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# Dynamic Landscapes, Artifact Taphonomy, and Landuse Modeling in the Western Mediterranean

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The Polop Alto valley, in eastern Spain, is characteristic of many Mediterranean landscapes. It has been sporadically reoccupied over the course of at least 80 kyr. Its landforms have undergone various geomorphic processes resulting from late Quaternary environmental fluctuations. During the Holocene, the valley has been modified by millennia of extensive land clearance, cultivation, and terracing. As a result, the evidence for human activity and landuse is a cumulative, but discontinuous palimpsest of the most durable behavioral residues—primarily stone and ceramic artifacts—whose distributions have been affected by diverse natural and cultural formation processes. Human occupation of the Polop Alto spans the evolution of morphologically modern humans and the replacement of foraging economies by farming, arguably the two most significant biobehavioral transitions for human life today. To better understand the changes in human landuse that accompanied these important transitions, we have employed an integrated suite of techniques aimed at unmixing the diverse formation processes that have affected Polop Alto landscapes and material culture. These include patch-based survey methods, photogrammetry, GIS-based spatial analysis, and using artifact morphology and distribution to assess artifact taphonomy. This has permitted us to develop a diachronic settlement model for the 80 kyr of human occupation in the Polop Alto.

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## INTRODUCTION

Although archaeologists are explicitly concerned with past human behavior, we must also understand the processes—both cultural and natural—that create the modern archaeological record in order to gain a reasonably accurate glimpse of the past. This issue is dedicated to understanding these formation processes. The Mediterranean landscapes of eastern Spain are the product of natural and cultural processes that have interacted in complex ways for more than 200 millennia. The residues of the prehistoric inhabitants of this region are a component of this landscape and, hence, have been affected by a suite of processes that have shaped the

region as a whole. Over the past decade, we have been actively pursuing a study of changing prehistoric landuse in this region. In the course of this work, we have had to come to terms with the dynamics of Mediterranean landscapes, including their role in human settlement and in the creation and alteration of the archaeological record. This long-term research has encompassed intensive pedestrian reconnaissance, systematic surface artifact collection, subsurface coring and excavation, and collection of paleoecological data in six valleys in northern Alicante Province (Figure 1). Increasingly, we have used a taphonomic approach to integrate the study of formation processes and archaeological residues. To illustrate some of the ways in which such integration can be undertaken and its potential benefits for archaeologists, we focus here on aspects of this work in one of these valleys: the Polop Alto.

## **BACKGROUND**

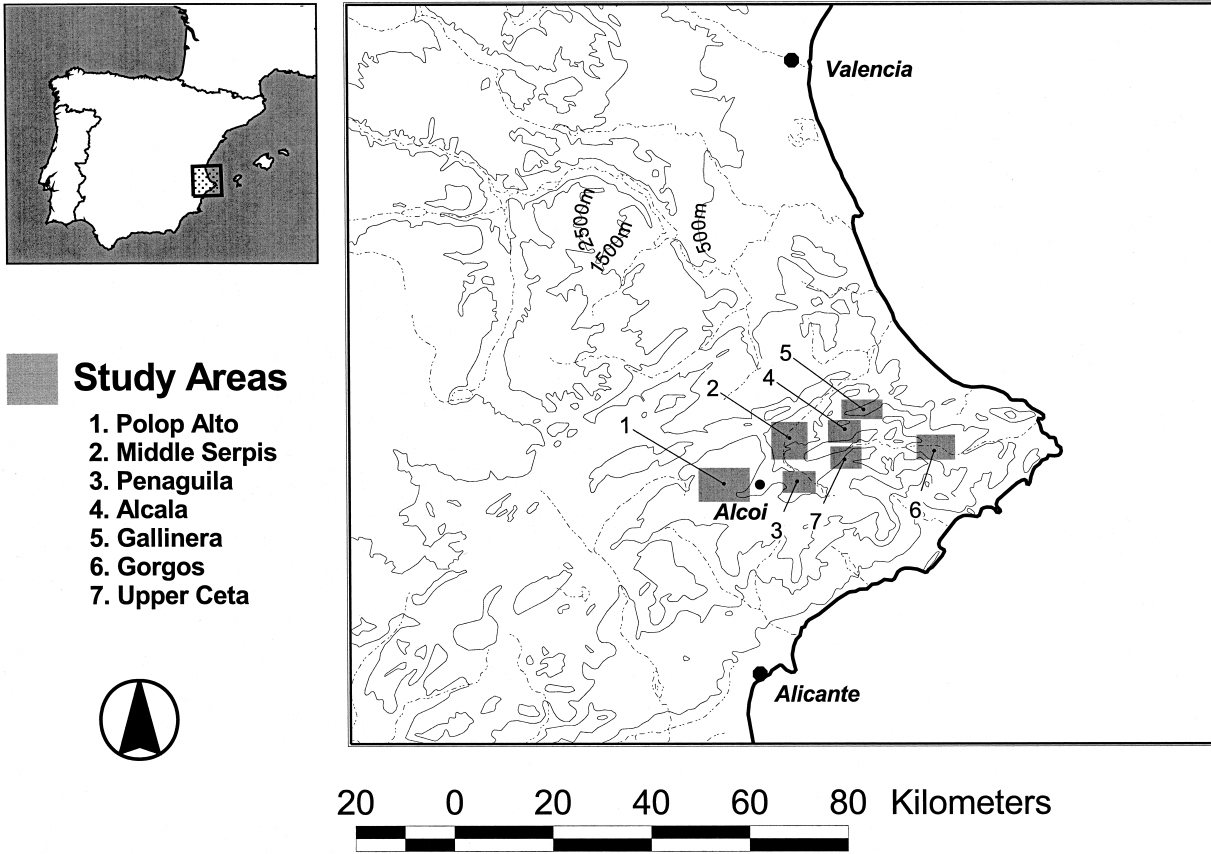
### **The Polop Alto Valley**

The Polop valley is located 6 km southwest of the city of Alcoi, in northern Alicante Province of eastern Spain (Figures 1–3). It lies within a mountainous region, between the Mediterranean coastal plain and the interior plateaus of the Meseta, that constitutes the northern extent of the Baetic system of mountain ranges that encircles the eastern and southern margins of the Iberian peninsula. Aligned southwest-northeast, the Polop is bordered to the southeast by the Sierra Carrascal, rising to more than 1300 m above mean sea level, and to the northwest by the Loma de la Fontfreda, with maximum elevations of about 1100 m; the valley bottom varies in elevation from 700 to 900 m above mean sea level. The greater Polop valley system covers almost 30 km<sup>2</sup>, and includes the headwaters for both the Río Polop and Río Barxell, two of the three sources of the Río Serpis, the major drainage of the region. The research discussed here focuses on the upper reaches of the valley, the Polop Alto, representing a little over 9 km<sup>2</sup>.

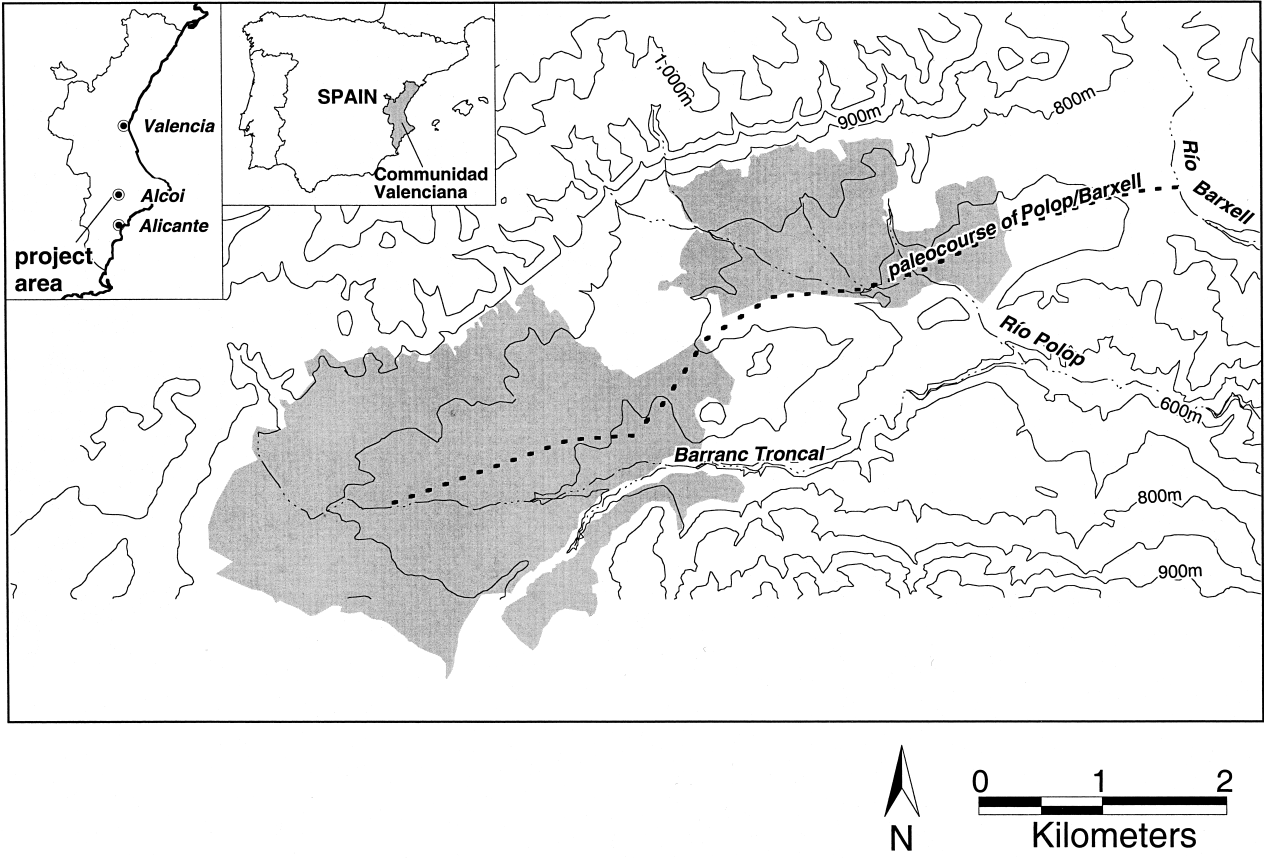
The area varies in elevation, topographic settings, and vegetation communities, offering a diverse range of wild resources to prehistoric inhabitants. The Polop also has extensive arable land, with sufficient rainfall for dry farming a variety of crops, and much of the valley is under cultivation today. Historically, these crops have included cereals, legumes, tree crops (especially olives and almonds), and grapes; sheep and goats have been pastured in upland areas.

