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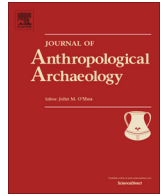Lipo, Carl P

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A tale of two technologies: Prehistoric diffusion of pottery innovations among hunter-gatherers

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ABSTRACT

We examine the diffusion of a successful and an unsuccessful innovation among hunter-gatherers in the western Great Basin, using a diffusion of innovation model. Modern and historical studies on the diffusion of innovations suggest that diffusion processes follow S-shaped curves, with small numbers of early adopters, followed by more rapid uptick in the rate of diffusion as the majority adopt a technology, concluding again with small numbers of late-adopting laggards. Distributions of luminescence dates on surface-collected pottery sherds show that the technology had a long period of experimentation. Beginning about AD 1000, direct-rimmed pots were introduced in Southern Owens Valley and were used in small numbers over hundreds of years. Likewise, around AD 1350 pots with recurved rims were introduced in Death Valley and were also used in small numbers. Around AD 1550 the direct-rimmed technology diffused to the east, to China Lake and Death Valley, where it was rapidly adopted. By contrast, recurved-rim technologies were abandoned, a failed innovation. Our data suggest that prehistoric pottery diffusions follow a similar S-shaped curve, but that diffusion among hunter-gatherers happens at a much slower rate, over centuries instead of decades.

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Introduction

One of the key components of human technology is information, and the means by which such information spreads among potential users. Anthropologists, especially archaeologists, have long made variation in technology a major focus of research. The archaeological record documents a remarkable and diverse range of technologies over time and across space. It is clear that technology, much more so than human biology, has been the major force in the spread of humans across the globe, promoting occupation of even the harshest of arctic, desert, and high altitude environments.

One long-standing pursuit of archaeologists is the identification of the oldest instance of a particular technology (e.g., Kuttruff et al., 1998; Pinhasi et al., 2010) since it is assumed that these events mark important inventions in human evolution (e.g., oldest fire, oldest tools) and their recognition contributes to national pride (e.g., oldest noodle). However, documenting the oldest often erroneously treats technological innovation as a single instance of human ingenuity (i.e., the "solitary genius"), rather than placing technology in a broader evolutionary context. A similar argument can be made regarding the youngest, or last, instance of a

technology (i.e., its extinction). As Basalla (1988) has argued, changes in technology are contingent since technological innovation continually borrows ideas and materials from other domains. The evolution of technologies, then, focuses on issues such as the technological environment and context of innovation, recombination and inheritance, the production and winnowing of technological variation, and rates of technological change (Henrich, 2001).

Such an approach is common among scholars of contemporary technology and it is not unusual to find ideas from the diffusion of innovation integrated into research (e.g., Hargadon, 2003; Henrich, 2001, 2009; Kameda and Nakanishi, 2002; Mesoudi and Whiten, 2008; Moore, 1991; Rogers, 2003; Wejnert, 2002). Archaeology, in contrast, has labored in isolation with its own limited and idiosyncratic language (e.g., Sackett, 1986; Schiffer, 2002, 2005a, 2005b, 2008). Due to its general common-sense based treatment of technology, the diffusion of this body of scholarship into archaeological research has been slow, despite the suitability of archaeological data for contributing to hypothesis testing and theory building.

Diffusion of innovations

Research on the diffusion of technologies in contemporary and historical settings suggests that technologies are adopted within

communities in a predictable manner (Rogers, 2003). A community, here, refers to a set of individuals who regularly interact with one another. It is assumed that the members of a community acquire traits with a distribution of probabilities. Individuals who are never exposed to a technology have zero chance of adopting it (unless they independently invent it, see below), while increasing exposure increases the probability of adoption. The absolute probability for any individual is related to a host of factors discussed further below. As a result, individuals of a community rarely adopt new technologies in a simultaneous fashion (Moore, 1991; Rogers, 2003). Instead, technological change occurs over a period of time by individuals with different goals and needs.

Although individuals within a community may be aware of and exposed to a new technology at the same time, some are more apt to try it out. A fraction of those may then decide to adopt the technology, either adding it to the suite of items they already use or replacing an existing technology with the new one. Such individuals are often termed "early adopters" or "innovators" (Rogers, 2003). Ethnographic studies characterize early adopters as venturous (i.e., not risk averse) and readily able to integrate novel and/or complex technical knowledge (Moore, 1991). These early adopters and innovators also play an important role in the subsequent spread of a technology within a community.

Others within the community, the "majority," only acquire traits from adopters in a secondary fashion. Although these individuals delay potential benefits of adopting a new technology, they also minimize risk by viewing the success and failure of early adopters. Observing early adopters using a new technology provides additional information regarding social and economic impacts of new technology, thus reducing the costs of trial-and-error use. Finally, some individuals within a community, "laggards," will only reluctantly, or never, adopt a new technology, preferring long-standing solutions to meet their technological needs. These individuals are often suspicious of innovation and change agents and have a strong connection to traditional means. Typically, they are unable to buffer against the possible risks of failure if they were to adopt a new technology (e.g., Martinez et al., 1998; Uhl et al., 1970; though see Goldenberg and Oreg, 2007 for a different interpretation of laggards).

