the Terminal Pleistocene/Early Holocene transition. McAuliffe and McDonald (2006), supporting the natural-origin perspective, suggested a similar age, based on speculations about the speed of revarnishing (Bull 1991; McDonald et al. 2004b). Alternatively, a variety of observers note that the pavements can regenerate in such small areas in a much shorter period (cf. von Werlhof et al. 1995; Ahlstrom and Roberts 2001; Haff and Werner 1996; Pewe 1978; Dietze and Kleber 2012), as discussed above, implying that cleared circles may only be a few thousand years or less in age (Whitley et al. 2025).

Despite the potential interplay of natural processes creating these features versus cultural perceptions of their origin and use, their age is still undetermined. Yet there are some potentially important problems related to the age of these enigmatic features, not least being a determination of their origin. If they are a by-product of a widespread vegetation die-off, as would be signaled by all or most of them dating to the same time period, they may document significant paleoclimatic and paleobotanical changes. As noted by Bullard et al.: "the age and distribution of these features may

hold important information about changing environmental conditions and may record long-term trends in regional climate, which comprise important data for interpreting human occupation of the area" (2012, p. 27). Given that large cleared circle fields in at least some cases are locationally associated with major petroglyph sites (Whitley et al. 2025), on the other hand, coterminous ages for a series of the circles could signal a period of ritual intensification, especially if that time period does not otherwise correlate with drought episodes documented by existing paleoclimatic reconstructions. Alternatively, a wide age distribution could suggest a cultural origin and continuity in ritual practices over time, as well as implying a cultural rather than natural origin for these pavement features resulting from a temporally uncoordinated process involving individual acts over an extended period.

5.1. Varnish Dating of Cleared Circles

We used VML and lead-profile dating to determine the age of varnish that has formed on upthrust cobbles within a sample of cleared circles. McDonald et al. (2004b) observed that plant scars in the Lower Sonoran Desert, our study area, are limited to locations with an average annual precipitation of 150 mm or less. The region is then historically so dry that an extended drought could readily push it to the threshold needed for some desert scrub plants to die off, such as creosote bush (*Larrea tridentata*) or white bursage (*Ambrosia dumosa*). This in turn would make it less likely to misinterpret cultural versus drought-based origins for these surface features.

We employed a stratified-random sampling procedure to select 16 cleared circles along the Gila and Colorado rivers, in areas known to have high concentrations of these features. Ten cobbles were collected from each of the 16 reformed pavements for VML dating. The typical cobble size had a diameter of about 5 cm. All collected clasts had small, millimeter-scale pieces of pedogenic carbonate, indicative of a former subsurface position prior to pavement reformation (Springer, 1958; McAuliffe and McDonald, 2006; Haff, 2014). Cobbles from the surrounding natural desert pavement were also collected and analyzed as controls.

Figure 14 illustrates our application of the VML method, where a cobble in a cleared circle has a VML stratigraphy that shows the three WH1 microlaminations formed between 300 and 650 cal yr BP and an orange varnish layer that is older than WH1 but not as old as WH2, indicating that this cleared circle dates between 650 and 900 cal yr BP.
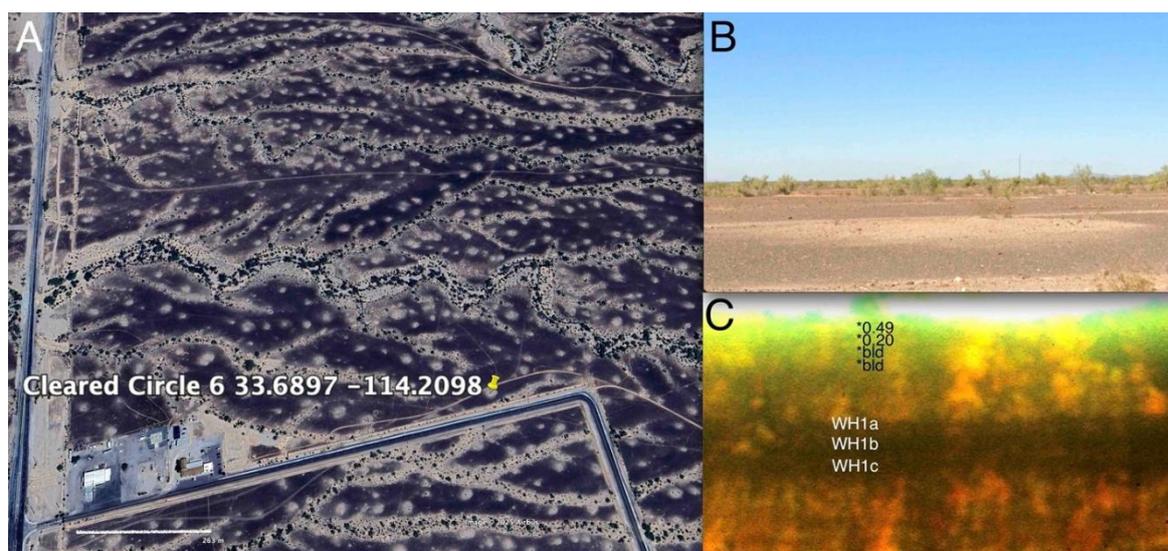

Figure 14. On the north end of Quartzsite, Arizona, desert pavement contains a high density of cleared circles. Circle #6 (Table 2) is shown here. (A) Google Earth image with 2-lane roads and a 200 m bar for scale. (B) 3-4 m diameter cleared circle sampled for VML. (C) Ultrathin section of rock varnish that is about 20 μm thick, displaying a VML sequence of the late Medieval Warm Period underneath the Little Ice Age (WH1a, b, c).

