

**SEDIMENTARY SUCCESSIONS OF THE
PREHISTORIC SANTA CRUZ RIVER
TUCSON, ARIZONA**

by

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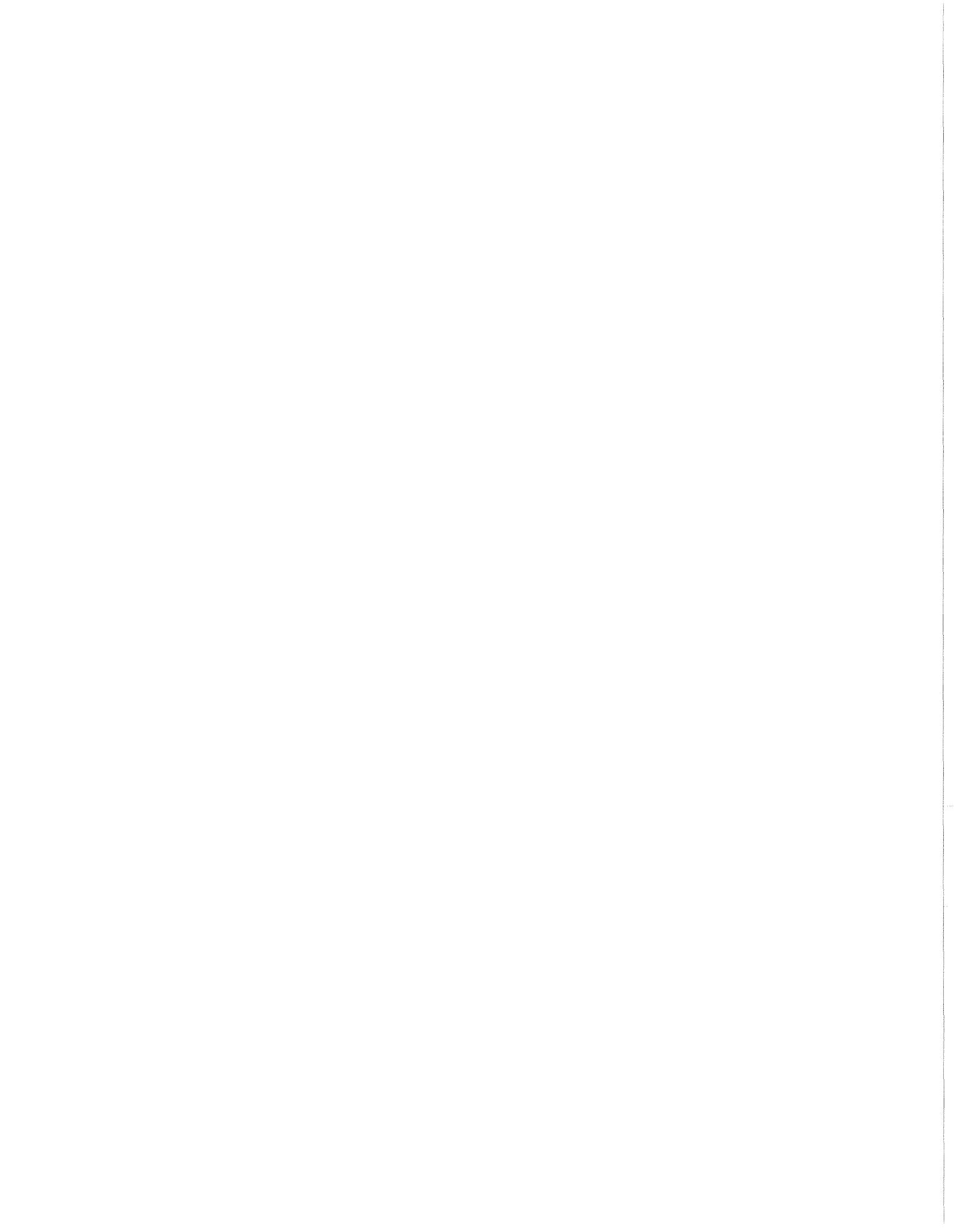
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Introduction

Like most river valleys, that of the Santa Cruz River contains a complex history of erosion, deposition, and stability spanning over a million years of geologic time. Unraveling this history is a laborious and often difficult process of mapping, analyzing, and correlating exposures of the sediments deposited by the river. Today this effort is aided by the fact that the river is a typical arroyo or entrenched drainage with vertical banks that expose the layers of sediment deposited in the past. Like pages in a book, these strata reveal the history of sequential deposition, but unlike a new book many of the pages are either missing (cut out by erosion) or mangled (altered by various processes).

The Santa Cruz through Tucson has not always been a steep-walled, normally dry, ephemeral river. Less than a century ago, near "A" Mountain, it flowed intermittently in a relatively narrow and shallow channel through a broad, flat, grassy valley with numerous mesquite thickets and occasional cottonwood groves (Bryan, 1922). In some reaches the channel became indistinct and gave way to wet meadows or cienegas that were commonly exploited for water by constructing earthen dams. The stored water was then used for either irrigation or mill power. Another technique of acquiring irrigation water was to excavate a trench at headcuts to intersect the shallow water table and direct the outflow to fields downstream by ditch or pipe (Betancourt, 1978; Betancourt and Turner, in press).

Entrenchment along some reaches of the Santa Cruz River may have begun in the middle of the 19th century, but by 1871 several deep headcuts had developed in the Tucson basin (Betancourt, 1983). Intense storms and flooding in the years 1887 and 1890, especially the latter, breached dams and caused severe headward migration of cuts until, by 1912, a continuous, vertical walled channel extended for 18 miles through Tucson (Cooke and Reeves, 1976). In effect the Santa Cruz has abandoned its floodplain. Today the wide arroyo configuration extends, with variations, from Pima Mine road, 15 miles south of downtown Tucson, to beyond Marana, 20 mi northwest of Tucson (Fig. 1). The vertical banks, 30 feet high along some reaches, are so far apart that the floods of 1977 and 1983 produced only relatively minor overbank flooding (Baker, 1984; Saarinen, et al., in press).

Exposures along the modern banks of the Santa Cruz and some of its tributaries within the Tucson basin reveal that the river has entrenched its channel and filled up again with silt, sand, and gravel at least four times in the past 5,000 years, a phenomena not uncommon in Holocene alluvial sequences (Haynes, 1968). These Holocene deposits are inset against a buried terrace consisting of 20 feet or more of silty sand with strong calcification over sandy gravel. These are probably latest Pleistocene in age. A generalized stratigraphy is shown in Figure 2, a cross section of the inner valley. South of Airport Wash (Fig. 1, loc. 10) all of these deposits underlie the present floodplain and are inset against older Pleistocene alluvium. North of Airport Wash Pleistocene deposits rise above the floodplain as three terraces first defined by G. E. P. Smith (1938). Subsequent investigations by Pashley (1966) indicated that the first, or Jaynes, terrace is inset against the second, or Cemetary, terrace, but these stratigraphic relationships have not been adequately observed in stratigraphic sections to our knowledge. Higher still and even less understood is the University terrace which is capped in places by a dense caliche or petrocalcic horizon. It is possible that the buried Pleistocene terrace

defended from erosion by Martinez Hill (Fig. 1, loc. 22) and extending northward 3.5 miles to Irvington Road emerges as the Jaynes terrace northward in which units A_2 and A_3 of Figure 2 would be combined to form a single unit, A_2 .

This study is concentrated mainly on the Holocene history of the Santa Cruz River in the Tucson area (Fig. 1) and is based upon examination of exposures along the river banks (Fig. 3) as well as those provided by mechanical excavations in the floodplain. Radiocarbon dating of charcoal and wood found in these exposures is the main method of dating the alluvial sequence, but archaeological evidence has also contributed to the geochronology (Table 1). This study also provides a stratigraphic framework not only for understanding the history of the cutting and filling of the river but also for understanding the development of prehistoric cultures in the valley and their dependence upon and interaction with the river.

The main localities investigated are natural exposures along the Santa Cruz and its tributaries between Pima Mine Road on the south and Hughes Access Road on the north (Fig. 1, locs. 1-6, 8, 9, and 21). In this area the location of the modern channel of the river was determined by artificial embankments built according to the plan of Olberg and Schanck (1913) to direct flow away from the west branch known as the West Side Barranca (Cooke and Reeves, 1976). This relatively small channel passed along the toe of the alluvial fan along the west side of the floodplain and went through the Punta de Agua ranch where natural seeps or springs maintained a small perennial flow in the immediate area. Whereas the diversionary effort succeeded in protecting the west channel from further entrenchment, it promoted entrenchment through the middle of the floodplain by steepening the gradient and concentrating flow between the two embankments of the Olberg-Schanck Canal. Thus the west channel was connected to an east side channel known as Spring Branch (Fig. 1, loc. 4).

This was fed by a spring known as Agua de la Misión until all discharge ceased with the Great Sonoran earthquake of 1887 (Dubois and Smith, 1980), but discharge from a new source appeared farther upstream. Flooding later that year promoted headward extension of Spring Branch to the new source (Betancourt, 1983). Near surface water was also known north of Saguarita Butte, now called Martinez Hill, where in 1881 Mr. Silvester Watts deepened a headcut and directed the flow from the bed of "Tucson channel" to the town of Tucson downstream (Betancourt, 1978). The floods in 1887 and 1890 caused the Tucson channel to erode headward and eventually link up with Spring Branch and the 1913 diversion channel of Olberg and Schanck. Today this originally straight channel is entrenched 30 feet below the floodplain and has widened as much as 400 feet eliminating the original embankments. The river is converting to a meandering pattern at each end of the Olberg and Schanck channel. It is only a matter of time before the straight reach of the Olberg-Schanck canal is obliterated by bank erosion.