Any single community is composed of a mixed population of attitudes towards innovation adoption at any point in time. The combination of innovators, early adopters, majority, and laggards within a community helps explain the way a technology changes and diffuses, but this structure is a dependent value and does not "cause" an adoption pattern *per se*. Thus, with time arrayed on the x-axis and the cumulative number of adopters on the y-axis, we can generate an "adoption curve" for a given technology in a community, generating a characteristic logistic or S-shaped distribution of values over time. The slope of the curve varies as a function of cost and performance of the technology relative to the structure of the local environment and communities. The steeper the leading edge of the slope, the more rapidly that diffusion took place. While the speed at which a technology is adopted has been shown to vary (e.g., Fischer et al., 1996; Mansfield, 1961) the basic shape of the adoption curve has been replicated in study after study (Brown and Cox, 1971; see also examples in Rogers, 2003). Indeed, the regularity of this finding in modern and historical studies has led some to suggest that this basic process explains configuration of *all* diffusions of innovation (Mahajan and Peterson, 1985:8).

Determinants for the speed of diffusion can be divided into three broad dimensions. The first dimension is composed of the properties of the technology relative to alternatives. These properties include its relative performance advantage, cost, indirect benefits (economic, or convenience), compatibility (especially with values of a community and other existing technologies),

complexity (highly complex technologies are less likely to be adopted), trialability, rate of beneficial returns (the faster the perceived return, the more likely a technology will be adopted), and observability (technologies that are easier to observe are more quickly adopted). The second dimension relates to the social and technological environment in which the technology interacts. This dimension includes how well an existing, competing technology is embedded within and/or interdependent with other parts of culture (the greater the number of interdependencies the lower the probability of adoption of a new technology) and the structure of the community, that is, whether individuals are alike (homophilous) or different (heterophilous) in their language and morals (more alike increases the probability). The third dimension concerns transmission of information within a community. This includes how individuals learn about a new technology (mode of communication; e.g., mass media vs. interpersonal, the former accelerating the rate of adoption) and how isolated a community and individuals within a community are from potential outside sources of innovation (communities on islands are often slower to adopt).

Together these dimensions explain why communities see rapid adoption of some technologies (e.g., mobile phone), while others have been slow to diffuse (e.g., electric vehicles), require state-level mandates (e.g., seat belts), or are not adopted at all (e.g., DVORAK keyboards) despite being generally perceived as "good" or "advantageous." Indeed, even "bad" or "useless" technologies, such as pet rocks, cigarette smoking, and the Windows operating system can be adopted by a majority of individuals within a community when costs are either negligible or difficult to assess over the lifetime of any individual, or are dependent on part of a contingent technological ecosystem.

Archaeological applications of diffusion of innovations research

Archaeological data are unlike historic and modern studies on the diffusion of innovations in two main ways. First, while archaeologists try to date artifacts as best as they can, the temporal resolution of most dating techniques, including luminescence dating of pot sherds used below, is at an altogether different scale than modern studies. For example, luminescence dates are associated with the measurement of events with a precision of roughly 10% of the absolute value in years. Thus, even in late prehistory, archaeological events have a degree of uncertainty measured in decades (for example, our average below is ±25.9 years, ranging between 8 and 160 years, for 167 luminescence dates). By contrast, modern ethnographic studies regarding the diffusion of modern innovations have error terms on the scale of months or weeks.

On the one hand, this difference may seem to put measurements of the archaeological record beyond the scale at which we can examine the diffusion of a technology. With such an uncertainty it is difficult to isolate individual events of technology adoption. In contemporary studies one may observe examples of technology diffusing through a community, often in a decade or less. Such examples suggest that archaeological descriptions may not provide good material for the study of prehistoric diffusions: our archaeological data may be at such a coarse scale that we cannot effectively observe and track a diffusion event. If so, a diffusion event will appear as a flash, with little evidence for "innovators," "early adopters," "laggards," and the like.

On the other hand, there is reason to believe that prehistoric diffusions occurred over longer periods of time. In the historic and modern cases, mass communication (e.g., radio, television), rapid transportation (e.g., automobiles, trains), and a greater degree of interconnectedness of people within communities rapidly spread information and knowledge about a technology over

a large spatial area. Moreover, corporate capitalistic goals, where manufacturing companies are encouraged by profit to spread their technology within as many communities as possible (using advertising and other means), also accelerate diffusion curves. The scale of populations who share language also contributes to more rapid technology changes in the contemporary world. Thus, diffusions in historic and modern settings are typically within more homophilous populations where people speak a single language and share similar cultural values. For example, a common cultural value of using technology to reduce time spent cleaning houses or increasing profit margins has been shown to increase the rate of diffusion (Rogers, 2003).

By contrast, in small-scale prehistoric settings such corporate capitalistic goals are minimal to non-existent. Communities were often more isolated from one another and interactions between communities were often limited to special events (e.g., marriage, feasts, religious ceremonies). Transmission of information about technologies was also limited to oral and personal (one-to-one) settings, such as parental training and/or apprenticeships. With transmission occurring between limited sets of individuals and primarily between generations, the rate of adoption of technology was necessarily slower and more limited than what we see today.

Furthermore, in many archaeological studies, the community under investigation is formed based artifact similarity, not necessarily cultural similarity, and we have no control over ethnicity. As a result, we are more likely to sample across what represent different language, religious, and cultural communities. As discussed above, such heterophilous conditions will slow the apparent rate of diffusion of innovations.

The second difference between archaeological data and historical/modern data concerns non-adopters of a technology. In ethnographic cases, it is often possible to observe which members in a community did *not* adopt a technology (and subsequently to ask them why they did not do so, though see Abrahamson, 1991 for a critique even in modern settings). In archaeological data sets such as this one, we can only examine the timing and archaeological context of people who *did* adopt a particular technology. By dating only pot sherds, as in this study, the people who did not adopt pottery are not represented. Thus, measuring relative adoption within a population is often not possible. Schiffer's (1987: 356) observation that the absence of archaeological evidence is not always evidence of absence clearly applies in this setting.

