A Prehistoric Sinagua Agricultural Site in the Ashfall Zone of Sunset Crater, Arizona

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A thermal infrared aerial image revealed evidence of human alteration of Sunset Crater basaltic ash over a 2 sq km area in north-central Arizona. Field investigation confirmed the presence of 19 linear ash ridges, reaching areal dimensions of 20 × 150 m, and 25 circular ash mounds ranging from 10 to 24 m in diameter. Independent lines of evidence (archaeological, chemical, and palynological) support the interpretation of these features as previously-unrecognized prehistoric agricultural plots. Associated ceramics place the use of these fields sometime between A.C. 1150 and A.C. 1250, a time when local Sinagua populations experienced significant changes in their social and natural environment. Pollen remains suggest that the fields were most likely used for growing Chenopodium *or* Amaranthus*—annual herbs with edible greens and seeds—rather than corn and squash. This unusual ridge-and-mound field system provides another example of the extent to which the Sinagua invested labor in agricultural production during the later half of the 12th century and first half of the 13th. This study provides a clear example of how remote sensing benefits archaeology, and should alert archaeologists to the possibility of finding similar agricultural features in other semi-arid regions of the globe covered with basaltic ash.*

Introduction

On April 12, 1966, at about 4:00 p.m. MST, a thermal infrared strip image was produced for a 2 km × 20 km section of the eastern San Francisco volcanic field in north-central Arizona (FIG. 1) as part of the NASA Earth Resources Aircraft Program. The image (FIG. 2) was produced by a HRB Singer-Reconofax IV Scanner operating in the 8 to 14 micrometer wavelength window of the electromagnetic spectrum. Although the strip image was to have been used to assess volcanic rock discriminations, three image areas displayed anomalous tonal patterns, suggesting that basaltic ashfall[1] deposits from the eruption of Sunset Crater had been reconfigured by some type of human activity. The blanket of ash covers an area of about 2100 sq km, largely to the north, east, and south of the crater, and forms what Colton (1960) called the "Desert of Black Sand." Tree ring dates suggest that the principal episode of ash deposition occurred at about A.C. 1064, with sporadic ejection of cinders continuing for almost the next 200 years (Downum 1988: 28–30).

Two of the sites displayed an anomalous pattern of parallel light and dark bands, while the third site was characterized by a series of light-toned, linear features of various sizes with approximate orthogonal alignments and several light-toned circular features (FIG. 3). Investigations at the former two sites disclosed a series of relatively straight, narrow ridges of Sunset Crater ash separated by slight troughs or swales of exposed soil and basaltic lapilli lag[2] (Schaber and Gumerman 1969; Berlin et al. 1977). One of these areas is shown as Site A in Figure 3. In this image, the ridges are represented by light tones indicative of warm radiant temperatures, while the swales are portrayed in darker tones that are indicative of cooler radiant temperatures. Individual ridges and swales at Site A average 265 m in length and 3–4 m in width; the depth of

1. In this paper, size limits in maximum dimension from Fisher's (1961) widely accepted classification scheme are used to define pyroclastic fragments: ash <2 mm, lapilli 2–64 mm, and blocks >64 mm.

2. Lag is a residual accumulation of coarse volcanic material.

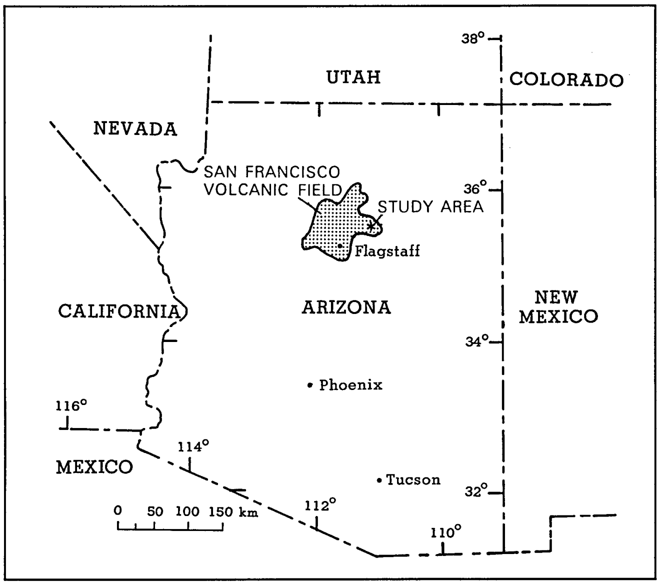


Figure 1. Map of Arizona showing the location of the study area and the San Francisco volcanic field.

the ridge ash varies from 10 to 30 cm (Berlin et al. 1977).

Fossil pollen analyses confirmed that the two ridge and swale sites were previously unrecognized agricultural fields that had been used primarily for the cultivation of corn (*Zea*) (Schaber and Gumerman 1969; Berlin et al. 1977). Differences in corn pollen abundance between the ash ridges and intervening swales at Site A revealed that corn was only grown in the soil lying beneath the ridges (Berlin et al. 1977). Potsherds of known cultural and temporal affiliation revealed that the land had been cultivated by a prehistoric group called the Sinagua, with the activity commencing sometime after the main eruptive phase of Sunset Crater in A.C. 1064 and terminating by about A.C. 1250.

It has been recognized for some time that the area covered by a relatively thick layer of ash from Sunset Crater was used by the Sinagua people for dry farming (Colton 1960, 1965). The loose ash acted as a mulch, readily transmitting snowmelt and rainfall to the underlying soil, thereby increasing moisture availability during the growing season. Berlin et al. (1977) proposed that the Sinagua who settled in areas where the natural ash cover was too thin to act as an effective mulch had to collect the ash into thicker accumulations to make the land suitable for dry farming. This reconfiguration of the Sunset Crater ash was responsible for the unique temperature signatures that were captured by the thermal infrared scanner.

Based on the positive findings of Schaber and Gumerman (1969) and Berlin et al. (1977), the objective of this study was to investigate the second type of anomalous image pattern, seen as Site B (NAU site number AZ I-11-33) in Figure 3 and in an enlarged perspective in Figure 4. A discussion of thermal infrared image interpretation principles can be found in Sabins (1987).