### **Regional Prehistory and Chronological Frameworks**

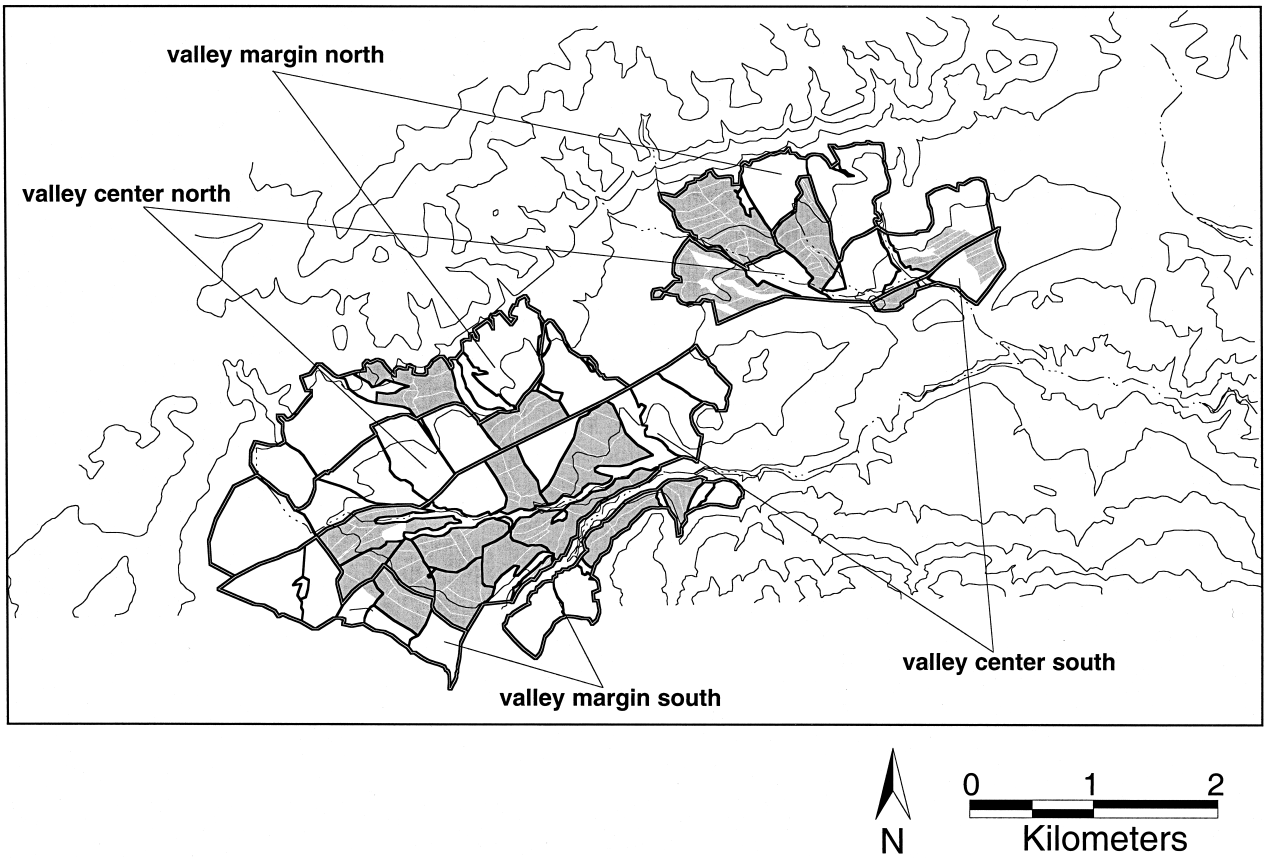
The regional prehistory recently has been reviewed in detail elsewhere (Aura and Pérez-Ripoll, 1995; Barton et al., 1999; Bernabeu and Juan-Cabanilles, 1994; Villaverde et al., 1998); we offer only a brief overview here. A human presence extends well back into the middle Pleistocene (Fernández Peris, 1993; Fernández Peris et al., 1997), and late Pleistocene Middle Paleolithic occupations are documented locally at Cova del Salt (Barton, 1988; Galvan, 1992), Cova Negra (Villaverde, 1984), and Cova Beneito (Iturbe et al., 1993). Beneito (15 km northeast of



**Figure 1.** Study areas in eastern Spain: (1) Polop valley, (2) middle Río Serpis valley, (3) Penaguila valley, (4) Alcalá valley, (5) Gallinera valley, (6) Gorgos valley, (7) upper Ceta and Famorca valleys.



**Figure 2.** Location of the Polop Alto survey project. Estimated course of Polop/Barxell drainage prior to mid-Holocene incision and stream capture (see text) indicated by dashed line.



**Figure 3.** Sampling strategy used in the Prolop Alto survey. Double lines outline sampling strata; heavy lines outline survey units; shaded survey units indicate areas sampled; white lines outline collection/provenience units (fields or field groups). A housing development that could not be surveyed, Montesol, occupies 1.3 sq km of the north valley margin stratum.

the Polop valley) also has a long Upper Paleolithic sequence, beginning at ca. 34,000 yr B.P. Late Upper Paleolithic industries appear ca. 14,000 yr B.P. in the regional Magdalenian at sites like Tossal de la Roca (Cacho et al., 1996) and continue on into the Holocene until the appearance of the Geometric Mesolithic at about 8000 yr B.P. exemplified locally at Tossal de la Roca and Cova de la Falguera (Barton and Clark, 1993, Doménech, 1990).

The regional Neolithic is divided into early and late phases. Following the Mesolithic, the Neolithic I (i.e., early Neolithic) begins by 7600 cal yr B.P. and continues until ca. 6500 cal yr B.P., representing the earliest clear evidence for the use of domestic plants and animals in the Iberian peninsula. Locally the Neolithic I is best known from the site of Cova de l'Or (Martí et al., 1980), with the open air locality of Mas d'Is currently in excavation. The Neolithic II (i.e., late Neolithic) is subdivided into three subphases. The Neolithic IIA (poorly represented regionally and unknown in the Polop) is dated to 6500–4900 cal yr B.P., and the Neolithic IIB dates to 4900–4400 cal yr B.P., making it roughly contemporaneous with the “Los Millares” culture of southeastern Spain. The final Neolithic IIC, also called the “Bell Beaker” after the form of characteristic ceramics, is dated to 4400–4200 cal yr B.P. Recently studied Neolithic II sites in the region include the Neolithic IIB settlement of Niuet (Bernabeu, 1993; Bernabeu et al., 1994) and the Neolithic IIC site of Les Jovades (Pascual Benito, 1989). The regional Bronze Age dates to between 4200 and 3200 cal yr B.P. and is broadly contemporaneous with the better-known “Argaric” culture of southeastern Spain. By 2600 cal yr B.P., a variety of Iron Age groups, generically known as the “Iberian Culture” occupied the area, interacting with Phoenician, Greek, and Punic traders, until the region became incorporated into the expanding Roman Republic at the time of the Second Punic War.

Evidence of human occupation within the Polop Alto itself dates from the Middle Paleolithic onward (Barton, 1988; Barton and Clark, 1993; Villaverde, 1984; Villaverde and Martí, 1984). Previous archaeological research in the valley includes excavations at the Cova del Salt (Barton, 1988; Galvan, 1992), the early Bronze Age site of El Corral (Trelis, 1992), and a few small salvage projects such as at the Mesolithic to Neolithic IIC site of Abric de la Falguera (Barton and Clark, 1993; Doménech, 1990). Available numerical ages that bracket human activities in the valley include U/Th dates of 80,157 and 81,583 yr B.P. at Cova del Salt (Barton and Clark, 1993; Galvan, 1992), a  $^{14}\text{C}$  age of  $7410 \pm 70$  yr B.P. (8307–8121 cal yr B.P.) for the earliest (probably Mesolithic) occupation at Abric de la Falguera (Barton et al., 1990), and  $^{14}\text{C}$  ages of  $3770 \pm 60$  yr B.P. (4231–3995 cal yr B.P.) and  $3710 \pm 65$  yr B.P. (4142–3928 cal yr B.P.) for the Bronze Age occupation of El Corral (Trelis, 1992).

## METHODS

The Polop Alto was intensively surveyed in 1991, and selected areas were subsequently resurveyed in 1993 and 1995. The overall goals of the survey project were to study the spatial and temporal dynamics of prehistoric landuse, economy, and

**Table I.** Survey coverage statistics for each of the four sampling strata.

		North Valley Margin	South Valley Margin	North Valley Center	South Valley Center	Survey Total*
Total area (sq km)		1.31	0.79	1.97	2.62	6.37
Total survey units		7	10	13	13	43
Random sample	Units surveyed	2	2	2	5	9
	Area surveyed (sq km)	0.60	0.21	0.42	1.30	2.53
	% of stratum total	45.8%	26.6%	21.3%	49.6%	39.7%
Nonrandom sample	Units surveyed	0	2	4	2	8
	Area surveyed (sq km)	0.00	0.15	0.49	0.55	1.19
	% of stratum total	0.0%	19.0%	24.9%	21.0%	18.7%
Survey total	Units surveyed	2	4	6	7	19
	Area surveyed (sq km)	0.60	0.36	0.91	1.85	3.72
	% of stratum total	45.8%	45.6%	46.2%	70.6%	58.4%

\* Excludes areas where survey not possible, such as housing development of Montesol.

social organization, and to identify settlements dating to the Paleolithic through Neolithic for future excavation.

Several considerations went into the sampling design for the initial 1991 survey. On the basis of previous work, and in line with common general valley morphology, we thought that older (late Pleistocene or older) intact surfaces would be more common on the upper terraces and alluvial fans of the valley margins, whereas somewhat younger surfaces (i.e., terminal or post Pleistocene) would be more prevalent in the valley bottom. We wanted to sample independently those areas of the valley bottom that bordered an abandoned drainage and the modern one (Figure 2). Finally, we independently sampled the northern and southern valley margins because of apparent topographic and geomorphic differences between these areas. The result was four sampling strata (Figure 3, Table I): two (north and south) valley margin strata and two (north and south) valley center strata.

Each stratum was subdivided into a series of survey units. These were roughly equal-area groups of fields divided by prominent *barrancos* (or roads in the cases where appropriate *barrancos* could not be followed). The survey units in each stratum were numbered, and a random sample was drawn for initial survey (Figure 3, Table I). Because of the expected greater diversity of cultural materials in the south valley center (also a potential locus of Neolithic settlement on the basis of other work in the region), a larger initial sample was drawn from this stratum than the others. Based on the results from the randomly selected units, additional survey units were selected nonrandomly for inspection. These were primarily in the valley center strata. In all, 40% of the Polop Alto was intensively surveyed.

In order to investigate spatial and temporal variation in prehistoric landuse, we employed a patch-based field strategy that is increasingly used in ecology to assess spatial variation in ecosystem characteristics (Collins et al., 2000). This methodology requires systematic data collection from a series of landscape patches defined geographically rather than on the basis of data characteristics one wants to observe

(e.g., patches chosen because of their high artifact densities—i.e., sites). In the Polop Alto, the small, clearly demarcated, terraced fields found throughout the valley served to geographically demarcate study patches for data collection. Crews of four to eight walked selected patches, spaced about 15 m apart. All observed prehistoric artifacts were collected within each patch, and modern landscape characteristics such as vegetation cover, surface visibility, and landform were recorded. Although not the focus of this research, later material, such as Ibero-Roman and Medieval ceramics, also was noted and diagnostic examples collected. Detailed topographic maps (1:10,000 scale) and high-resolution aerial photographs (~1:8,700 scale) were used to define survey units and locate study patches on the ground during fieldwork.

Preliminary analysis of collections was conducted in the field laboratory with more detailed analysis conducted later at the University of Valencia and Museo d'Arqueologia in Alcoi. Lithics were size-graded and sorted primarily into technological categories; modified forms also were noted (e.g., scrapers, sickle blades, and geometric microliths), and taphonomic information (see below) was collected. Prehistoric ceramics were classed by vessel form, surface treatment, and taphonomic alteration.

Much of the analysis presented below was performed with the aid of GIS tools, primarily MapInfo. The 1:10,000 topographic maps of the valley were digitized and overlain with survey unit and patch outlines digitized from the aerial photos to create the base maps for this analysis.

## **OVERVIEW OF LANDSCAPE FORMATION PROCESSES**

Our reconstruction of the Quaternary history of the Polop Alto is based on work by the late Pilar Fumanal, and fieldwork by Barton and project geomorphologist Neus La Roca (Barton et al., 1992, 1999; Ferrer et al., 1993; Fumanal Garcia, 1986).