Before the developments just described the floodplain of the Santa Cruz in this area was a relatively undissected flat plain heavily vegetated with grass and mesquite supported by shallow ground water. Discharge was normally confined to the relatively small channels along both sides. Only during infrequent storms did water flow over the floodplain itself. Today the East Side Barranca has become a vertical-walled channel several hundred feet wide and nearly 30 feet deep. Upstream it is joined by a somewhat smaller gully known as Brickyard Arroyo (Fig. 1, locs. 1 and 2) where, since World War II, a north-south artificial embankment directed westward-flowing runoff from the Santa Rita bajada northward to East Side Barranca.

In the early 1950s archaeologists from the University of Arizona discovered prehistoric artifacts and fire hearths exposed in the floor of Brickyard

Arroyo. This preceramic-period site, known as the Joe Ben site after its discoverer, archaeologist Joe Ben Wheat, has been visited periodically ever since by University faculty and students. In spite of the existence of field notes of six different individuals made from visits between 1955 and 1966, the precise location and depth of the site have never been adequately stated and are, therefore, not known. In the middle 1950s intense discharge left a 20-foot deep plunge pool in the floor of the wash near the now abandoned brickyard that gave this reach its name. Below a resistant caliche layer in the fresh exposure, University geologists discovered a few bones of extinct bison, mammoth, horse, and turtle in a mudstone clearly of Pleistocene age (Lance, 1960). Our objective in this part of the valley has been to describe stratigraphic sections pertinent to radiocarbon dating and/or exposed archaeology and to correlate the units described to other sections exposed along the river. For the moment and until more detailed mapping is done, the stratigraphic units are given informal letter designations with subscript numerals (Fig. 2). Artifacts have been collected only when they were in imminent jeopardy of being swept away by the next storm. They are retained by the Arizona State Museum.

San Xavier Reservation area

The oldest Holocene deposit, unit B₁, is exposed along Brickyard Arroyo in sections 7 and 18, Township 16 South and Range 14 East. The alluvium of unit B₁ consists of reddish-brown, poorly sorted, clayey, silty, pebbly, very calcerous sand interbedded with lenses of pebble-to-cobble size gravel (Fig. 4, A-A'). It appears to derive from the adjacent bajada by slope wash. The deposit, up to 12 feet thick, is firm to hard with zones bearing very irregular, jagged nodules of secondary calcium carbonate. Artifacts of the preceramic Cochise culture occur in a zone four to five feet above the floor of the arroyo. The rock hearths and associated artifacts found at the Joe Ben site in 1949 are possibly from this zone.

Four radiocarbon dates, 4260 ± 140 (A-2234), 4850 ± 90 (A-1854), 3980 ± 100 (A-1783), and 4400 ± 220 (A-1858), (Table 1) from unit B₁ between sites 1 and 2 (Fig. 1) were obtained on fragments of charcoal from various levels in the upper two-thirds of the deposit. (All radiocarbon dates are in years B.P.; i.e., before 1950.) Unfortunately, these samples, consisting of individual lumps an inch or two in median dimension, were without cultural associations. It should be cautioned that throughout the 25 years or so of intermittent observation of the Joe Ben site area no artifacts, features, or charcoal have been found completely within and surrounded by unit B₁. The original hearths were discovered exposed on the floor of the wash which is probably four to five feet deeper than it was then. In some cases, artifacts, such as handstones, have been found only partially exposed with the larger mass still buried, but in all cases there has been partial exposure. Furthermore, the radiocarbon dates are not consistent with their apparent depth. On the other hand, and in spite of the fact that unit B₁ forms a distinct, more erosion-resistant bench along the arroyo, there has undoubtedly been erosion of the bench thus exposing artifacts therein.

Down stream where a tributary enters from the east (Fig. 1, loc. 2), unit B₁ overlies a hard caliche developed in similar sands and gravels, unit A, but with much stronger calcification. Although the contact is gradational, unit A is believed to be Pleistocene because of much greater induration and calcification than observed in Holocene sediments in southern Arizona. It is apparently a higher part of the same strata that contained the Rancholabrean fauna at the Brickyard site about 0.7 miles farther downstream. Possible confirmation of a Pleistocene age for this unit was obtained in January of 1985, when turtle (probably Gopherus, according to Kevin Moodie of the Department of Geosciences) carapace fragments were found in an exposure of unit A in the floor of the draw. This exposure occurred upstream of the plunge pool noted above by an estimated one quarter to

one half mile. Unlike the plunge pool locality, the turtle remains occurred in the hard, resistant caliche rather than in the underlying mudstone.

Along Brickyard Arroyo unit B_1 is overlain by unit B_2 , a reddish-brown to brown, compact, clayey, fine to medium sand, which in its uppermost few feet, contains a weakly to moderately developed paleosol. Only a thin edge of the unit B_2 valley fill is exposed along Brickyard Arroyo, and the basal contact with unit B_1 is gradational over approximately 5 inches (Fig. 4, A-A'). Two radiocarbon dates that apply to the top of unit B_2 in Brickyard Arroyo are 2520 ± 140 (A-1857) and 2630 ± 100 (A-1892) on charcoal (Table 1). The first date is from a rock hearth originally believed to be in unit B_2 , 3 feet below its upper contact, but the date, is slightly too young for this depth, leading us to suspect that the hearth or firepit was dug into unit B_2 when it formed the valley surface. Although only equivocal evidence of a pit was found upon re-examination of the site, this interpretation is consistent with subsequent findings on the age of unit B_2 described later. Furthermore, we have repeatedly observed prehistoric firepits dug from ancient, buried surfaces that have had the upper outlines obliterated by animal and insect turnover (bioturbation) of the soil.

The second radiocarbon date is from a section of a burned log 20 cm below the top of unit B_2 and within a gray cienega soil. Across the valley to the west a reddish-brown, weakly to moderately developed paleosol is exposed 6 feet above the streambed at the head of the Olberg-Schanck reach (Fig. 1, site 3) of the main Santa Cruz River. Whereas no radiocarbon dates have been obtained for unit B_2 in this exposure, it is overlain by unit C_1 with radiocarbon dates on hearth charcoal from the upper half of the unit of 2030 ± 230 (A-1883) and 2330 ± 180 (A-2217) but below a weak cienega soil at the top (Fig. 4, A-A'). The top of unit B_2 appears to represent an ancient floodplain stabilized some 10 to 20 feet below the present floodplain of the Santa Cruz river. Downstream, where Brickyard Arroyo

becomes East Side Barranca (Fig. 1, loc. 4), burned grass on the upper contact of unit B₂ dated 2520 ± 130 B.P. (A-2817). Here the upper six feet of unit B₂ consist of gray to brown laminated muds alternating with sand partings and overlying six feet of brown, iron-stained sand.

Approximately three miles upstream from the Joe Ben site and north of Pima Mine road, unit B₂, exposed in westside tributaries, consists of poorly sorted reddish-brown, firm, silty, fine to coarse sand obviously derived by slope wash directly from the alluvial fan extending from the Sierrita Mountains (Fig. 4, B-B'). A charcoal mass (burned log?) from the base of a soil near the top of unit B₂ (Fig. 1, site 5) dated 3020 ± 90 (A-2815) and a charcoal log (Fig. 1, site 6), near what may have been the middle of the unit before erosion, dated 3650 ± 100 (A-2816). No radiocarbon dates have been obtained from the base of unit B₂, but the youngest date obtained from the underlying unit B₁ is 3980 ± 100 (A-1783) in Brickyard Arroyo, as mentioned previously (Table 1).

Typically, unit C₁ consists of alluvial silts and sands separated by two or three, and possibly more, bands of clayey silt and sand with numerous fine root molds and moderately well developed, medium, angular blocky, soil structure. The nonpedogenic clayey sediment is believed to have been deposited in vegetation on the floodplain with the watertable (capillary fringe) at or very near the surface. The clayey layers are thickest near the center of the floodplain and pinch out towards the margins. They also merge in places and may be cut out in others by a low gradient erosional surface such that it is hazardous to attempt to correlate the layers on the basis of their number in stratigraphic successions. They must be physically traced out to be certain, which is easier said than done in many cases. They represent an aggradational succession of azonal alluvial soils separated by fluvial sands.

In addition to the radiocarbon dates mentioned previously for unit C₁ exposed in the Olberg-Schanck reach, there is a date of 1680 ± 170 (AA-113) on the top of C₁, but, as discussed later, dates from overlying unit C₂ indicate that the top of unit C₁ is probably close to 2,000 years old. In Brickyard Arroyo charcoal from near the top of unit C₁ dated 1960 ± 80 (A-1887) and charcoal from near the middle of the unit dated 2290 ± 80 (A-1782) and 2300 ± 110 (A-1781). Downstream, near Drexel Road about 0.5 miles south of loc. 10 (Fig. 1), charcoal from the floor of a pithouse buried by 70 cm of overbank sand dated 2200 ± 130 (B-7167) (Doelle, 1985) and was overlain by a late Rincon phase archaeological site (Bradley, 1980) within what is probably unit C₂.

Unit C₂, composed of fluvial sands and sandy clay layers with alluvial soils much like the previous two units, is well exposed in East Side Barranca. A small buried channel, exposed in the left bank of the barranca (Fig. 1, loc. 4) approximately 400 yards upstream from the confluence with the Olberg-Schanck reach, contains several clay bands in fluvial sands (Fig. 4, A-A'). Dispersed lumps of charcoal in the lower third dated 1790 ± 120 (A-2813) and 1620 ± 180 (A-2814). A dense mass of charcoal near the middle of unit C₂, apparently the charred remains of a tree, dated 1950 ± 120 (A-2812). Overbank silty sand at the San Xavier gravel pit (Fig. 1, loc. 7) between Valencia Road and Martinez Hill contained archaeological hearths with charcoal that dated 1820 ± 90 (A-2454) and 1650 ± 80 (A-2216). Because of the isolation of the deposit by gravel mining, the radiocarbon dates are the main basis for assigning the overbank alluvium to unit C₂, but this is consistent with the sedimentary matrix of the late Rincon phase archaeology of the Hohokam site (BB:13:15) that extends along the east bank of the Santa Cruz from Drexel Road to Valencia Road (Bradley, 1980; Betancourt, 1978).