Location and Environmental Setting

The study area is located in the eastern section of the semi-arid San Francisco volcanic field, about 40 km ENE of Flagstaff and 20 km east of Sunset Crater (FIG. 2), at an elevation of about 1640 m amsl. Precipitation averages slightly less than 250 mm per year, with more than 50% of this normally occurring during July, August, and September. Natural vegetation is composed mainly of grasses, including grama (*Bouteloua rothrockii*), hilari (*Hilaria jamesii*), and Indian ricegrass (*Oryzopsis hymenoides*); and shrubs such as rabbit brush (*Chrysothamnus nauseosus*), four-wing saltbush (*Atriplex canescens*), and Apache plume (*Fallugia paradoxa*). The grass-shrub community is interspersed with occasional shrub-like juniper (*Juniperus monosperma*).

The 2-sq-km study area is underlain by the horizontal Kellam Ranch basalt flow whose potassium-argon age is 1.51 ± 0.28 my (Moore and Wolfe 1987). The flow is capped by a pale brown soil (Munsell 10YR 6/3) derived principally from underlying basalt and pyroclastics. The soil has an average thickness of about 25 cm and lacks a well-developed genetic profile. Dark gray ash (Munsell N3) and lapilli deposits from the eruption of Sunset Crater mantle only parts of the preexisting landscape. Undisturbed ash deposits are less than 10 cm thick in open areas, while they reach a thickness of several meters along the lee margin of the Kellam Ranch flow.

Description of Ash Features

Using the thermal infrared image for ground orientation (FIG. 4), 19 ridges and 25 mounds of Sunset Crater ash were field-identified in the study area (FIG. 5). Their morphological characteristics are not explainable by natural depositional or erosional processes. In their present state, both types of ash features display a wide range in dimensions. For example, the largest and smallest ridges measure 20 m × 150 m and 9 m × 25 m, while the mounds have diameters ranging from 10 m to 24 m. Measurements from 29 test holes excavated in the crests of ridges and mounds indicate that the ash depth ranges from 17 cm to 42 cm, with a mean of approximately 28 cm.

The ridges have two primary, long-axis orientations: 30° and 300°; the latter azimuth is approximately equal

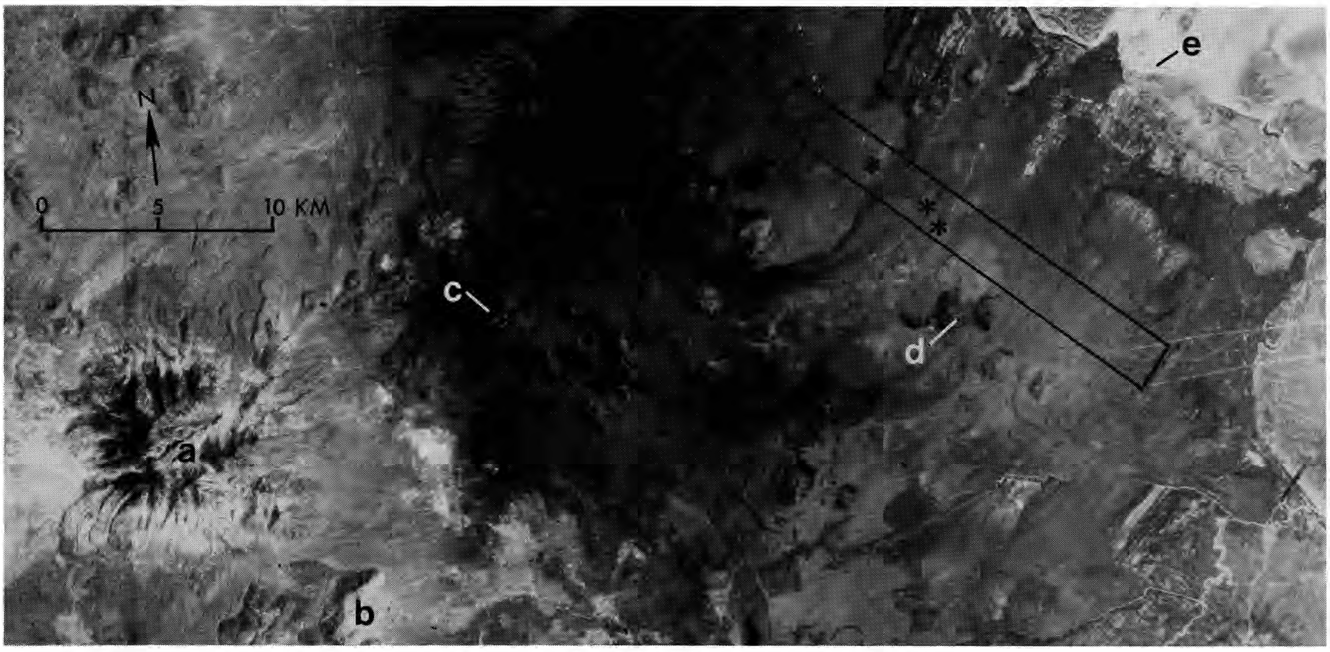
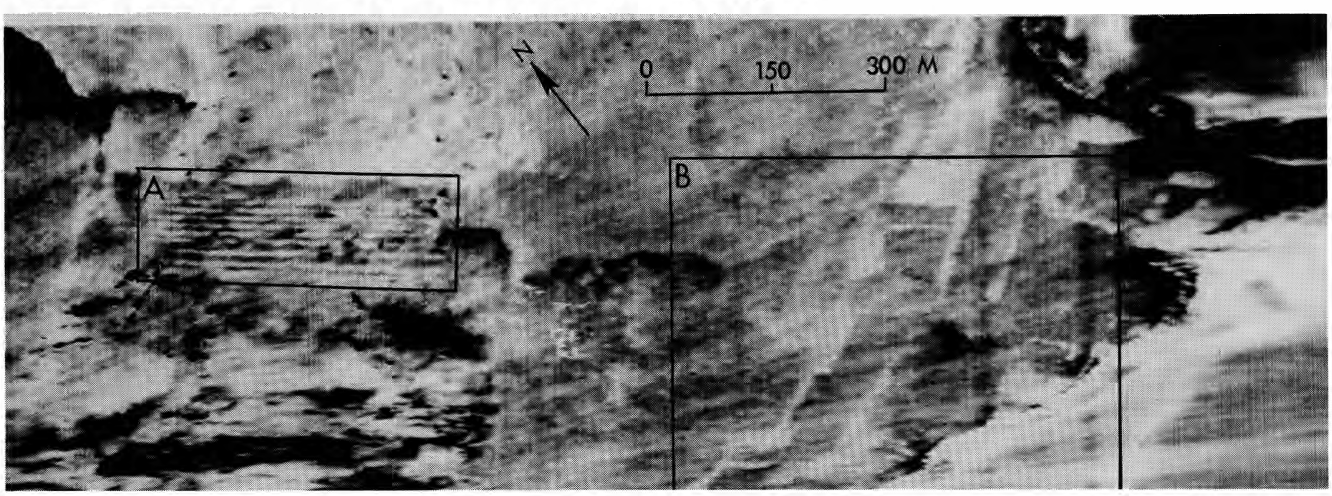