### **Valley Origin**

The Polop valley formed as part of the Baetic uplift, one of a series of southern European mountain systems that resulted from the collision of the African and European plates throughout much of the Cenozoic. Initially, much of the Baetic highlands existed as a chain of barrier islands along the southern and eastern margins of the proto-Iberian peninsula. In the region of the Polop valley, intermontane areas filled with a thick sequence of Neogene marls. These carbonates may have formed in shallow lagoons between the proto-Baetic islands and the Iberian mainland. Alternatively, they may be ponded freshwater sediments formed as crustal deformation connected the proto-Baetic islands with the peninsula, creating interior-drained valleys prior the establishment of the modern drainage net. These marls include a lower, virtually lithified series, and an upper, softer series.

### **Pleistocene Landscapes**

With the establishment of exterior drainage, probably by the middle Pleistocene at the latest, one or more series of high benches were cut into the marl along the



upper margins of the valley, especially noticeable today along the southern side. Following this initial episode of downcutting, alluvial fans developed in several locations, especially along the northern margin, and the marl was mantled with terrestrial deposits of variable thickness. Deposition was probably episodic, if not cyclic, and varied across the valley. However, there is no evidence that the valley subsequently filled to the level of the earliest benches. The Mediterranean region as a whole remains tectonically active. However, we currently lack information on the degree to which tectonism (e.g., uplift, tilting, and faulting) contributed to the formation of these Pleistocene landforms.

Soils developed on the alluvial fans and benches are deeply reddened and exhibit well developed  $\text{CaCO}_3$  morphology, suggesting considerable antiquity. During the survey, artifacts of probable Upper Paleolithic age were found some 2 m below the present surface in fan deposits at the southwestern margin of the valley, corroborating this age estimate. Such soil development indicates long-term surface stability or, more likely, long-term, slow net aggradation with episodic surface stability, interspersed with erosion.

A more recent set of deposits is present in the central part of the valley, representing a localized cut and fill sequence. The soil developed in these sediments is less reddened and has weak  $\text{CaCO}_3$  morphology. On the basis of stratigraphy, soil development, and associated artifacts, it is likely that these sediments date to the terminal Pleistocene, and soil development to the early- to mid-Holocene. Overall, the Polop Alto is characterized by a series of land surfaces over much of the valley that have been relatively stable (i.e., minimal erosion or aggradation) since the terminal Pleistocene and even earlier in some areas.

Evidence from other contexts suggests that even as hunter-gatherers, humans played a significant role in the development and modification of Pleistocene landforms in the Polop Alto. Anthropogenic fire (see Pyne, 1998; Webb, 1998), both intentional and/or unintentional, likely had significant impact on the structure of vegetation communities, as did human consumption of herbivores and plants themselves (Rindos, 1980). This, in turn, would have affected both sediment movement and soil formation (Birkeland, 1999). Intriguing as this possibility is, we do not yet have direct evidence of the extent to which human activities shaped Pleistocene landforms in the Polop. Nevertheless, we need to consider that over the long term, these landscapes have co-evolved with their human occupants.

### **Holocene Landscape Evolution**

Characterized increasingly by agro-ecosystems, Holocene landscapes of the Polop Alto bear a much clearer human footprint. Agriculture has been practiced in the Polop Alto for more than 7500 years, and terracing from the Bronze Age onward (Trelis, 1992). Cultivation is a mixed blessing for archaeologists. On the one hand, it makes buried cultural materials visible at the surface. On the other, it reduces the resolution of spatial patterning. Still, artifacts do not seem to move far from their positions before plowing, and the rate at which they disperse from their orig-

inal locations rapidly decreases with time (Cowan and Odell, 1990; Odell and Cowan, 1987; Steinberg, 1996). The pervasive terracing throughout the valley presents similarly positive and negative aspects for the archaeological record. In most cases, agricultural terraces in the Polop seem to have been created by removing sediment from upslope and redepositing it downslope. This means that artifacts found near the upslope edge of an agricultural terrace may have been buried; those near the center of the terrace tread were near the former surface; those at the downslope edge may be mixed buried and surface material. Systematic auger coring during the 2000 field season has verified this general terracing model, at least in the areas tested.

Agriculture can also variably affect the degree to which artifacts are observed and collected during survey. Cultivation of different forms of crops (cereals versus orchards, for example) differentially disturb the ground surface. For cereal cultivation, entire fields are plowed and disked, exposing artifacts at the time of cultivation. Cultivation is relatively shallow, usually less than 0.5 m in depth. In orchards, cultivation can be very deep for initial planting, more than 0.5 m in depth, exposing deeply buried artifacts. After planting, orchards are periodically cultivated to a shallow depth between the trees for weed control and soil improvement. Furthermore, the timing of survey with respect to the cycle of agricultural activities also affects artifact recognition. Ground visibility is near zero in stands of ripe cereals, but nearly 100% in the same field when it is cultivated for a new crop. In orchards (and vineyards to some extent), ground visibility is never 100% after initial planting. However, in well cared for orchards, frequent cultivation between trees may continuously expose artifacts. Fields that are in a fallow cycle or abandoned can also be covered with vegetation, affecting artifact visibility. Although more generally considered a pragmatic difficulty to be overcome in field methods rather than a formation process *per se*, variability in modern landuse practices indirectly, but significantly, affects modern recognition of prehistoric behavioral residues as much as erosion or burial.

At a larger scale are changes to the drainage network of the valley. Throughout the Upper Pleistocene, the primary drainage of the Polop valley probably was along its northern side, exiting along the course of the present day Río Barxell in the vicinity of the Middle Paleolithic site of Cova del Salt (Barton, 1988:37). This paleodrainage pattern is still visible in the valley's modern topography (Figure 2). Sometime following deposition of the late Pleistocene sediment series, the Río Polop and its primary tributary, the Barranc del Troncal, captured most of the Río Barxell drainage system. This shifted the valley's primary drainage from the north to the south side and is associated with the deep incision (30 m or more) of the Río Polop and its major tributaries.

The exact timing of this change in the valley hydraulics is not known. However, deep incision of the upper Río Serpis postdates the Neolithic IIB occupation at the site of Niuet (Bernabeu et al., 1994). The Serpis serves as base level for the Polop Alto streams, suggesting that incision of the Río Polop and its capture of Barxell

drainage net postdates the Neolithic IIB (i.e., after 2400 B.C.). Such incision is usually the result of increased runoff or significant regional base level changes. While tectonic uplift could have effectively changed base level by raising the Serpis drainage higher above sea level, increased runoff seems more likely given the timing, and vertical and aerial extent of this downcutting. This leaves open the possibility that human activities of Neolithic II or later age, especially land clearance, tillage, and pastoralism, contributed to this erosional event. In this respect, paleobotanical evidence from downstream in middle Río Serpis valley indicates that significant clearance had already occurred by the Neolithic IIB (Dupré Ollivier, 1988:38–39) accompanied by higher energy surface flows and transport of slope sediments (Fumanal Garcia, 1995). This downcutting also would have altered the Polop archaeological record by removing all previously accumulated cultural deposits in affected areas. However, this incision only affected a comparatively small part of the valley aerially—primarily along the Río Polop and its main tributaries. Fortunately for archaeological study, this incision and related stream capture also resulted in the effective abandonment of much of the original Polop valley drainage net, preserving it from subsequent fluvial erosion.

The most recent evidence for large-scale landscape alteration is in the form of relatively recent sheet erosion, stripping away Pleistocene soils and exposing the underlying marls. This form of sheet erosion has been documented in Murcia and Almería, to the south of Alicante Province, with evidence for the most intensive erosion linked to changing landuse and abandonment following the expulsion of the Moors and Jews at the end of the 15th century (Arteaga et al., 1987; Butzer et al., 1986; Schubart et al., 1990; Van der Leeuw, 1994). Similar timing for sheet erosion in the Polop Alto is consistent with the observation that only subrecent artifacts have been found in such areas. This sheet erosion has removed sediments and all evidence of human occupation from irregularly distributed zones in the Polop valley. In some cases, these sediments have filled in and choked minor drainages; in others, they have been washed into major drainages and transported down the Río Serpis. In choked minor drainages (comparatively easy to recognize in the field, because of sediment color and structure), prehistoric artifacts are rare or missing at the surface, although they may be buried under marly redeposited C-horizon materials, removed last in areas affected by sheet erosion.

Another effect of human landuse on landscape evolution is the creation of palimpsest accumulations of artifacts (Stafford and Hajic, 1992; Wandsnider, 1992). That is, the repeated use of places will lead to the superimposition of artifact accumulations from temporally distinct episodes of artifact discard. When deposition is slow or there is deflation, the very conditions that make evidence for human landuse more visible to archaeologists, the residues of such temporally distinct episodes can be combined into a single accumulation. While this is a particularly acute problem in spatially restricted locales such as occupied caves and rockshelters (Barton and Clark, 1993), it can also affect open-air contexts and becomes an increasing problem as decreasing residential mobility results in increased reoccu-

pation of particularly favored locales (Wandsnider, 1992). When reuse episodes are separated only by thin sediment layers, cultivation, too, will produce effective palimpsests.

Overall, as the above discussion indicates, much of the Polop Alto seems broadly characterized by surfaces that have been comparatively stable since at least the late Pleistocene. Significant disturbance since the mid-Holocene includes deep, but aerially limited incision by the major streams and occasionally severe sheet erosion that has locally removed patches of Pleistocene sediment down to the marls. Both of these forms of Holocene landscape change are probably indirectly due in part (if not primarily) to human landuse.

## **FORMATION PROCESSES AT REGIONAL SCALES**

### **Artifact Taphonomy and Landscapes**

The residues of past human behavior can potentially comprise a wide diversity of phenomena, including ruins of stone structures, earthworks, sedimentary fills, burned or chemically altered sediments, and anthropogenic soils. However, artifact accumulations make up the most common class of behavioral residues encountered by archaeologists, especially in the context of surface survey. The conceptual tools developed by Michael Schiffer (Schiffer, 1980, 1983), and subsumed under the term site formation processes, have proven useful in guiding archaeologists' understanding of the ways in which the archaeological record is produced and in forging more realistic links between the archaeological record and past human behavior.

Site formation processes, as the phrase implies, are primarily concerned with the processes that create "sites." The concepts used in dealing with site formation processes generally assume some form of close spatial equivalence between locales of prehistoric human residence (i.e., a group of humans occupying and using a particular place more or less continuously for several days at least) and clusters of behavioral residues found by modern archaeologists that are significantly denser than residues on the surrounding landscape (Dunnell, 1992). For sedentary agricultural villagers, living in settlements with significant labor investment in built features (for habitation, storage, ritual, and so forth), this equivalence is accurate in many cases. For foragers and small-scale agriculturalists who practice shifting cultivation or for whom wild resources constitute a significant part of the diet, this equivalence is much less certain.