In the west wall of the Olberg-Schanck reach (Fig. 1, loc. 3) a hearth near the top of unit C₂ contained a Santa Cruz red-on-buff sherd with the "flying bird"

motif which dates approximately 1250 ± 100 B.P. (Haury, 1976, and personal communication) and a Rillito phase sherd of essentially the same age was observed in the opposite wall. Approximately 2.2 miles upstream, near Pima Mine Road, a tributary gully (Fig. 1, loc. 6) exposed a Rincon red-on-brown sherd in slopewash alluvium overlying unit B_2 with the charred log mentioned previously that dated 3650 ± 100 (A-2816). The archaeological age range of the sherd, 925 ± 125 B.P., is consistent with the radiocarbon date of 1020 ± 200 (A-3140) on dispersed charcoal in the same level. This unit is, therefore, a slopewash facies of unit C_2 .

Up to 3 feet of pale brown, silty sand overlying unit C_2 in the Brickyard Arroyo area has a very weak soil at the top and is designated unit C_3 . Radiocarbon dates on charcoal from the upper half range from 190 ± 190 (A-1891) and 330 ± 60 (A-1785) at the top to 630 ± 80 (A-1885) and 610 ± 90 (A-1890) in the middle of the unit. A charcoal date of 490 ± 180 (A-2444) came from what apparently is the middle of a channel exposed in the west bank about one-half mile upstream from the head of the Olberg-Schanck reach (Fig. 1, site 8). An archaeomagnetic date of 750 ± 50 B.P. was obtained on a hearth at the base of either slopewash or overbank facies of unit C_3 at the Drexel Road site (Bradley, 1980). Stafford (1984) obtained dates of 730 ± 90 (AA-721) and 960 ± 120 (AA-720) from near the base of the C_3 channel exposed in the east bank two miles north of Pima Mine road (Fig. 1, loc. 9).

Vegetated dunes to the west of Brickyard Arroyo are partly buried by unit C_3 (Fig. 4, A-A') and contain surface archaeological sites with Tanque Verde and Rincon pottery sherds. Therefore, the dunes must predate 900 ± 150 B.P., the age range of the Rincon phase, and represent eolian activity at the end of C_2 deposition possibly coinciding with erosion of the C_3 channel.

In the Brickyard Arroyo area, unit D, consisting of up to eight feet of brown, rudely laminated, clayey silts and clayey sands, overlies the surface of unit

C₃ in which numerous dead and decayed mesquite trees are rooted (Fig. 4, A-A'). Radiocarbon analyses of these invariably reveal radiocarbon contents of 2 to 4% in excess of modern (1950) wood indicating growth during the early years of the atomic era. Burned layers at the base of the unit yielded values of 101.2 ± 1.8 percent modern (A-1894) and 150 ± 220 (A-1889) indicating that deposition began sometime in 1954 or 1955 according to the plot of atmospheric radiocarbon produced by nuclear testing (Cain and Suess, 1976).

Airport Wash area

In 1983 a study of Airport Wash, west of Interstate Highway 19 (Fig. 1, loc. 10), was made prior to bank stabilization by the City of Tucson as a part of the Santa Cruz Industrial Park Project (Haynes and Huckell, 1985). A radiocarbon date of 490 ± 90 (A-3626) was obtained on carbon from an overbank slopewash facies of unit C₃ (Fig. 4, C-C'). Two radiocarbon dates on dispersed charcoal from a third of the way down in unit C₁ are 2420 ± 70 (A-4080) and 2450 ± 220 (AA-887), and charcoal from near the top of unit B₂ dated 2650 ± 120 (A-3627).

The exposure along Airport Wash, west of I-19, was of particular interest because of the well-displayed but gradual transition from poorly sorted slopewash alluvium near I-19 to interbedded layers of fluvial sands and muds near the Santa Cruz channel. The contact between units B₂ and C₁, not obvious in the walls of Airport Wash, is discernable in the east bank of the Santa Cruz where a distinct channel is seen about 1500 feet upstream from the mouth of the wash (Fig. 4, C-C').

The Holocene deposits are underlain by Pleistocene sands and gravels that rise above the historic floodplain to form the first (Jaynes) terrace. After the 1983 October flood a camel bone was found in a mud deposit interbedded with the sand and gravel exposed at the base of the south wall of Airport Wash. The stratigraphic position of the bone is shown schematically in unit A_{2a} of Figure 4,

C-C'). We estimate the geologic age of the deposit to be beyond 45,000 B.P., the normal limit of radiocarbon dating.

Ina Road area

In 1979 the City of Tucson, in the process of extending a new sewer line along Ina Road and under Interstate 10, excavated a trench that exposed several concentrations of pre-historic charcoal at depths ranging from 1 to 5 feet at a point 200 feet south of Ina Road and between the Southern Pacific Railroad tracks and the I-10 exit ramp (Fig. 1, loc. 11). Archaeological charcoal, stratigraphically related to three alluvial units separated by sharp contacts, produced six radiocarbon dates that provide a basis for correlation to the San Xavier Reservation area. The upper two units are a succession of two overbank deposits of silty sand representing the final stages of two episodes of aggradation (Fig. 4, D-D'). The middle of the uppermost sand dates 1400 ± 220 (A-3141) indicating it is the upper part of unit C₂. Three dates, 2820 ± 280 (A-2237), 2970 ± 100 (A-2451), and 2720 ± 210 (A-2452), from the upper foot of the underlying sand indicate correlation with upper unit B₂. A sample collected from the west side of I-10 provided an additional corroborative date of 2700 ± 130 (A-2453).

Weak soil development at the top of unit B₂, as exposed in the trench, leaves open the possibility that some of the unit may have been stripped by erosion before burial by unit C₂. This is consistent with the absence here of unit C₁.

A charcoal sample collected from 5 feet below the surface a few yards east of the railroad track dated 4260 ± 140 (A-2234). Unfortunately, the trench was filled before a detailed stratigraphic description could be made so we can only assume that the date applies to the top of unit B₁ or the contact between it and overlying B₂. In either case the interpretation is consistent with additional radiocarbon dates from Santa Cruz alluvium exposed in the landfill excavations approximately 3000 feet to the west (Fig. 1, loc. 12). Excavations by Pima County

in 1980 revealed a number of preceramic fire hearths 12 to 15 feet below the modern floodplain (Fig. 4, D-D'). Many of these were destroyed during excavation before their archaeological significance was recognized, but it is a credit to county personnel who not only held up further work until archaeologists from the University of Arizona could examine the features and collect samples but provided the services of a backhoe to help us expose the strata underlying the level of preceramic hearths. These were mostly simple, shallow basin hearths with at least one large rock-lined hearth all within a clayey, silty sand alluvium conformably overlying at least 9 feet of loose, current-bedded fluvial sand. A moderate to weak paleosol overlies the hearth level and formed on a buried surface 2 to 3 feet above the hearths.

Two of the simple charcoal lenses, exposed in the west wall, dated 3260 ± 100 (A-3145) and 3730 ± 110 (A-3104) with the older one about a foot stratigraphically below the younger. The charcoal and rock hearth, exposed in the floor of the pit, could not be stratigraphically correlated to the others because the overlying units had been removed, but the date of 3240 ± 50 (A-3147) indicates contemporaneity with the younger one. A charred log in the east wall about 5 feet higher than the rock hearth dated 3140 ± 90 (A-3146). These dates are all consistent with dates from the middle of unit B₂ in the San Xavier Reservation area. Three additional charcoal samples were collected from three successive overlying levels in the Ina Road landfill pit, but all are too small for conventional dating and have been submitted to the Arizona-NSF Regional Facility for accelerator dating. Until the results are known we cannot tell which of the unit C subunits are represented.

On the west side of the Santa Cruz and north of Ina Road (Fig. 1, loc. 13), Katzer and Schuster (1984) found Tanque Verde pot sherds (670 ± 60 B.P.) in what is apparently unit C₃ and overlying a preceramic horizon apparently in unit B₂ or C₁. South of Ina Road we found a burnt log or stump (Fig. 1, loc. 14) in a poorly

sorted gravel 16 ft above the floor of a gully near Abington Road and 4 ft below the surface. A date of 2760 ± 90 (A-4038) indicates a colluvial facies of unit B₂.

Miscellaneous Radiocarbon Dates

In 1979 a drainage trench was excavated along the east side of north First Avenue. A short distance south of River Road the trench (Fig. 1, loc. 15) exposed, 5 feet below the surface and in silty sand, a concentration of charcoal that dated 1240 ± 210 (A-2236). A single date for Rillito floodplain alluvium is inadequate for confident correlation, but unit C₂ is indicated. A buried paleosol showing weak to moderate pedogenic development overlay the charcoal and laid under 3 feet of silty sand alluvium.

Between Wetmore and Limberlost roads south of the Rillito River the trench showed a weakly developed brown paleosol in Holocene alluvium that may be younger than that of the north side, but without a means of dating, it is not possible to be certain. Farther south, between Limberlost and Roger roads, the trench exposed the upper few feet of the Jaynes terrace which contained a brownish red (5YR) calcic paleosol in poorly sorted, clayey arkosic sand and gravel. Unfortunately, the trench where it crossed the contact zone between the floodplain and the terrace was filled before the stratigraphy was observed. Schedule commitments plus the modern technique of backfilling construction trenches continuously with pipelaying add to the frustrations of the stratigrapher. However, the inset relationship is clearly indicated by the differences in the lithology and pedogenesis. The Jaynes terrace is most likely late Pleistocene in age.

Farther south, at Pastime Road, the trench cut into the Cemetary terrace, but once again the critical contact relationship between it and the Jaynes terrace was not adequately observed before filling. However, the paleosol on the slope between the Cemetary and Jaynes terraces, partly removed by the construction activity, was observed and found to have a strong, though

discontinuous, caliche (petrocalcic) horizon. A weak contact truncating a more continuous petrocalcic horizon in the higher terrace indicates that an erosional interval separates at least the upper part of the Jaynes terrace from the Cemetery terrace.

