Final Report:

Characterizing the Habitat of Slender-Horned Spineflower (*Dodecahema leptoceras*): Geomorphic Analysis

by

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1.0 INTRODUCTION

1.1 Statement of Purpose

The slender-horned spineflower (*Dodecahema leptoceras*) is a state and federally-listed endangered species found solely in Southern California. It is threatened by extinction due to the rapid pace of development in this region. This plant is found associated with fluvial and alluvial fan sediments related to streams draining the Transverse (San Gabriel) and Peninsular (San Bernardino and San Jacinto) Mountain Ranges. Known occurrences of *Dodecahema* are not in active channels but are typically found on nearby stream terraces and alluvial fan surfaces which have been estimated to be the result of 100 year flooding events (M. Meyer, 1994, pers. comm.). Recorded populations are spatially distinct from one another and have shown no areal increase in historic times (M. Meyer, 1994, pers. comm.). Little is understood about this species' method of dispersal; and while seeds can be propagated under greenhouse conditions, the resulting plants produce few seeds. Thus, there is great concern about the future viability of *Dodecahema leptoceras* (DOLE) as increased alteration of its habitat occurs.

The goal of this research project component is to provide an understanding of the geomorphic setting of the DOLE habitat sites, including the ages of the alluvial sediments which support populations of the slender-horned spineflower. This research project component primarily included reconnaissance of sites on selected fluvial drainages supporting these populations: the Santa Ana, Bautista Creek, San Jacinto Wash, Big Tujunga Wash, Bee Canyon, and Arroyo Seco fluvial systems. Detailed field studies were undertaken on four of these fluvial systems: Santa Ana, San Jacinto, Bautista, and Arroyo Seco.

The results of this study are submitted separately, but they compliment the ecological research project component supervised by Dr. Edith B. Allen.

1.2 Regional Overview of Study Sites

The stream systems whose sediments support DOLE are similar in their source lithology and their fluvial geomorphology, as affected by a Mediterranean climate and an active tectonic regime. Both of these latter two characteristics promote increased sediment production and storage in mountain valleys. This sediment becomes available for deposition during flooding events. The observed stream deposits in the study channels most likely resulted from (a) climatic changes or severe weather events (i.e., increased sediment yield related to more moist climatic regimes or 100 year flood events); (b) tectonic processes (i.e., increased sediment yield associated with tectonic uplift, oversteepend terrain, and deeply fractured bedrock); or (c) combinations of these two forcing factors.

1.2.1 Climate

A region's prevailing climate has a major effect on the natural vegetation and also strongly affects fluvial geomorphic processes. In Southern California's south coast basin, a semi-arid Mediterranean climate periodically produces intense winter rain events which orographically impact steeply inclined mountain ranges resulting from active tectonics. These conditions, in turn, promote the accumulation of sediment on hillslopes and valleys during dry spells. This sediment becomes available for transport during intense rain. Primary precipitation occurring during the winter months and long, dry summers generally inhibits forest cover lower than 1500 meters except on some north facing slopes. Below this level, chaparral and coastal sage scrub communities predominate.

1.2.2 Tectonics

The lowlands of Southern California's coastal region are rimmed by steeply-sloping mountain ranges with peaks of 3000 to 3500 m. Much of the area of these ranges is above 2000 m in elevation. An active, complex tectonic system composed of the San Andreas fault and associated faults controls most of the region's topography (Muhs, 1987) and impacts its fluvial geomorphology. Regions in faulted shear zones also provide increased amounts of sediment to stream systems and basin catchments.

1.2.3 Lithology

The lithology (bedrock) of the region is varied. However, the four drainages studied are all predominately composed of coarse to fine grained plutonic and metamorphic clasts. Different lithologies have differing resistance to weathering, susceptibility to slope failure, and contribute differing particle sizes to fluvial systems. Additionally, the following three drainages all have Pleistocene sediments as source material in close proximity to the spineflower populations -- the Bautista and Soboba Beds near Bautista Creek and the San Jacinto River, and the Potato Sandstone near the Santa Ana River.

1.2.4 Fluvial geomorphology

One major effect of these components -- active tectonics, a Mediterranean climate, and granitic and metamorphic lithologies -- is the production of large quantities of sediment for transfer to the valley bottoms. Mass movements -- such as soil slips, debris flows, mudflows, and earthflows -- may be of greater importance to stream systems in this region than most others because of the combined effects of climate and lithology (Muhs, 1987). Most of these mass movements occur on slopes holding sediment accumulated during dry spells after heavy rainfall events. They differ in particle size distribution and other features, but they have in common the deposition of sediment upon low gradients. Debris flow deposits form alluvial fans at mouths of tributaries and debris trains in and along trunk streams (Campbell, 1974).

Geomorphic features of semi-arid and arid fluvial systems can differ significantly from the 'classic' floodplain of the eastern United States. Semi-arid and arid stream systems and their bedforms reflect flashy conditions where debris flows or highly concentrated flows impinge on channels. These stream systems produce alluvial fans, with sediment-rich flows leaving patchy deposits as gradients decrease at the front of mountain ranges. Channels in alluvial fans often avulse -- that is 'jump' to a new location -- over short periods of geologic time. Thus, significantly older sediments can be found abutting an active channel instead of the surface adjacent to an active channel being a recent floodplain. "The presence of compound channels and the absence of geomorphologic flood plains are significant differences that result from the operations of the arid-regime hydroclimatic systems." (Graf, 1988).

2.0 METHODOLOGY

2.1 Introduction

The primary goal of this project is to establish age control, where possible, for surfaces supporting DOLE. Methods of dating Holocene surfaces include: 1) numerical age dating including radiogenic methods such as ^{14}C; 2) relative age dating based on establishing spatial relationships between surfaces and then assigning positional ages or by comparing the physical effects of time on soil development between surfaces; and 3) correlative age dating in which a series of relatively established age sequences are tied to numerical time by correlation with another regional surface of known age. Material for absolute age dating is relatively rare on quaternary surfaces and can have constraints on its accuracy when found. As a result, a strong reliance is placed on the use of relative and correlative dating techniques -- such as soils, landscape position, degree of lichen growth, degree of surface smoothing, and relative clast integrity.

The fluvial systems included in the scope of this study were investigated through: (1) a review of written materials containing geological and soils data; (2) interpretation and mapping of aerial photographs; (3) field observation of the surfaces; (4) radiocarbon dating; and (5) soil descriptions that allowed comparisons to regional dated surfaces.

2.2 Brief Descriptions of General Methods

2.2.1 Aerial Photographic Interpretation and Mapping

Aerial photographs obtained from local flood control agencies and the UC Riverside aerial photography collection were analyzed through a stereoscope. From this analysis, maps were drawn of the relative topographic position of surfaces. These maps were then 'field-truthed' through on-site examination of surfaces.

2.2.2 Field Observations

General field observations were made on trips to the sites including the morphologic character of the stream channel reaches, relations with terraces and surrounding hillslope colluvial wedges and alluvial fans. Detailed observations of surface microtopography, slope, clast weathering, and lichen cover were made for sites supporting DOLE.

2.2.3 Radiocarbon Dating

Geomorphic surfaces which could be related stratigraphically to the spineflower surface in each drainage were searched for the presence of material which could be radiocarbon dated. Such material could include charcoal, charred wood, peat, or freshwater snail shells. The occurrence of such material is relatively rare. When found, this material must be examined for evidence of possible fluvial reworking and redeposition. Found samples were submitted to Beta Analytical in Florida for analysis, either through conventional methods or through AMS dating. Appendix A provides the laboratory results as well as a description of calibrated radiocarbon dating methods.

2.3 Principles of Soil-Stratigraphic and Geomorphic Analysis

2.3.1 Application of Fundamental Concepts in Soil-Stratigraphy and Geomorphology

Engineering geologic analyses typically depend upon soil stratigraphy to date Quaternary deposits (e.g., Harden and Matti, 1989; Rockwell et al., 1990) because radiometrically datable material is rare in many types of continental depositional environments. Soil development is influenced by five major variablesincluding climate, parent materials, topography, vegetation, and time (Jenny, 1941). Soils form in response to complex gains and losses of matter and energy distributed vertically below a land surface, and changes in rates of gains and losses with the soils result from changes in the five major variables. As a consequence of the interactions of these variables, soil development is a natural, complex system that evolves over time (Birkeland, 1984). Soil data can be used to interpret the ages of a given sequence of deposits by ascertaining that four of the five major variables remain relatively constant over time (Jenny, 1941; Birkeland, 1984, 1991). Under these conditions, a soil chronosequence can be established whereby soil development is primarily controlled by changes over time.

Soil typically develops on abandoned geomorphic features such as fluvial (stream) terraces that are no longer serving as hydrologically active channels or floodplains. The degree of soil profile development (e.g., the formation of a vertical sequence of horizons, each with distinct mineralogical, physical, and biological characteristics that differ from the parent material due to secondary weathering processes) on terraces reflects the time since these geomorphic features were abandoned by active channels and floodplains. Within a given region of relatively similar climate, parent material, biota, and topographic position, soil geomorphologists may establish the chronologic sequence of geomorphic features and their associated deposits by describing the progressive degree of soil profile development on these geomorphic features. In the absence of radiometric age control (e.g., ^{14}C or thermoluminescence dating) and assuming relative similar soil-forming conditions, numerical age estimates may be established for an area by comparing a sequence of radiometrically dated soils and associated geomorphic features to an undated sequence.

Soil geomorphic research focuses upon the genetic relationship of soil and landscapes. Linking soils and geomorphic relationships is crucial and necessary in order to develop a framework for a reasonable interpretation of soil stratigraphy and chronosequence development. As stated by Birkeland (1990, p. 207), "geomorphic input is required to ask and answer such fundamental questions as (a) can the geomorphic setting give an idea of the age of the soil, (b) can it show whether part of the soil has been eroded, and (c) are some of the clay minerals of eolian origin." Enhanced understanding of the chronologic interpretations of soil sequences requires that such questions be addressed.

2.3.2 Field Descriptions of Soil Morphology

Soil profiles (or pedons) are described at sites (cuts or trenches) which reflect the most stable landscapes (i.e., surfaces which display minimum erosion or deposition) in order to assess the maximum degree of soil development for a given landform. Soil profiles are also described in the field using the terminology of the U.S. Soil Conservation Staff (1975) with 1981 revisions (see Birkeland, 1984; Birkeland et al., 1991). Approximately 12 soil properties are recorded at each site including: horizon designation, depth, thickness, dry and moist color, texture, structure, dry and moist consistence, clay film development, stone content, root and pore development, pedogenic carbonate development, and lower boundary characteristics. Special features, such as the degree of clast weathering recognized during profile description, are noted for each horizon. The vertical arrangement of the soil horizons and their properties are described from the land surface down to the parent material and/or bottom of the cut or trench. In addition, the properties of the land surface features (i.e., topography, vegetation, slope aspect and amount) near each trench and profile site are recorded.

The similarity of parent materials (granitic alluvium), climatic environment, and the close geographic proximity of the sites allow for comparisons of soil morphological characteristics developed on different geomorphologic surfaces. Differences in soil morphological characteristics are usually noted on different aged surfaces because of varying lengths of time available for soil development. The five soil forming factors recognized are climate, organisms, topography, parent material, and time (Jenny, 1941). In a geographical region where these factors are all nearly identical except for the passage of time, the impacts of the passage of time on soil development can be examined and compared. This allows for comparison of soils developed on landforms of different ages within different drainages.