In order to address issues of comparability and visibility in the study of technology diffusion in our present study we make three main assumptions. First, we assume that our physical collections of ceramic sherds represent unbiased samples of sherds across time. That is, we assume our sample is not disproportionately represented by materials from particular windows of time because they are more visible archaeologically or because they preserve better. Given that our sample is primarily from surface surveys, that pottery is a durable material, and sediment deposition is low in these desert environments, we believe our samples are diachronically representative of pottery production and use.

Second, we assume that the number of sherds deposited on the landscape in a given window of time is directly proportional to the number of people using pottery technologies. In other words, we assume that the average number of pots used by an individual or a family group was roughly constant over time. In this way, increasing numbers of sherds over time represents either increasing populations (see below) or an increasing frequency of individuals using pottery technologies, rather than a small number of families ramping up the scale of vessel production. We believe that our sampling strategy minimizes the potential of this factor to skew our results because, first, we tended to sample widely from different sites or site component (i.e., one or two sherds per site or house depression), rather than intensively from certain sites.

Different sites or site components will *tend* to reflect the behavior of different family groups. Second, there is no evidence that the physical form or composition of a vessel led disproportionately to more or less numbers of sherds present in the archaeological record (i.e., certain pot forms are more brittle and break into more sherds).

Third, we assume that population levels were relatively constant through time (at least during the ceramic period), such that increases or decreases in the absolute number of sherds reflect changes in the proportion of people using pots rather than changes in the number of people. If the population significantly increased, for example, then our study would overestimate the frequency of individuals who had adopted pottery. This is probably the most questionable of our three assumptions. Controlling for population levels is notoriously difficult in archaeological research. However, tabulations of radiocarbon and obsidian hydration dates in the Owens Valley (Basgall, 2008), one means of estimating population levels (though see Surovell and Brantingham, 2007), suggests that there is no marked increase or decrease in population levels in the Western Great Basin during the last 600 years of prehistory.

Given these assumptions, histograms of dated artifacts can then potentially inform us about the waxing or waning of popularity of a particular technology. Fig. 1 presents several idealized possibilities. A rapid diffusion of a widely used technology should generate a histogram that approximates the shape of a box (Fig. 1A), where the technology suddenly appears and is used by a significant and constant proportion of the population. After appearing, the community becomes saturated with this new technology and there is no further proportional increase in the number of artifacts. Such a curve is predicted by the diffusion of innovations model if the rate of diffusion is faster than the precision of the dating method. For example, if the performance/cost advantage of a technology has a dramatic beneficial effect and is adopted by everyone in a window of time that is smaller than the error terms (precision) of a particular dating method, we are unable to resolve the details of the diffusion process.

An alternative scenario (Fig. 1B) is a more triangular-shaped histogram of dates. Such a distribution suggests a constant rate of diffusion throughout the population, where the numbers of adopters increases linearly with time. As discussed above, this type of curve is not predicted by the diffusion of innovations model. The model in Fig. 1B suggests that we cannot divide individuals into early adopters, majority, and laggards, but instead, that all individuals adopt at the same rate.

Fig. 1C shows a third possibility, where a technology diffuses slowly at first, but then rapidly reaches saturation. Again, this model would not be predicted by the diffusion of innovation model. The model in 1C lacks laggards who are predicted to be slow in the adoption of the technology.

Finally, Fig. 1D shows the classic diffusion of innovations model. A technology is innovated, diffuses slowly within the population at first (early adopters), is gradually adopted by more and more (the majority), with the rate of adoption decreasing thereafter (laggards), followed by eventual saturation.

Predictions for western great basin pottery

Our goal in this paper is to evaluate whether the diffusion of innovations research is suitable for application in the archaeological record and to explore the degree to which diffusion models account for technological change in a prehistoric instance. Our study examines pottery from four areas of the Western Great Basin. In our analysis, we make several predictions. First, we predict that the diffusion of pottery technology within a region will follow an S-shaped pattern, as is consistent with modern and
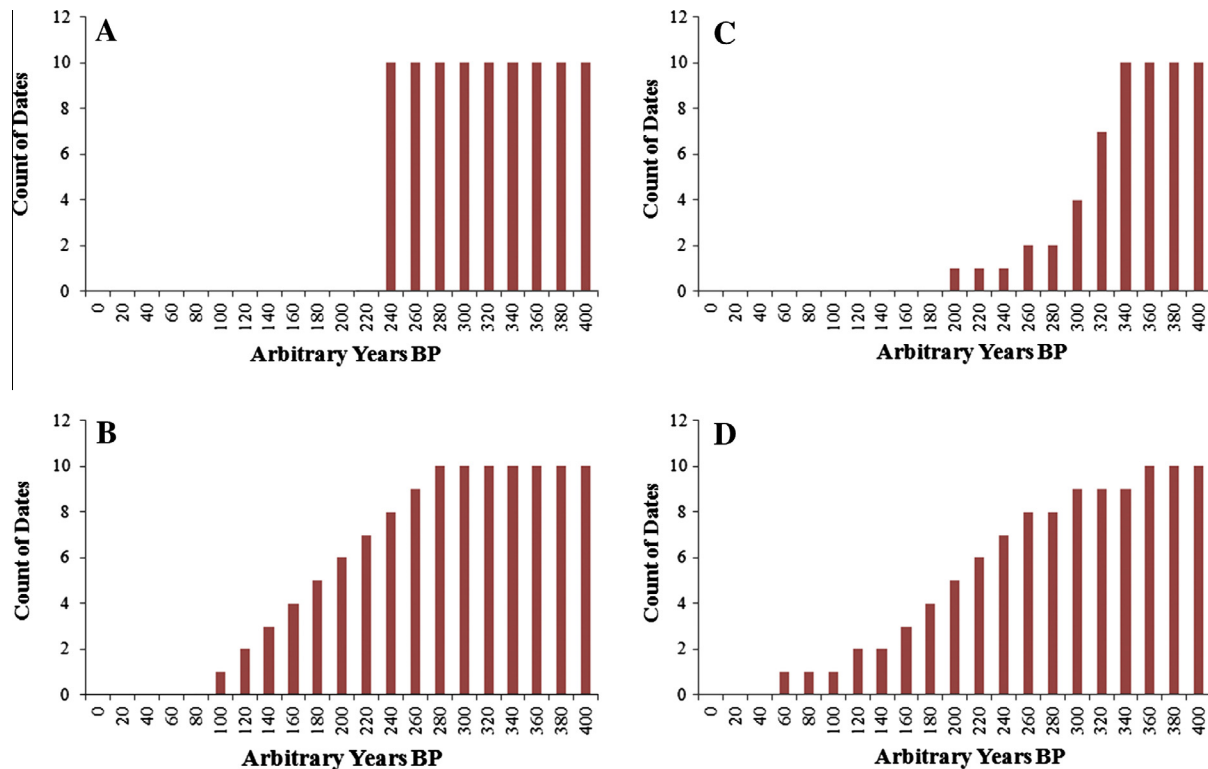
Fig. 1. Hypothetical diffusions of an innovation, and resulting histograms of predicted dates.