Four radiocarbon dates have been obtained from alluvial fan deposits on the southwest side of the Tortolita Mountains (Field, 1985). One from a hearth buried in an alluvial fan deposit (Fig. 1, loc. 16) of Derrio Wash east of Interstate 10 at Marana dated 440 ± 240 (A-2811). The charcoal and rock hearth, 4 feet below the surface, was exposed by an arroyo system that has been cutting headward up several distributaries. Several earth checkdams constructed in the recent past to halt headward migration have been breached. Two other charcoal radiocarbon dates, one from farther up Darrio Wash (Fig. 1, loc. 17) and one from Cottonwood Wash (Fig. 1, loc. 18), are 780 ± 100 (A-4274) and 800 ± 80 (A-4275) respectively (Field, 1985). These indicate that aggradation of Derrio and Cottonwood alluvial fans was contemporaneous with unit C₃ aggradation farther up the valley. The fourth radiocarbon date is from dispersed charcoal downstream from locality 16 (Fig. 1) at the same level as A-2811 (Field, 1985). The date of 2160 ± 100 (A-4273) indicates correlation with unit C₁.

The Avra Valley, west of the Tucson Mountains and part of the Santa Cruz drainage, contains two preceramic sites that have provided charcoal for radiocarbon dating. Samples from the La Bossiere site on Brawley Wash (Fig. 1, loc. 19) are in the process of being analyzed, but the preceramic occupation overlies an erosional surface on alluvium containing bones of a Pleistocene horse. This site has produced Pinto points, San Pedro points, and a triangular, concave base point style of uncertain though presumably Archaic age. Other stone tools include bifaces, unifaces, cores, debitage, thermally shattered rocks, and ground stone implements. Also present are sherds of Classic and Preclassic Hohokam origin, as well as a few

arrow points representing the same culture and broad time period. All of these artifacts tend to occur together in small "pockets," or in some cases, in obvious erosional channels, suggesting that much of the archaeological material exposed along this wash has been redeposited in secondary contexts.

Farther downstream the Collins mammoth discovery (Fig. 1, loc. 20) consisted of several ribs and vertebra exposed on the floor of Los Robles Wash. Three overlying alluvial units provided charcoal that yielded radiocarbon dates of 3420 ± 90 (A-4041), 1880 ± 170 (A-4039), and 760 ± 110 (A-4043) in proper stratigraphic order. More radiocarbon dates are in process and are needed before the stratigraphy of either site can be confidently correlated to the alluvial sequence along the Santa Cruz proper, but correlations to units B₂, C₂, and C₁ are suggested.

Caliche Apparent Ages

Caliche, a pedogenic or groundwater-deposited calcium carbonate, is a notoriously unreliable material for radiocarbon dating because of uncertainties regarding contamination by chemical exchange with younger carbonate ions as well as by older carbonates derived from groundwater (Sigalove, 1968) or redeposited from the dissolution of eolian dust (Gardner, 1971). With these severe limitations in mind it was decided to analyze carbonates from two terraces to see what differences there might be. Samples of firm, microcrystalline, sandy caliches were collected from exposures in the gravel pit of the San Xavier Gravel Company between Valencia Road and Martinez Hill (Fig. 1, loc. 7). The oldest sample, believed to be from a groundwater deposit, came from a depth of 20 feet below the surface of the Cemetery terrace exposed in the east wall of the pit. Because of the aforementioned uncertainties it would be fortuitous if the results of the radiocarbon analyses were within a standard error deviation or two of the true age. Therefore, we call the result of $25,900 \pm 840$ (A-2187) an apparent age. The true

age could be 1000 years or more either side of this value. On the other hand, radiocarbon investigations of groundwater in the Tucson Basin have shown that the shallow aquifers adjacent to streams are actively being recharged and, therefore, contain the youngest groundwater in the basin (Bennett, 1965). Therefore, we consider the apparent age of the Cemetery terrace caliche to be a minimum value.

The next two caliche samples came from the west wall of the pit at depths of 12 and 8 feet below the surface of what is thought to be either a buried remnant of the Jaynes terrace or a younger inset of latest Pleistocene age. Both caliches are in silty sand directly overlying the commercial grade gravel and are apparently the result of groundwater deposition. An apparent age of $16,070 \pm 110$ (A-2188) for the lower, essentially on the contact with the gravel, is not consistent with an apparent age of $18,400 \pm 120$ (A-2189) for the upper caliche. The lower sample has probably been contaminated by carbonate exchange with younger groundwater. A third caliche, possibly pedogenic, at the top of the unit has not been dated.

The groundwater origin of the caliches at or immediately above the terrace gravels and below the near surface caliche, partly if not totally of pedogenic origin, is indicated by the fact that they conform to the topographic variations on the top of the gravels. In other words, as the top of the gravel undulates so does the carbonate halo just above it in the overlying finer grained alluvium. The carbonate is a secondary deposit caused by periodic wetting and drying as fluctuating groundwater passes through the permeable gravel. The phenomena is similar to that observed along some small tributary channels where secondary calcium carbonate is deposited from ephemeral flow, only in this case the carrier of carbonate ions is surface water coming from above as opposed to groundwater from below. Sooty coatings of manganese oxide and rust-colored iron oxide stains in the gravel deposits attest to the former presence of groundwater.

An excellent example of these phenomena can be seen along the east bank of the Santa Cruz between Airport Wash and Drexel Road (Fig. 4, C-C').

The deposition of microcrystalline calcium carbonate from groundwater probably corresponds to a time when the water table fluctuated above and below the contact between the gravel and the finer-grained alluvium such that calcium carbonate was precipitated in response to evaporation at the capillary fringe within the finer-grained alluvium.

If the relative ages implied by these results are correct, they are consistent with the inset relationship of the Jaynes and Cemetary terraces hypothesized earlier. The oldest caliche would have been deposited from a capillary fringe when the water table was higher than that from which the lower caliches were deposited.

Archaeological Associations

The Tucson Basin has a long, rich culture history, but at present this history is only beginning to be understood in detail. Certain portions of the archaeological record remain little studied; this is particularly true of the preceramic period, which as late as 1982 had not received a single professional study (Huckell 1984). While this is slowly changing with the advent of a few very recent contract archaeological projects (Dart 1983; Douglas 1984; Huckell and Huckell 1984), our understanding of this period is still quite rudimentary. The succeeding occupants of this area, the Tucson Basin Hohokam, have received more attention from archaeologists, and several sites of varying ages have been excavated and reported. Excellent summaries of current knowledge of these agriculturalists may be found in Doyel (1984) and Wallace and Holmlund (1984). The basic refinements to the nature, content, and temporal boundaries of these continue to be made. The early Pima occupants of the Tucson Basin have received little archaeological study (Hard and Doelle 1978; Brew and Huckell in prep), and

the time of their arrival in the region (or development out of the local population) remains uncertain. Fortunately, Spanish documentary sources have left some good descriptions of these people and their lifeway (Treutlein 1949). In summary, the general culture history is sufficiently well understood so that archaeological materials can serve as an aid in the chronological ordering of the alluvial units exposed in the drainages of the Tucson Basin.

Examination of the sediments exposed along the Santa Cruz and its tributaries not infrequently reveals artifacts or features. Culturally and temporally diagnostic artifacts, and charcoal associated with artifacts or features, were used to help obtain relative and absolute dates for the geological units in which they occurred. None of the sites discovered during these examinations has yet received detailed excavation, so what follows is an attempt to present a general summary of the kinds of archaeological manifestations thus far encountered.

Figure 5 has been prepared to present a general outline of the cultural history and the preliminary relationships of the stratigraphic units of the Santa Cruz alluvium to that culture history. It must be emphasized that this is generalized, and will undoubtedly need adjustment as new data make possible the refinement of the dating of both cultural entities and geological units. Two sources have been used in the preparation of the culture historical framework for Figure 5. The preceramic Archaic period is subdivided using the terminology and chronology suggested by Huckell (1984: 189-214). The expanded cultural chronology for the Hohokam and Historic periods is taken from Gregonis and Huckell (1980, Fig. 3), with minor modifications. Figure 5 will serve as the basis for subsequent discussions of the relationships of cultural manifestations encountered within the various geological units in the Tucson Basin.

Because the archaeological materials exposed in the banks of entrenched streams or artificial excavations have only been investigated in sporadic, non-intensive fashion, our understanding of their precise temporal and cultural affiliations is rather limited. Further, their numbers are as yet small, so the following discussion is necessarily broad.

Evidence of Arizona's earliest known occupants, the Clovis Culture, is quite rare in the Tucson Basin. Two Clovis points have been found on the surface (Huckell, 1982), but no buried Clovis sites have been found along the Santa Cruz River or any of its tributaries. To the north of Martinez Hill, at the Valencia Road Hohokam site (AZ BB:13:15), a single, broken Clovis point was found in a disturbed surface context. Whether this specimen represents a later Hohokam find of an old fluted point, an artifact left from an in situ Clovis occupation, or one slope washed from higher ground is not known. In any case, work along the Santa Cruz and its tributaries has indicated that exposures of the late Pleistocene units likely to contain Clovis sites are rare.

Also lacking at this time are any Early Archaic period sites, buried or otherwise. In fact, the nature and identity of the Early Archaic is unclear—is it something akin to the Sulphur Spring Stage of Sayles (1983: 82-89), or is it more like the Lake Mohave (Campbell and others, 1937) or Jay (Irwin-Williams, 1973) complexes? At present the closest material representing this time period is the Ventana-Amargosa level of Ventana Cave (Haury, 1950). The resolution of this question, as well as the exact temporal boundaries for the Early Archaic, remain major research topics to be investigated in the future.