Figure 2. Computer-enhanced Landsat Thematic Mapper band 4 (0.76–0.90 micrometers) index image showing the eastern San Francisco volcanic field in north-central Arizona and footprint of a thermal infrared strip image that has led to the discovery of three previously-unknown agricultural sites (asterisks) of the prehistoric Sinagua Indians. The southernmost site is the focus of this investigation. Annotated features are as follows: (a) San Francisco Peaks; (b) Elden Mountain; (c) Sunset Crater; (d) Merriam Crater; and (e) the intermittent Little Colorado River. The city of Flagstaff is located just to the south of Elden Mountain. Much of the dark area to the north, east, and south of Sunset Crater represents a blanket of volcanic ash that was deposited during the crater's main eruptive phase in A.C. 1064.

Figure 3. Thermal infrared subscene image (8–14 micrometers) showing two types of Sinagua agricultural sites. Site A represents the ridge-and-swale type that has been described by Berlin et al. (1977). Site B, the focus of this investigation, represents a ridge-and-mound agricultural field system. Tonal signatures associated with Sites A and B are discussed in the text. The image was acquired from a flight altitude of 760 m above mean terrain. A detailed view of Site B is presented in Figure 4.



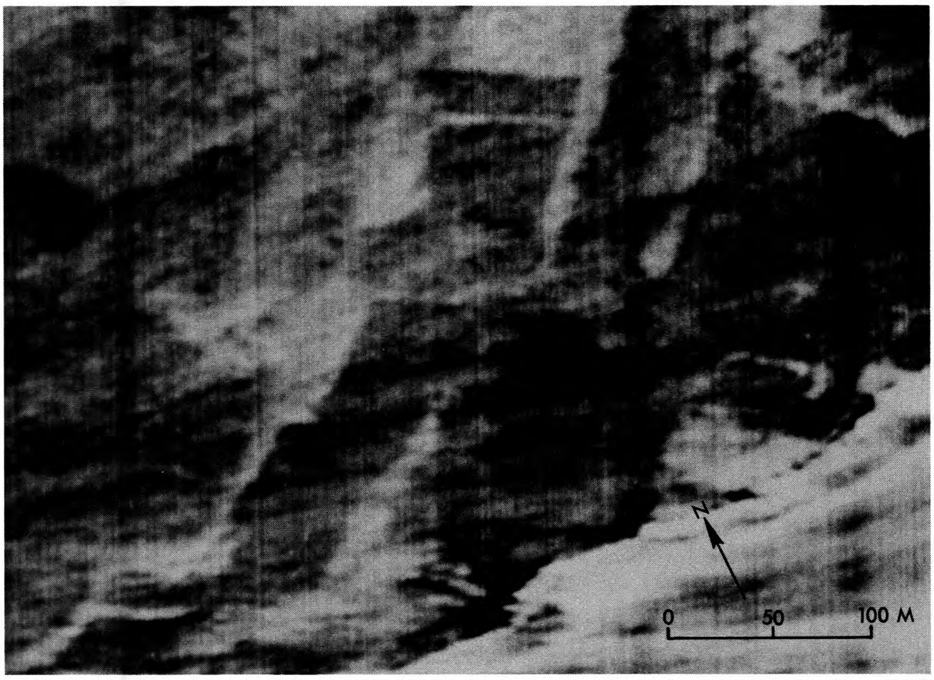
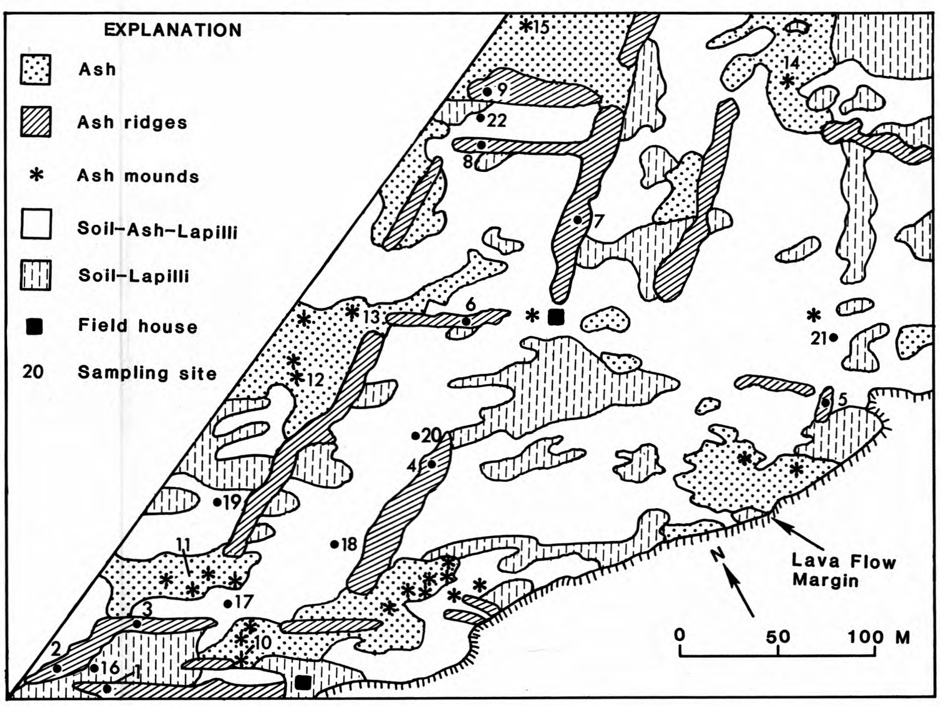


Figure 4. Enlarged thermal infrared image of a Sinagua ridge-and-mound agricultural complex (Site B in FIG. 3). Compare with Figure 5.