2.3.3 Regional Correlations and Soil Ages

The degree of soil-profile development, as determined by field descriptions, is used as: (1) a quantitative method to assess the amount of pedologic change that has taken place since the parent material was deposited; and (2) a tool in Quaternary stratigraphy where soils are used to correlate surficial deposits (Birkeland et al., 1991). Studies demonstrate that comparisons and correlation of general profile development across broad regions yield relatively consistent results.

Age estimates of a given soil and its associated landform are based on comparisons of soil profile properties, associated Soil Development Indices (not part of the scope of this project), and appropriate correlation soil chronosequences which have isotopic numerical age control. The two comparitive areas closest to the study sites are: the Cajon Pass region of the western San Bernardino Mountains and the Anza region near the southwestern flank of the San Jacinto Mountains. The soils developed on a suite of terraces in the Merced area of central California are typically used to provide additional age limitations in the Inland Empire Region (Rockwell and others, 1990; Kendrick et al., 1994). Because the Merced, Cajon Pass, Anza, and other Inland Empire sites differ in geographic location and geologic settings, trends in the degree of soil development may vary. The differences are discussed below. An additional area with isotopic numerical age control is the Soda Mountains piedmont in the Mojave Desert. However, due to the striking differences in climate, vegetation, and topography, comparisons are made to the Soda Mountains piedmont only in terms of pedogenic carbonate development observed within the San Timoteo area.

McFadden and Weldon (1987) elucidated the rates and processes of soil development on 11 well-dated fluvial terraces in the Cajon Pass region along the western flank of the San Bernardino Mountains. These terraces, spanning an age range of the past 500,000 years, are located approximately 30 km northwest of the study site. The deposits and associated soils have been dated by radiocarbon techniques and numerically constrained by slip rate and paleomagnetic data. Rockwell and others (1990) provided a radiocarbon-dated, soil chronosequence near Anza, which is located approximately 60 km east of the study site and is latest Pleistocene through Holocene in age. Rockwell and others (1990) compared soil-forming factors across xeric climatic and vegetative settings of inland southern California and concluded that soil formation in the Anza and Cajon Pass areas follows similar trends.

The vegetation in the Inland Empire area consists of a soft chaparral (coastal sage scrub) community (Clark, 1979). This vegetational community is very similar to the chaparral communities found in the Cajon Pass and Anza areas. The study area is transitional between the more moist and more elevated areas of Anza and Cajon Pass and the much drier regions of the Mojave Desert and Coachella Valley. The Riverside-Moreno Valley-Beaumont area has a mean annual precipitation of about 28 to 48 cm (U.S. Weather Bureau, 1952), whereas the Anza and Cajon Pass areas receive between 60 and 73 cm of precipitation annually. The area of the Soda Mountains (Mojave Desert) receives only about 10 cm of rainfall per year. Recognizing that the study region is relatively drier than the Anza and Cajon Pass regions and relatively more moist than the Mojave desert sequence, soils in the study area site may be correlated to the Anza and Cajon Pass regions.

The topographic setting of the Cajon Pass, Anza, and Inland Empire areas are reasonably similar with soils forming on the surfaces of narrow to broad fluvial terrace remnants and alluvial fan surfaces. The width of the surface on which the soils were described and the proximity of the surface to upland areas, however, can influence the relative amount of colluvial contributions of clay, silt, and fine sand (Harrison et al., 1990). The parent materials of each region are similar in that they are typically alluvial deposits with relatively short transport distances (i.e., not axial fluvial systems) and are composed predominantly of a mixture of metamorphic and granitic clasts. The parent materials differ slightly from each area in the relative proportions of the rock types and the grain-size properties. In the Cajon Pass area, gravelly fluvial sediments have clasts that are derived from metamorphic, melanocratic, and leucocratic granitic and, to a lesser degree, sedimentary terrain (McFadden and Weldon, 1987). The parent material at Anza is composed of sandy, gravelly alluvium derived predominantly from granitic rocks with locally significant contributions of metamorphic rocks (Rockwell et al., 1990).

3.0 RESULTS

3.1 Introduction

The sections below include descriptions of field observations, geomorphic measurements, and soil profile descriptions made at the primary study sites. The primary focus of these sections is the presentation of data on the age of fluvial sediments and the types of process operating on the associated surfaces where spineflower populations exist. Details of geomorphic processes associated with high-magnitude flooding on Arroyo Seco is given in Section 4.0.

3.2 Upper Santa Ana River Site

The slender-horned spineflower is found at several locations in the upper Santa Ana River: (1) near East Highland, San Bernardino County, on the east and west sides of Orange/Boulder Ave; and (2) near the confluence of Mill Creek and the Santa Ana River. The geomorphic surfaces of the Santa Ana River were mapped to show their relative positions (Figure 3.1). These surfaces have been drawn using aerial photographs and topographic maps and are based on relative height of features, slope as delineated by topographic lines, and flooding evidence from the 1938 flood.

Auger samples of soil were taken from surfaces at the east Highland site, near Orange/Boulder Avenue to allow visual analysis of soil development. These data are presented in Table 3.1.

Table 3.1 Soil characteristics of surfaces in vicinity of Orange/Boulder Ave. spineflowers.

Surface	**Auger Sample Horizons**	
Qf4 (Spineflower surface)	AO	1.5 cm thick
	Bw	4 cm thick.
	C	below 5.5 cm.
Qf4 (higher level above spineflowers)	AO	4 cm thick
	C	Rock fragments
Qf3 surface	AO	3.5 cm thick
	Bw	25 cm thick
	C	below 28.5 cm

Spineflower populations at the Orange/Boulder Avenue surface are found associated with trash, which has become partly buried. Populations occur in slight depressions on this already relatively flat surface, perhaps in abandoned areas of rodent burrowing. Evidence of sand to silt size grains infilling depressions was observed in the field after storm events, especially the movement of these fine particles down slopes by overland flow. Higher run-off values are expected from older surfaces because they tend to be less permeable due to increased amounts of silt in their soil profiles. Also a linear 'flow' of spineflower populations over the edge of one of the terraces was observed. Lichens with diameters of 2.5 cm are found on this surface. Surface slope was ~ 1-2°. The Qf4 surface had moderately weathered surface clasts, loss of surface bar and swale topography, and lichens up to 8 inches in diameter.

3.3 Upper San Jacinto River Wash Site

A geomorphic map was developed of surfaces supporting DOLE in the reach of the San Jacinto River (Figure 3.2). Spineflower populations have been observed south of San Jacinto River, ~1.5 miles east of Valle Vista on the southwestern side of the San Jacintos. These populations are geographically located between the two strands of the San Jacinto Fault. The extant populations in this drainage occur on a terrace which shows no historic evidence of flooding.

A charred wood sample found in a lower (younger) terrace across the channel from the spineflower terrace was submitted to Beta Analytical for radiocarbon dating. Results from this analysis (Appendix A) indicate a conventional radiocarbon date of 240 +/- 90 years BP [before present (1950)] and a calibrated age of AD 1660 (336 years old) based on the intercept of the conventional radiocarbon age with a calibration curve.** These dates reflect the death of the tree from which the wood was derived. Since the wood was encased in charcoal, it is assumed that this wood was deposited in the sediments in which is was found soon after a fire. In a fluvial setting, the possibility exists that this sample could have been reworked and thus does not accurately date the age of the deposition of the terrace. That is, this sample may have originally been deposited at an earlier time in an older terrace which was subsequently washed away and redeposited. However, the condition of the found sample argues against reworking in that it showed no evidence of breakage or pitting which should occur during reworking. Figure 3.3 is a generalized cross-section of the drainage showing the relative location of the spineflower populations and the position of the radiocarbon dated surface. Based on relative position of the surfaces, the spineflower surface must be older than an historic date (older than 336 years).

A soil description was completed utilizing a road cut in the terrace supporting the spineflower populations. The work was undertaken at a distance from known populations so that no destruction would be done to their habitat. The results of this description are included in Table 3.2. The slope of the surface supporting DOLE is ~0-1°. The surface's microtopography is flat with no surface expression of bar and swale topography.

Table 3.2. Pedon description of San Jacinto River near Valle Vista, upper terrace supporting spineflower.

Horizon	Depth (cm)	Thickness (cm)	Description
A	0-1	1	2.5Y 5/2, grayish brown, (d); 2.5Y 4/2, dark grayish brown, (m); sandy loam texture; moderate fine platy structure; firm consistence (m); ~ 10% gravel; no roots; few very fine (<0.5 mm) pores; no effervescence; abrupt smooth boundary; slightly hydrophobic.
AB	1-12	11	2.5Y 4/4, olive brown, (d); 2.5Y 3/1 very dark gray, (m); sandy loam texture; weak medium platy structure; firm consistence (m); ~5% gravel; common fine and coarse roots; no pores; no effervescence; abrupt smooth boundary; hydrophobic.
B	12-32	20	2.5Y 5/6, light olive brown, (d); 2.5Y 4/2, dark grayish brown (m); sandy loam texture; weak fine prismatic to subangular blocky structure; slightly hard consistence (m); ~2.5% gravel; few very fine, fine, and medium roots; no pores; no effervescence; wavy smooth boundary; no hydrophobicity.
Bw	32-68	36	10YR 6/3, pale brown, (d); 10YR 4/4, dark yellowish brown, (m); sandy loam texture; weak medium prismatic structure; very friable consistence (m); ~5% gravel; ~1% cobble; few very fine and fine roots; no pores; no effervescence; wavy smooth boundary; no hydrophobicity.
	68-84	16	Krotavena (infilled animal burrow).
E	84-121	37	2.5Y 7/2, light gray, (d); 2.5Y 6/2, light grayish brown, (m); loamy sand texture; weak medium sub-angular blocky to fine subgranular structure; loose consistence (m); 2.5% gravel; few fine roots; no pores; no effervescence; abrupt smooth boundary; no hydrophobicity.
Bw (Bt?)	121+	20+	2.5Y 6/3 light yellowish brown, (d); 10YR 4/2, dark grayish brown, (m); clay loam texture; moderate medium sub-angular blocky structure; friable consistence (m); <1% gravel; no roots; no pores; no effervescence; no hydrophobicity; few thin clay coatings on 2 mm gravel sieved from sample.

3.4 Bautista Creek Site

Bautista Creek flows northwest to southeast and is south of the Thomas Mountain batholith which has been uplifted to form the San Jacinto mountains. Bautista Creek parallels and then intersects and follows the San Jacinto Fault. In the lower reach, which currently supports citrus orchards, the Bautista Beds (nonmarine sediments which contain vertebrate fauna of Pleistocene age) form the northern boundary of the channel. The six identified DOLE populations occur just upstream from this reach before the intersection of the stream with the fault. Along the stretch supporting DOLE, the steep hills bounding the channel are primarily pre-Cenozoic granitic and metamorphic rocks.* (Rogers, 1965). The Bautista Bed formation occurs approximately two miles upstream of the DOLE populations.

DOLE populations are found on surfaces in braided regions of the narrow channel of Bautista Creek. The geomorphic surfaces of the segment of Bautista Creek supporting the population of DOLE studied in the ecological section of this report are mapped in Figure 3.4. Preserved in this section of the channel are old terrace deposits into which the channel has incised. Clasts were sampled from one of these terraces immediately to the north of the road near the DOLE population. Several clasts disintegrated completely into grus using hand strength. Recent fluvial action has undermined the terrace to the south of the channel, away from the San Jacinto fault. At this location, a sharp cliff of approximately 10 meters height has been produced by the stream.