The earliest archaeological remains yet encountered are present in unit B₁ and are clearly of Archaic age. One habitation site of moderate size, AZ BB:13:70, has been located in this unit in Brickyard Arroyo (Fig. 1, loc. 1). This site has yielded flaked stone implements such as bifaces, scrapers and non-

diagnostic projectile point fragments; flaked stone debitage and cores, ground stone seed milling equipment such as handstones or one-hand manos and slab metates, small clusters of fire-cracked rocks, and fragments of burned animal bone. Unfortunately, only one, non-diagnostic, leaf-shaped projectile point has been found, so the precise cultural and temporal affinities of the site remain unknown. All of the artifacts and features exposed at this site appear to occur in a marked carbonate horizon as opposed to being on a buried erosion surface. This, coupled with the sharp margins of the flakes and the tightly concentrated rock clusters, argue that this site is in situ in unit B₁.

On the other hand, we have noticed that unit B₁ becomes soft and muddy when wet and a modern beer can was observed partly buried and cemented in the upper part of the unit after a recent flood. This indicates that debris from human occupation of the unit B₁ surface could, through bioturbation, wetting events, and subsequent burial by overlying units, give the appearance of being in unit B₁ instead of on it. Controlled excavations are needed to clarify the situation.

As one proceeds downstream from AZ BB:13:70, occasional isolated artifacts and rock cluster features in unit B₁ have been exposed by, and eventually lost to, continued erosion of the arroyo walls and floor. Again, however, no culturally or temporally diagnostic projectile points have come to light. Another buried Archaic locus, the Joe Ben Site (AZ BB:13:11) noted earlier, may have been in unit B₁ or B₂ approximately 1 mile downstream of AZ BB:13:70. It was found in 1949, and periodic excavation over the next 15 years produced a small sample of artifacts, two pits, and an apparent cremation. Two projectile points recovered from the Joe Ben Site (although with poor stratigraphic provenience data) include a Late Archaic San Pedro form and a triangular dart point with a concave base. Ground-stone milling equipment like that from AZ BB:13:70 is also present in the Joe Ben Site collection, as are various flaked stone implements and debitage.

Insofar as can be determined, the site was largely, if not completely, removed by erosion.

Exposures of unit B₁ in the Hughes Wash area (Fig. 1, loc. 7) south of the present San Xavier materials pit have also produced isolated Archaic artifacts, and slightly further to the north in Airport Wash more isolated artifacts and features are present in this unit (Betancourt, 1978: 97-98; Haynes and Huckell, 1985). Again, no temporally or culturally specific artifacts have yet been found in these exposures either.

Radiocarbon dates from unit B₁ range from approximately 3900 to 4800 YBP, placing it within the Middle Archaic period (Fig. 5). Assuming that the site and isolated artifacts and features discussed above are in situ in this unit, they too should represent this interval of time. Therefore, it may be expected that stemmed projectile points such as Pinto or Gypsum Cave forms will be found in unit B₁ rather than notched forms such as the San Pedro point. The one San Pedro point from the Joe Ben Site may thus suggest that that site was stratigraphically above unit B₁, or that the point itself is intrusive or ultimately derived from younger sediments, or that the upper part of B₁ is younger than is presently documented. Only intensive work at sites such as AZ BB:13:70 will aid in resolving the exact cultural and temporal affinity or affinities of sites within this unit.

The area at and near the confluence of Canada del Oro Wash with the Santa Cruz River just south of Ina Road has also produced evidence of buried Archaic habitation and resource procurement and processing sites. One of these sites, AZ AA:12:111 (Fig. 1, loc. 11), was exposed in a sewer trench just east of Interstate 10 and south of Ina Road (Fig. 5). As mentioned earlier, it consisted of three buried occupational horizons separated from one another by culturally sterile alluvial sediments. The lower horizon yielded charcoal dating 4260 ± 140 (A-2234), animal bone, and fire-cracked rocks. From the middle horizon came flaked stone

debitage, burned and unburned animal bone, and four charcoal concentrations that yielded dates between 2700 and 2900 B.P. (Table 1). Both occupational horizons were contained within silty to clayey fine sand, probably derived from overbank flooding. While again no culturally or temporally diagnostic artifacts were recovered, the lower occupational horizon would appear to be in part coeval with Archaic remains observed in unit B₁ to the south, and is probably thus of Middle Archaic age. The uppermost charcoal concentration, dating 1400 ± 220 (A-3141), was without artifacts but is probably of cultural origin.

Within one mile to the west lies the Ina Road landfill. Expansion of the landfill to the north in 1980 revealed a number of (perhaps as many as 80) small and large rock-filled hearths buried under an estimated 4 m of silty sand (Fig. 1, site 12). Profiling of a test trench generously cut by a county backhoe in the west wall of this new area of the landfill revealed a weakly defined occupational horizon with scattered artifacts, rocks, and charcoal throughout a 1.5 m zone of fine silty sand. The hearths apparently fall within this zone. This site, AZ AA:12:130, received only minimal investigation over the course of a day, and no culturally or temporally diagnostic artifacts were recovered. Nevertheless, as mentioned earlier, four radiocarbon dates ranging from approximately 3100 to 3700 YBP were obtained from three hearths and a burnt log in unit B₂, suggesting a late Middle Archaic or perhaps early Late Archaic age for this occupation.

Returning to the area south of Martinez Hill, it has been found that unit B₂, overlying unit B₁, also contains archaeological remains. These too are apparently preceramic, but as yet no sites have been systematically defined or investigated within this unit. As was the case for unit B₁, isolated features and localized occurrences of artifacts have been recognized in Spring Branch Arroyo and Airport Wash. Radiocarbon dates obtained from this unit range from approximately 3700 to 2600 B.P. (Table 1.), which would suggest that unit B₂ should

span the transition from the Middle Archaic period to the late Archaic period (Fig. 5), primarily encompassing the latter. No sites of any size comparable to AZ BB:13:70 in unit B₁ have yet been found within unit B₂, and as yet no culturally or temporally diagnostic artifacts have been recovered from it. However, as mentioned above, it is possible that the San Pedro point recovered from the Joe Ben Site originally came from this unit, and that perhaps the site itself lay within unit B₂. Those isolated features and artifact concentrations that have been found appear to represent short-term resource procurement and processing activities or small group campsites.

Unit C₁ overlies unit B₂, and like it has produced only limited evidence of human activity at this time. Again isolated features have been recognized with very few or no associated artifacts. Radiocarbon dates from this unit of silts, sands, and clayey silt or sand bands range from approximately 2500 to 2000 B.P. (Table 1), placing it entirely within the Late Archaic period. At the Valencia Road Site (AZ BB:13:15), Late Archaic pit houses have been dated to approximately 2200 YBP; these lie atop a terrace just east of the Santa Cruz River channel, and are apparently coeval with the deposition of unit C₁. Thus, more isolated features and artifacts, and perhaps larger sites as well, may be expected within this unit.

In unit C₂, overlying unit C₁, few archaeological remains have been encountered and all have been isolated features. It appears to date between 1800 B.P. and perhaps 1000 B.P., thus encompassing the very Late Archaic period and the Pioneer, Colonial, and most, if not all, of the Sedentary periods of the Tucson Basin Hohokam chronology. Two buried hearths lacking associated artifacts were reported from an arroyo to the northeast of Spring Branch Arroyo in 1967 (Fig. 1, loc. 21); charcoal samples, from what we shall call the Roberts site (Table 1.), dated to approximately 1600 and 2000 B.P. (Ayres, 1980), indicating that they may pertain to unit C₂ and the C₂/C₁ contact, respectively. Two other buried hearths

lacking artifacts were encountered in place in an overbank facies of unit C₂ in the San Xavier gravel pit (Fig. 1, loc. 7) in 1980, and were dated to approximately 1600-1800 B.P. (Table 1). Further, the upper occupational horizon described above from AZ AA:12:111 just south of Ina Road would also appear to fall into this same interval of time. Presently available information indicates that these hearths and the occupational horizon probably represent Late Archaic resource procurement and processing activities and a campsite. Based upon radiocarbon dates from the Pantano site (AZ EE:2:50), the preceramic period in the Tucson Basin and southeastern Arizona appears to last until the second or third century A.D. (Huckell, 1984: 141), thus encompassing the lower portion of unit C₂.

The Hohokam occupation of the area is well represented in the upper half of unit C₂. Although no Pioneer period material has been observed, buried sherds, artifact scatters, and at least one major habitation site of the succeeding Colonial and Sedenary periods have been identified in the Spring Branch Arroyo, the Santa Cruz Eastside Barranca, Airport Wash, and elsewhere along this general part of the river valley. Recent survey work on the San Xavier Papago Reservation just to the west of this area has disclosed the presence of numerous surface village sites of Pioneer through Classic period age (Heuett, personal communication), and Greenleaf (1975) excavated a series of Colonial through early Classic period sites in the same area. This material is relatively abundantly exposed in the arroyos, but has not been systematically sought out nor studied.

This abundance of ceramic-period remains is continued in unit C₃, which contains both Sedenary and Classic period Hohokam sites and features, and may contain Protohistoric to early Historic Pima remains as well. Radiocarbon dates from it range from approximately 190 B.P. to 1000 B.P.

The work accomplished thus far with archaeological remains buried in the alluvium of the Santa Cruz River and its tributaries can only be termed prelimin-

ary; however, it has important implications for our knowledge of Tucson Basin prehistory. It has helped to document the presence of a substantive preceramic occupation of the Santa Cruz River floodplain, and by providing radiocarbon dates these buried loci are also helping to create the rudiments of an absolute temporal framework for this period. Some of these loci would also be well worth serious investigation; AZ BB:13:70 was mapped in July 1984 and over 100 artifacts exposed but still in situ were collected. Other such sites undoubtedly exist and could be of major utility in learning more about the activities of these early hunter-gatherers and incipient agriculturalists.

The ceramic-period remains buried in the alluvium have received even less attention by us than have the Archaic loci. Still they too are important, because they can aid in the definition of Hohokam activities on the floodplain of the river. While several Tucson Basin Hohokam sites along the drainage terraces have been excavated, the use these people made of the river floodplain remains little known. In recent years systematic search for additional buried Hohokam sites, as well as work at selected localities, has been inaugurated by Paul and Susan Fish in the northern Tucson basin for the Arizona State Museum (Fish, et al., 1985). This continuing project, including close cooperation with the Department of Geosciences, has resulted in three Master's theses (Katzner and Shuster, 1984; Field, 1985) and promises to shed important new light on the prehistory of the Tucson Basin.