Figure 5. Surface-cover map of study area and location of Sinagua field houses and sampling sites. The surface-cover units were differentiated on the basis of image tone (FIG. 4) and field observations. Sampling sites mark areas where one or more of the following procedures were completed: (1) soil sample extractions for fossil pollen analysis and chemical property measurements; (2) vegetation cover measurements; and (3) relative relief measurements.



to that of the ash ridges at Site A (see FIG. 3). Both of the ridge alignments at Site B are oblique in relation to the prevailing SW wind. Cooley et al. (1969) note that the regional wind pattern has been from this direction for the past million years or so because they observed that longitudinal sand dunes of late Pleistocene and Recent ages on the nearby Navajo and Hopi Indian Reservations are aligned to the NE.

The ridges and mounds were found to be bounded by three general types of surfaces: 1) a surface composed of exposed soil and a lag of varying concentrations of lapilli interspersed with occasional pyroclastic blocks; 2) a surface similar to the previous type but with the added component of patches of thin ash; and 3) a surface composed primarily of thin ash interspersed with minor patches of soil and lapilli lag. Representative views of these surface types are presented in Figure 6, and their areal distributions are shown in Figure 5.

On the thermal infrared image, the ash ridges and mounds are visually enhanced when bounded by surface types 1 and 2. The dark color and loose packing of the ash causes it to efficiently absorb incident radiation, concentrate the resulting heat energy along its skin layer, and efficiently emit thermal infrared energy from its surface during daylight hours. These factors contributed to the ash unit's warm radiant temperature and thus to light tones in the thermal infrared image. By comparison, the bounding non-ash surfaces incorporate higher spectral reflectances (albedos) and densities that are responsible for a reduced solar absorption rate and a more efficient transfer of resulting heat energy to the subsurface. Consequently, such surfaces have lower radiant temperatures during daylight and hence produce darker tones in the thermal infrared image. Where the ridges and mounds are in contact with thin deposits of volcanic ash, they are not distinguishable in the image because a measurable thermal contrast did not exist between the features and their adjacent backgrounds (i.e., ash versus ash).

Contemporary Vegetation Associations

Major differences in both vegetation type and density of cover were strikingly evident during our field study. The ash ridges and mounds were found to be associated with well-developed and abundant shrubs, especially rabbit brush (FIGS. 7, 8). By comparison, the exposed soil and lapilli areas largely support low-lying grasses that impart an "open" appearance. The preferential association of rabbit brush with the ash features is attributable to the enhanced moisture capacity of the buried soils because this particular plant thrives only where there is a perennial and secure supply of soil moisture.

To make possible a statistical analysis and synthesis of the differences in vegetal patterns, the line-intercept method of Canfield (1941) was used for determining the number of rabbit brush plants per unit area and vegetation coverage for five ridge and mound sites and three exposed soil sites. Measurements and counts at each site were made along 30 m transects.

Results reveal that rabbit brush is nearly three times more abundant on the ash features; the ash ridges and mounds rendered a mean of 18.7 plants, compared to 6 for the surface soil sites (TABLE 1). Also, the density of plant coverage in the measured ash areas is predominantly rabbit brush ($\bar{X}$ = 35.4%), with grass cover about 50% less ($\bar{X}$ = 16.2%). By comparison, the most abundant plant coverage for the exposed soil sites is represented by grasses ($\bar{X}$ = 24.9%), with rabbit brush having a mean cover of 11.2%. Total vegetation cover for the ash features

Table 1. Vegetation measures for ash-ridge, ash-mound, and exposed soil sites.

*Site No.**	*Rabbit brush* (*N*)	*Rabbit brush cover* (%)	*Grass cover* (%)	*Total cover* (%)
Ash ridges and mounds				
2	16	33.2	15.0	48.2
7	21	41.4	18.3	59.7
8	24	36.7	17.7	54.4
11	12	36.9	16.8	53.7
13	16	28.6	13.2	41.8
$\bar{X}$	17.8	35.4	16.2	51.6
s.d.	4.2	4.3	1.9	6.1
Surface soils				
16	4	9.2	20.0	29.2
21	3	5.8	29.9	35.7
22	11	18.7	24.7	43.4
$\bar{X}$	6.0	11.2	24.9	36.1
s.d.	3.5	5.4	4.0	5.8

*Site locations are shown in Figure 5.

Figure 6. Close-up photographs of the three surface types that bound the ash ridges and mounds: A) surface composed of exposed soil and a lag of varying concentrations of lapilli interspersed with occasional pyroclastic blocks; B) surface similar to the previous type but with the added component of thin ash; and C) surface composed primarily of thin ash interspersed with minor patches of exposed soil and lapilli lag. The areal distributions of these surface types are shown in Figure 5. Rock pick is 32 cm long.

and exposed soil sites averages 51.6% and 36.1% respectively (TABLE 1).

Archaeological Associations

In association with the ash ridges and mounds were several types of surface cultural remains that suggested the area may once have been an agricultural complex: 1) two field houses; 2) hundreds of fragments of prehistoric pottery; and 3) numerous fragments of thin slabs of Moenkopi sandstone.

Field Houses

Two masonry structures with minimal trash scatters were observed at ash ridge termini (see FIG. 5). One structure is a single room defined on three sides by basalt blocks and open to the NE. The room measures roughly 2.7 × 2.2 m. The walls are now collapsed but perhaps once stood about 50 cm high. The second structure is somewhat larger, measuring 4.7 × 3.5 m, and perhaps had an original wall height of about 1 m. Now collapsed, the walls here were also constructed of basalt blocks. This structure appears to have two entrances, one on the NE and another on the SE, and may have consisted of two separate rooms. Debris associated with these structures is sparse, consisting of about 30–50 sherds and a few stone flakes. No stone tools were observed.