historical cases. In other words, we predict that the diffusion of innovations model applies in prehistoric cases as well.

Second, given the lack of mass media, we also predict that the diffusion process will transpire more slowly than in a modern setting, in particular, over several generations within a community. This is particularly important given our resolution in dating artifacts, where error terms are typically at the level of a generation (e.g., ±25 years). As a result, we predict a distribution of dates similar to what is shown in Fig. 1D (as opposed to Fig. 1A).

Finally, we predict that the areas where pottery appears first will have a longer period of experimentation, that is, a longer and more gradual left-hand tail. In these cases initial use of pottery will not compete with alternative technologies or have costs that mitigate its initial adoption. These initial areas of experimentation exhibit the first cases of the use of pottery and thus in the long run will become areas where pottery is more frequently used (i.e., a higher density of users). As pottery out-performs other container technologies in these regions and the details for adapting pottery to local conditions are worked out, pottery will spread geographically to nearby areas. Such details include where to obtain clay, which members of society will be responsible for procuring raw materials and/or producing items, and what form of pot works best given clay, temper, fuel, and use in a given environment.

Western great basin pottery

Despite the fact that many hunting and gathering groups produced pottery around the world (e.g., Close, 1995; Griset, 1986; Jordan and Zvelebil, 2010; Mack, 1990; Thompson et al., 2008), we still know relatively little about ceramic technological developments among such populations. Prehistoric populations of the western Great Basin (see Fig. 2) provide an opportunity to study such processes. Past work has documented the role of pottery in plant processing and cooking (Eerkens, 2003a, 2004, 2005), but less

is known about the timing and development of pottery in this region.

This semi-arid region averages just 5–15 cm of rainfall per year and is characterized by mountain ranges that rise over 3000 m separated by deep valleys at elevations ranging between 0 and 1400 m. Paiute and Shoshone people exclusively occupied this region prior to the mid 1800s, at which point Euroamerican settlers began to displace local groups and/or remove them to small reservations. Although Paiute and Shoshone people continue to live in these regions, pottery quickly disappeared from the toolkit as they gained access to metal pots. Hunter-gatherers here were residentially mobile, though the degree varied from group to group (Steward, 1933, 1938), ranging from semi-sedentary in Owens Valley to highly residentially mobile in places such as China Lake.

Pottery is a late prehistoric technology in the western Great Basin and is consistently associated with sites that date after 650
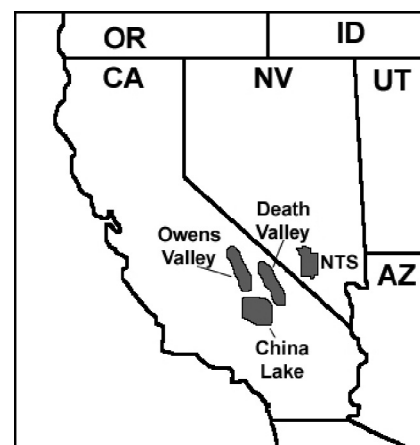

Fig. 2. Map of the western Great Basin region.

BP (Pippin, 1986; Rhode, 1994). In the Owens Valley, small numbers of pots appear around 1200 BP, indicating some latent knowledge and experimentation with the technology (Eerkens et al., 1999). It is possible that technological information about pottery diffused from agricultural societies in the Southwest, where pottery production already had a long history (Crown and Wills, 1995; LeBlanc, 1982). However, if so, it is clear that the technology was organized in a manner that is completely different than in the Southwest, and resulting vessels have a markedly different form and aesthetic. In other words, even if the technology diffused, Great Basin communities adapted it to suit their local needs.

Despite some early experimentation, radiocarbon dates from features associated with pottery indicate that the craft did not become commonplace in Owens Valley until 650 BP (Delacorte, 1999). The distinctive pottery is often referred to as "Owens Valley brownware," even when found in other geographic locations, however, we prefer the a-geographic and more general term of "brownware." This period (650 BP – contact) is also a time when small seeds such as chenopod, blazing star, rice grass, and other grasses began to be intensively harvested (Bettinger, 1979, 1983, 1989; Delacorte, 1999). Residue studies suggest that a major role of pots was to boil such seeds (Eerkens, 2005).