Electron microprobe measurements of lead (PbO) reveal the 20th century spike in lead with natural background levels ("bld" – below level of detection) underneath.

Table 2 presents the results for the 16 randomly selected cleared circles. While our VML dates on 16 cleared circles are minimum-limiting ages, they all fall within Medieval Warm Period (650 – 1100 cal yrs BP; Cook et al., 2004; Jimenez-Moreno et al., 2021). Ten of the 16 had lowest laminations falling between WH1 and WH2 at their bases, corresponding to an age between 650 and 900 cal yr BP. Five had the WH2 basal layer deposited about 900-1100 cal yr BP. One had a basal VML falling between WH2 and WH3, corresponding to 1100 to 1400 cal yr BP. Lead-profile dating was also completed on eight of the cleared circles. In each case, lead concentrations dropped to background levels beneath the top few microns of contaminated varnish, verifying pre-20th century ages for the initiation of varnish formation – and also providing an independent check on the VML assignments.

Table 2. Minimum VML ages for randomly selected cleared circles in the lower Sonoran Desert.

No.	Coordinates	Lead Profile	VML Sequence	Age (cal years BP)
1	33.8261 -114.0570	pre-20th Cent	WH1-WH2	650 - 900
2	33.1261 -114.2908	pre-20th Cent	WH1-WH2	650 - 900
3	32.9698 -114.2845	pre-20th Cent	WH1-WH2	650 - 900
4	32.6897 -114.2098	pre-20th Cent	WH1-WH2	650 - 900
5	32.8656 -114.3477	pre-20th Cent	WH1-WH2	650 - 900
6	33.6897 -114.2098	pre-20th Cent	WH1-WH2	650 - 900
7	33.6693 -113.9893	pre-20th Cent	WH2	900-1100
8	32.9852 -112.9911	pre-20th Cent	WH1-WH2	650 - 900
9	33.0285 -113.1485	n/a	WH2	900-1100
10	33.0449 -113.4311	n/a	WH1-WH2	650 - 900
11	32.9596 -113.5975	n/a	WH1-WH2	650 - 900
12	32.9041 -113.6529	n/a	WH1-WH2	650 - 900
13	32.8881 -113.6857	n/a	WH2	900-1100
14	32.8481 -113.8429	n/a	WH2	900-1100
15	32.7940 -114.0436	n/a	WH2-WH3	1100-1400
16	32.6267 -114.3696	n/a	WH1-WH2	650 - 900

5.2. Natural Versus Cultural Origins of Cleared Circles

Our 16 sampled cleared circles all date to a relatively restricted time frame extending from about 900 to 1100 cal yrs BP. As noted above, this corresponds to the Medieval Warm Period occurring between 650 and 1100 cal yr BP. Although there is debate about whether this was a global versus regional phenomenon (e.g., Hughes and Diaz 1994; Broecker 2001; Wangh et al. 2023; Zorita et a al. 2024), there is a consensus that, in the North American desert west (Cook et al., 2004; Jimenez-Moreno et al., 2021), it was a period of environmental stress marked by multi-decadal droughts which resulted in substantial disruptions in the archaeological record (e.g., Jones et al. 1999; Gardner 2006; Jones and Schwitalla 2008).

Given our results, a natural origin resulting from drought and plant die-offs is the most likely explanation for many if not most of these cleared circle features, as suggested by prior researchers (e.g., McAuliffe and McDonald, 2006; McAuliffe and Hamerlynck, 2010). This is consistent with the limited temporal distribution of our randomly sampled examples, the correlation between their chronometric ages and the well-established regional paleoclimatic reconstruction, the complete or near-complete absence of surface artifacts associated with them, as well as their massive numbers and extensive distribution at certain locations.

We emphasize that it is not possible to preclude the possibility that other cleared circles may be different in age, nor that some may also have been humanly created and/or ritually employed. Our

results are simply that some, perhaps most, cleared circles appear to have had a natural origin resulting from climate change during a restricted time period.