In such contexts, artifact accumulations (including their density, diversity, location, and morphology) are likely to be the result of a complex mix of a variable suite of cultural and natural processes that differentially affect the landscape (Dunnell, 1992; Stafford and Hajic, 1992; Stafford, 1995; Waters, 2000; Zvelebil et al., 1992). Integrating information about the effects of these processes on artifact assemblages is similar to incorporating taphonomic information (such as evidence for accumulating agents, differential element loss, and morphological alteration) into interpretations of faunal assemblages. Hence, we think it useful to employ the

**Table II.** Surface visibility and artifact density for lithics and ceramics.

Visibility	N of units	Mean density	$\sigma$	CV	Visibility comparisons	T	<i>p</i>
Table IIa: all collection units							
Lithics							
poor	22	1732.6	2885.1	1.7	Poor vs. fair	0.77	0.44
fair	15	1047.5	2320.4	2.2	Poor vs. good	0.99	0.32
good	117	1030.5	3071.7	3.0	Fair vs. good	0.02	0.98
Ceramics							
poor	22	43.7	84.1	1.9	Poor vs. fair	1.60	0.12
fair	15	12.7	27.9	2.2	Poor vs. good	-0.45	0.65
good	117	251.4	2135.2	8.5	Fair vs. good	-0.43	0.66
Table IIb: collection units with artifacts							
Lithics							
poor	17	2242.2	3116.2	1.4	Poor vs. fair	0.85	0.40
fair	12	1309.4	2545.3	1.9	Poor vs. good	0.98	0.32
good	89	1354.7	3463.2	2.6	Fair vs. good	-0.04	0.96
Ceramics							
poor	17	56.5	92.1	1.6	Poor vs. fair	1.69	0.11
fair	12	15.9	30.6	1.9	Poor vs. good	-0.46	0.64
good	89	330.5	2446.1	7.4	Fair vs. good	-0.44	0.65

concept of artifact taphonomy in inferring past human activities from modern artifact distributions at landscape scales, especially when dealing with behavioral residues from residentially mobile foragers and simple agriculturalists. Employing the perspective of artifact taphonomy, we seek not simply to identify gaps or distortions in the archaeological record but to match inferences to the appropriate resolution for the available data and use an understanding of formation processes to gain additional information about past human behavior (see Paddayya and Petraglia [1993], Stafford [1995], and Zvelebil et al. [1992] for examples of similar endeavors). We discuss below our attempts to apply a taphonomic approach to artifact accumulations in the Polop Alto valley in order to better understand changes in human landuse.

### Modern Landuse and Artifact Visibility

As discussed above, modern landuse practices can affect archaeological recognition and perception of artifact accumulations. This, in turn, can affect the inferences we derive about past human behavior from these accumulations. This realization has led us to systematically record modern landuse in order to assess its effect on the recognition of artifact accumulations. Here, we have reclassified modern landuse into three ordinal categories of surface visibility—good, fair, and poor—and compare the density of lithics and ceramics for patches assigned to each category. The results are shown in Table II.

**Table III.** Counts of lithic artifacts recovered from resurveyed collection units.<sup>a</sup>

Collection Unit	Artifacts Recovered by Survey & Collection Date						Total Artifacts from All Collections
	Oct 1991 (initial survey)	Dec 1991	Mar 1993	Oct 1993	Mar 1995	Oct 1995	
NA-5-IBI	50	26					76
NB-11-1*	139		<b>231</b>		120	<b>315</b>	805
SB-10-4	14	8					22
SB-11-1	216	40					256
SB-12-1*	15	<b>18</b>					33
SB-12-10	110			51			161
SB-12-11*	18			<b>38</b>			56
SB-12-13*	90			<b>182</b>			272
SB-12-14	112	13		47			172
SB-12-2*	39	<b>61</b>					100
SB-12-5	15	5					20
SB-3-1	156			59			215
SB-3-2	130		12	27			169
SB-3-3*	48		<b>91</b>	11			150
SB-3-4	166		27	73			266
SB-3-5*	43			<b>53</b>			96
SB-9-1	96	45					141

<sup>a</sup> Units in which a resurvey recovered more artifacts than the initial one are indicated with an asterisk. Artifact counts exceeding initial survey values are shown in bold.

As can be seen, mean artifact densities vary considerably among patches with different levels of visibility. Indeed, mean lithic densities are much higher in patches with poor visibility than in other patches. However, there is so much variation in artifact density, especially in patches with good visibility, that the difference in mean values is not very significant. This is seen in T-test values for comparisons between groups of collection units with different levels of surface visibility. In general, the pairwise comparisons show high p values, and all p values are greater than 0.1. This is the case for comparisons between all patches, and even among only those patches in which artifacts were found (eliminating the potential for confusion between a lack of surface artifacts and the invisibility of surface artifacts due to landuse practices). Hence, while some variability in observed artifact density probably is due to differential modern landuse practices, it is largely overshadowed by variability caused by other factors.

This analysis suggests that the primary effect of land cover is the nonrecognition of low-density artifact accumulations in patches with low visibility. In such patches, only moderate to high density artifact accumulations were initially noticed, but these were subsequently well-collected. This would account for the comparatively high mean artifact density in patches with poor visibility. In this case, surface visibility makes an important contribution to spatial patterning in low-density artifact accumulations, and inferences about the distribution of human activities should not be based on such accumulations. However, as indicated above, factors

other than modern landuse must be invoked to account for spatial variability in moderate and high density accumulations.

Another way to assess the effects of modern landuse on archaeological recognition of artifact accumulations is to repeatedly resurvey and recollect the same piece of ground. Several archaeologists have conducted experimental programs to assess the combined effects of cultivation and resurvey (e.g., Ammerman and Feldman, 1978; see discussion in Steinberg [1996]). We resurveyed several tracts in the Polop Alto, providing an alternative way to evaluate potential variation in recognition of artifact accumulations in the valley. The results are shown in Table III.

As can be seen, there is no consistent patterning in the numbers of artifacts recovered in resurvey of the same fields, nor in the number of artifacts recovered from the same fields at different times of the year. In approximately half (7 of 17) of the units resurveyed, a subsequent collection exceeded the initial one in size. This does not seem to be associated with season, even though fields were surveyed at several different times of year.<sup>1</sup> This suggests to us that our initial survey in the fall of 1991, the dataset used for most of the landuse study described below, lacks systematic artifact recognition and collection bias due to modern landuse or season of survey and, again, that most observed spatial variation is a result of factors other than modern landuse.

### **Postdepositional Transport and Modification**

As previously discussed, two forms of erosion have affected landscapes and artifact accumulations in the Polop Alto. Arroyo cutting has affected a comparatively small part of the valley. It may have horizontally truncated artifact accumulations or divided continuous artifact distributions into discrete segments. This is almost certainly the case in the central part of the Polop Alto, immediately north of the confluence of the Barranc Troncal and Barranc de Calavera (see Figure 2). This is a more pervasive feature of landscapes in several other valleys we have surveyed, especially the middle Río Serpis and Río Penaguila valleys, but has had relatively little effect on artifact patterning in the Polop valley because incision is primarily limited to the Río Polop and the lower reaches of its two major tributaries, the Troncal and the Calavera, along the southern margin of the valley.

Recent sheet erosion has played a more dramatic role in the taphonomy of artifact accumulations. The current lack of prehistoric artifacts in areas from which Pleistocene and Holocene soils have been stripped could indicate that artifacts never accumulated in these areas. However, it is more likely that artifacts were transported along with the sediments in which they were buried. While some of these sediments, including the artifacts they contained, may have been redeposited in adjacent, minimally eroded areas, most seem to have been reburied or removed from the valley. As noted above, much of the sediment derived from sheet erosion seems to have choked minor drainages in the Polop Alto, where redeposited, ar-

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<sup>1</sup> Summer is generally avoided for survey because many fields have standing crops.

tifact-bearing soils were buried by archaeologically sterile C horizon material. Alternatively, given the quantity of sediment accumulated in the lower reaches of major drainages (Arteaga et al., 1987; Schubart et al., 1990; Van der Leeuw, 1994), much of this eroded sediment, and any artifacts it originally contained, has been removed entirely from the Polop Alto.

In the course of excavation, geoarchaeological study of sedimentary contexts of artifacts can provide valuable information about taphonomic processes (e.g., Stafford and Hajic, 1992). However, obtaining relevant geomorphic information is considerably more problematic in the context of surface survey, although road and stream cuts and other fortuitous exposures can be helpful when available. Fortunately, artifacts themselves can provide information about transport and depositional environments. Although artifacts are generally considered as cultural phenomena by archaeologists, from a geological perspective they are simply moderately coarse clastic sediments. As sedimentary clasts, their morphology is altered by the nature and duration of transport and by the environment of deposition (Paddayya and Petraglia, 1993). In our analysis of collections from the Polop Alto, we recorded two morphological characteristics related to postdepositional transport of chipped stone artifacts: noncultural edge damage and significant abrasion of the exterior surface. Edge damage is defined as irregular, alternating (or sporadically bifacial) flake removal (including step flaking and crushing) along the edges of lithic artifacts. This differs from regular bifacial or unifacial retouch or macroscopic usewear. It was recorded in ordinal categories of none, present on less than 25% of the total artifact margin, and present on more than 25% of the margin. Although some such damage may be the result of use, most probably is not. A considerable amount of edge damage is probably the result of agricultural activities, including land clearance, tillage, and trampling by domestic animals. Colluvial/fluvial transport can also cause edge damage, with low energy/short distance transport causing minimal amounts of damage and high energy/long distance transport producing more intensive damage in combination with surface abrasion.

Surface abrasion is defined as significant rounding/crushing/striating of flake scar ridges on the exterior face of lithics. Given that polishing by eolian sediments is not a common feature in this environment, abrasion is most often an indication of colluvial/fluvial transport. It is almost always accompanied by a considerable amount of edge damage. It was recorded as present or absent.

Breakage also was recorded. This can be caused by techniques of lithic manufacture, trampling by humans or animals, postdepositional transport, or (especially mechanized) cultivation. An analogous index of fragmentation was recorded for ceramics (see Bernabeu et al., 1999, 2000). This, too, can result from several processes, including postdepositional transport, but is not discussed here due to low ceramic frequencies in the Polop Alto (although higher ceramic frequencies in other valleys we have surveyed make this a more useful measure elsewhere).

We have examined variation in lithic edge damage and surface abrasion in several ways. Clearly if more time has elapsed since an artifact was used and discarded by humans, the chance that it has been moved from its original discard location is



**Table IV.** Frequency of transport damage on different artifact classes.<sup>a</sup>

Type	Abrasion (%)	≥25% Edge Damage (%)	<25% Edge Damage (%)	No Edge Damage (%)
Levallois core	28	35	61	04
Flake core	11	13	77	10
Blade core	4	4	64	32
Unretouched flake	8	31	55	14
Unretouched blade	0	21	68	11
Unretouched bladelet	0	0	73	27
Mousterian point	13	23	70	07
Side scraper	11	22	67	11
Notch/denticulate	17	28	61	11
Retouched blade	0	0	100	0
Retouched bladelet	0	0	75	25
Geometric	0	0	5	50

<sup>a</sup> See text for descriptions of abrasion and edge damage.

higher. Similarly, by being potentially exposed to a wider range of geomorphic processes, older artifacts are more likely to be moved farther than younger artifacts. Although dating of lithic artifacts on the basis of their morphology is often problematic, certain lithic forms can be assigned a relative age at a coarse scale with reasonable confidence. For example, discoid and “Levallois” flake cores have been made to varying degree from the initial appearance of bifacial technology in Europe during the middle Pleistocene through the Neolithic. Nevertheless, they are most commonly found in Middle (and to some extent Lower) Paleolithic contexts. Prismatic blades, while occasionally made far into antiquity, really only became a common lithic product with the Upper Paleolithic. Similarly, small bladelets, and especially geometric and nongeometric microliths, are most common from the later Upper Paleolithic through the Neolithic I, although they can occur in other contexts.

Using these rough indications of age, we have evaluated evidence for post-depositional modification and transport of artifacts through time in the Polop Alto. These results are shown in Table IV. Surface abrasion is generally rare, only affecting over 10% of the pieces in those few artifact classes likely to contain the oldest specimens and exceeding 20% of pieces only for Levallois/discoidal cores. Light edge damage is very frequent, reflecting the long history of cultivation in the Polop, but more intensive edge damage is much less common. Except for unretouched blades, it exceeds a frequency of 20% only for those categories likely to include the oldest artifacts. Overall, abrasion affects 10% of the total lithic collection and more intensive edge damage 13% of the total.