Both the nature of their construction and the meager artifact assemblages are consistent with interpreting these structures as field houses associated with seasonal agricultural activities (Pilles 1978: 120–128; Baldwin and Bremer 1986: 102). Such sites were used to exploit secondary farm plots located some distance from the permanent residences and are usually located immediately adjacent to agricultural land. The occurrence of field houses in the study area provides circumstantial evidence that the ash ridges and mounds were used for agricultural purposes.

Figure 7. Ground view of ash ridge #2 looking east (FIGS. 4, 5). Maximum ash thickness is 35 cm. Predominant vegetation is rabbit brush. Note the "open" appearance of adjacent areas that represent exposed soil sites with associated grass cover.

Ceramics

Hundreds of prehistoric pottery fragments were distributed across the entire study area, but especially around the margins of the ash features. In a few cases, 20–40 sherds from several different vessels occurred in definable concentrations. These may represent the remains of temporary agricultural field camps (see Sullivan 1984: 93) that were used on an ad hoc basis for short periods during the growing season. For the most part, however, the pottery fragments occurred as a diffuse scatter, perhaps representing vessels or portions of vessels broken during use in various farming-related tasks. In the Grasshopper region of east-central Arizona, Tuggle, Reid, and Cole (1984) report that agricultural features are associated with specific soils and that artifacts not derived from habitation sites are lightly scattered across the same soils. They suggest that "such scatters may represent refuse from field activities . . . [and] may be another artifactual marker of agricultural activity" (Tuggle, Reid, and Cole 1984: 105). Along similar lines, Lindauer (1984) argues that "sherd areas" (diffuse, extensive sherd scatters) can provide indirect evidence of prehistoric Hohokam agricultural areas.

Ceramics were collected from the field houses and large portions of the study area to determine when this area was used. The decorated sherds were classified by ware and type (TABLE 2) following standard typologies (Colton 1955, 1956, 1958). Decorated ceramics (white wares and orange wares) have more precisely defined periods of manufacture than undecorated or culinary pottery; consequently, the decorated sherds are those principally used for chronological inference. All of the decorated pottery was produced north and east of the study area by the Anasazi and was traded to the Sinagua.

The two major classes of undecorated pottery in the collection include Alameda Brown Ware (Colton 1958), the locally produced Sinagua utility pottery, and Tusayan Gray Ware (Colton 1955). The latter was classified into standard types with the addition of Hopi Buttes Variety of Tusayan Corrugated (Andrews and Tsosie 1980). Types of Alameda Brown Ware (the locally-produced Sinagua utility pottery) are distinguished primarily on the basis of different temper inclusions. The heterogeneity of these inclusions (see Wilson 1969: 315–330) is important for inferring manufacturing loci and directions of local interaction and, to a lesser extent, for chronological purposes. The temporal sensitivity for Alameda Brown Ware types is not great, however, especially when compared to the associated decorated wares. The important distinction for present purposes is between Alameda Brown Ware tempered with cinders and sherds tempered with other materials. This dichotomy separates the sherds into those that definitely post-date the Sunset Crater eruption (i.e.,

Figure 8. Ground view of ash mound #13 looking north (FIGS. 4, 5). Arrows mark limits of E–W dimension (15 m). Predominant vegetation on the mound and in adjacent areas of thin ash cover (<5 cm) is rabbit brush. Exposed soil areas are associated with grass cover. The mound's maximum ash thickness is 20 cm.

Table 2. Pottery type frequencies and their common periods of manufacture for sherds collected from perimeters of the ash features and the associated field houses that are shown in Figure 5.

Pottery type	*Frequency*	*Period of manufacture**
Tusayan White Ware		
unclassifiable	64	n/a
Flagstaff Black-on-white	27	A.C. 1150–1220
Tusayan Black-on-white	32	A.C. 1200–1300
Little Colorado White Ware		
unclassifiable	59	n/a
Walnut Black-on-white	44	A.C. 1150–1250
Tsegi Orange Ware		
unclassifiable	1	n/a
Cameron Polychrome	2	A.C. 1100–1200
Tusayan Gray Ware		
unclassifiable	10	n/a
Lino Gray	1	A.C. 500–900
Tusayan Corrugated	21	A.C. 1020–1200
Tusayan Corrugated: Hopi Buttes Var.	52	unknown
Moenkopi Corrugated	8	A.C. 1130–1250
Alameda Brown Ware		
Cinder tempered	484	Post-A.C. 1064
"other" tempered	29	Cannot be specified
Unclassifiable white ware	1	n/a
Total	835	

*Period of manufacture after Downum (1988).

are later than A.C. 1064), and those that could be earlier, although not necessarily.

Results of the sherd classification (TABLE 2) show that temporally-sensitive white wares all date to the later half of the 12th century and the first half of the 13th (ca. A.C. 1150–1250; see Downum [1988] for a current evaluation of pottery dates for the Flagstaff region). Had the area been occupied much past A.C. 1250, later types such as Kayenta Black-on-white and Leupp Black-on-white should have been present. The great frequency of cinder-tempered Alameda Brown Ware (over 90% of the culinary pottery) is consistent with the suggested temporal placement. This age range is similar to that assigned the nearby ridge-and-swale agricultural plots at Site A in Figure 3 (Berlin et al. 1977).

Sandstone Slabs

The third type of cultural remains found in association with the ash ridges and mounds consists of numerous small, thin fragments of sandstone slabs. The sandstone is derived from the Moenkopi Formation, which outcrops within 1 km of the study area. Because the ash features are found on a basalt flow that postdates and caps the Moenkopi Formation, human agency had to be involved in movement of the slabs to the study area. These same slabs are quite numerous in the trash middens and room blocks of local habitations; apparently they were used for making various tools and facilities. In the study area, the slabs might have been used as expedient tools for scraping up the ash into ridges and mounds and/or as simple agricultural implements. A number of the larger slab pieces were collected to examine them for use-wear evidence that might support this interpretation. Unfortunately, all of the slabs were too weathered (the stone is relatively friable) to reveal any such traces.