On the island supporting DOLE in this section (Figure 3.4), the plants are found in open areas associated with slight surface depressions and rodent burrows. No trees grow on this island, although there is one dead black cottonwood at the downstream end of the island. The ten largest clasts on the surface were measured and had an average maximum length of 25 cm. The average clast was 10 cm in length. The smallest clasts averaged 1 cm in maximum length. DOLE was found in fine-textured sediments with a grain size of sand or less. Surficial sediments from the vicinity of the DOLE were hand textured and yielded textures of loam and silt loam (from 10 - 30% clay, from 30-80% silt, and from 0-50% sand). Surficial sediments of a bar to the south of the DOLE surface yielded a hand texture of loamy sand. Examination of a recent incision into the DOLE surface (February, 1996) showed no soil horizonation. The slope of the surface supporting the DOLE is ~5° toward the downstream. The plants are found ~35 cm above the active stream.

Fine charcoal found on a nearby surface was sampled for radiocarbon dating and yielded a date of 90 ± 70 ^{14}C years. This surface was upstream from the DOLE surface and appeared to be in the same stratigraphic position. In a fluvial setting, the possibility exists that this sample could have been reworked and thus does not accurately date the age of the deposition of the terrace. We infer, therefore, that this surface is most likely younger than 100 years. Lichen size and morphology were compared from the two surfaces and appeared very similar. Both had largest lichen growths of approximately 10 - 15 cm.

3.5 Big Tujunga Wash Site

Tujunga Creek drains a frontal watershed of the San Gabriel Mountains which has an drainage area of 115 mi^2 above the mountain front (Scott, 1973). The final 3 miles of its course prior to leaving the mountain front is through a broad fanhead valley called Big Tujunga Wash. Fanhead valleys are like alluvial fans in their fluvial processes; however, these valleys act to confine the lateral movement of a stream to a narrower arc. Four known occurrences of DOLE are found within the reaches of this fanhead valley.

DOLE populations (Numbers 1,2, and 3) in Big Tujunga Wash were examined as part of reconnaissance visits. At this time, clast size data was noted from a bar upon which one of the spineflower populations (Number 2) is located. The following relates data collected during this visit as well as observations made based upon reports of others (Scott, 1973; PSomas study; Army Corp of Engineers, 1993).

1. According to maps produced by PSomas showing the probable distribution of flows of discharge magnitudes (Q) relating to 150 and 500 year flood events, the occurrences of DOLE (Numbers 2 and 3) examined in September, 1995 were on surfaces which would be flooded by a 500 year event. This is based on relating these Q values to the Discharge Frequency Curve done by the Army Corps of Engineers (1993).

2. Two occurrences of DOLE in Big Tujunga Wash (Numbers 2 and 3) are on surfaces which showed no evidence of flooding during the 1969 event which destroyed several homes built on terraces of the stream (Scott, 1973). The DOLE surfaces examined are the highest on cross-sectional surveys done by Scott (1973) after the 1969 event (cross sections E-E' and F-F') and appear to have not been produced or flooded during this event.

3. The clasts of the bar supporting population Number 2 are sub-rounded to well-rounded boulders. Ten largest were measured and were as followed: 4' x 2.5', 3' x 3', 3.5' x 2.5', 5.5' x 5.5', 4' x 4', 5.75' x 4.5', 5' x 3', 4.5' x 5', and 5' x 4'). One 4' by 4' has spalled in place on the surface of the island. The deposits of this bar fall in the larger of the two bi-modal units mentioned by Scott (1973).

4. On this island the spineflowers are present on the edge of the bar, running down the surface of a slope. This is marked on E - E' cross-section.

5. The main channel of the wash saw an avulsion during the 1969 event to produce two channels. This demonstrates some of the processes which can produce a complex array of surfaces in alluvial fans and fanhead valleys.

6. Current known locations for DOLE were not noticed by Krantz during a 1979 survey. Either they were missed, or they weren't there. If the second option were true, what happened between 1949 and 1979 for them to disappear? Perhaps the event of 1969 had an effect. Obviously it did not remove extant populations by overbank flooding (because at least those DOLE at location 2 and 3 were not flooded). Perhaps these populations have responded to overland flow or other slope processes related to this large event.

3.6 Bee Canyon Site

No data were recorded from Bee Canyon reconnaissance visits. Immediate observations were that it was similar to other occurrences of DOLE in that both Pleistocene sediments and a fault are found in the immediate vicinity of the populations.

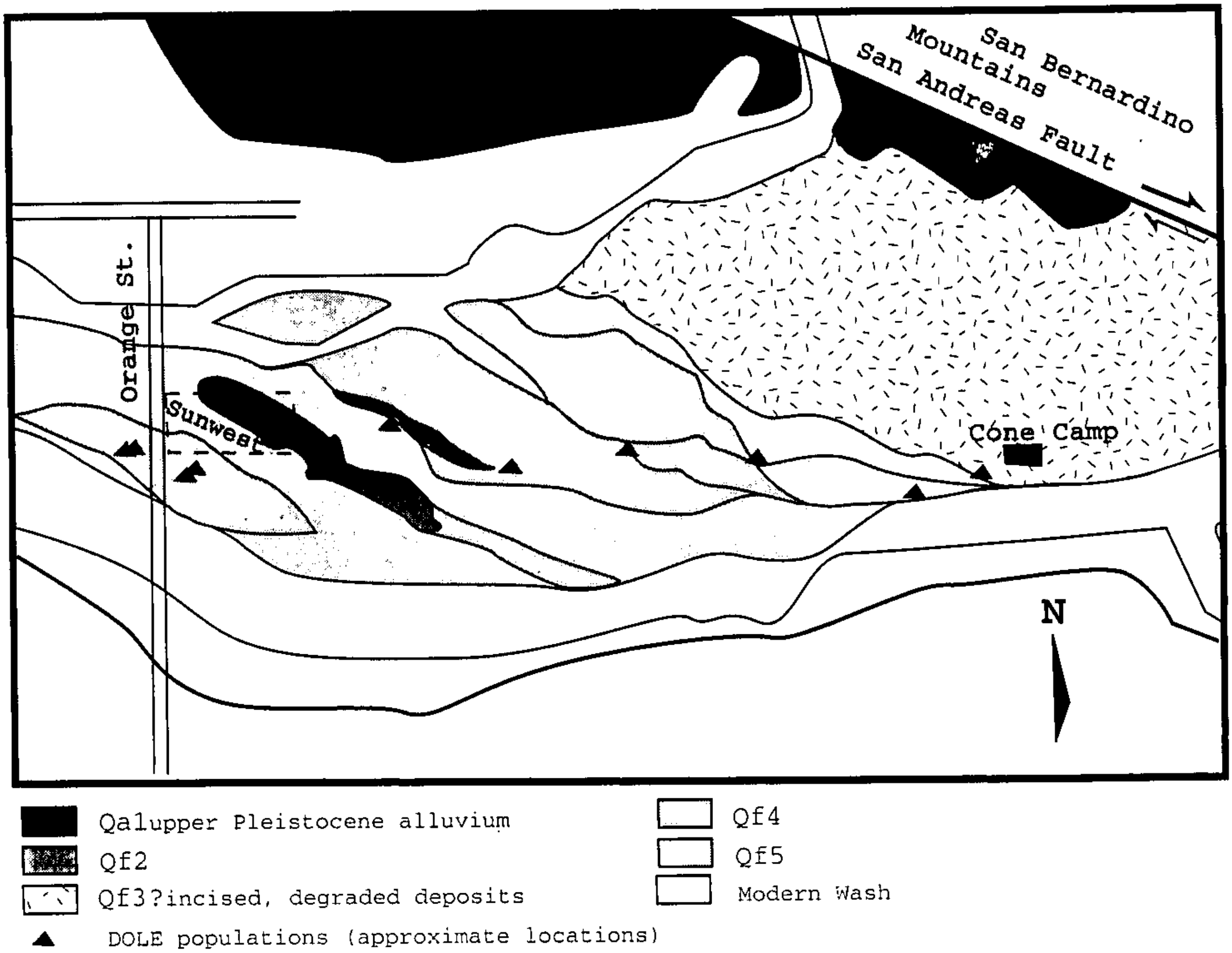
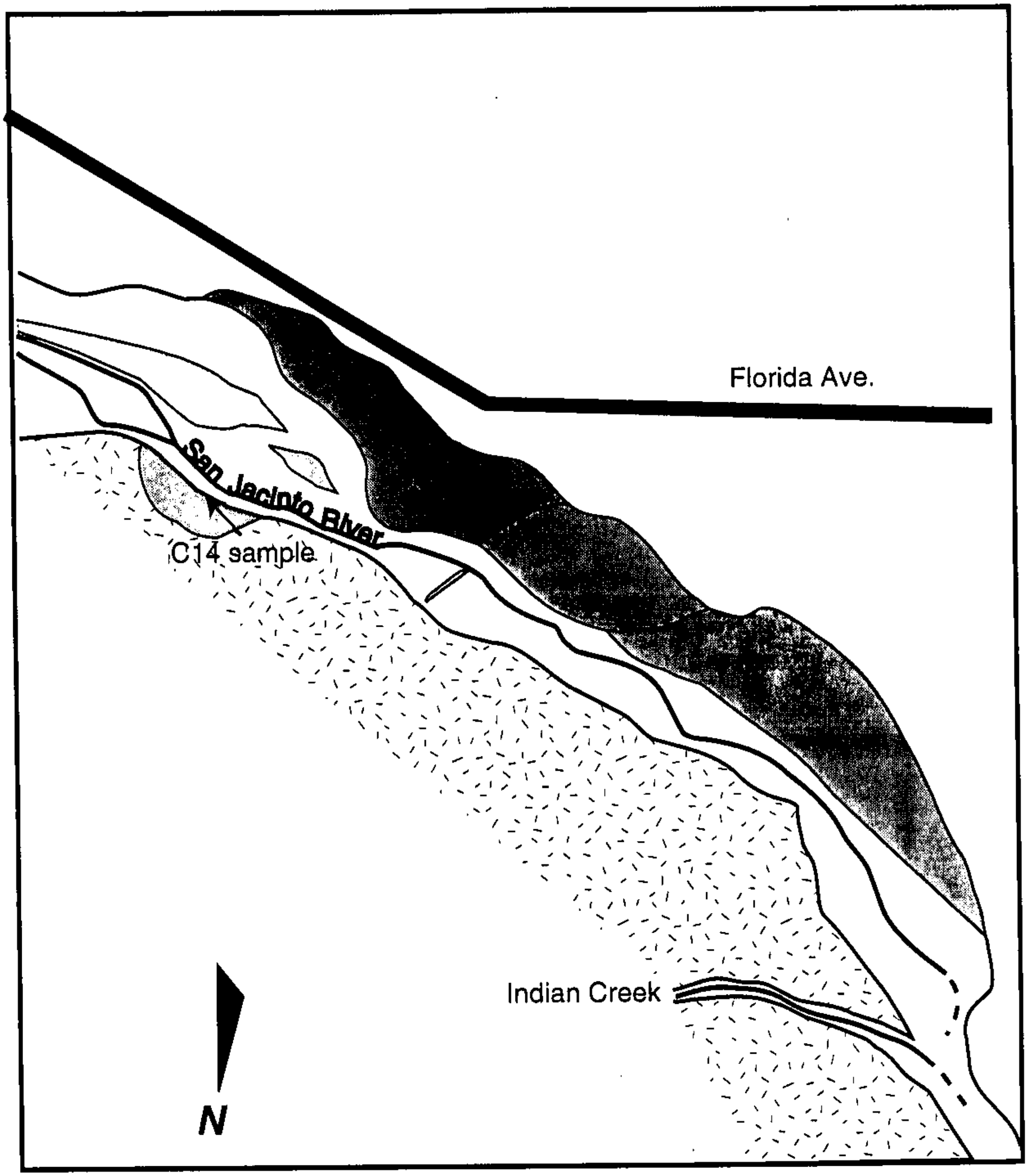


Figure 3.1. Geomorphic surfaces from aerial photo-mapping of Santa Ana River Wash. Surfaces are numbered Qa1 through Qf5, with Qa1 being older surfaces.