Pieces with both surface abrasion and intensive edge damage are those most likely to have experienced significant postdepositional transport, but constitute only 0.7% of the entire assemblage from the Polop Alto. In sum, the effects of agriculture on artifact accumulation are pervasive in the Polop Alto. However, the

effects of postdepositional transport and redeposition on artifact accumulations present today in the valley are of much lesser import, although older artifacts display more evidence of transport than more recent ones. The potential effects of these processes on spatial patterning of artifact accumulations is discussed further below.

### **Erosion and Artifact Density**

Even though a comparatively small portion of the artifact accumulations recovered during our survey in the Polop shows evidence of postdepositional transport, sheet erosion has removed most of the artifacts in areas where the transport was most intense. It seems likely that many or even most of the artifacts so removed have been buried in choked minor drainages or carried to the major drainages rather than being redeposited in adjacent, less eroded areas. This effectively reduces artifact counts for the most intensely eroded collection units. To compensate for this, we have incorporated information about the intensity of sheet erosion in our calculations of artifact density in landuse modeling discussed below.

In the Polop, as well as in many surrounding valleys, the red and brown Pleistocene and Holocene soils that formed in Pleistocene deposits are clearly distinct from the whitish marls that underlie them. Hence, those areas where sheet erosion has stripped away these soils and exposed the underlying marls are easy to recognize on the ground and in aerial photographs. Although we noted areas of exposed marls during survey, aerial photographs have provided a more systematic way to evaluate the effects of sheet erosion on artifact accumulations (Figure 4).

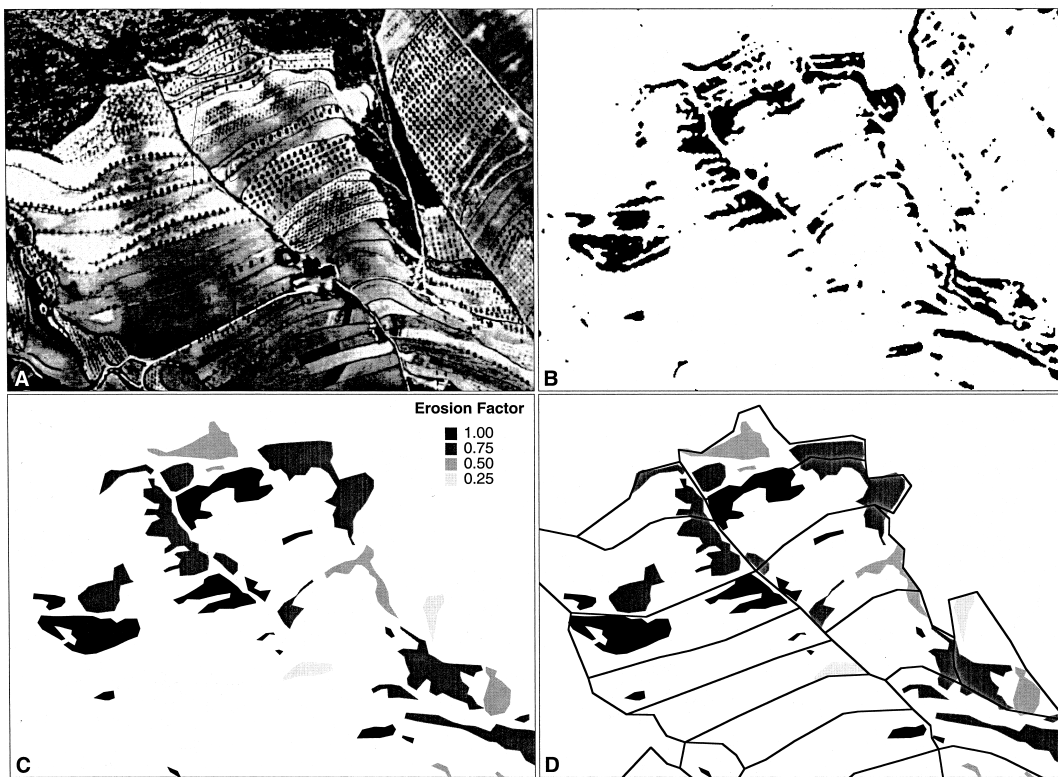
Aerial photographs were scanned (Figure 4A) and then analyzed in an image analysis program.<sup>2</sup> A thresholding operation was initially performed to isolate areas of bright white marls; these were then filtered to remove noise<sup>3</sup> (Figure 4B). The resulting image was then imported and registered in a GIS program (MapInfo), where polygons were traced around eroded areas (Figure 4C). The areas enclosed by these polygons varied from almost complete eroded (i.e., solid white on aerial photographs) to a dense patchwork of erosion (i.e., enclosing many small patches of eroded areas). This variability was visually evaluated for each polygon, and an erosion factor of 1.00, 0.75, 0.50, or 0.25 was assigned to each polygon (1.00 for solid erosion and 0.25 for many tiny patches).

In the GIS, the polygons outlining collection units were overlaid with the polygons representing erosion (Figure 4D). The area of overlap (i.e., the intersection of the two polygon layers) for each collection unit was multiplied by the erosion factor and subtracted from the total area of the collection unit. The resulting “un-

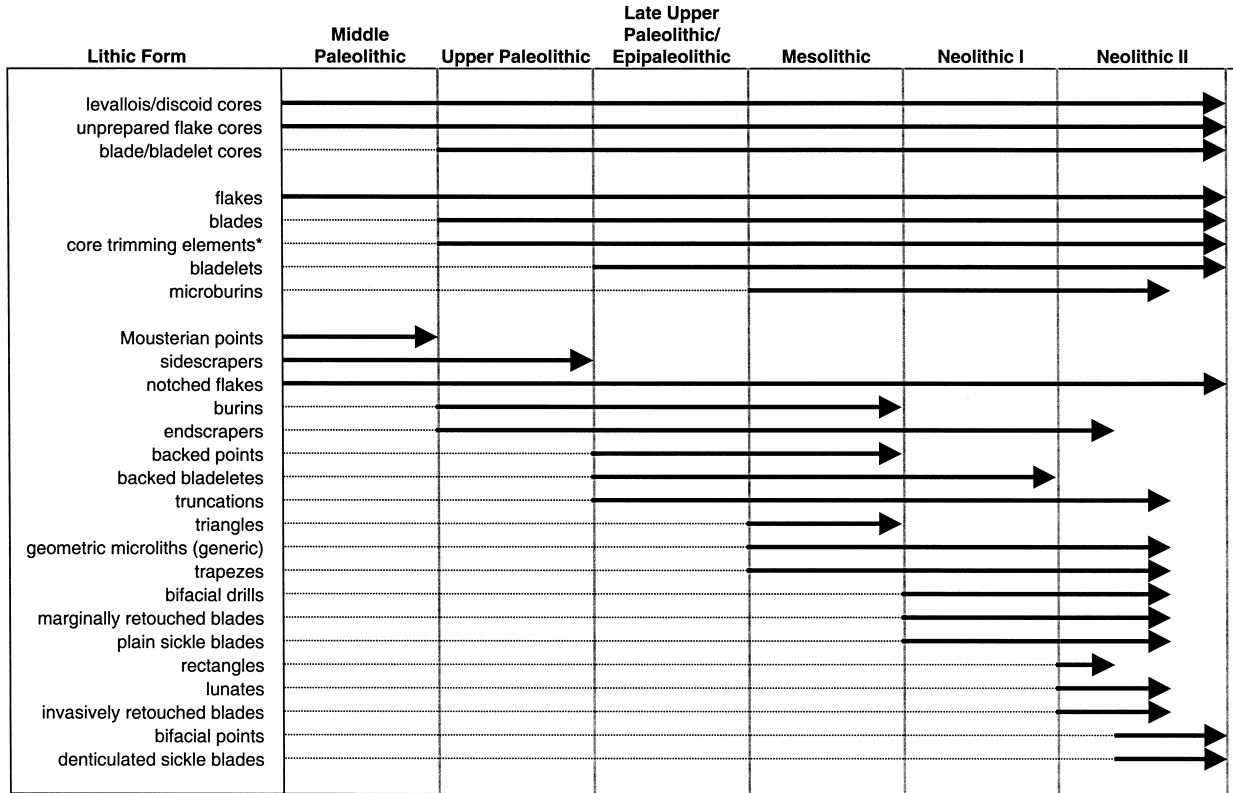
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<sup>2</sup> We used NIH Image, a public domain image analysis program for the Macintosh developed by the National Institutes of Health and available on the internet at <http://vsb.info.nih.gov/nih-image/>.

<sup>3</sup> A empirically determined value of 20, out of 256 shades of grey, was used as a cutoff point for thresholding. Noise reduction was done through performing two dilate operations, followed by two close operations.

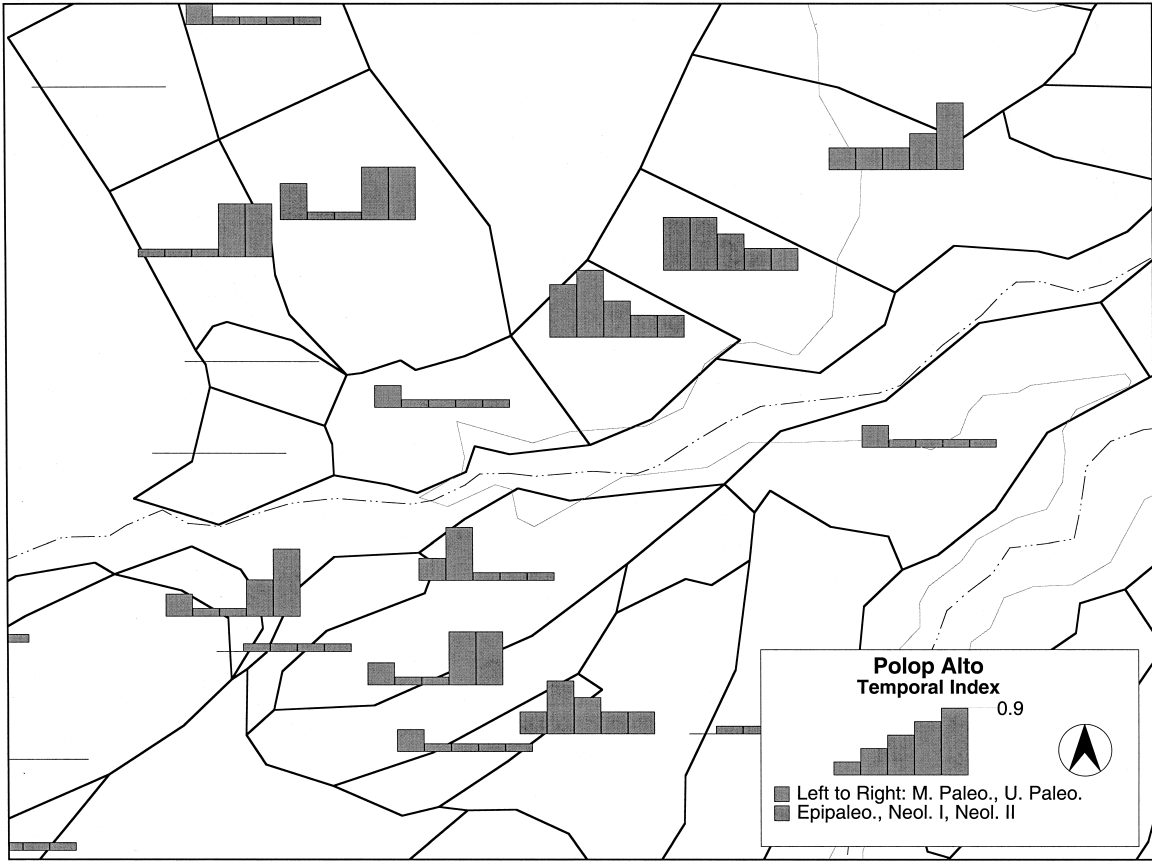


**Figure 4.** Mapping sheet erosion. (A) Aerial photo of part of the Polop Alto Valley; bright white zones indicate areas of erosion exposing underlying marls. (B) Result of image analysis and filtering (see text); black shapes indicate severely eroded areas. (C) Polygons have been traced around severely eroded areas (from B) and assigned an “erosion factor” representing the amount of erosion in each polygon. (D) Collection unit polygons are overlaid by erosion polygons so that the effective “uneroded” areas of collection units can be calculated.