Although there is variance in form and design, brownware ceramic vessels are generally plain (undecorated) and usually medium-sized (ca. 15–25 cm high and 18–25 cm wide at the mouth). Vessel wall thickness varies between 4 and 9 cm just below the rim. Conical straight-sided pots (i.e., V-shaped) are the most common form, but spherical bowls with recurved rims are also present (Bettinger, 1989; Hunt, 1960; Lyneis, 1988; Pippin, 1986; Prince, 1986; Touhy, 1990; Touhy and Strawn, 1986; Wallace, 1986). Fig. 3 shows two examples of complete pots that represent typical forms found in the region.

Based on ethnographic descriptions (Gayton, 1929; Steward, 1933) and archaeological analyses (Bettinger, 1989; Hunt, 1960), vessels were constructed mainly by stacking coils of clay on a circular disk base and scraping these together with fingers or a small smooth object. Most pots are tempered with sand and/or crushed granitic rock, though organic fibers were also commonly added (or were present naturally within the clay). Vessels were fired at relatively low temperatures, often in uncontrolled atmospheres, a process that resulted in uneven oxidation and brown-red colored pastes.

Chemical composition analyses using Instrumental Neutron Activation Analysis (INAA) demonstrate that prehistoric potters used a range of discrete and local clay sources to make pots (Eerkens et al., 2002). It is not yet known if these different clay sources were used simultaneously, perhaps by different potters or for different functions, or if there is a temporal component to clay source use, for example, if potters were experimenting with different clay-temper recipes. Analysis of the spatial distribution of sourced sherds suggests that pots were only occasionally transported outside their region of manufacture (Eerkens et al., 2002). Typically, only 5-15% of sherds are exotic. Overall, production seems to have been on a small scale, likely at the family or individual level, for local and domestic use (Eerkens, 2004; Eerkens et al., 2002).

At the same time, research shows that pottery was not a static technology. Instead, there appears to be experimentation and innovation in pot form throughout the late prehistoric period. For example, Eerkens (2003b) showed that the earliest pots in southern Owens Valley, those dating older than 450 BP, are generally over 7.0 mm thick, often contain mica, more frequently have organic temper, and are usually smoothed on their exterior surfaces. Between 300 and 450 BP pots become somewhat thinner (ca. 6.5 mm), contain less mica, and are less frequently smoothed on their exterior surfaces. After 300 BP, assemblages contain the thinnest sherds, usually less than 5.5 mm, have little mica or organic temper present, and are rarely smooth on their exterior or interior surfaces. Eerkens argued that these diachronic changes reflect experimentation, including the use of different clay and temper recipes, a result of the transmission of accumulated information on potting knowledge. Small innovations spread within the population and made the technology more suitable to local lifestyles.

Case study

Here, we examine the temporal distribution of optically stimulated luminescence (OSL) dates of pot sherds in two regions, Southern Owens Valley (SOV) and Death Valley. Sherds were dated using techniques described by Murray and Wintle (2000) and Banerjee et al. (2001). Pot sherds are common in late prehistoric sites in both regions and were an integral part of the technological toolkit and represent at least two different vessel forms. One is a pot with a recurved or reverted rim (i.e., a constricted neck) that is found primarily in Death Valley (see Fig. 4). The other is a vessel with a direct and non-constricted neck found in both regions. As we will demonstrate, the former was a failed invention that was ultimately replaced by the latter.

The use of luminescence dating as a means of dating ceramics has distinct advantages over other forms of archaeological dating. First, luminescence dating of ceramics reflects the event of pot firing (Aitken, 1985; Feathers, 2003; Lipo et al., 2005). In the case of radiocarbon dating, in contrast, the event that is measured is associated with the removal of the organism from the carbon cycle. This event may or may not be associated with the event of interest, the manufacture of the pot. Consequently, radiocarbon dates have

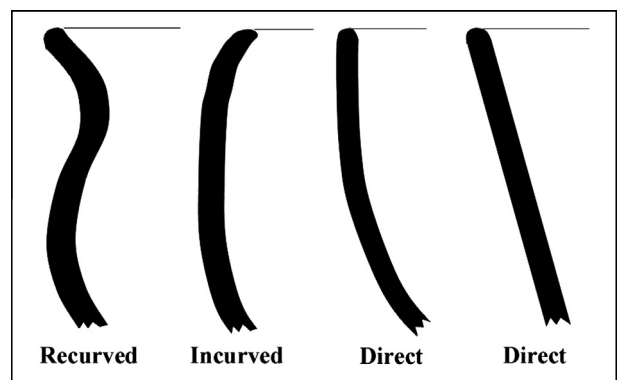**Fig. 3.** Two examples of complete pots from the China Lake region.

Fig. 4. Examples of rim forms present in Southern Owens and Death Valleys.

Recurved   Incurved   Direct   Direct

an unknown amount of error that can be hundreds of years or more, in the case of the use of old wood, from the event related to the creation and use of the vessel (Dean, 1978).

Second, quantitative uncertainty associated with OSL dating is measurement error that has a normal distribution. This situation contrasts with calibrated radiocarbon dates that have complex probabilistic relations between the radiocarbon measurements and the calendric age of the sample. This relation is particularly complicated in last 300 years of prehistory due to variability in the amount of ^{14}C in the atmosphere and radiocarbon age estimates often have multiple calibrated windows of calendrical dates. This situation makes distinguishing the hypothetical cases posited in Fig. 1 difficult.