▨ Bautista Beds -- Pleistocene nonmarine sediments.

■ Qa1 -- terrace deposits; DOLE populations.

▨ Qa2 -- terrace deposits; C14 date of 240 (± 90) yrs BP.

☐ Qa3 -- bar deposits.

☐ Qa4 -- modern wash.

▲ DOLE populations (approximate locations)

Figure 3.2. Geomorphic surfaces from aerial photo-mapping of San Jacinto River Wash. Surfaces are numbered Qa1 through Qa4, with Qa1 being older surfaces.

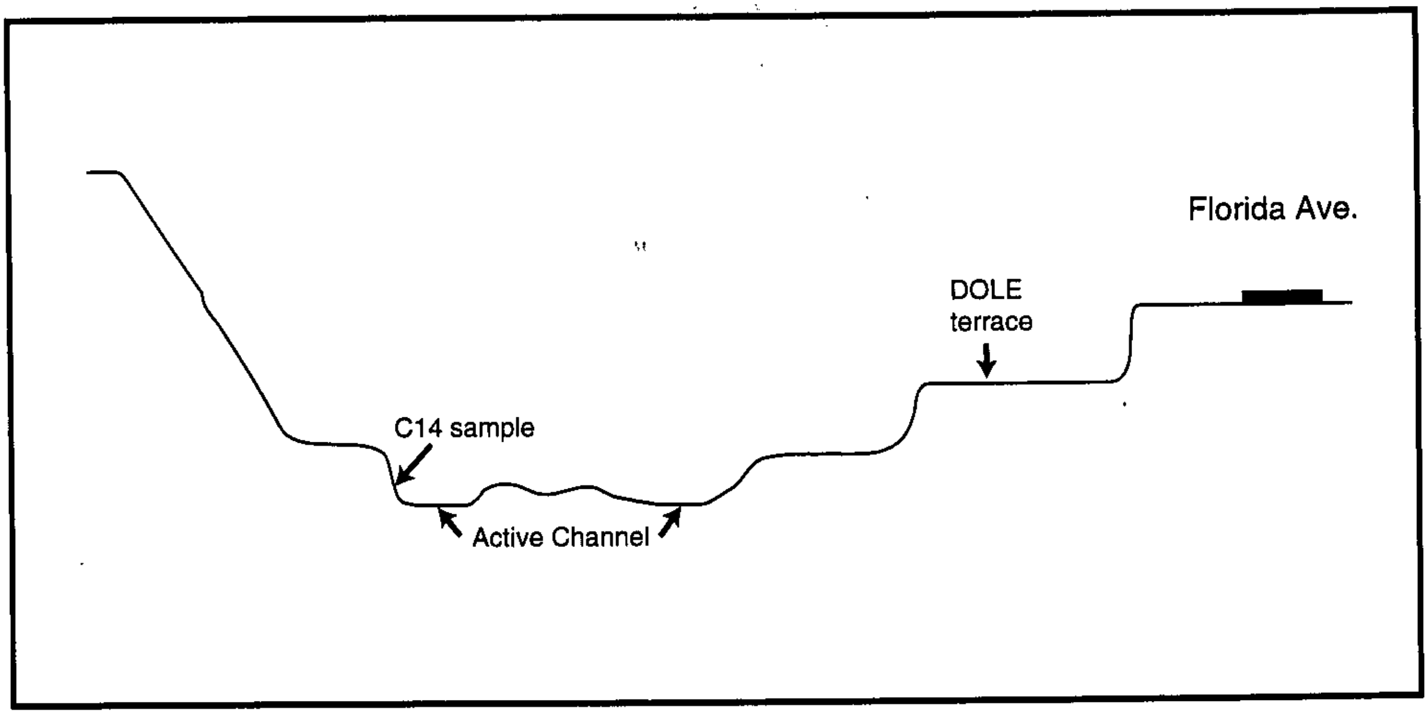
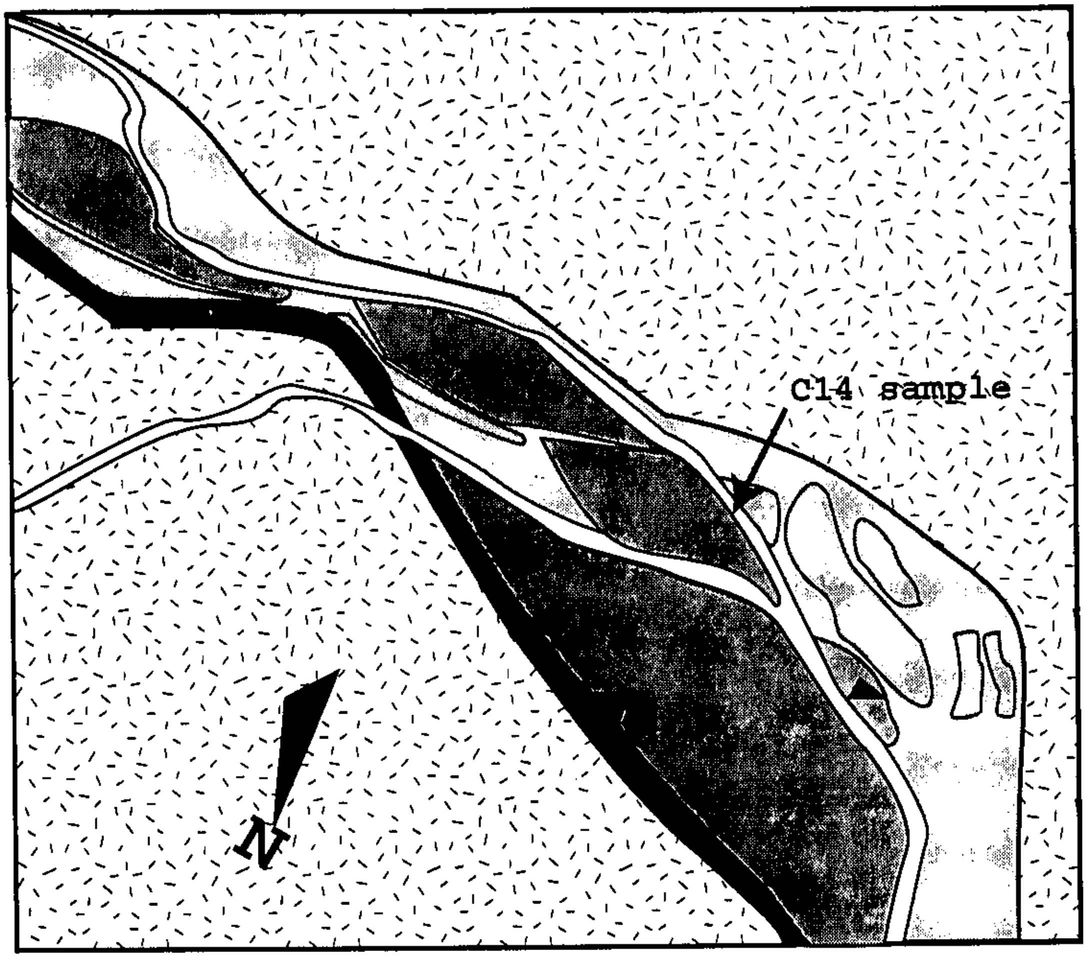


Figure 3.3. General cross-section of terraces in reach of San Jacinto River Wash supporting spineflower. Location of terrace where charred wood sample was taken for radiogenic dating and spineflower terrace are indicated.



▨ Bedrock -- pre-Cenozoic granitic and metamorphic rocks

■ Qf1 -- modern terrace deposits; C14 date of 90 (± 70) years BP.

▨ Qf2 -- modern bar deposits of Bautista Creek.

☐ Bautista Creek Wash.

☐ Baustista Creek channel.

▲ DOLE population (approximate location of EO21)

Figure 3.4. Geomorphic surfaces from aerial photo-mapping of Bautista Creek in upper reach.

4.0 GEOMORPHIC ANALYSIS OF A RECENT, LARGE-MAGNITUDE FLOOD EVENT AT THE ARROYO SECO STUDY SITE

(contributers to this chapter include the graduate students of the UC-Riverside Quantitative Geomorphology class)

4.1 Introduction

During the winter of 1993, southwestern Riverside County experienced approximately 140 mm of rain in 48 hours. This storm was followed by a larger event including 100 mm of precipitation in one day. The areas of Temecula and Murrieta were devastated by flooding during this event which has been estimated to be a 100 year flood (NOAA; James Price, personal communication, 1993). One stream channel which appears to have been significantly modified during this event is Arroyo Seco.

There are three main objectives for this type study of the Arroyo Seco Stream Channel. The first is to identify channel alteration that resulted from the most recent flooding. In order to accomplish this objective, analysis of aerial photographs was combined with field observations. The second objective is to estimate the velocity and volume of water that flowed through a portion of the channel. This required measurements of maximum flow geometry, which can be reconstructed from the height of flotsam, slackwater deposits, and recent erosion along the cut banks of the stream. The velocity and discharge calculations resulting from this reconstruction were compared to those determined from the maximum clast size that was mobilized in the most recent flooding. The final objective is to compare the deposits associated with the most recent flooding event with those of the deposits associated with a locally preserved stream terrace which supports spineflower populations (Figures 4.1, 4.2). This terrace occurs several meters above the active channel and is referred to as the "high terrace". In making this comparison, an estimate of the magnitude of the flood event that might be required to be recorded in the sedimentary record can be elucidated. Age control of the high terrace permitted an estimate of the recurrence frequency for events of this magnitude. Dendrochronology, though not the ideal method of age determination, provided a numerical minimum estimate of the timing of abandonment of this terrace and a method for evaluating the ability of tree growth patterns to provide an independent record of the flood history of this area.

Arroyo Seco flows northerly from the Devil's Hole and Agua Tibia uplands to the Vail Lake Reservoir (Figure 4.1). For ease of discussion, Arroyo Seco Creek is separated into three sections within the studied area (Figure 4.2). Section 1 is a narrow, predominantly bedrock, confined channel. Section 2 is a composite stream, comprised of the modern main channel (2B) and two anabranches (2A and 2C). The north end of Section 2 is coincident with a fault trace. The northernmost reach, Section 3, is broadly braided with a locally preserved terrace defining the western active channel wall. An overflow channel is present to the east of the main channel in this section.

The northern Arroyo Seco drainage basin is underlain by three lithologies: pre-Cretaceous metasediments, Mesozoic granites, and the Pleistocene Pauba beds (Figure 4.3). These three units are exposed in roughly northeast-trending bands and are in both fault and depositional contact. The fault contact between the metasediments and the Pauba beds coincides with a 90^0 deflection in Arroyo Seco (at the north end of Section 2); however, field observations show that this deflection is not unique for Arroyo Seco (Figure 4.1). Section 3 is incised into an older fanglomerate surface unconformably overlying the Pauba beds (not shown on Figure 4.3).

Vegetation within Arroyo Seco is riparian and dominated by oak, sycamore, and cottonwood trees. Sycamores are found on the older (i.e. 10 m) terrace surfaces of Section 3.

The cottonwoods dominate the bedrock channels of Sections 1 and 2. Oak trees are located on and help to define the lateral extent of local terrace surfaces in all three sections.