Discussion

From the observations presented here it is apparent that the alluvial history of the Santa Cruz River over the past 6000 years has been one characterized by five episodes of deposition separated by relatively brief episodes of channel entrenchment. The frequency of cutting and filling appears to have increased for the late epicycles (Table 1), but the vertical amplitude has remained essentially

constant for at least three epicycles. That is, the river has cut to approximately the same depth and filled back to essentially the same level at least three times in the past 2500 years.

The depositional units are lithologically similar consisting of basal sands and gravels of fluvial origin similar to the present bed load. These are overlain by multiple layers of relatively thin, somewhat organic, clayey sands or silty clays separated by varying thicknesses of silty sands and all gradational laterally to less sorted slopewash alluvium that in some cases could probably be traced to segments of adjacent alluvial fans.

Each depositional unit represents a period of net aggradation over several centuries (Table 1) characterized by the accumulation of sediments derived more from adjacent slopes than from very far upstream. Only during occasional flood events are significant amounts of sediment flushed through a particular reach. The entire length of the river is probably traversed by sand grains only during the infrequent, high discharge events. The more normal mode appears to have been one of inadequate discharge to flush slopewash out of the drainage system. The result has been net aggradation separated by occasional flood events that may momentarily reverse the trend and scour the floodplain.

The clayey layers, occupying the relatively flat, low gradient portions of the floodplain, are actually lenses that pinch out laterally indicating that they are the fine grained facies winowed from the more coarse-grained facies along the margins of the floodplain and upstream. In places where the zone of saturation intersects the surface or where spring water seeps onto the floodplain cienegas or wet meadows occur.

Anytime the floodplain is not actively aggrading or being eroded soil development takes place as vegetation grows and helps to stabilize the surface by a combination of root growth, reducing the velocity of overflowing water, and

trapping sediment. The top of each major depositional unit, where adequately preserved, has a soil indicating a longer period of pedogenesis and stability than any of the soils buried within the units, but the time of stability and soil development must be relatively short compared to the time for aggradation. The arroyo cutting or entrenchment phases appear to be even shorter because radiocarbon dates either side of the erosional event represented by the erosional contacts are commonly within a hundred years or so of each other for the earlier part of the record and possibly even less for the latter part. The radiocarbon dates commonly overlap within one sigma (Table 1).

The causes of arroyo cutting and filling have been debated for decades (Haynes, 1968a; Webb, 1985) and will not be addressed here except to say that entrenchment of the Santa Cruz through Tucson was triggered by three successive years of flood events that lasted several days. These were preceded by several decades of shallow groundwater exploitation that had lowered the water table probably already on the decline due to climatic factors. The result was a very unstable floodplain ripe for entrenchment. The large flood events of 1887 and 1890 had the power to erode a continuous channel over 20 feet deep completely through Tucson and beyond (Cooke and Reeves, 1976; Betancourt and Turner, in press).

In the valleys of perennial streams, more typical of the eastern United States, floodplains are the bottom lands that are either reached by high discharges or flooded about two out of three years (Leopold, et al., 1964). In the southwest once the ephemeral streams have become typical arroyos they have effectively abandoned their floodplains because it requires abnormally high discharges for a stream to top its banks. The depth of cutting is usually limited by the depth of the water table, theoretically, and by more resistant deposits encountered by the channel. Such deposits may be cemented beds, more clayey beds, or gravels with clasts too large for the stream to adequately transport. In Tucson it is the latter

cause that predominates. Once this more resistant level has been reached, further channel erosion takes the form of channel widening rather than deepening. The banks are cut away by even normal discharges, to say nothing of the high intensity discharge events that can cause catastrophic bank retreat such as the 1983 Tucson flood (Saarinen, et al., in press). This is the stage of the Santa Cruz today, and unless the banks are stabilized the channel will continue to widen until all of the Holocene sediments are swept away and the older, more indurated terrace deposits are reached. A similar state of erosion appears to have happened before 5000 B.P. in the Santa Cruz Valley and between 8000 and 6000 B.P. in the San Pedro Valley (Haynes, 1981).

In the alluvial record we see that the arroyos of the past had begun to fill within 100 years or so after the initial entrenchment, and the buried channels are not as wide as the modern channel. From this one might conclude that if the cycle is to continue the Santa Cruz should begin aggrading anytime within the next decade or so. However, this is most unlikely because the water table, which is a major factor limiting the depth to which the channel can cut, is now more than 100 feet below the present channel, which will, therefore, be more inclined to cut than fill, other factors being the same. This degradational mode is further enhanced in Tucson by the increased storm runoff carrying reduced sediment because of increased areas of pavement in the urban area. So, for the foreseeable future, the bed of the Santa Cruz and its major tributaries will get wider with each passing storm at the expense of the floodplain. In regard to geologic hazards, the only positive effect of this process is that as the channel widens the probability of overbank flow is reduced by the greater carrying capacity of the wider channel.

In its widened condition it is conceivable that with less discharge sediment would accumulate in reaches of relatively low gradient. Aggradation by

backfilling could then propagate upstream, but a single high discharge event could reverse the process.

Going back in time beyond the Holocene, we see from the Pleistocene terrace deposits that the Santa Cruz was a much larger, more competent stream at several times during the late Pleistocene. The channel deposits are not only successively larger in volume but their grain size is several orders of magnitude larger than that of the Holocene alluvium. Only during the late stage of terrace aggradation are the deposits of comparable grain size. The stratigraphy suggests that each major period of Pleistocene aggradation is characterized by streams (perennial?) transporting sand and cobble gravel. This changes with time to finer-grained alluvium and slope-wash deposits overlying the gravels. Deglaciation in the mid-continent area was probably accompanied by a net decline in southwestern water tables. Reduced discharge is indicated before entrenchment.

The contrast between the Holocene and late Pleistocene alluvial deposits is marked and typical of that seen throughout the continent (Haynes 1968a, 1984). Correlation with the climatic changes attending the transition is unavoidable. Sand and gravel deposition during the full late glacial period, 22,000 to 16,000 years ago, gives way to sand and slopewash deposition during deglaciation, 16,000 to 12,000 years ago, to be followed by epicycles of cutting and filling with fine-grained alluvium during the Holocene, 11,000 years ago to the present. This changing pattern probably reflects the net trend from cooler Pleistocene climates producing more freeze-thaw cycles, higher water tables, and higher stream discharge to warmer Holocene climates with lower water tables, less effective moisture regimes, and arid to semiarid vegetation (Spaulding, et al. 1983).

Ancient dunes on the floodplain west of Brickyard Arroyo appear to have been active after unit C₂ aggradation and stabilized early during aggradation of unit C₃. The dunes are apparently derived from fluvial silt and sand deposited on

the aggraded floodplain. The dune morphology is not well preserved but barchanoid forms are suggested by convex and steeper slopes facing northward. This implies that southerly winds, typical of today's summer monsoon season, occurred about 1000 B.P., but whether or not the overall climate was drier when the dunes were active cannot be stated with any confidence.

In the San Pedro Valley, east of and roughly parallel to the Santa Cruz, a more detailed and better dated record of late Quaternary alluvial deposits exists because of the several important fossil localities and prehistoric archaeological sites that have been discovered and studied over the past half century or so (Haynes 1968b, 1981). Geological examination of Paleoindian sites has revealed alluvial deposits of early Holocene age overlying the latest Pleistocene deposits and underlying a younger Holocene alluvial sequence much like that of the Santa Cruz. But these occurrences have been found only in tributary drainages. The apparent absence of early Holocene deposits from the main river deposits of both the San Pedro and Santa Cruz rivers might be the result of a more sustained period of channel erosion and widening before a swing to aggradation returned. Such a period is in evidence in the alluvial record of the tributaries of the San Pedro where the most pronounced period of post Pleistocene channel erosion occurred between 7500 and 6500 years ago. This suggests that during a period of perhaps 1000 years the floodplains of the degraded rivers were essentially completely removed by channel widening. As mentioned earlier, the buried channels of all subsequent alluvial deposits are much smaller than even the modern channels.

This major episode of erosion at the early end of a proposed hot-dry climatic event known as the Altithermal (Antevs 1948, 1955) may have been responsible for the scarcity of buried archaeological sites between 8000 and 6000 years old in the Santa Cruz Valley. Not only was there active erosion but ecological conditions may have been worse than those before and after.

Recent archaeological surveys on the San Xavier Reservation has produced a significant number of ceramic period sites along the west bank of the Santa Cruz that show a trend of increasing age southward, upstream from Martinez Hill (Steere, personal communication). A possible explanation is population shifts reflecting a declining watertable that was directed to the surface or near surface by the buried volcanic ridge between Martinez Hill and Black Mountain. As the watertable dropped the floodplain closest to the upstream side of the ridge would remain wet longer than areas farther upstream. There may have been springs, similar to Punta de Agua, along the west side of the floodplain as far south as Pima Mind Road in prehistoric times.

Conclusions

The alluvial record of the Santa Cruz River in the Tucson Basin reflects a history of at least five cycles of cutting and filling (erosion and deposition) over the past 5000 years. In the historic part of the record the impact of human utilization of the floodplain on erosion is clear, but the degree to which it affected erosion as compared to climatic causes remains enigmatic. Major prehistoric episodes of deposition, on the other hand, are undoubtedly due principally to non-human factors, mainly climatic change. The older the record the less human factors can be invoked as causal for either erosion or deposition.

In the early part of the historic record emergent groundwater characterized much of the Santa Cruz River and supported cienegas and erosion inhibiting vegetation. Today the river is an arroyo essentially without emergent groundwater and highly susceptible to bank erosion. The state of bank retreat today is approaching that of perhaps 7000 to 5000 years ago during which time most of the earlier Holocene alluvium had been swept from the Tucson Basin. Will this modern trend continue? We think it will for two reasons: (1) a water table too low to

promote sediment trapping vegetation, and (2) reduced sediment yield due to increased urbanization of the Tucson area.