Many cleared circles then represent a heretofore unrecognized paleoclimatic indicator, in this case reflecting the localized effects of climate change that result from the interplay of shifts in annual rainfall and area-specific soil properties (cf. Sponsellar et al. 2012). It is most likely that these features were the by-products of creosote brush (*Larrea tridentata*) die-offs, since this has been the dominant shrub in this portion of the desert west since about the Middle Holocene. Creosote itself was not a significant food source for Native Americans. It was primarily used for medicinal purposes and to obtain a resinous mastic/sealant (cf. Sutton 1990), perhaps suggesting that the loss of creosote fields had minimal impacts on local Indigenous lifeways. These shrubs however are recognized as 'islands of fertility' that foster the lives of not only a wide array of animals but also a variety of annual plants (Thompson et al. 2005; Schafer et al. 2012). The loss of these creosote fields, as a result, would impoverish the flora and fauna in a localized area and thus potentially impact the carrying capacity of these locales with respect to human occupation in ways that may not otherwise be immediately apparent.

The conclusion that extensive fields of cleared circles are natural however needs to be matched against Native American statements that they are prayer or vision quest circles. As noted above, Bullard et al. (2012) first observed that there was no necessary contradiction between the possibility that the circles had natural causes even while having cultural uses. Notably in this regard, while Indigenous statements that the circles had religious uses are common, these are assertions about their use, not their origin. None of these same accounts to our knowledge claim that the circles were humanly created, and a difference between human versus natural origin would in fact be metaphysically irrelevant in Native American terms. This results because the actions of ritual officiants and spirits with regard to religious matters were ontologically equivalent (cf. Applegate 1978; Gayton 1948; Laird 1984; Siskin 1983). Ritual "re-use" based on the (false) assumption that they had been created by a previous ritual supplicant, or by a spirit, is a reasonable inference explaining this circumstance.

Importantly, ethnographic data indicate that visible evidence of previous ritual activities on the landscape promotes subsequent religious uses of the same locale (Whitley et al. 2025). For example: When ceremony or power seeking is successful at such places, they are selectively marked so future human visitors can more fully understand the purpose of the place. (Stoffle et al. 2011, p. 11)

> The logic was simple—if knowledge resides in powerful places, then let us return to those places where we can recapture it. (Carroll et al. 2004, p. 141)

This evidence would include obvious ritual features, like rock art, but also things like ritual offerings, cairns and, of course, cleared circles. The presence of these circles, thought to result from prior ritual use even if in fact natural in origin, would then have contributed to the perception of these places as sacred, helping to perpetuate continued ceremonial use of these features and the specific locales where they are found.

6.0. Conclusions

The use of three rock varnish dating techniques has allowed us to resolve three longstanding controversies concerning surface features on desert pavements in the North American desert west. The Topock Maze, first, has long been a source of popular fascination and professional debate. Some have argued that it is a by-product of late nineteenth century railroad construction while others, including the Mohave tribe, have contended that it is both Indigenous in origin and that it was used for ritual purposes. Our chronometric ages indicate that the extant portion of this large construction, originally roughly 250 acres in size, is at least 900 years old. Other, now destroyed, sections could have been older or younger. Our review of pertinent ethnographic data, furthermore, indicates that it was believed to represent the start of the path towards to Land of the Dead, hence it was understandably associated with ghosts and spirits, and is correspondingly a place of great religious importance.

The intaglios along the lower Colorado River represent another example of ritual activity in this region. Rock varnish dates on these extend back to 5900 years B.P., demonstrating the existence of a lengthy religious tradition and artistic practice. Although there is rarely a perfect correlation between culture, language and physical/biological type, we believe the mid-Holocene age of these geoglyphs may signal the presence of Yuman-speaking peoples in this area by that early date. This in turn would suggest that existing archaeological models and linguistic reconstructions arguing for a much more recent Yuman-speakers arrival are wrong. Instead, our evidence supports other reconstructions suggesting that the lower Colorado River and southernmost California region may have been the original homeland of these peoples.

The nature and age of cleared circles, which are common in western desert pavements, were our final concern. These have been argued to be either natural in origin, resulting from plant die-offs, or cultural constructions used for prayer and vision questing. In a random sampling of cleared circles around the Gila and lower Colorado Rivers, ages of these features all cluster in a relatively narrow time range with minimum ages extending from about 650 to 1100 years BP. This corresponds to the Medieval Warm Period, a time of extensive droughts along with a series of disruptions evident in the archaeological record. Although there undoubtedly will be cleared circles that prove to be older and younger, as well as examples that were humanly made, many if not most of these features appear to be natural in origin. Despite this fact, they are perceived by, and have been used by, Native Americans for religious purposes. It is then not surprising that fields of cleared circles are often locationally associated with other kinds of ritual remains, including especially petroglyph sites. This circumstance points to the interplay between sacred locations and what we consider, in contemporary Western terms, as natural landscape features. But no such binary ontological distinction existed in Native America, for whom the so-called natural world was equally charged with sacred implications and potential uses (Whitley m20245; Whitley et al. 2025). We recommend that for heritage management purposes, accordingly, cleared circles be treated as important cultural resources due to their continued religious significance to and use by Native Americans.

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