\* core trimming elements refers to preparation and rejuvenation flakes from blade/bladelet cores, including platform tablets, crest blades, and removal face rejuvenation flakes.

Figure 5. Use chronology of selected lithic artifacts forms from the survey area.



**Figure 6.** Graphical representation of Temporal Index applied to study patches. Histogram in each patch indicates TI values for each time period for that patch.

eroded" area (rather than original total collection unit area) was then used to compute artifact density (i.e., artifact count/uneroded area).

## PREHISTORIC BEHAVIOR AND ARTIFACT ACCUMULATIONS

### Chronology

Although an understanding of the cumulative effects of taphonomic processes on the archaeological record is fundamental to making inferences about past behavior, it is also necessary to establish and apply a chronological framework to these processes in order to model the long-term dynamics of geoarchaeological landscapes and human ecosystems. However, chronology building is generally more problematic for surface artifact accumulations than is the case with buried, stratified archaeological materials (Jones and Beck, 1992; Zvelebil et al., 1992). For our work in the Polop Alto, the absence of surface materials datable by numerical methods (organics for  $^{14}\text{C}$  analysis, for example) and the general lack of cultural materials with a fine degree of temporal resolution, is exacerbated by taphonomic processes discussed above, a common situation for surface survey, making it difficult to apply many surface dating methods of use to geomorphologists in non-agricultural areas (Dorn and Phillips, 1991).

Fortunately, as archaeologists know, artifact accumulations themselves are potentially useful for dating if used judiciously. Our approach to chronology makes use of artifacts while taking a number of factors into account (see Figure 5). First, an artifact class may be temporally meaningful in its initial appearance but may persist for a long time. For example, prismatic blade technology first appears in the Upper Paleolithic of this region but persists into the Bronze Age. Second, the absence of an artifact class, as well as its presence, may be of chronological importance. For example, an assemblage that includes blades and ceramics is likely of Late Neolithic or Bronze age, while an assemblage of blades without ceramics is more likely to be Upper Paleolithic. Third, in an area like the Polop, which has seen human occupation since the Middle Paleolithic, there is a likelihood that many assemblages represent a palimpsest of human activities. Fourth, and perhaps most important, dating artifact assemblages is a statistical estimate regardless of the method used. Different methods (e.g., soil development, radiocarbon, and inscribed coins) provide different degrees of reliability in dating, but all are probabilistic.

With these considerations in mind, we developed a means of ranking artifact assemblages according to the probability that they derive from a particular chronological interval. Each study patch was assigned an ordinal "Temporal Index" value, ranging from 0 to 0.9, for each of five time intervals on the basis of the artifacts recovered (Figures 5 and 6). A detailed description of the ranking procedure can be found in Barton et al. (1999). This method of estimating the age of surface artifact accumulations is not fundamentally different from widely used archaeological approaches to dating for surface survey. However, we have tried to systematize (and make more replicable) what is usually a more subjective assessment. Also, our age estimates explicitly include a level of uncertainty, which we think is

more realistic. Finally, our approach to chronology also has allowed us to incorporate taphonomic information into our modeling of prehistoric landuse. The intervals used (Middle Paleolithic, Upper Paleolithic, late Upper Paleolithic/Mesolithic, Neolithic I, and Neolithic II, primarily Neolithic IIB/C in the Polop) reflect both the overall coarse temporal resolution of surface collections and the increasingly finer resolution possible with later materials. In other areas we have surveyed, where the availability of more detailed data permit, we have tested more detailed chronologies (Bernabeu et al., 1999, 2000). Nevertheless, the framework used here still provides adequate chronological resolution to examine the dynamics of human activities in the Polop Alto.

### **Modeling Landuse Intensity**

The Temporal Index (TI) provides an estimate of the age of artifact accumulations but is not sufficient, in and of itself, to permit modeling of landuse patterns over time. To the extent that artifact accumulations are the result of discard behavior, TI values for collection units can indicate where human activities took place in the past. However, landuse varies spatially in terms of the types of activities performed, numbers of individuals participating in activities, duration of occupation, and frequency of reoccupation, for example. Taken together, these various dimensions constitute a scalar measure we term the “intensity” of landuse (Barton, 1988:108). For a given class of artifactual material (lithics, for example) this landuse intensity usually is grossly proportional to the amount of material discarded. The way in which a material is used and (for lithics, especially) the availability of needed raw materials also can affect discard rates, of course. However, lithic material availability can be taken as roughly equivalent for localities across the Polop Alto, where flint occurs as nodules in the marls that underlie much of the valley. Lithic use certainly varied, but it is likely that multiple activities are represented in most artifact accumulations of sufficient density to be archaeologically visible given the long-term occupation of the valley, the shifting nature of settlement through time, and the strong potential for many locales to have been used more than once. Ongoing analyses of lithic forms and their spatial and temporal distributions, not presented here, are helping to better assess this (Barton et al., 1999). Within these limits, artifact frequency, therefore, can serve as a surrogate measure of landuse intensity where the spatial variation in artifact accumulation patterns can be linked primarily to human discard behavior (see below), especially in cases, such as in the Polop, where built features are not preserved on the surface. Although the various components of landuse intensity, mentioned above, can be difficult to distinguish (see Kvamme, 1997; Schreiber and Kintigh, 1996; Wandsnider, 1992), assessing overall landuse intensity at a regional scale provides information about spatial configurations of prehistoric human ecosystems.

There remains the palimpsest problem, in that some (perhaps many) artifact accumulations are the result of temporally distinct deposition episodes. It is generally impossible to assign most individual artifacts from a temporally mixed sur-

face assemblage to distinct time periods, even when the periods are clearly indicated by the presence of chronologically sensitive artifact forms. Rather, we make the reasonable and often justifiable assumption (commonly, though usually implicitly made in most survey projects) that the accumulation interval in which the greatest proportion of an artifact assemblage is deposited also is most likely to leave the clearest temporal signal in the assemblage. This is due to the usually strong positive relationship between assemblage size and artifact diversity (Jones et al., 1983; Kintigh, 1984; McCartney and Glass, 1990). Because TI is an ordinal measure of confidence (i.e., clarity) in temporal signals, it allows us to estimate at regional scales the proportion of the assemblages from each study patch that accumulated during each time interval.

To accomplish this, we weighted an ordinal derivative of artifact density in each patch by TI (also an ordinal measure).<sup>4</sup> This produced a temporally referenced estimate of the relative intensity of artifact accumulation during each of the five time intervals considered for each patch. Optimistically and somewhat unimaginatively, we call this estimate “settlement intensity index” or SII. While computing SII does not allow us to divide an artifact assemblage from a study patch into temporally distinct components, to the extent that artifact accumulations indicate landuse, it does allow us to quantitatively model variation in landuse intensity through time across our study patches and, at a regional scale, to model changing landuse patterns in the Polop Alto valley.

Although we think that SII provides a very useful means to unmix artifact accumulations and model landuse, care must be taken in interpreting SII values. We avoided using raw artifact density in creating SII to reduce variance due to a few extreme density values and to scale SII between 0 and 1. Nevertheless, because considerable variation is likely for artifact accumulation rates during different time periods (e.g., Paleolithic vs. Neolithic), it is inappropriate to compare SII values across time periods (i.e., an SII value of 0.5 could have a different meaning in terms of landuse intensity for the Middle Paleolithic than it would for the Neolithic II). Rather, we rank SII values within each time period and compare the spatial distributions (and other characteristics) of patches with equivalent rankings of SII for each time period. In the following section, for example, we compare distribution patterns of patches in the upper quartile for each time interval.

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<sup>4</sup> Assemblages from all patches with artifacts were ranked into six percentile groups according to artifact density (pieces per km<sup>2</sup>). This reduced the effects on SII of outlier patches with extreme values for artifact density. Units with no artifacts were assigned a value of 0, patches with densities in the lowest 25th percentile were assigned 0.25, patches in the 26th–50th percentile were assigned 0.50, patches in the 51st–75th percentile were assigned 0.75, patches in the 75th–90th percentile were assigned 0.90, and patches in the 91st–100th percentile were assigned a value of 1.00. For every patch with artifacts, the value assigned for artifact density percentile group was multiplied by the TI value for each for each chronological period to produce a “settlement intensity index” (SII) value for each time period. In this way a patch could have a high SII value for one or more periods and low values for others; it could also have equally high values (if it had many artifacts and clear temporal signals) or low values (few artifacts and/or ambiguous temporal signals) for all periods.



In addition, we focus exclusively on comparatively high SII values. Very low SII values derive from low TI values and low artifact densities. This indicates ambiguous temporal signals and the possibility that modern landuse (and attendant surface visibility) has affected spatial patterning. Slightly higher to moderate values of SII result from either low TI values (ambiguous temporal signal) and high artifact densities or high TI values and low artifact densities. In the first case, we can document intensive landuse but cannot say with confidence when it occurred. In the second case, human presence is documented at a particular time, but landuse intensity is minimal. Also, since only a few artifacts are represented, the possibility that they may be redeposited from their discard location is higher. Hence, we do not think that spatial patterning is meaningful in terms of human behavior for patches with low SII values for a particular time interval, and that spatial patterning for patches with modest SII values is ambiguous. For this reason, we do not display patches with SII values below the median for any time interval and base our interpretations on patches with SII values in the upper quartile for all time periods.