Bank erosion along the Santa Cruz, Rillito, Pantano, and Canada del Oro drainages is being checked by a major program of bank stabilization in which deep concrete footings are being placed along contoured banks covered with "earth" cement. Eventually there will be no natural banks remaining in the Tucson area, and studies of the rivers' histories like the study presented here will no longer be possible, except via artificial excavations. In this regard, ditch and foundation excavations in or near the Santa Cruz, Rillito, or Canada del Oro floodplains can provide useful information for reconstructing river history. If interested geologists are informed in advance we could at least examine and photograph the exposure with a minimum of interference in the construction operation.

Finally, the presence of buried sites of all ages in the buried alluvium of the Santa Cruz and its tributaries has major implications for cultural resource management archaeologists. On the basis of this preliminary study, which revealed numerous buried prehistoric remains exposed in arroyo banks and in excavations for various facilities such as the landfill and the sewer trench near Ina Road, it is clear that any land modification activities entailing earth-moving operations on any of the major wash floodplains may well impact buried sites that have no surface indications. Testing or monitoring of such projects is recommended, and will be quite valuable in the on-going effort to describe and document the stratigraphy of the Tucson Basin and the history of human occupation of the area.

In the meantime, any occurrences of charcoal in Santa Cruz alluvium is of value for better understanding the fluvial history and, therefore, better predicting future changes. It would be helpful if such occurrences, before removal, could be brought to the attention of geologists working on these problems in time to allow proper evaluation of the stratigraphic context and proper collection to avoid

contamination for radiocarbon dating. Of course, if archaeological associations are found, professional archaeologists should be notified as soon as possible. Every occurrence provides an important piece of information towards completing the puzzle of the rivers' history in relation to culture history. Trained professionals can collect a sample and record the pertinent stratigraphic data usually in less than an hour and, therefore, not significantly delay construction operations. Each sample lost is a loss of valuable information of use to mankind now and in the future.

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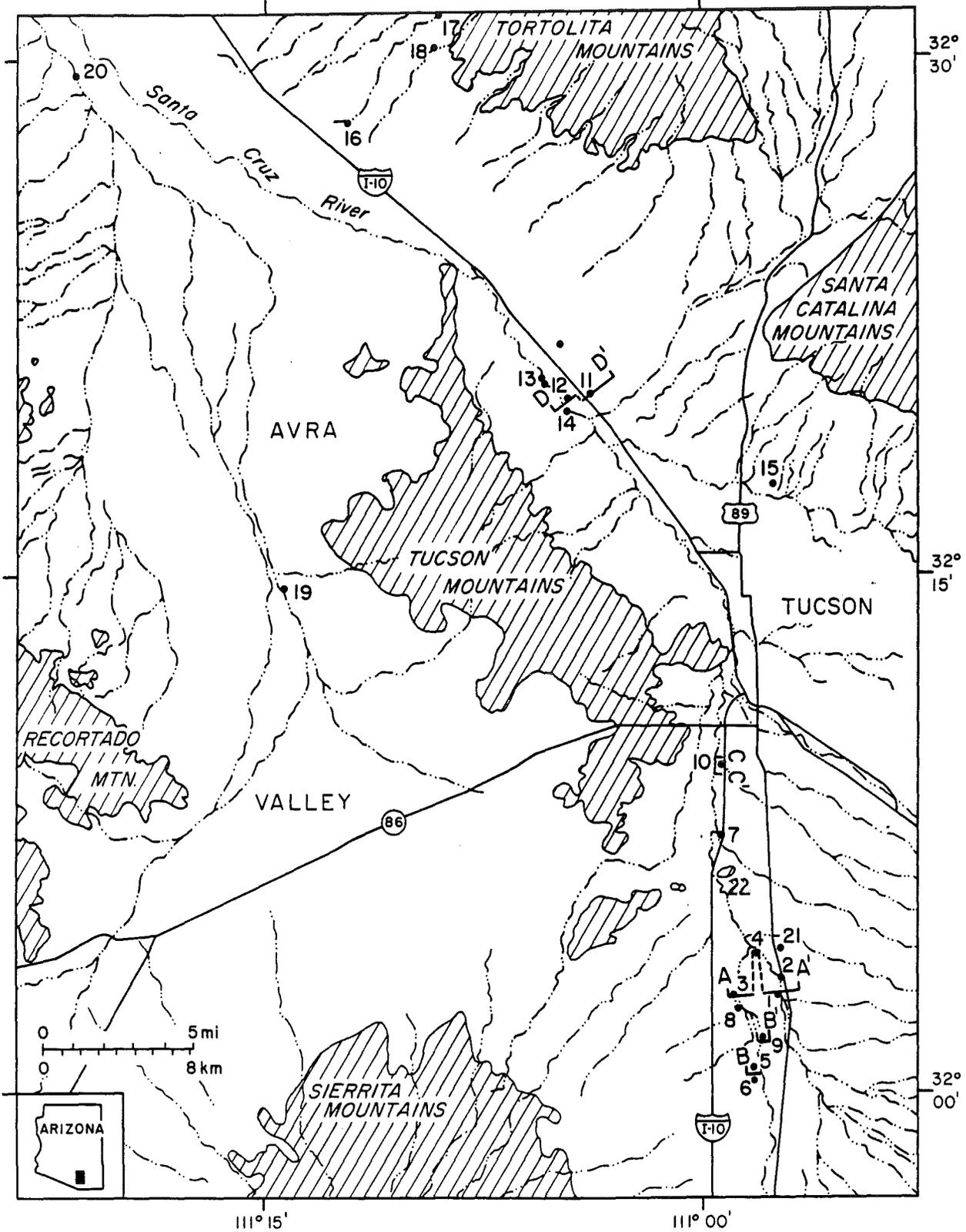
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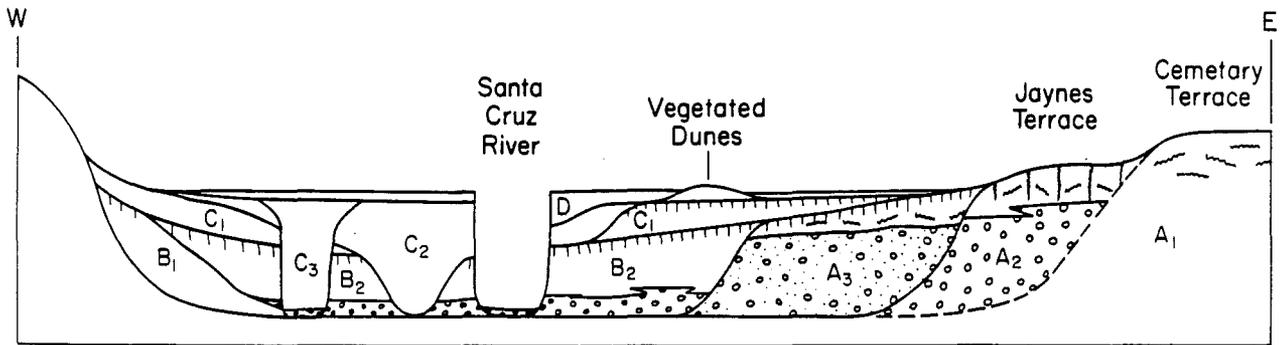
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S. 2. P. 5