In addition to the OSL dates generated for SOV and Death Valley, we also examined a small series of luminescence dates from a region between Owens and Death Valleys, China Lake, where pottery is less common. These data provide information about the timing and structure of pottery adoption in an area where there appears to have been fewer consumers. In addition, we have compiled previously published luminescence dates from the Nevada Test Site (NTS; Rhode, 1994; Feathers and Rhode, 1998), to examine the timing and adoption process of pottery there.

Luminescence samples from SOV, Death Valley, and China Lake are all new dates produced by the authors. Sherds represent surface-collected artifacts generated from surveys carried out by a range of researchers (e.g., Delacorte, 1999; Gilreath and Hildebrandt, 1997; Hunt, 1960; Wallace, 1986; as well as still-unpublished collections generated by JWE). The goal in our study was to sample widely from a range of different sites in each region. Sherds included are mainly from the rim, and each sherd represents a different pot (i.e., sherds that looked alike from the same site, and thus, could have come from the same pot, were only sampled once). In this respect, our sample is intended to maximize regional variation in the size, shape, temper, and surface characteristics of pots. By contrast, the NTS sample simply represents an assemblage of dates produced in two previous studies, but we have no further information about the form of the pots or the archaeological context.

In total, we have assembled 97 dates from SOV, 37 from Death Valley, 17 from China Lake, and 16 from NTS in the analyses below, for a total of 167 OSL dates.

Results

Fig. 5 shows the distribution of luminescence dates from SOV and Death Valley, binned into 50-year intervals. In Death Valley, dates from pots with recurved rims ($n = 9$) are shown separately from those with direct rims ($n = 28$). The numbers along the *x*-axis indicate the midpoint within each bin (i.e., the bin marked 1600 is actually AD 1575–1624). One outlying old date from Owens Valley

at AD 954 is not shown to focus attention on the later diffusion process, but supports the notion that there was some early experimentation with potting technologies in the region (Eerkens et al., 1999).

The distribution of dates from SOV and Death Valley is consistent with the technology diffusion model and suggests that people were experimenting with pottery in both regions between AD 1275 and 1375 (and perhaps earlier in SOV as indicated by the date of AD 954). In SOV this was a direct-rimmed pot, with relatively thick and smoothed walls and more organic temper and mica (Eerkens, 2003b). In Death Valley these pots were bowled with a recurved and relatively thick rim. In both regions, the frequency of these early-dating sherds is small, suggesting experimentation with a new, or at least rare, technology.

In the ensuing centuries, pottery slowly diffused throughout the SOV region, as witnessed by the increasing number of luminescence dates between AD 1425 and 1824 (median date = AD 1701). A drop-off in the frequency of dates after AD 1825 is considered further below. The slow increase in dates is much as we expect for a successful innovation that is spread within a hunter-gatherer population. As the costs for learning the technology decrease due to greater numbers of people become increasingly familiar with the technology, including various clay sources, firing conditions, and functional properties of different forms, new initiates adopt the technology and begin producing pots as well.

By contrast, the pot with the recurved rim in Death Valley does not successfully spread. Initially, only recurved pots were produced in Death Valley and it appears that they became more popular in the ensuing two centuries, peaking between AD 1425 and 1525. This pattern suggests, as with direct-rimmed pots in SOV, a successful start to the diffusion process. However, no recurved pots date between AD 1525 and 1675, suggesting an abandonment of the technology, and only a minority of the 28 pots dating after AD 1710 are recurved ($n = 4$). This suggests that the technology may have been occasionally revived, but never again became the dominant pot form.

In some respects the shape of the histogram of luminescence dates on direct-rimmed pots in Death Valley is more similar to that in SOV. Here, there are a small number of early-dating direct-rim sherds, followed by a sharp increase after AD 1750 as the technology spreads, pointing to a very successful diffusion. Relative to SOV, it is also notable that the diffusion of direct-rimmed pots in Death Valley is shifted later in time by 100–200 years (median date = AD 1801) and is much quicker, as indicated by the steeper slope in Death Valley.

Fig. 6 shows the distribution of luminescence dates from China Lake and NTS. The dates from China Lake represent a small sample ($n = 17$), but all are from direct-rimmed pots (recurved pots are rare in this region and were not in our sample). Together, the dates show a very similar pattern to the direct-rimmed pots in Death Valley. The dates are shifted slightly earlier in time compared to
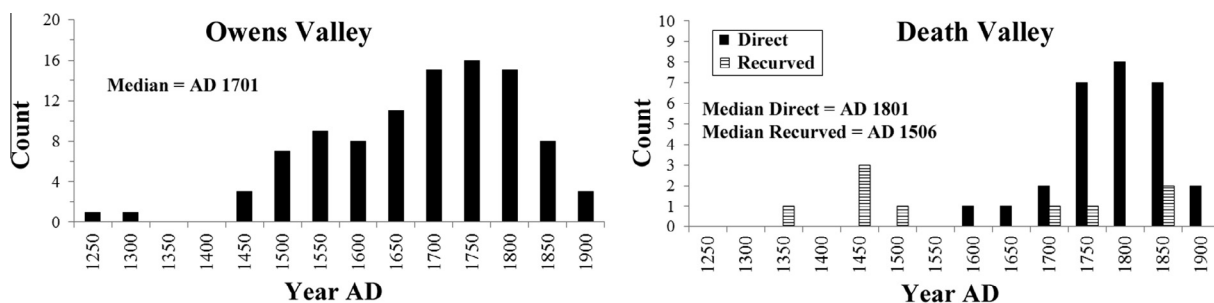