Data Analysis

The archaeological associations provide circumstantial evidence that the ash features were created and used for agricultural purposes. To ascertain whether this was indeed the case, field sampling for more direct evidence of agriculture was necessary. Therefore, we collected soil samples from various portions of the study area and analyzed them for chemical and pollen content.

Soil Chemistry

Domesticated plants generally remove nutrients from the soil, and prolonged use of a field can severely deplete the soil of certain essential chemicals. Chemical analysis has revealed distinct differences in the chemical profiles of soils from cropped and adjacent non-cropped areas at Site A (Berlin et al. 1977: 594–596, table 4). Given the premise that the ash features of the study area were used for agricultural purposes, then the soils of these features, relative to soils adjacent to the features, should be significantly depleted in chemical properties that are relatable to agricultural practices.

Chemical properties were measured for 16 soil samples representing seven ridge, three mound, and six off-feature soil sites. Nitrogen (NO_3), phosphorous (PO_4), and potassium (K^+) were selected for measurement because they are three primary macro-nutrients required for the successful growth of higher-order plants (Bidwell 1979). Differences in these chemical properties between ash feature soils and adjacent soils would be indicative of agricultural practices.

The buried soils were found to have significantly lower levels of NO_3, PO_4, and K^+ relative to the surface soil samples (TABLE 3). Comparison of computed means for the surface and ash-buried soil samples show depletions for the latter to be approximately 50% for NO_3, 36% for PO_4, and 42% for K^+. These discrepancies are of such a magnitude that they clearly support interpreting the ridges and mounds as agricultural plots.

Palynology

Pollen remains can provide an independent line of evidence concerning whether or not the ash features were agricultural plots, and can help us to ascertain what crops might have been grown. Pollen from the four main Southwestern domesticates—corn (*Zea*), beans (*Phaseolus*), squash (*Cucurbita*), and cotton (*Gossypium*)—should be found close to where the plants were grown or otherwise manipulated. Corn pollen, despite wind-pollination, does not travel far from its source because of its large grain size (Jones and Newell 1946). The three other domesticates are insect pollinated, and all such entomophilous pollen is noted for not traveling far from source plants. Finding pollen from one of these domesticates in the ash features would consequently provide substantial evidence that they were used for agricultural purposes. A lack of domesticate pollen does not necessarily imply that the features did not have an agricultural function, and depends upon the domesticate in question. This issue is discussed in greater detail below.

The pollen of weedy or ruderal plants also can be used to infer agricultural activities (Minnis 1978). Weeds are "evolutionary and ecological products adapted to survival in habitats disturbed by human activity" (Bye 1981: 110). They are prevalent around human habitations and are particularly common in agricultural fields since the latter represent a maintained early successional stage (Odum

Table 3. Chemical measures for ash-ridge soils, ash-mound soils, and exposed soils.

Site No.*	NO_3 (ppm)	PO_4 (ppm)	K^+ (ppm)
Ash-ridge and ash-mound soils			
1	5	3	375
2	8	11	580
3	8	6	590
4	5	4	470
7	12	8	380
8	10	8	280
9	9	19	370
10	7	5	100
11	9	6	540
14	10	5	280
$\bar{X}$	8.3	7.5	396.5
s.d.	2.1	4.4	146.1
Surface soils			
16	10	9	670
17	20	24	740
19	12	10	510
20	33	8	845
21	10	8	640
22	13	12	710
$\bar{X}$	16.3	11.8	685.8
s.d.	8.2	5.6	101.7

*Site locations are shown in Figure 5.

1969). What is more, because most Native American groups of the greater Southwest used the greens and seeds of many weeds as food (e.g., Bye 1981; Castetter and Bell 1942; Stevenson 1915; Whiting 1939), many species were tolerated in fields or even encouraged (Ford 1981: 21). Because of these factors, an abnormally high frequency of pollen from weedy species would be expected for agricultural fields. For example, *Cleome* (beeweed) pollen was encountered at relatively high frequencies in prehistoric agricultural terraces on Wetherill Mesa, SE Colorado (Martin and Byers 1965: 132), while Cheno-Am pollen occurred at relatively high frequencies for the ridge-and-swale field system (FIG. 3, Site A) near our study area (34% for ridges planted with corn, 20% for adjacent swales, and 17% for off-field samples; Berlin et al. 1977: 593).

In the previous study of the nearby ash ridge-and-swale agricultural site, Berlin et al. (1977) found abundant pollen in soil immediately beneath the ash, but very few pollen grains in the ash itself. Water filtering through the loose ash moves pollen grains downward and concentrates them at the ash-soil interface. Based on these findings, the pollen samples for this study were taken from immediately beneath the ash. The samples came from eight ash ridges, four ash mounds, and four off-feature, surface soil sites distributed throughout the study area. Pollen was extracted from the 16 soil samples using standard techniques (Faegri and Iversen 1975), and 200-grain pollen counts were made for statistical reliability. Additionally, all samples were extensively scanned for domesticate pollen. Table 4 presents the pollen taxa percentages for ash-ridge soils, ash-mound soils, and exposed soils.

Pinus is represented primarily by pinyon pine (*P. edulis*), with a probable minor percentage of ponderosa pine (*P. ponderosa*); degradation of the pollen grains prevented precise discrimination of the two pine species. Cheno-Am pollen is a combination of the family Chenopodiaceae and the genus *Amaranthus* from the family Amaranthaceae. These two groups are combined because of the difficulty in distinguishing one pollen taxon from another using an optical microscope. The two genera of Chenopodiaceae that likely contributed pollen to the Cheno-Am counts are *Chenopodium* (goosefoot) and *Atriplex* (saltbush). *Sarcobatus* (also Chenopodiaceae), was counted separately. The Compositae were categorized into high spine and low spine composites with a separate category for *Artemesia*. The Gramineae (grasses) were combined into one family because of morphological similarities.

No pollen of corn, beans, squash, or cotton was found (TABLE 4). Corn pollen is produced in great abundance, is easily recovered, and is easily recognized; not finding pollen of this plant therefore provides a good basis for concluding that corn was not being grown in the study area. The reader should recall that extensive scans were made of each pollen sample specifically looking for corn and other domesticate pollen. The pollen of squash, beans, and cotton is less likely to be recovered from fields, even if these plants were cultivated in great abundance. All are insect pollinated, and this severely limits the incorporation of their pollen into the fossil record. The chances of recovering squash pollen are much better, however, than

Table 4. Pollen taxa mean percentages for ash-ridge soils, ash-mound soils, and surface soils.