SANTA CRUZ VALLEY

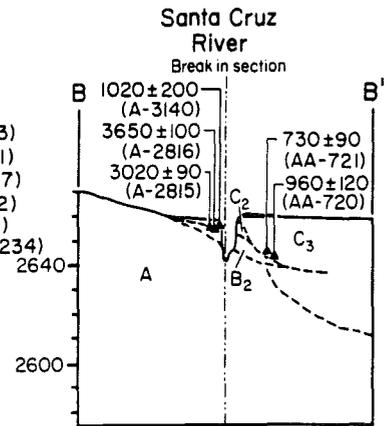
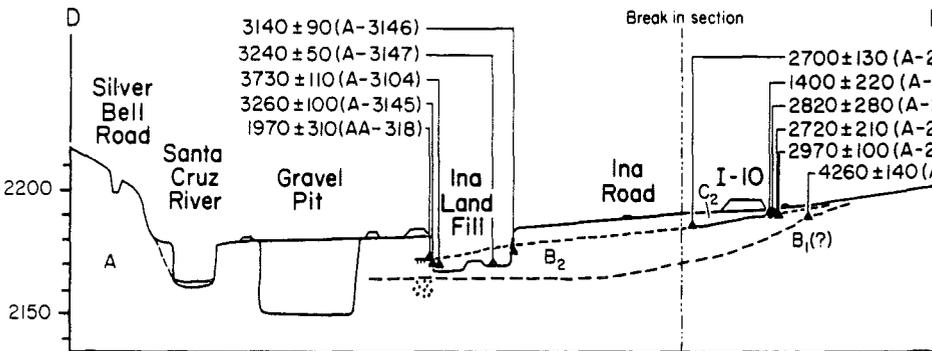
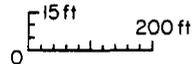
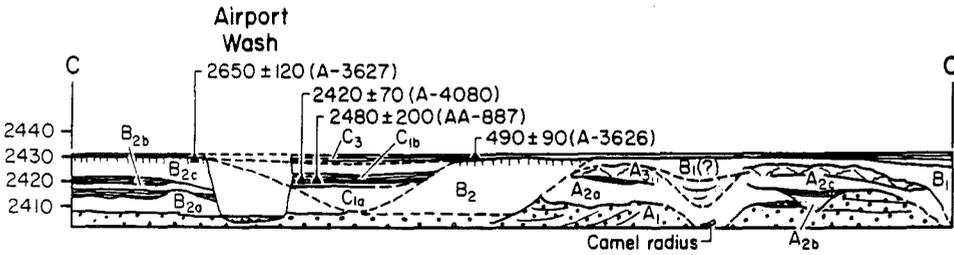
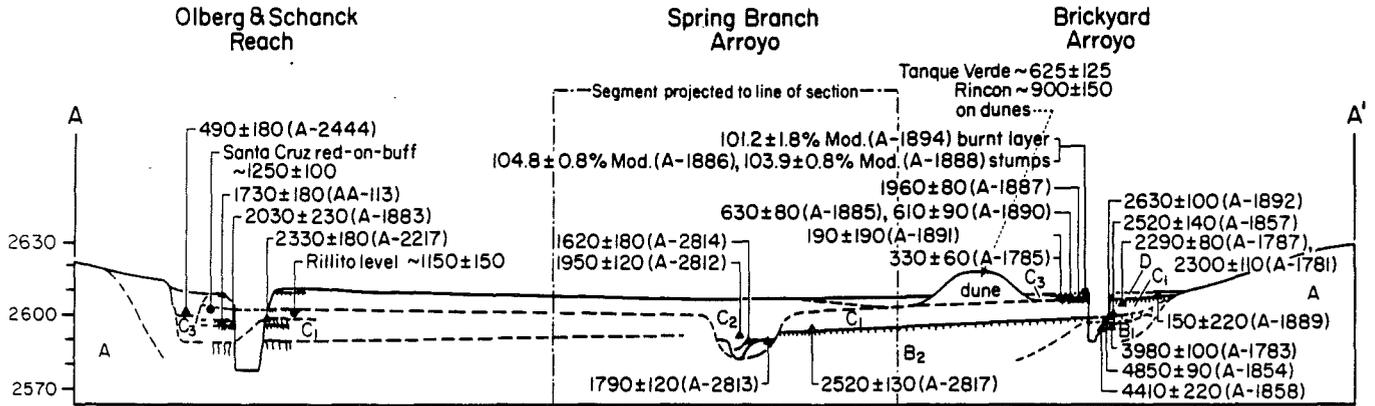
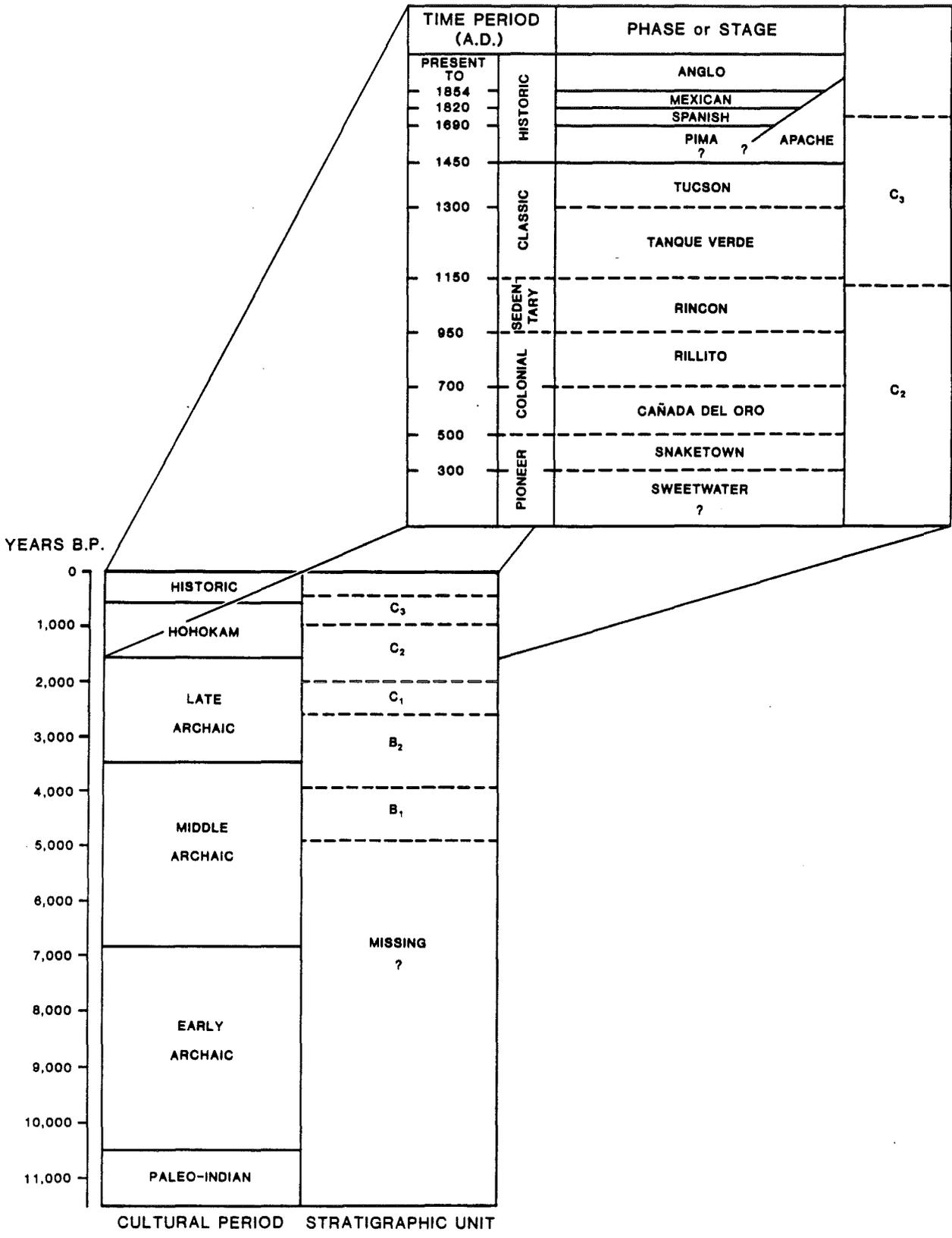


Fig 4.



5/25/58

Table 1. Radiocarbon dates in years B.P. (before 1950) from Tucson basin alluvium, and arranged in approximate relative stratigraphic order.

Radiocarbon age in years B.P.												Cultural Period
Unit	Pine Mine Road (B, C, & D) ¹	Brickyard Arroyo (1)	Brickyard Tributary (2)	Oberg & Schenk Channel (3 & B)	Spring Branch Arroyo (4)	Tucson Arroyo Valencia to Ave (7 & 10)	San Road Area (11, 12, & 14)	Airport Wash (10)	Tortilla Fans (19, 17, & 18)	N. First Ave. & Rillito River (18)	Avra Valley (19 & 20)	Cultural Period
E		40230(A1883)										Modern (Atomic era)
D												
C ₃		104 B-40, 85M(A1880) 103 B-40, 85M(A1888) 101, 21, 85M(A1884)	180±250(A1889)			103, 24, 37(A-110)						Historic
		730±80(AA-721) ² 860±120(AA-720) ²	630±80(A1885)	610±90(A1880)	480±180(A244)		780±80 ²	490±60(A868)	440±240(A2811) 780±100(A4274) ⁴ 800±80(A4278) ⁴		760±110(A4043)	
C ₂		800±180 ² Dunes										Hohokam
		1020±200(A3140) 925±125 ²	1800±70(A1214) ¹	1580±100 ²	1880±130(A2812) 1880±180(A2814) 1790±150(A2813)	1400±220(A3141)	1580±100 ²			1240±210(A238)	1880±170(A4038)	
C ₁												Late Archaic
			1880±80(A1887) 2280±80(A1782) 2300±110(A1781)	2030±180(A1218) ¹	2030±250 (A1883) 2350±180(A2217)	2200±130(B7187) ²	1870±310(AA-318)	2450±70(A4080) 2480±200(AA-887)	2160±100(A4273) ⁴			
B ₂												Middle Archaic
		3020±80(A2815) 3880±100(A2818)	2850±140(A1887) 2850±150(A4038)			2820±130(A2817)	2760±170(B7188) ²	2780±80(A4038) 2780±130(A4039) 2720±110(A4040) 2820±280(A2237) 2870±100(A2481) 3140±80(A3148) 3280±100(A3148) 3240±80(A3147) 3730±110(A3104)	2650±120(A3827)		3420±80(A4041)	
B ₁		480±80(A1884) 3880±100(A1783) 4400±220(A1888)										

¹ Site location on Figure 2. ² Archaeomagnetic date. ³ Ayers, 1980. ⁴ Stanford, 1984
⁵ Archaeological date. (Bender, 1980) ⁶ Bender, 1980. ⁷ Pluck, 1985

DATE	CULTURAL TRADITION	CULTURAL PERIOD (All Regions)	CULTURE PHASES FOR INDIVIDUAL REGIONS		
			Tucson Basin & Avra Valley	Phoenix Basin	Papaguerfa
1700	MIXED	Historic Period	(Tohono O'odham & Euro-American)	(Pima, Tohono O'odham, & Euro-American)	(Tohono O'odham & Euro-American)
1450	PIMAN	Protohistoric Period	(Sobaipuri & Tohono O'odham)	(Pima & Tohono O'odham)	(Tohono O'odham)
1300	HOHOKAM	Classic Period	Tucson Phase	Civano Phase	Sells Phase
1150			Tanque Verde Phase	Soho Phase	Topawa Phase
1100			Late Rincon Subphase		Sacaton Phase
1000			Sedentary Period	Middle Rincon Subphase	
950		Early Rincon Subphase		Gila Butte Phase	
850		Colonial Period	Rillito Phase	Gila Butte Phase	Gila Butte Phase
750			Cañada del Oro Phase	[Unnamed]	
200 A.D.		Pioneer Period	Snaketown Phase		Snaketown Phase
			Sweetwater Phase		Sweetwater Phase
			Estrella Phase		Estrella Phase
	Tortolita Phase		Vahki Phase		
B.C.	ARCHAIC	PRECE-RAMIC PERIODS	Red Mountain Phase?		
			Late Archaic Period		
			Middle Archaic Period		
			Early Archaic Period		
10,000	PALEO-INDIAN	PERIODS	Classic Paleoindian Period		
			Pre-Projectile-Point Horizon?		

Table 1. Comparative cultural sequences for south-central Arizona.