4.2 Distribution of Spineflower Populations at Arroyo Seco

DOLE populations observed in the Arroyo Seco/Vail Lake region of Riverside County occur in the Agua Caliente Fault Zone which contains predominately NW trending members. The known DOLE populations occur on Pleistocene deposits mapped as undeformed or slightly deformed, dissected alluvial fan deposits (Pauba Beds). The populations studied in the ecological section of this report are found on a high terrace above the high water mark of the 1993 event. The surface of this terrace is nearly flat bar and swale topography, largely smoothed. The plants are found in open areas on the terrace: one location is near the border of a paleochannel; the second location is near the edge of incision of the terrace by the modern channel. Surficial sediments from the vicinity of the DOLE were hand textured and yielded a texture of sandy loam.

A second DOLE population is found on dissected Pauba Bed sediments at least fifty meters above and to the east of the current channel. This surface shows no evidence of fluvial modification of the original deposits of the Pauba Beds. A third population is found on alluvially deposited sediment which has moved downslope into the vicinity of the stream channel. The deposits which support this third population show no evidence of fluvial reworking. Rather, these deposits appear to result from downslope movement of sediments of the dissected Pauba Beds through the action of slope run-off. Additionally, observed locations of other populations to the north of the Dripping Springs campground (across Highway 74) occur high on dissected surfaces of the Pleistocene age Pauba Beds, above the realm of fluvial processes.

4.3 Methods

Stereo pairs of aerial photographs from 1974, 1980, 1983, 1989, and 1990 were reviewed to determine channel history. Photographs were interpreted using a Sokkisha MS27 stereoscope with a 3X magnification. The active channel in Section 2 was identified by either reflection of water in the stream, a lack of accumulation of flotsam, and/or change in the density of vegetation within the channel.

A longitudinal profile of the thalweg (Figure 4.4) was measured using a combination of instruments. The northern third of the profile (Section 3) was measured with a Wild-Heerbrug total station. The remainder of the longitudinal profile was measured using a Ushikata LS-25 compass transit and stadia. Since these survey methods have significantly different precision, thalweg measurements along the upstream portion of the longitudinal profile have a much lower spatial resolution compared to total station measurements. Integration of upstream and downstream profile segments was accomplished by measurement of a thalweg point common to both surveys. The intersection between transverse profiles and the thalweg was also surveyed. Profile elevations and distances are arbitrarily referenced to the southernmost surveyed point.

Eight transverse profiles were established at constricted stream sections where well defined high water marks were evident on both sides of the channel (Figure 4.4). The eight transverse profiles describe four reaches of "uniform" channel, three in the upper bedrock section (Reaches AB, CD, and DE within Section 1), and one at the fault zone (Reach FG between Section 2 and 3). At each transverse profile, a tape was stretched and secured by pins set at the same elevation on opposite canyon walls above the high water marks. Breaks in slope and features of interest were surveyed along the cross section. Roughness values (Manning's n) were estimated for each transverse profile by comparing photographs from Barnes (1967). Photographs of each transverse profile were taken but are not included this report.

The profile data were plotted with no vertical exaggeration, and a water surface was drawn by connecting the high water marks on opposite banks. On each plot, the thalweg high water depth was measured with a ruler. The flow cross sectional area (A) was determined by planimeter, and the wetted perimeter (WP) was measured with a map wheel. The horizontal distances (L) and the vertical elevation differences (Dh) of the water surface for each of the four reaches were computed from the longitudinal profile and the thalweg depth. For each reach, the hydraulic radius ($R = A / WP$) and the water surface slope ($S_w = Dh / L$) were calculated. Water surface slope was used as a surrogate for energy gradient or friction slope, which requires an independent measure of velocity.

Determination of the maximum clast size transported during the most recent flood episode was based on the following criteria: (1) imbrication; (2) position of boulders on loose, unweathered sands; and (3) flow-transported vegetation wedged under the boulders. Boulders located near the base of older alluvial deposits were not measured because they may have been derived from slope processes and may not have been transported fluvially. Boulder dimensions were measured within the main channel and overflow (anabranch) channels (along Section 2). Boulder dimensions were also collected for those exposed in terrace risers and for longitudinal paleobars on the terrace surfaces. Criteria used to define acceptable boulders from the terraces included size and imbrication.

Velocities (V) for the four reaches were calculated using the Manning equation ($V = (1/n)\ R^{0.67}\ S^{0.5}$) and, using the boulder sizes, applying Costa's (1983) relationship ($V = 0.18\ D^{0.49}$), where D is the average value of the intermediate (b-axis) dimension. Discharges (Q) were calculated for each reach using both $Q = V A$ (velocities from Manning equation) and Riggs' (1976) relationship ($Q = 3.39 A^{1.30} S^{0.32}$). Boundary shear stress (t) was calculated for each reach using both DuBoys equation ($t = r g R S$) and, from the sizes of the boulders, Baker and Ritter's (1975) relationship ($t = (D/65)^{1.85}$).

In sampling for dendrochronologic analysis, both cores and trunk circumferences were obtained from trees that were selected to represent differing generations. Trees sampled were oak (*Quercus*), sycamore (*Plantanus*), and cottonwood (*Populus*). Additional circumferences were obtained from no-cored trees to supplement the database through correlations of circumference with age. Cores were obtained as close to 15 centimeters from the base of the trees as possible. Trees exhibiting significant historical damage or twin growth shoots were not sampled.

The cores were dried, sanded, and polished to remove the effects of extraction and to enhance the visibility of the rings based on the methodology given to Phipps (1985). Rings on the prepared cores were counted using an optical microscope. Magnification and intensity of illumination were varied to enhance visibility. The visibility of individual rings in cores is species dependent. The rings of the cottonwoods and oaks were extremely subtle, resulting in a significant variability in the age assessment of the cores. Two sycamore cores were used for tree-to-tree correlation due to the increased reliability of the counts.

4.4 Results and Discussion

Aerial photographic interpretation was used to infer the stream evolution for the past 20 years. The photographs indicate that in 1974 all three of the currently recognized channels in Section 2 were fully formed and that the active channel was the eastern channel (2A). The central channel (2B) showed no evidence of recent sedimentation or erosion while the eastern channel (2C) had received a minor amount of sediment. A flotsam debris dam observed across the northerly end of the western channel (2C) was in place at that time. In 1980, the central channel (2B) was active. No significant flow appears to have occurred in either of the other two channels in this section of the stream. Water reflections in the 1983 photographs reveal that flow had transferred back to the eastern channel (2A). By 1989, flow is difficult to determine but appears to still be along the eastern channel. Increased vegetation within all three channels in Section 2 was visible at the time of the 1989 photography. This suggests that significant flow had not occurred for several years prior to 1989. In 1990, flow within this section had returned to the central channel (2B).

In Section 3, the current main channel appeared to be accommodating the majority of the 1974 and the 1980 flow. Evidence for recent sedimentation and erosion is visible in the overflow channels to the east at the time of the 1974 photography. Field observations indicate that floods subsequent to the 1990 photography have laterally eroded up to 10 meters of the high terrace deposits at the northern end of Section 3 and approximately 1.5 meters of the terrace at the fault zone.

Throughout the historical aerial photographic sequence, Section 1 appears unchanged. With the exception of boulder movement and high flotsam lines, there is little evidence that this constrained reach was significantly impacted by the recent high flows.

Velocities determined using the Manning equation are only half as large as those computed using Costa's (1983) boulder relationship (Figures 4.5, 4.6). As the inherent error in boulder-derived velocities may be 25 to 100 percent (Costa, 1983), there is a reasonable chance that the boulder-derived velocities are too high.

The discrepancy between the Manning and Costa calculations of velocity might arise from the variables determined for the Manning equation. The roughness values (Manning's n) are determined in a somewhat subjective manner. However, roughness values of 0.03 would be required to result in velocities comparable to Costa's boulder method. These values are much too low for a boulder-bed channel. Alternatively, some error was introduced into the hydraulic radius determinations, as tape sag affected both cross sectional area and wetted perimeter measurements. The largest uncertainty in the Manning equation parameters, though, is in the estimated value for slope. Although the values for water surface slope are based on reasonably accurate data from the longitudinal profile and the thalweg water depths, they might not truly reflect the slope conditions at the bottom end of the reach. This is a result of the operational problem of having the reaches defined by the transverse profiles, rather than vice versa. Still, in order to approach the boulder-derived velocities, water surface slopes would have to have been 0.06 to 0.16, some 3 to 4 times greater than the measured values. If the measured boulders moved, they probably did so at velocities less than Costa (1983) predicts given the limitations on the variables in the Manning equation..

The velocity estimates derived from the boulder measurements are internally consistent, however, and confirm field observations. The calculated velocity was 5.9 m/s for the upper part of Section 1 and 5.4 m/s for the lower part of Section 1. The calculated velocities for the combined Sections 2 and 3 were 5.9 m/s. A longitudinal bar in Section 2B, thought to have formed during the last flood episode, provided an estimated velocity of 4.7 m/s. As expected from field observations, calculated velocities for the current overflow channels were somewhat lower than those of the main channel. In section 2, velocities for the west (2C) and east (2A) overflow channels were 4.9 m/s and 4.0 m/s, respectively. The east overflow channel for Section

3 has an estimated velocity of 3.5 m/s. The velocities in the main channel should have decreased below the confined bedrock section as energy was dispersed across the wider floodplain section. This was not observed.

Paleovelocities were determined for the alluvial terraces preserved in the study area (Sections 2 and 3) and were generally consistent with the calculated velocities associated with the recent flood event. Paleovelocities for the terrace upstream of the fault (Section 2) ranged from 4.3 m/s to 5.9 m/s. Paleovelocities for the terraces below the fault (Section 3) ranged from 5.0 m/s to 6.3 m/s. This might suggest that the event of 1993 was of a comparable magnitude to that associated with these deposits and might be expected to be preserved in the sedimentary record. The congruence of velocity calculations might also suggest that the boulders are being reworked from the terrace deposits and that the boulders which appeared to have been moved in the latest event are largely dependent on the clast sizes available. In all measurements made on terraces, the velocities determined from paleobars are greater than those determined using deposits exposed in terrace risers. This indicates that consistency of measurement is required in this technique, and comparisons should be restricted to those between similar depositional features and similar orientations of these features.

There is close agreement in discharge values between the Manning and Riggs (1976) methods (Figures 4.6, 4.7). This is encouraging in that the equations use many of the same parameters. However, the Riggs relationship does not have a roughness term. Therefore, these comparable results further suggest that the field-determined Manning's n values are reasonable. The variance of discharge between reaches, though, is quite high. The largest discharge is 3-4 times greater than the smallest. This suggests that either the measurements had a large associated uncertainty or that the flow was non-uniform.

Boundary shear stresses determined by the DuBoys equation are twice as large as those computed using Baker and Ritter's (1975) boulder relationship (Figures 4.6, 4.8). Moreover, the DuBoys determinations are conservative, as the density of sediment-laden flow may be twice that of clear water (Costa, 1988). Hence, the disparity in shear stress values is perhaps even greater.

For Arroyo Seco, neither the Baker and Ritter shear stress/boulder size relationship nor the Costa velocity/boulder size relationship appear to fit with the data. Since both relationships were developed on larger rivers in other climatic regimes, they may not be applicable to southern California systems. In any event, the shear stresses calculated by the DuBoys equation suggest a flow regime capable of moving boulders 2-3 meters in diameter (Baker and Ritter, 1975). This would have required a velocity of some 9 m/s according to Costa (1983) or 2-3 times that determined using the Manning equation.