Pollen taxa	Ash-ridge soils* (N = 8)	Ash-mound soils† (N = 4)	Surface soils‡ (N = 4)
Pinus	12.0	16.5	34.4
Juniperus	12.0	7.2	13.9
Quercus	<1.0	<1.0	-
Ephedra	1.6	<1.0	<1.0
Sarcobatus	<1.0	<1.0	-
Cheno-Am	41.7	42.4	19.5
Artemesia	2.8	2.5	2.2
High spine Compositae	5.4	6.1	6.3
Low spine Compositae	8.3	7.1	7.0
Gramineae	5.9	5.9	7.8
Unknown and degraded	12.5	13.6	9.4

*Sites 1–6 8, 9 in Figure 5.
†Sites 10–12, 14 in Figure 5.
‡Sites 16, 18, 19, 22 in Figure 5.

Table 5. Cheno-Am measures for ash-ridge soils, ash-mound soils, and exposed soils.

*Site no.**	*Percent*	*No. of aggregates*
Ash-ridge soils		
1	52.8	14
2	38.2	3
3	44.0	0
4	37.3	6
5	48.8	3
6	35.6	3
8	37.4	2
9	55.5	11
$\bar{X}$	43.7	5.2
s.d.	7.3	4.5
Ash-mound soils		
10	39.5	9
11	38.3	2
12	40.4	4
14	38.3	7
$\bar{X}$	39.1	5.5
s.d.	0.9	2.7
Surface soils		
16	19.1	2
18	28.2	2
19	14.3	2
22	16.3	0
$\bar{X}$	19.5	1.5
s.d.	5.3	0.9

*Site locations are shown in Figure 5.

for the other two domesticates. Low frequencies of squash pollen have been found in numerous archaeological contexts in the Southwest, albeit often in scans rather than normal 200-grain counts. Indeed, Berlin et al. (1977: 593) found a single squash pollen grain at the nearby ridge-and-swale field system (FIG. 3, Site A). Bean and cotton pollen, on the other hand, are nearly nonexistent in the Southwestern archaeological record. Even when macrobotanical remains make it clear that these domesticates were extensively used, their pollen is rare or absent. Consequently, the lack of pollen from either plant cannot be construed as evidence that these domesticates were not grown in the ash ridges and mounds reported here.

Although domesticate pollen was not observed, agricultural use of the study area is supported by Cheno-Am pollen frequencies and aggregates. Cheno-Am percentages in the ridge and mound soil samples are slightly greater than twice that of the exposed soil samples (TABLE 4). The ash-buried soils from the ridges and mounds (TABLE 5) have mean Cheno-Am percentages of 43.7 and 39.1, respectively, while the surface soil samples have a mean Cheno-Am percentage of only 19.5. Furthermore, the mean numbers of Cheno-Am pollen aggregates in the ridge and mound samples are 5.2 and 5.5, respectively, while the surface samples average only 1.5 (TABLE 5). The presence of aggregates comes from the inclusion of anthers, buds, and flowers into a sample and would not be expected to occur under most natural conditions (Gish 1982). In the process of tending, harvesting, and preparing fields, however, there is ample opportunity for these plant parts to be incorporated into the soil.

Data Summary

Archaeological remains associated with the ash features provided circumstantial evidence that they had been created and used for agricultural purposes. This possibility was assessed by sampling for more direct evidence of farming, involving pollen and chemical analyses of soils from the features and adjacent cleared areas. Ridge and mound soils exhibit significant depletions in chemical properties relatable to agricultural practices as well as high frequencies of pollen from weedy plants common to agricultural fields. These independent lines of evidence coincide to support interpreting the ash ridge and mound features as agricultural plots.

Discussion

Having established to our satisfaction that the ash features were created and used for farming purposes, two questions remained—what was being grown in them and why did the local Sinagua populations adopt this more labor intensive method of farming? Based on the previous discussion, we conclude that the lack of corn pollen can be taken at face value; that is, this domesticate was not grown in either the ridges or the mounds. If corn had been planted in these features, a few grains of their pollen should have been identified, at least in the extensive scans of the pollen slides. We draw the same conclusion for squash, although the negative evidence is less convincing for this domesticate. Beans or cotton may or may not have been grown in the fields, but the pollen evidence is inadequate to make a determination. Because *Phaseolus* is a nitrogen-fixing plant, the low nitrogen content of the ash covered soils could be considered as evidence that beans were not grown in the ash features.

Amaranthus or some genus of Chenopodiaceae, most likely *Chenopodium*, is what the pollen evidence allows us to conclude was grown in the ridges and mounds. This conclusion is reasonable in a larger historical context of the economic significance of *Amaranthus* and *Chenopodium*. Both plants were cultivated by native groups throughout the Americas (Sauer 1948; Sauer 1967; Dobyns 1974), and both plants were important subsistence resources to many historical tribes living on the Colorado Plateau, such as the Hopi (Whiting 1939), Zuni (Stevenson 1915), and Navajo (Elmore 1944). Analyses of macrobotanical and pollen remains from prehistoric human feces have amply demonstrated the widespread use of *Chenopodium/Amaranthus* by prehistoric farmers in the Southwest (e.g., Fry and Hall 1986; Gasser 1982).

It is our contention that the Sinagua created the ash ridges and mounds for the principal purpose of planting *Chenopodium* or *Amaranthus*. As noted by Sauer (1948) and Dobyns (1974), both genera produce abundantly at high elevations. Collecting the ash into ridges and mounds ensured that dry farming would provide the plants with sufficient moisture for maximum yields. Because both *Chenopodium* and *Amaranthus* produce well in crowded conditions, the large ridge and mound ash configurations documented here could have produced abundant harvests of spring and summer greens followed by seeds in the fall. Possibly these weedy plants were double cropped with domesticates (see Bye 1981: 117) whose pollen we have not recovered.