Fig. 5. Distribution of luminescence dates in Southern Owens Valley and Death Valley.
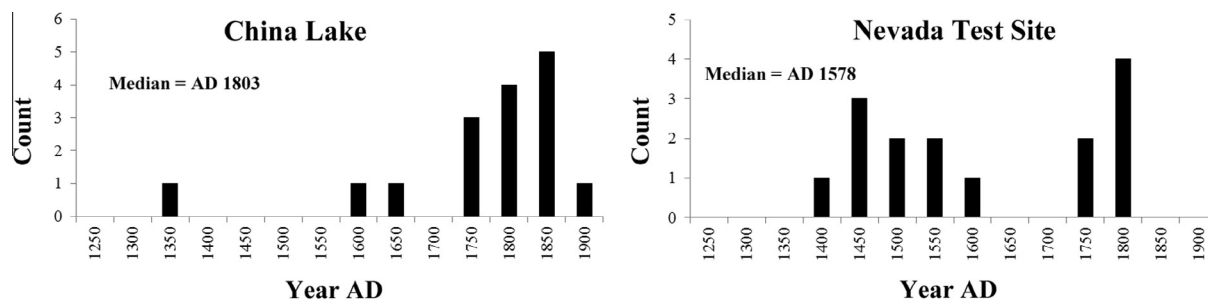
Fig. 6. Distribution of luminescence dates in China Lake and NTS.

Death Valley, by about 25 years, but indicate some early experimentation followed by a relatively rapid adoption of the technology. As in Owens and Death Valleys, a fall-off after AD 1850 is evident.

By contrast, the NTS distribution is clearly bimodal, with one set of dates between AD 1375 and 1625 and a second set between AD 1760 and 1840 (one early outlier at AD 1081 is not plotted). Because we did not generate or analyze this sample of sherds, it is unclear whether this is a byproduct of sampling strategy or represents a random sample of all sherds in the NTS region. Furthermore, we do not have the information to determine whether these samples are from direct-rimmed or recurved pots, as the majority are wall, not rim, sherds. However, recurved pots are not uncommon in the NTS (Lockett and Pippin, 1990), and the distribution of early dates is similar to those of recurved pots in Death Valley (though the sample sizes are admittedly small for both). We consider this issue briefly again below.

Discussion

We believe the distribution of luminescence dates from the western Great Basin suggest a tale of two innovations, one successful (direct-rimmed pots), the other a failure (recurved pots). We have only sampled pots from three regions and some of the details may change with additional data, especially from other regions and valleys. Based on the evidence at hand, however, we believe the tale of the successful innovation begins in Owens Valley, likely the southern end. Here, the innovation of the direct-rimmed pot included a long and extended period, lasting several centuries, where few pots were produced. We interpret this period as an extended window of early experimentation with pottery. Based on our luminescence dates, this may have begun as early as AD 950 and continued through AD 1475. Such an early date for experimentation with pottery is not unprecedented, and is supported by additional data from excavation (Eerkens et al., 1999).

The period of experimentation in SOV is followed by a gradual increase in the adoption of the technology, between AD 1475 and 1825. This slow and steady diffusion resulted in increasing numbers of pots at sites in the region through AD 1800, producing an adoption curve that is most visually similar to that in Fig. 1D. This suggests something similar in basic structure to a typical diffusion of an innovation. We note that there is a slight inflection in the histogram curve around 1650 BP. Our sample size is not large enough to determine if this is a real pause in the diffusion of direct-rim technologies, or simply a sampling error. We note, however, that such curves have been observed in modern studies where a significant innovation occurs within a technology, or when two rival technologies compete with one another and one ultimately outcompetes the other (Sood and Telllis, 2005). In other words, such curves are expected when two diffusion S-curves intersect one another. Additional technological analyses of the direct-rim sherds

before and after AD 1650, as well as additional luminescence dating, may help resolve this issue. In particular, this may indicate the shift from thicker to more thin-walled pots (Eerkens, 2003b).

In the late 16th century AD, we suggest that direct-rimmed pots diffused from SOV to other regions, but only after a significant period of experimentation in SOV. In other words, SOV potters may have gained enough experience that technological information about the craft could be transmitted to inhabitants of nearby regions, who could successfully incorporate the craft into local toolkits. Luminescence dates suggest direct-rim pottery technologies diffused to China Lake around AD 1580 (one earlier date at AD 1329 notwithstanding), and to Death Valley shortly thereafter. In both these regions, the subsequent internal diffusion is much faster than it was in SOV. Direct-rimmed pots are rapidly adopted and the technology quickly spreads among inhabitants in these regions, as indicated by a steep increase in the number of luminescence dates on direct-rimmed sherds over time (i.e., steeper slope of the adoption curve).

A comparison of the distribution of dates from direct-rimmed pots in China Lake and Death Valley, using a Kolmogorov–Smirnov (K–S) test, shows the suites of dates are nearly identical (Table 1). By contrast, K–S tests indicate that the cumulative frequency curve of dates in Southern Owens Valley is significantly different than the curves for Death Valley and China Lake. In other words, the process of diffusion for direct-rimmed pots was entirely different in the former. This is due to the significantly longer period of experimentation and the slower rate of adoption in Southern Owens Valley.

The second tale is that of the failed innovation of the recurved pot. We lack sufficient information to establish where the recurved form was originally invented. We suspect it was invented in an area to the east of Death Valley, such as NTS, and diffused into the former. This hypothesis should be tested with additional luminescence dating of recurved rim sherds from Death Valley and NTS. In any case, the recurved pot was the dominant form in Death Valley between AD 1325-1525. This innovation, however, did not diffuse west into China Lake or SOV, at

Table 1

Results of K–S Tests on distributions of dates, comparing regions (with Death Valley run twice, once for all sherds and once for sherds with direct rims only). The upper shaded cells give the D statistic (maximum distance between curves), while the lower unshaded cells give the probability the two curves are drawn from the same underlying distribution.