Dendrochronology was pursued as a method to examine the temporal and spatial correlations between past flood events and tree growth patterns in this study area. Data from trees have been used in previous studies of geomorphic processes through analysis of corrosion damage suffered by trees, changes in their quantitative growth rates and form, and in their areal distribution and succession (Alestalo, 1971). Dendrochronological analysis provides an extreme minimum age estimate for some of the geomorphic surfaces in the Arroyo Seco drainage basin.

The tree circumferences fall into a tripolar distribution independent of species. Field observations indicate that the tree sizes are age dependent, as no significant environmental differences are observed that would account for the size differences. The sycamores were generally growing as clumps, with all specimens of similar size. Occasionally an older, much larger residual stump was observed in the center of the clump, from which we concluded that the trees were sprouting from older root stock.

The distribution of ring widths between Cores 1 and 2 (Figure 4.9) shows a distinct temporal pattern between two sycamores aged 48 - 50 years old that germinated no later than the mid-1940's. The growth rings appear to correlate well with recorded historic rainfall, especially the late 1960's and late 1970's high-precipitation years, the drought of the late 1980's, and the increased precipitation of the last few years. Unfortunately, the oak cores were extremely difficult to count. As these were assumed to be the oldest specimens in the Arroyo Seco drainage, correlation with climatic events prior to 1945 was not possible.

4.5 Conclusions

1. The stream appears to have responded to the events of the past three years by significant lateral erosion along the lower part of Section 3. There appears to be no discernible morphologic response in Sections 1 and 2, although there is a shifting of flow between channels over the past 20 years. Although the recent flooding represents a large magnitude event, the impact on the stream is not as significant as might have been expected. Little evidence was found to show any flooding occurred on the high-terrace of Arroyo Seco.
2. There are significant discrepancies in the velocities and boundary shear stresses between those calculated on the basis of boulder mobilization and channel morphology. While there could be significant uncertainties associated with the estimation of roughness, the measurement of wetted perimeter and cross sectional area, or the determination of water surface slopes, the values which would be required to match the boulder-derived velocities fall outside the range of reasonable error. This suggests that at least some of the discrepancy must be due to the boulder derived velocities and shear stresses, either due to misidentification of mobilized boulders or the inappropriate application of the Costa equation to this stream. The results of the discharge calculations, while in close agreement between

methods of determination, are quite variable between reaches. This may reflect the uncertainties in the measurements or variability in the flow conditions which were recorded.

3. The boulder-derived velocities within the active channel are quite similar to those determined for the deposits associated with the terrace. This could be due to a similarity of flood magnitude between these two events or may indicate a limitation of the size fraction available for mobilization. If there is a similarity between the events, it would suggest that the event of 1993 should be preserved in the sedimentary record. Given the discrepancy in calculated velocities, it is possible that the boulders may not have been mobilized according to the process envisioned by Costa (1983). Instead, there may have been an inheritance of boulder structures from the erosion of the terrace deposit.

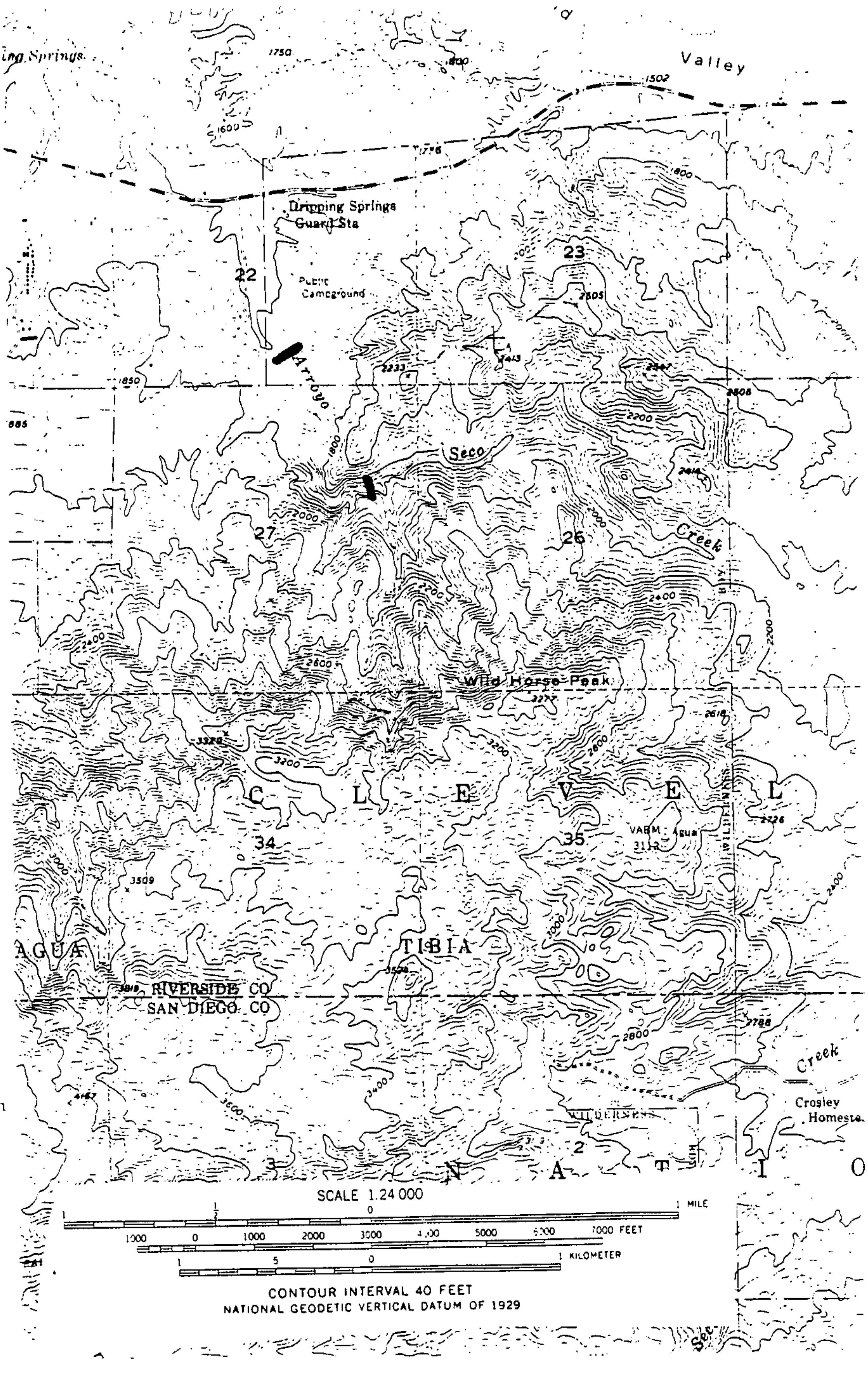


Figure 1:
Index Map with
Study Area
Outlined
(Figure 4.1)

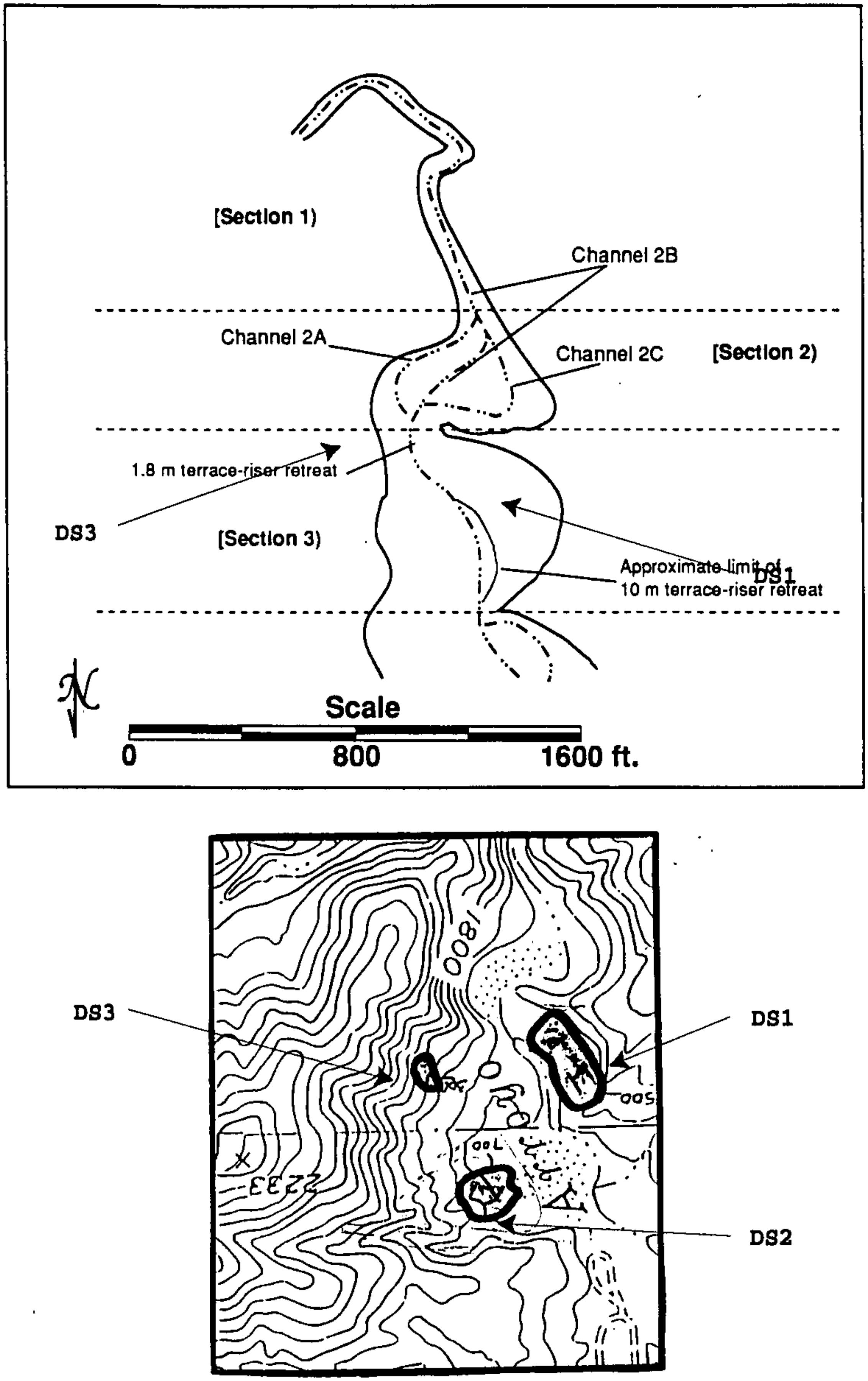


Figure 4.2 Maps of sites at Arroyo Seco: A. Sketch map derived from 1990 aerial photographs shows study reaches (sections) and amount of lateral retreat on terrace risers; B. Topographic map showing primary locations of spineflower populations. Note that all spineflower sites are well above the 1993 flood heights.