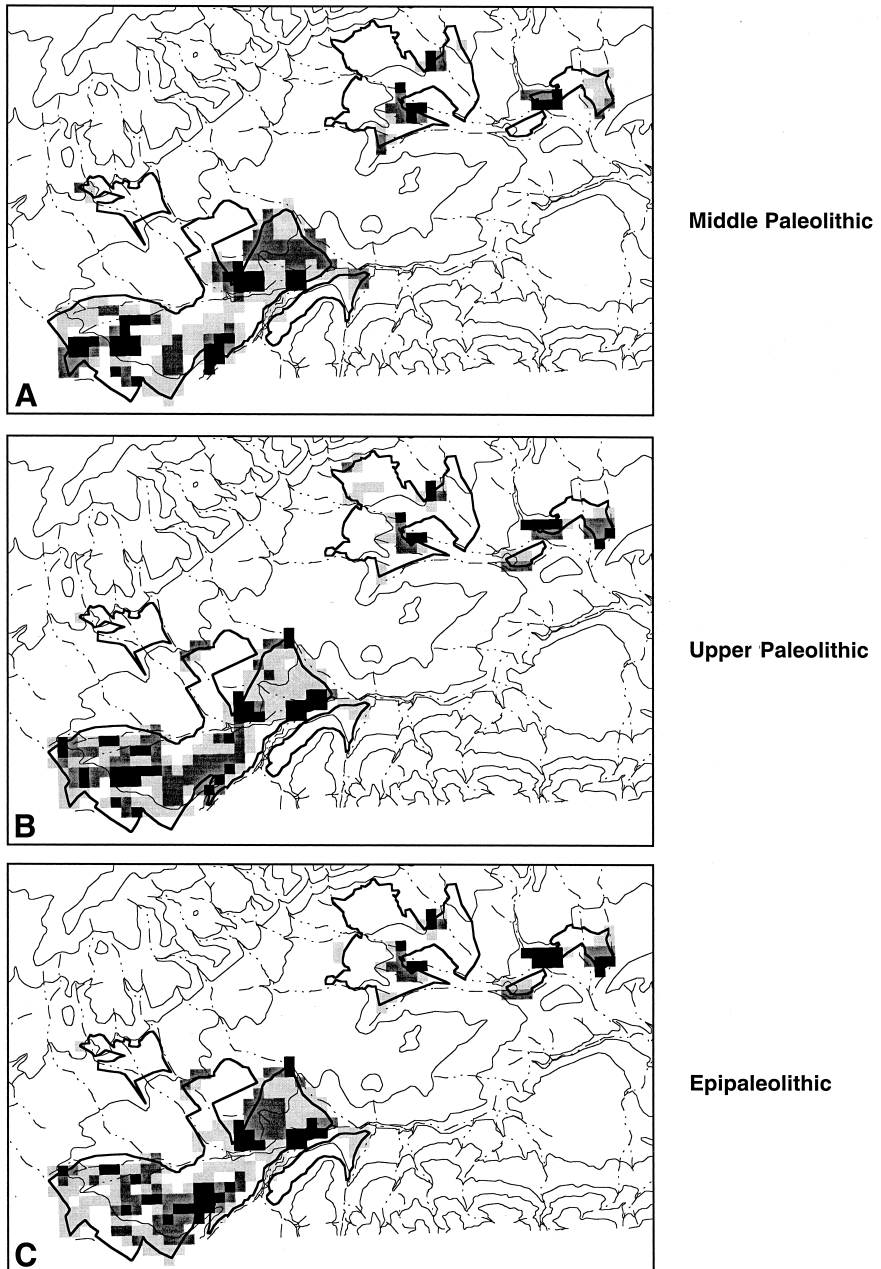
Finally, because the original study patches, individual fields, are irregular in size and shape, we overlaid the valley with a regular grid, transferring SII values from original collection units to overlying grid squares.<sup>5</sup> This effectively acts as an image filtering process to smooth landuse patterns and make them more visually apparent. This regular grid of SII values also facilitates additional quantitative spatial analysis. The result of this modeling is shown in Figure 7.

Before attempting to interpret this model in terms of human behavior, it is necessary to reassess potential noncultural sources of the spatial patterning in a temporal framework. We indicated above that artifacts of probable greater age showed a higher incidence of postdepositional transport. This leads to the question of whether areas of apparently higher occupational intensity for earlier time periods are more the result of artifact accumulations by human activities or by geomorphological processes. We, therefore, examined the spatial distribution of artifacts with probable transport damage by time period. In Figure 8, we compare the frequency of pieces with edge damage and surface abrasion in collection units with values for SII in the upper quartile for each time period. All time periods appear nearly identical in the graph and are statistically equivalent in an ANOVA of the same dataset. Hence, while assemblages from earlier time periods show more postdepositional transport, it is not of sufficient magnitude to affect spatial patterning.

We also noted previously that some areas of the Polop Alto have suffered the loss of Pleistocene and Holocene soils from sheet erosion. Figure 9 serves to evaluate the potential for this stripping to affect landuse patterning for different time periods by differentially removing artifacts. There do indeed seem to be some dif-

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<sup>5</sup> The grid size chosen,  $100 \times 100$  m, is close to the minimum collection unit size so as not to greatly exceed the resolution of the original data. SII values were assigned to grid squares on the basis of a weighted average of the SII values of the underlying collection units. Grid squares wholly overlaying a single collection unit were assigned the SII value from that unit; those overlaying more than one unit were assigned an average value of the underlying units, weighted by the percent area of the square that overlays each unit.



**Figure 7.** Maps of changing landuse as indicated by Settlement Intensity Index (SII) for each chronological period. SII values are grouped into first quartile above the median (values in the 50–75th percentile), values in the 75–90th percentile, and values in the 90th percentile.

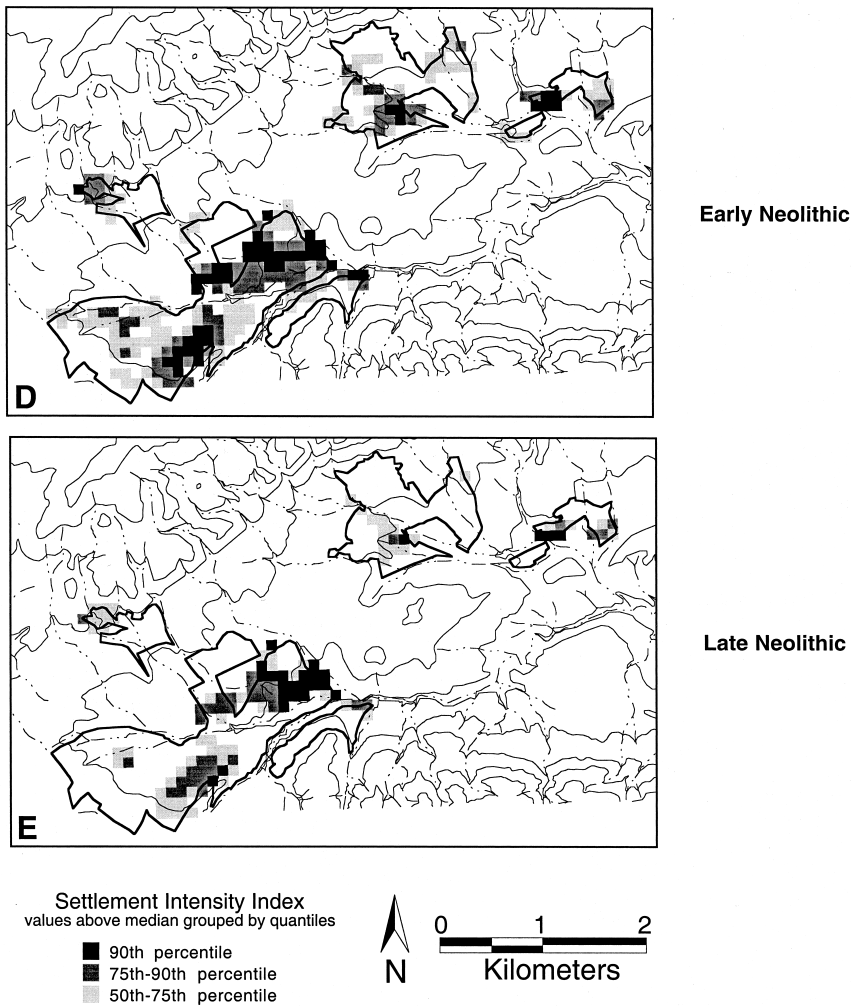
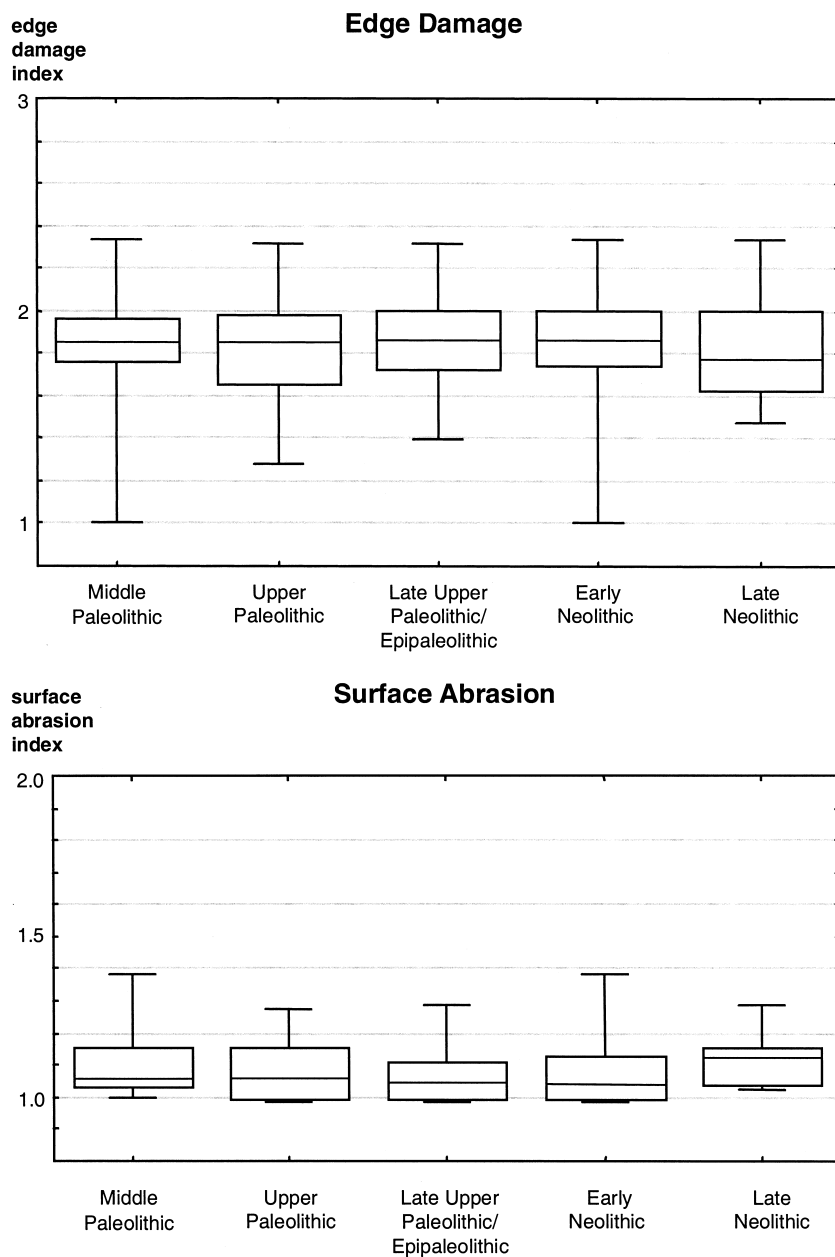
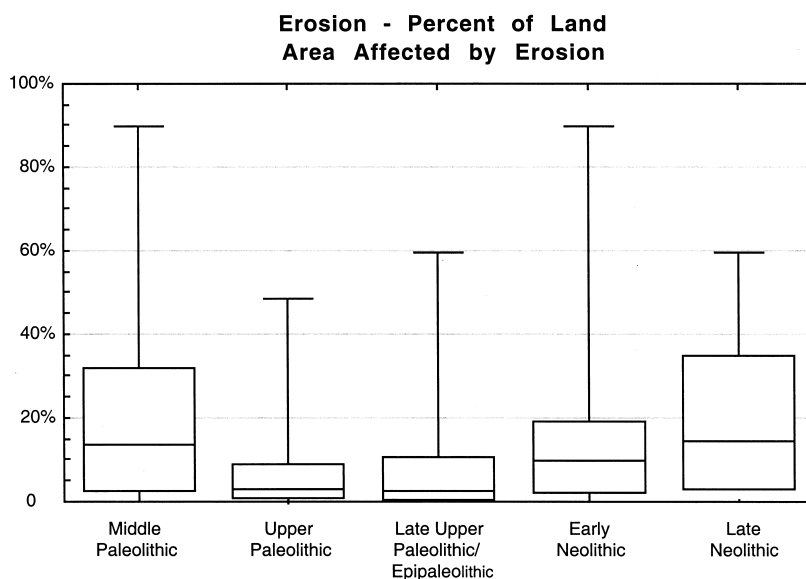


Figure 7. *Continued*

ferences in the degree of erosion affecting areas of most intensive landuse (i.e., those patches with SII values in the upper quartile for each time period) at different times; an ANOVA indicates that there is less than a 15% probability that these differences are due to random chance alone. Nevertheless, these effects do not seem to be the source of differences in landuse patterns discussed below. Notably, areas with the most intensive Middle Paleolithic and Late Neolithic occupation have experienced the most sheet erosion. However, these two periods also display the most different landuse patterns for the time intervals discussed here. Likewise, Middle and Upper Paleolithic landuse patterns are virtually identical, but the rele-



**Figure 8.** Box and whisker plots (showing median, mid-spread, and range) of mean intensity of edge damage and abrasion of flake scar ridges for lithic assemblages from collection units with Settlement Intensity Index values in the upper quartile for each chronological period. ANOVA results for edge damage:  $df = 4$ ,  $F = 0.1690266$ ,  $p = 0.9538484$ . ANOVA for abrasion:  $df = 4$ ,  $F = 0.7447714$ ,  $p = 0.5631146$ .