Regardless of which specific plants were grown, the ash features clearly represent an intensification of labor invested in the production of subsistence resources. An important anthropological question, therefore, is why did the Sinagua intensify their agricultural efforts? This question must be considered in a regional context. The field system discussed here was used during the latter half of the 12th century and first half of the 13th century. This corresponds to the Elden Phase in the culture-historical framework for the region (Pilles 1988). Many other types of agricultural features indicative of intensification became common in the Sinagua area during the Elden Phase, including rock-outlined fields, check dams, ash ridge-and-swale systems, and rock piles (Berlin et al. 1977; Marozas 1984; Ritterbush 1984; Scott Travis, personal communication, 1989). Thus, the ash ridges and mounds discussed here were part of a regional trend towards greater labor investment in agricultural features during the Elden Phase. An extraordinary number of field houses belonging to this phase occur widely over the local region (Pilles 1979: 478) and can be viewed as another reflection of increased labor investment in agricultural production.

Agricultural intensification in the prehistoric Southwest is commonly viewed as an adaptive response by a society during periods of significant environmental change or population growth that produced population-resource imbalances (e.g., Cordell and Plog 1979: 419; Plog et al. 1988: 231; Vivian 1970: 76–77). As such, intensification is a behavioral response that is dependent upon environmental (climatic) and demographic variables producing subsistence stress. An alternative theory links agricultural intensification with the production of food surplus in order to create and maintain social hierarchies (Lightfoot and Plog 1984: 181; Upham, Lightfoot, and Feinman 1981: 823). Accordingly, "the decision of individuals, households, and other task groups to intensify production may be based on the expansion of regional exchange networks, the growth of major ceremonial institutions, and the development of leadership positions . . ." (Lightfoot and Plog 1984: 181).

Precipitation was above average and temperatures were warmer during several decades preceding the Elden Phase (Hevly et al. 1979: 508–509, table 16.1). These conditions would have greatly benefited crop growth, especially since much of the moisture increase was apparently in the form of summer rains (Hevly et al. 1979). Most of the Elden Phase, however, as indicated by smaller-than-average tree-ring widths, was characterized by lower-than-average effective moisture levels (Robinson and Dean 1969). Although precipitation was below average, the temperature continued to be warm. Sinagua population increased during the decades prior to the Elden Phase, a growth that is believed to be primarily indigenous and "possibly fostered by favorable climatic conditions" (Pilles 1979: 479). This growth is largely coincident with a general trend of demographic increase across the Colorado Plateau between about A.C. 1050–1200 (e.g., Euler 1988). Sinagua population reached its maximum size and greatest areal spread during the Elden Phase (Baldwin and Bremer 1986: 37; Wilcox 1986: 34) at a time when climatic conditions were perhaps less conducive to agricultural production. These demographic and paleoclimatic reconstructions reveal trends that together could have resulted in population-resource imbalances and subsistence stress during the Elden Phase.

Subsistence stress could have been exacerbated by soil depletion in traditional farming areas of higher elevations (Pilles 1978: 131). Pilles has argued that Sinagua farmers actually had to shift cultivation to previously unused farm plots at lower elevations where soil nutrients were not depleted. By doing so, however, extra measures had to be taken in order to ensure an adequate water supply: thin ash cover was shaped into ridges and mounds of thick ash to retain soil moisture.

Besides the deterministic factors sketched above, there might have been a strong motivation for surplus production during the Elden Phase. Sinagua populations were aggregating into pueblos that were much larger than those of preceding phases, with an evident architectural and settlement hierarchy (Pilles 1978: 130, 1988: 149; Baldwin and Bremer 1986; Hohmann 1983: 67). Wilcox (1986: 37–42, 113) theorizes that this process of village nucleation may be attributable to large scale shifts in pan-

Southwestern economic/exchange systems that led to local social competition and an increasingly volatile social environment. Wilcox (1986: 113) sees agricultural intensification as one expression of this process. Mortuary offerings suggest that Sinagua society had changed by the Elden Phase to one with social differentiation based on ascribed rather than achieved status (Hohmann 1983: 50–61). Again, agricultural intensification could have resulted from a desire for surplus production to support and maintain leadership positions.

This review indicates that climate, demography, soil depletion, and the social environment all could underlie the process of agricultural intensification in the Sinagua region and the creation of the ridge-and-mound field system reported here. The tendency to focus on climatic and demographic factors can be understood by the fact that tree-rings, pollen, room counts, and floor areas provide tangible evidence of environmental and population changes that can be temporally correlated with evidence of agricultural intensification. Consideration of demography, climate, and soil properties may also appeal to those who believe that cultural change must be explained by external causes that stimulate the system from outside. Entrepreneurial decisions to increase production for self-interest and "social climbing" have to be inferred from after-the-fact consequences such as the burial evidence for social stratification. The potential temporal lag in these consequences could be such that evidence for intensification predates evidence for stratification, leaving in doubt which factor is causal. Assigning causality to any one factor would be tenuous and perhaps misleading since there was probably no single cause; rather, the Sinagua intensified agricultural production in response to the coincidence of multiple factors.

Conclusion

We have documented a new type of Sinagua agricultural system that consists of large linear ridges and circular mounds of basaltic ash. These features were created to increase effective soil moisture so that *Chenopodium* or *Amaranthus*, and perhaps domesticates other than corn, could be grown successfully in a semi-arid environment. This type of ridge-and-mound field system is another example of the extent to which the Sinagua invested labor in agricultural production during the Elden Phase (ca. A.C. 1150–1250), a time when Sinagua society was undergoing significant change. Discovery of these features provides another example of the diversity of agricultural strategies that were employed by prehistoric Southwestern societies, strategies that have no parallel in ethnographic accounts. Because these features probably would have gone unnoticed by archaeologists conducting a conventional ground survey, this study highlights how remote sensing benefits archaeology. Once alerted to the possibility of encountering such features, field investigators can begin to discover them by learning to be cognizant of large and geometrical ash configurations, especially when these are associated with diffuse artifact scatters and field houses. In other semi-arid volcanic regions of the globe, prehistoric agricultural populations may also have created similar ash features for moisture retention. Thermal infrared aerial imaging could well prove to be a valuable reconnaissance tool in searching for these features.

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