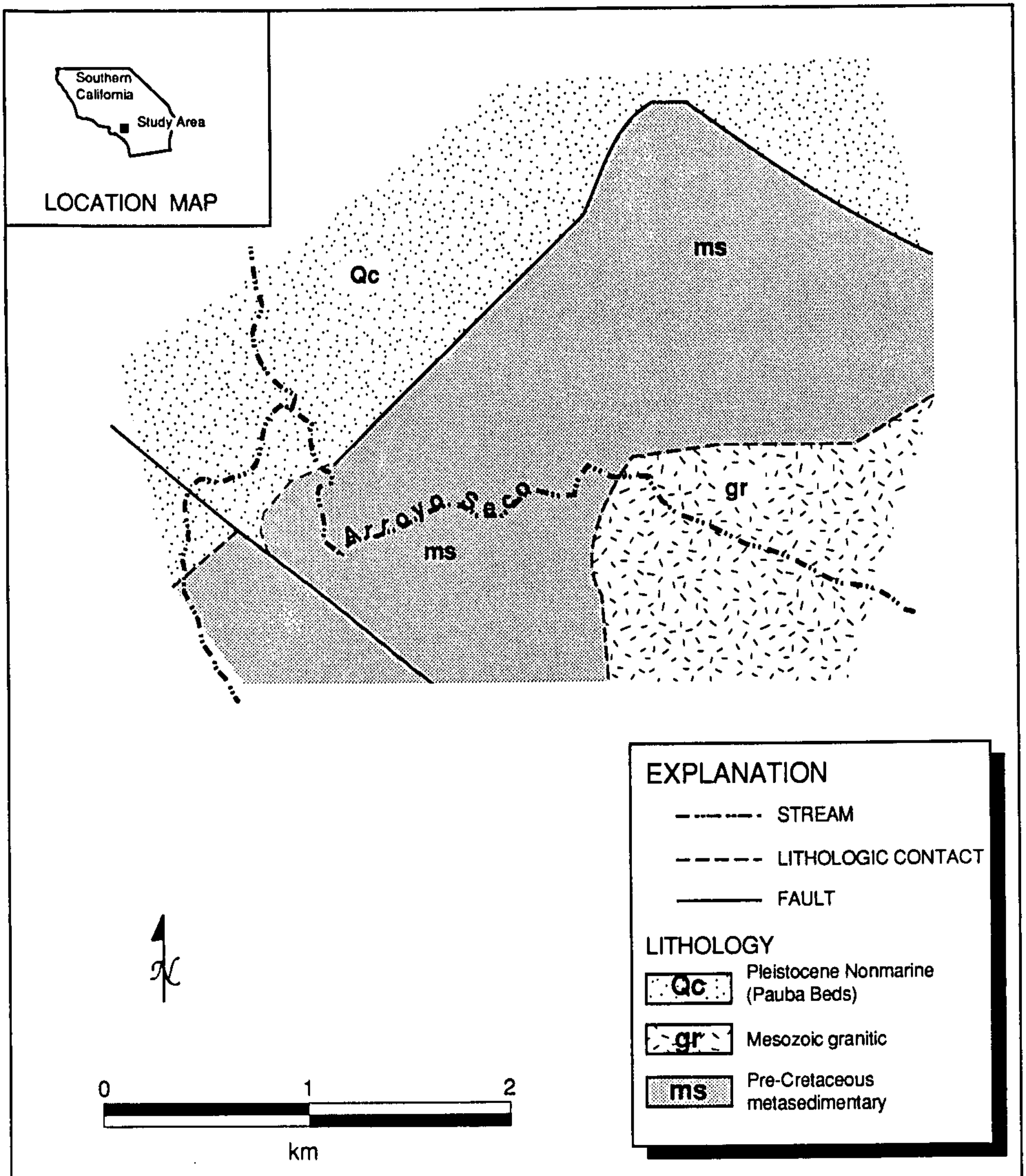


Figure 3: Schematic geologic map of the Arroyo Seco area, Riverside County California. Geology taken from Santa Ana Sheet, California Division of Mines & Geology (1966; scale = 1:250,000). (Figure 4.3)

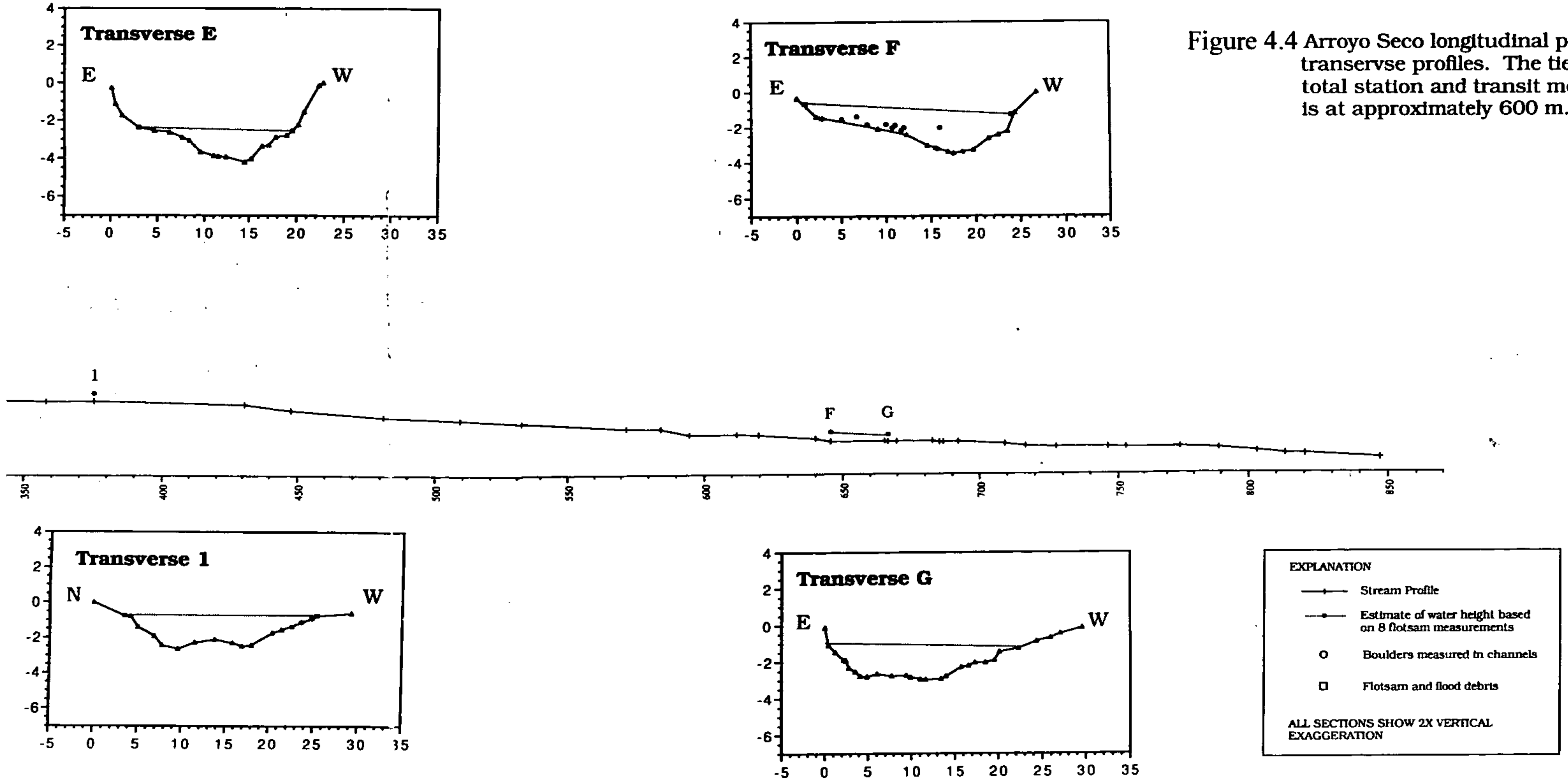
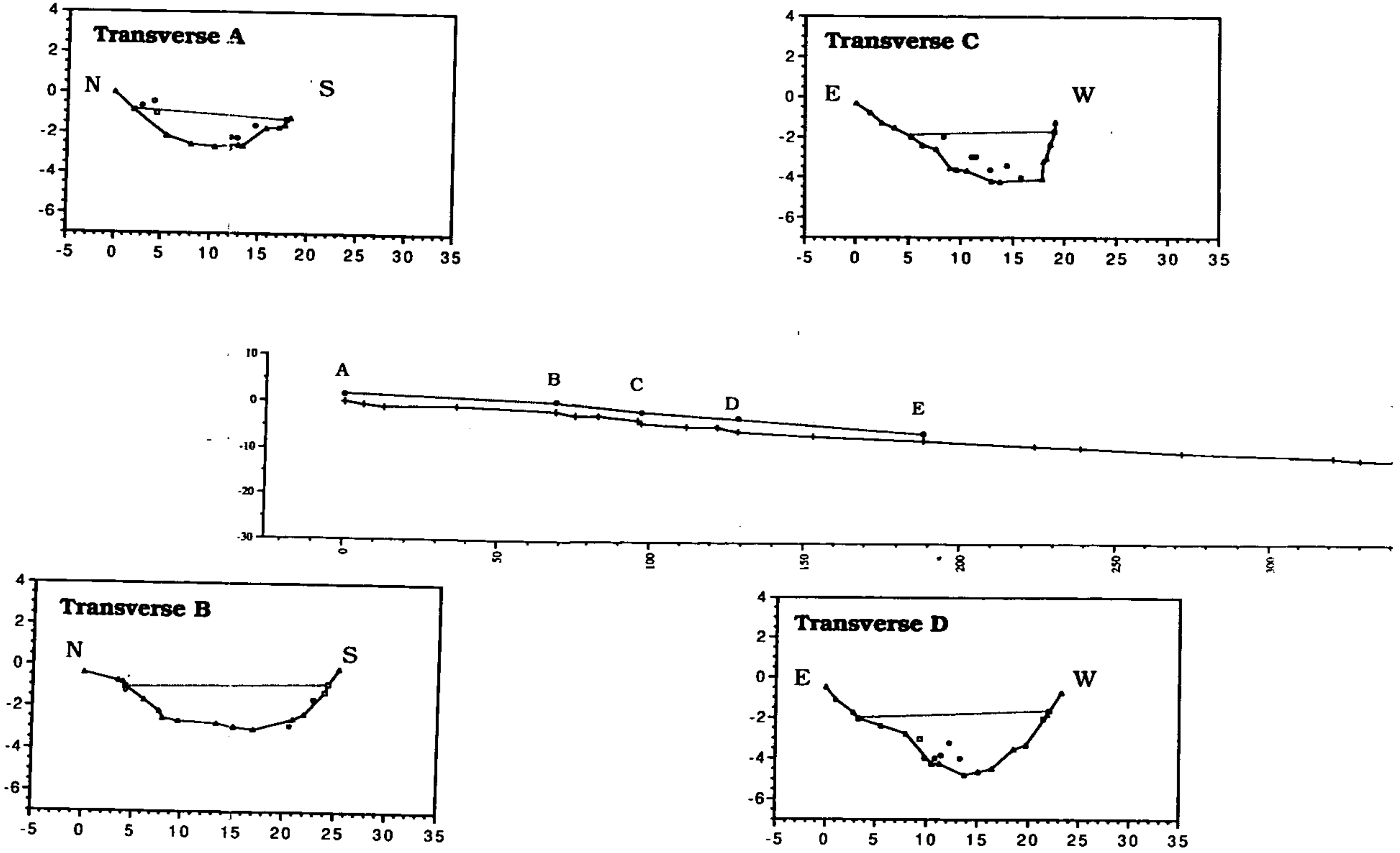


Figure 4.4 Arroyo Seco longitudinal profile and transervse profiles. The tie point between total station and transit methods is at approximately 600 m.