**Figure 9.** Box and whisker plots of percent of collection unit with evidence of severe sheet erosion, for units with Settlement Intensity Index values in the upper quartile for each chronological period. ANOVA results:  $df = 4$ ,  $F = 1.762657$ ,  $p = 0.1427084$ .

vant land areas have experienced the greatest difference in degree of sheet erosion. These results seem to verify our previous interpretation that most sheet erosion apparent in the Polop Alto is a comparatively recent phenomenon and its effects on landuse patterns essentially can be treated as random noise.

### Landuse Dynamics in the Polop Alto Valley

Given the discussion above, modeling prehistoric landuse on the basis of artifact accumulations in the Polop Alto valley seems justified. These models are presented as a series of maps in Figure 7. We want to stress that these maps represent models of spatial patterning in landuse, not reconstructed settlement patterns. The complexities of geoarchaeological landscape change and attendant taphonomic processes over the long time frame of our study largely preclude an accurate reconstruction of prehistoric settlement patterns. Rather, our models represent landuse-related spatial patterning in artifact accumulation averaged over the temporal periods we employ, and our interpretations follow this perspective.

Figure 7 shows changing patterns of landuse in the Polop Alto valley. Most notable is a change from dispersed to aggregated landuse. Middle and Upper Paleolithic landuse exhibits a dispersed pattern. Areas of most intensive landuse (areas with SII values in the 90th percentile for the relevant temporal intervals) are small and evenly distributed across the survey area. Landuse patterns appear very similar

for the Middle and Upper Paleolithic, though Upper Paleolithic landuse appears slightly more dispersed and less aggregated than Middle Paleolithic landuse. This pattern shifts by the Late Upper Paleolithic/Epipaleolithic, with the most intensive landuse focused in fewer but spatially larger localities. However, there is still evidence for significant landuse in many of the intervening areas, in the form of a few of the dispersed and areally restricted localities that typify the earlier Paleolithic. This configuration continues into the Neolithic I, with most intensive landuse centered on a few localities located along the probable course of the Río Polop paleodrainage. The major difference between the Epipaleolithic and Neolithic I pattern is the general lack of small, dispersed locales of intensive landuse. The most striking change in landuse patterns appears with the Neolithic IIB/C. Most prehistoric activity residues seem concentrated in a single locale, suggesting most landuse in the valley coalesced into a single locale (at the center of the Late Neolithic map in Figure 7). Two small outlier areas of human activity are located at opposite ends of the valley, but there is little other evidence of intensive landuse. This is a very different pattern from that seen for either the Paleolithic or Early Neolithic.

Quantitative measures of spatial aggregation support the more qualitative assessment of the landuse models presented above (Barton et al., 1999, 2001). In particular, local density analysis (Johnson, 1984; Kintigh, 1990) indicates that the most dramatic change in landuse patterning occurred with the Late Neolithic rather than the initial appearance of domesticates in the Early Neolithic. On the contrary, the Early Neolithic appears more similar to the Paleolithic/Epipaleolithic in terms of spatial clustering than to the Late Neolithic.

## DISCUSSION AND CONCLUSIONS

In the Polop Alto, we see three spatial configurations of human landuse over time. The Pleistocene/Paleolithic configuration is characterized by small locales of most intensive landuse that are rather evenly dispersed across the landscape (see Barton et al. [1999] for discussion of variation within the Paleolithic). We interpret this configuration as developing from long-term use of the landscape by small forager groups whose occupations were restricted in area, temporal duration, and in the quantity of material residues left. Any given occupation was conditioned by a set of contextual constraints that varied from time to time as well as place to place, and occupations were not consistently tethered to any particular landscape features over the long-term (Wandsnider, 1992). The accumulation pattern derived from such landuse pattern would be a more or less continuous background of artifacts whose variation in density was affected by periodic reoccupation of particular locales (intentional or unintentional) and by postdepositional processes that could concentrate or disperse and/or bury or expose different portions of this background.

A different spatial configuration of human landuse characterizes terminal Pleistocene through mid-Holocene (Epipaleolithic/Mesolithic-Neolithic I) occupation of the Polop Alto. This configuration is characterized by more diversity in the geo-

graphic size of locales of most intensive landuse, with some as small as those in the Pleistocene/Paleolithic configuration and others larger by several orders of magnitude, but with an overall low to modest artifact density. There are several potential causes for the larger areas of intensive landuse, including more frequent reoccupation, longer duration occupations, and larger group sizes. Given the generally low to modest artifact densities (Barton et al., 1999; Bernabeu et al., 1999, 2000), we tend to favor the reoccupation hypothesis in which human landuse became increasingly tethered to particular locales, most likely to acquire and process more efficiently (and possibly store) a more restricted set of resources. The fact that this configuration appears at the beginning of the Holocene is not surprising. In many places in the world, the rapid and profound changes that marked the end of the last glaciation were accompanied by a shift to foods that required more processing. Investment in processing facilities (grinding stones, roasting pits, drying ovens, etc.) can encourage the return to particular locales where such facilities remain from previous occupation to reduce overall processing costs by reducing the costs of construction/manufacture of needed processing facilities. Of course, increased tethering also is often linked to growth in social group size and increased sedentism. In any case, additional data collection, especially subsurface testing and excavation, will be necessary to begin to sort out these possible explanations for this landuse configuration. We have begun such work at several localities.

Finally, in the Neolithic IIB/C, we see a third configuration of landuse in which the most intensive accumulations of activity residues are concentrated in a single locale. Unlike the other configurations, this is more likely to be capturing part of a prehistoric settlement pattern. Within the zone of most intensive landuse during the Late Neolithic in the Polop Alto are surface staining and stone concentrations along the *barranco* walls that have marked Neolithic farming hamlets in a few other locales such as Niuet (Bernabeu, 1994). Here artifact densities are much higher in the most intensively used locales for other periods (Barton et al., 1999; Bernabeu et al., 1999, 2000). We interpret this configuration as resulting from long-term use (including possible year-round sedentism) of a single locale by the human population of the Polop Alto. A very few, spatially tiny zones of equally intensive landuse away from the main one could be locales associated with fieldworking or pastoralism, but this is not yet corroborated by architectural, faunal, or other potentially informative remains.

If this interpretation of the temporal dynamics of our landuse models is correct, it has implications for understanding the processes associated with the beginnings of agro-ecosystems in this region. Although domesticates were available by 7600 cal yr B.P., they had little impact on the spatial configuration of human landuse in the Polop Alto that initially appeared at the beginning of the Holocene. This suggests that domesticates were incorporated, possibly as alternative food resources, into essentially a hunter-gatherer ecosystem in the valley. The appearance of a landuse configuration associated with agro-ecosystems does not appear until the Neolithic IIB/C, some 2500–3000 years later. In this case, it does not seem that the availability or management of domestic plants and animals *per se*, but rather the

long-term cumulative effects of domestication that leads eventually to the beginnings of what we would consider agricultural societies.

These dynamics are made even more intriguing by ongoing, parallel studies in the Río Penaguila valley, only 20 km southeast of the Polop (Barton et al., 2001; Bernabeu et al., 1999). There, similar methods have been applied to examine long-term landuse patterns. Preliminary results suggest little change throughout the Pleistocene and into the early Holocene, and in fact less evidence of human use of the Penaguila valley than the Polop (although this apparent lack of evidence may be in part a function of subsequent landscape change in the Penaguila). The most marked change in landuse configuration comes with the Neolithic I in the Penaguila, which is marked by clearer temporal signals, more ubiquitous assemblages in study patches, and higher artifact densities than in the Polop. Bernabeu has interpreted this as evidence that the domesticates were introduced into the Río Penaguila valley by farming populations who also brought extant agro-ecosystems to the valley. If so, this stands in marked contrast to the process of neolithization seen in the Polop Alto, a short distance away. Whether this apparent difference in the evolution of agro-ecosystems in eastern Spain is a function of edaphic factors or landscape history (including human landuse history) of these two valleys is an important objective of our ongoing research. In a final note, it currently appears that the Penaguila has suffered much more erosion, including barranco incision, wide-spread downcutting, and the loss of a significant portion of the pre-Holocene land surface, than the Polop Alto. Another question that we hope to address is whether the apparently different neolithization histories of the two valleys contributed to the difference in landscape dynamics that are apparent today.

Rather than treating formation processes as problems to be overcome or noise to filter out in order to reconstruct the past, we consider an understanding of formation processes as essential to interpretation of the archaeological record. They provide important information about the context and character of past human behavior, often as much as do artifacts themselves. Because our study is directed at regional scale processes, we have found a taphonomic perspective on formation processes to be useful. That is, we have focused on understanding the various processes responsible for the creation of the diverse artifact accumulations that comprise the modern archaeological record. Understanding these processes have allowed us to model a set of human behaviors that are a subset of the total suite of these taphonomic processes.

Standard practice in archaeology focuses on detailed data recording at sites. Besides being tiny windows on a much larger landscape, human landuse must be interpreted through the filter of the durable residues that are returned to such locales by their inhabitants. Any activities which do not return residues to a site are invisible. When studied in the context of an archaeological survey, multiple locales offer a better look at spatial variation but still suffer from the same problems as site studies. Furthermore, studies of human activities from this perspective are biased by an exclusive focus on locales with high artifact densities and/or preserved built features. The result is a lack of systematic information (or any information in



many cases) on spatial variability in the full range of human activities across landscapes.

This is not to say that either detailed site-oriented studies should be abandoned. Excavations provide detail about the human past that is otherwise inaccessible, especially from surface data. On the other hand, extensive studies of large regions and interregional interaction have only been accomplished by focusing on those locales with easily recognizable traces of human activity. Nevertheless, we think that there is a place for a middle ground that focuses on restricted regions and seeks to acquire and integrate information about the dynamic interplay of human and natural processes, and the complex evolution of archaeological landscapes. It is at this scale, beyond the site but within the geographic range of most human activities for a social group, that many human ecosystems operate, and we think that much can be learned from studies of these phenomena. We have learned, however, that standard archaeological practice, both in the field and in subsequent analysis, may not serve for such research endeavors. In seeking to address middle-scale socio-ecological processes, we have found it necessary to expand our methodological repertoire by developing field and analytical methods more suited to answering questions at this scale.

Landscapes and the archaeological materials that they contain are dynamic phenomena. Recognizing the dynamic aspects of landscapes has helped us to model the dynamics of human use of these landscapes. We are not the first to do this, and our efforts are still a work in progress. However, we hope that some of the conceptual and methodological tools we have developed for our work in eastern Spain will be of value to others involved in similar endeavors. We also hope that the trend, exemplified in other papers in this issue, toward studying the dynamics of regional systems, rather than simply reconstructing pseudo-contemporaneous snapshots of the past, continues. Only in this way can we begin to explain the evolution of human behavior systems.

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