	SOV	China Lake	Death Valley	DV direct	NTS
SOV	-	.45	.36	.47	.32
China Lake	.007	-	.19	.11	.56
Death Valley	.001	.777	-	-	.50
- DV direct	.000	.999	-	-	.59
NTS	.086	.009	.005	.001	-

least in significant numbers such that it appeared in our sample of sherds. Furthermore, the direct-rimmed form in Death Valley eventually replaced it. We note that recurved pots do appear in small numbers in areas to the north of SOV, such as central Owens Valley and Deep Springs Valley (Delacorte, 1990). Although they are never dominant and co-occur with direct-rimmed pots, we hope to conduct future luminescence dating on a suite of recurved and direct rim sherds from these other areas to evaluate this hypothesis.

Why the recurved pot failed as an innovation in Death Valley is unclear and must await additional analysis. However, a clue may come from residue analyses. Eerkens (2005) found that that recurved pots have residue profiles that are consistent with the cooking of meat, while direct-rimmed pots were typically used to cook seeds. Functionally, a pot with a recurved rim will retain heat better than a pot with a direct rim and open mouth. A recurved rim, then, is better suited to simmering and stewing activities, those typically associated with meat preparation, while a direct-rimmed pot is better suited to high temperature boiling, which is typically associated with seed preparation (Reid, 1990). Because seeds were an ever-increasing component of the Late Prehistoric diet, recurved pots may not have met the needs of western Great Basin inhabitants as well as direct-rimmed pots.

Conclusions

We made three predictions about the diffusion of pottery technologies among hunter-gatherers of the western Great Basin. First, we predicted that pottery would diffuse following the same pattern observed in modern and historical cases. In particular, we predicted S-shaped curves to the diffusion process. We believe this prediction is mostly met. All four regions show long left-hand tails in their distribution of dates, indicating the presence of early experimenters with the technology, followed by a shorter window where the majority of dates appear. We believe the latter represents when the majority of people within the population adopted the technology.

At present, we lack the kind of resolution to determine whether other elements of the S-shaped curve are present. In particular, it is difficult to detect the presence of laggards as predicted from diffusion of innovation models, that is, people or families who only grudgingly adopt the technology long after the majority. This is partly due to a common attribute of the distribution of dates in all four regions, which show a fall-off of dates at the end of the sequence, or complete absence in the case of the NTS. We believe this fall-off effect is caused by two factors that disrupted the diffusion of pottery. First, there appears to have been a reduction in population levels in the proto-historic or early historical-period dates due to the spread of European diseases ahead of actual contact with Euroamericans (ca. AD 1850 in the western Great Basin). Second, following contact, there was a general replacement of earthenware pots with metal containers, such as cast-iron pots (Eerkens, 2003a). Both of these factors then serve to confound the detection of laggards in our sample.

Our second prediction was that the diffusion process among hunter-gatherers of the past would be slower than in modern and historical settings where mass media and modern transportation is more effective at transmitting information over time and space. We believe the suites of dates in all four regions support this hypothesis. Although the diffusion of pottery was faster in some regions where it appeared later (e.g., China Lake, and for direct-rimmed pots in Death Valley), the process took place over centuries, rather than decades. Based on our data, the rate of diffusion seems to be an order of magnitude slower than in modern and historical settings.

Our third prediction was that there would be a longer period of experimentation, causing a longer left-hand tail to the distribution of dates, in regions where pottery appears first. Again, this prediction was supported by data from SOV and the NTS, where the earliest dates on pottery were obtained. There, the bulk of dates come long after this early experimentation. By contrast, the majority/bulk of dates Death Valley and China Lake come sooner after the earliest recorded date, as if there was minimal experimentation required after initial diffusion to bring the technology into widespread use.

Overall, our results demonstrate that the diffusion model accurately accounts for patterns of technology change within prehistoric populations of the western Great Basin. Just as modern studies on the diffusion of innovation have revealed important insight into cultural transmission processes and individual decision-making, there is much potential for this approach in archaeology in general, though to date applications are few.

We argue that certain aspects of the modern literature on the diffusion of innovation are directly relevant to archaeological studies regarding the diffusion of ancient innovations. In particular, our data set is able to detect the effects of early innovators and early adopters of pottery technologies in the Western Great Basin. Two different pot forms were developed within three centuries of one another, one with a direct rim and one with a recurved rim. The use of pots continued in low frequencies for two to five centuries and slowly spread within local communities. While the recurved pot failed to spread, the direct-rimmed form was very successful.

We argue that the several centuries of experimentation with the direct-rimmed pot in Southern Owens Valley set the stage for its adoption by the majority and its eventual spatial diffusion, especially to the east, but likely to the west as well (Jackson, 1990). The slope of the adoption curve in Southern Owens Valley is quite gradual, indicating slower internal diffusion. By comparison, direct-rim pots were adopted much more quickly in China Lake and Death Valleys. Experimentation in Southern Owens Valley likely worked out many of the difficulties that hunter-gatherers of the Western Great Basin faced in trying to incorporate potting into their lives (Eerkens, 2008). Once improved in Southern Owens Valley, the new technology spread easier in adjacent regions. In this respect, our data set is also able to detect the effects of the majority on diffusion processes. While the effects of laggards may also be present in the data set, disruptions in diffusion processes caused by contact with Euroamericans may obscure their detection archaeologically.

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