Transverse A
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-4
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-5
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35
Transverse C
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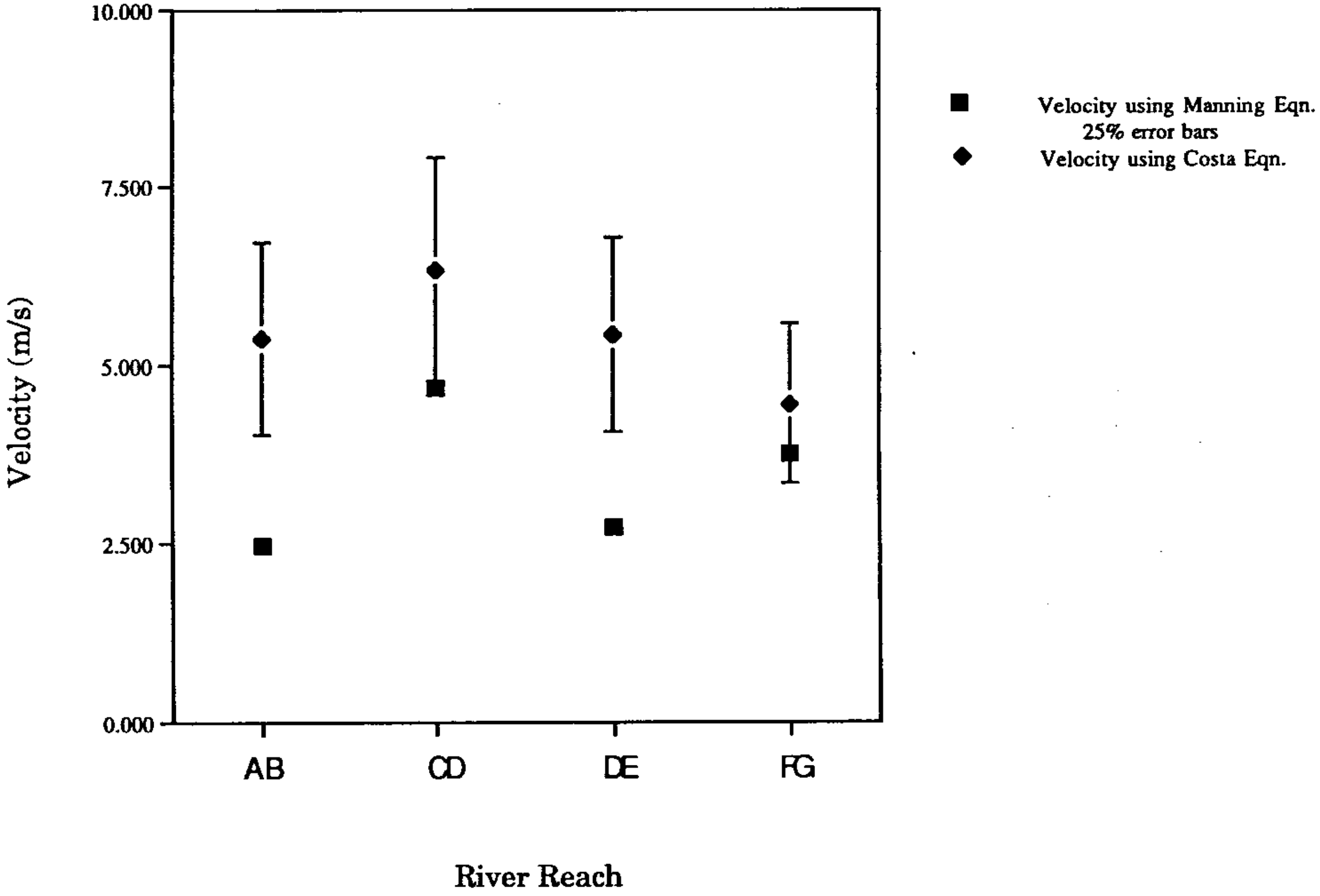
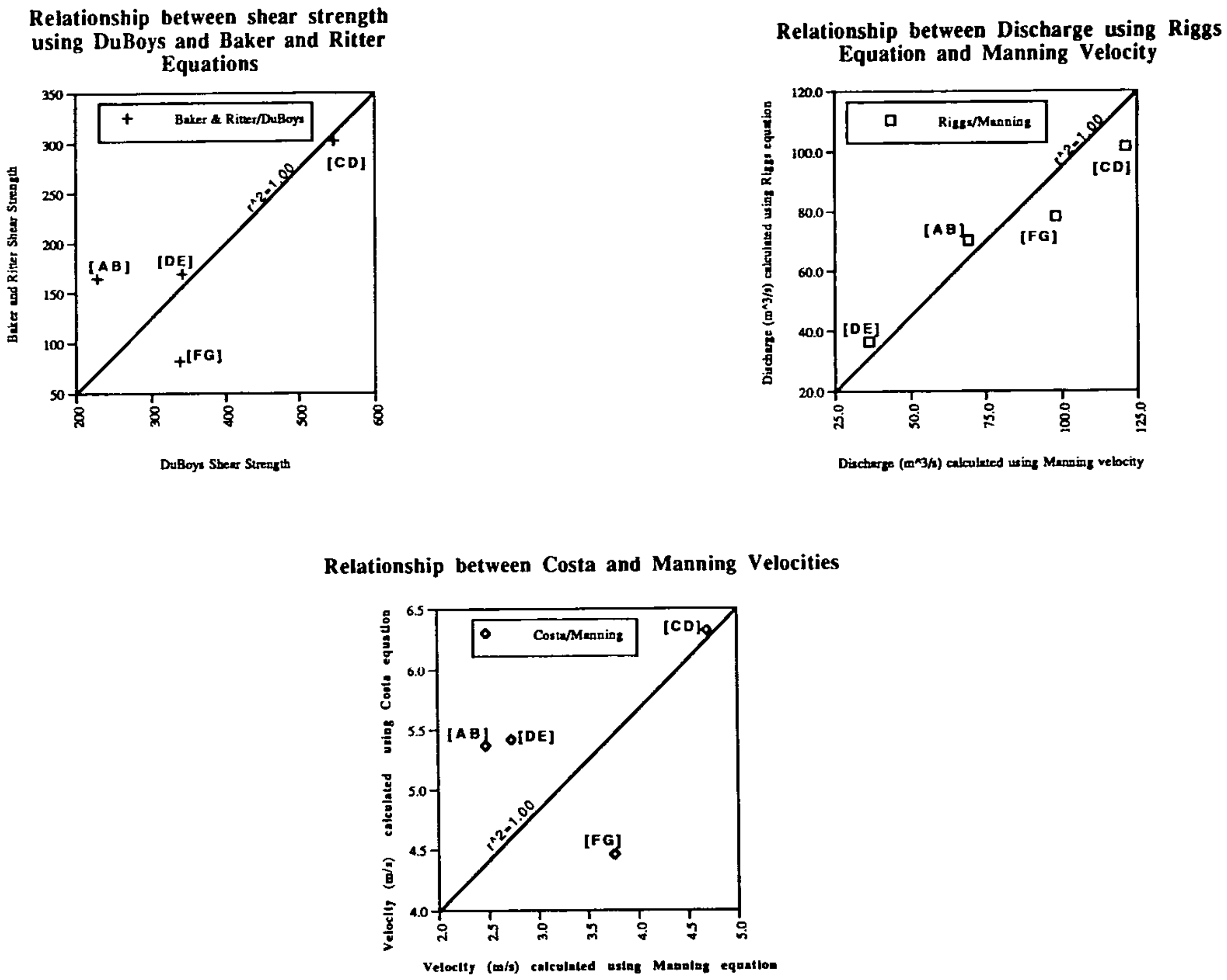


Figure 5. Velocity Estimates by the Manning Eqn. ($V=1/nR_{0.67}S_{0.5}$) and the Costa Eqn. ($V=0.18D_{0.49}$). Error bars (25%) shown for Costa Eqn.
(Figure 4.5)


Relationship between shear strength using DuBoys and Baker and Ritter Equations

Relationship between Discharge using Riggs Equation and Manning Velocity

Relationship between Costa and Manning Velocities

Figure 6. Relationships between calculated values of discharge, velocity and shear strength using different methods. Bracketed letters in figure represent stream reaches.

(Figure 4.6)

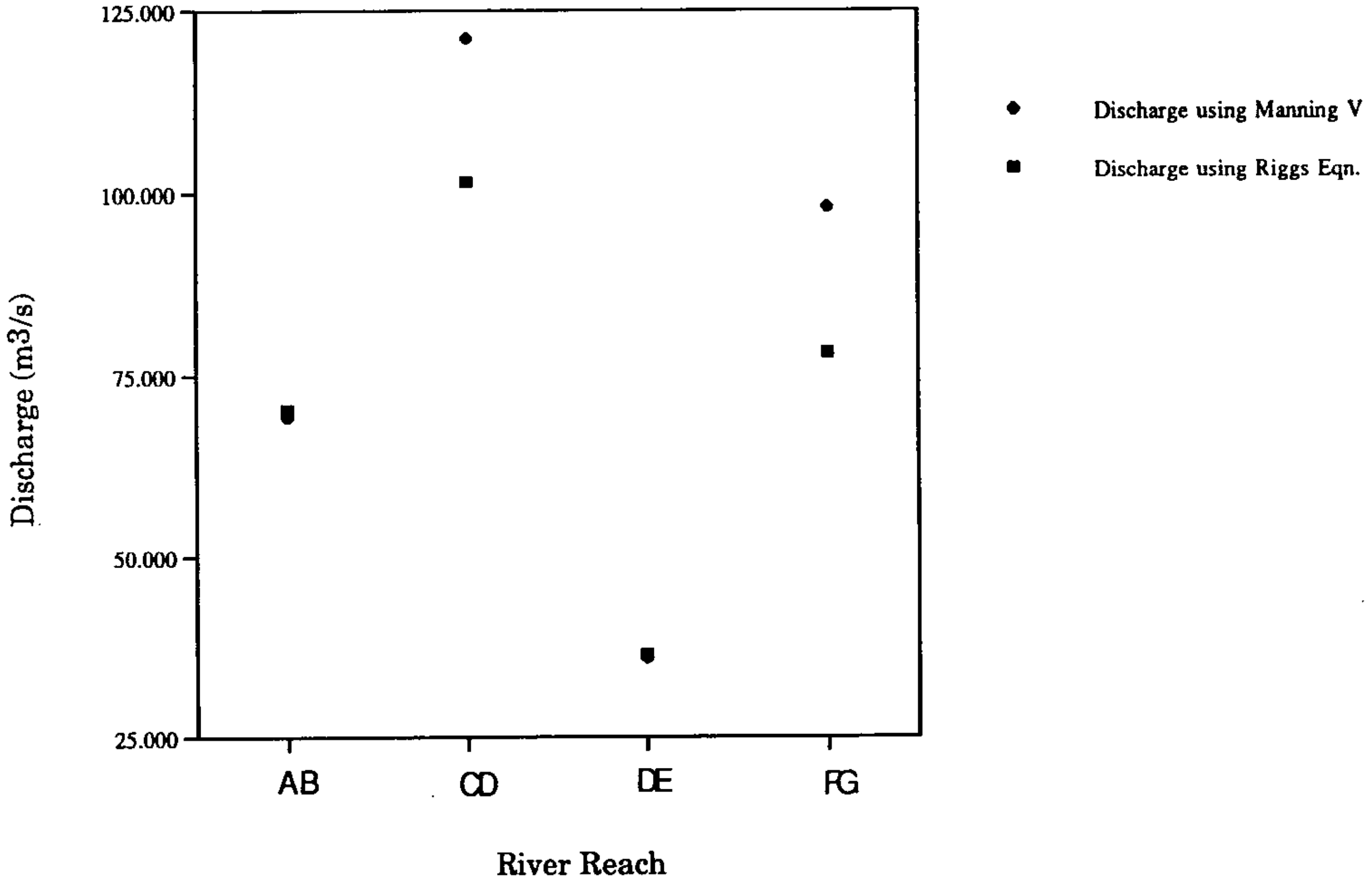


Figure 7. Discharge Estimates using Q=AV (Manning V) and Riggs Eqn. ($Q=3.39A^{1.3}S^{.32}$)
(Figure 4.7)

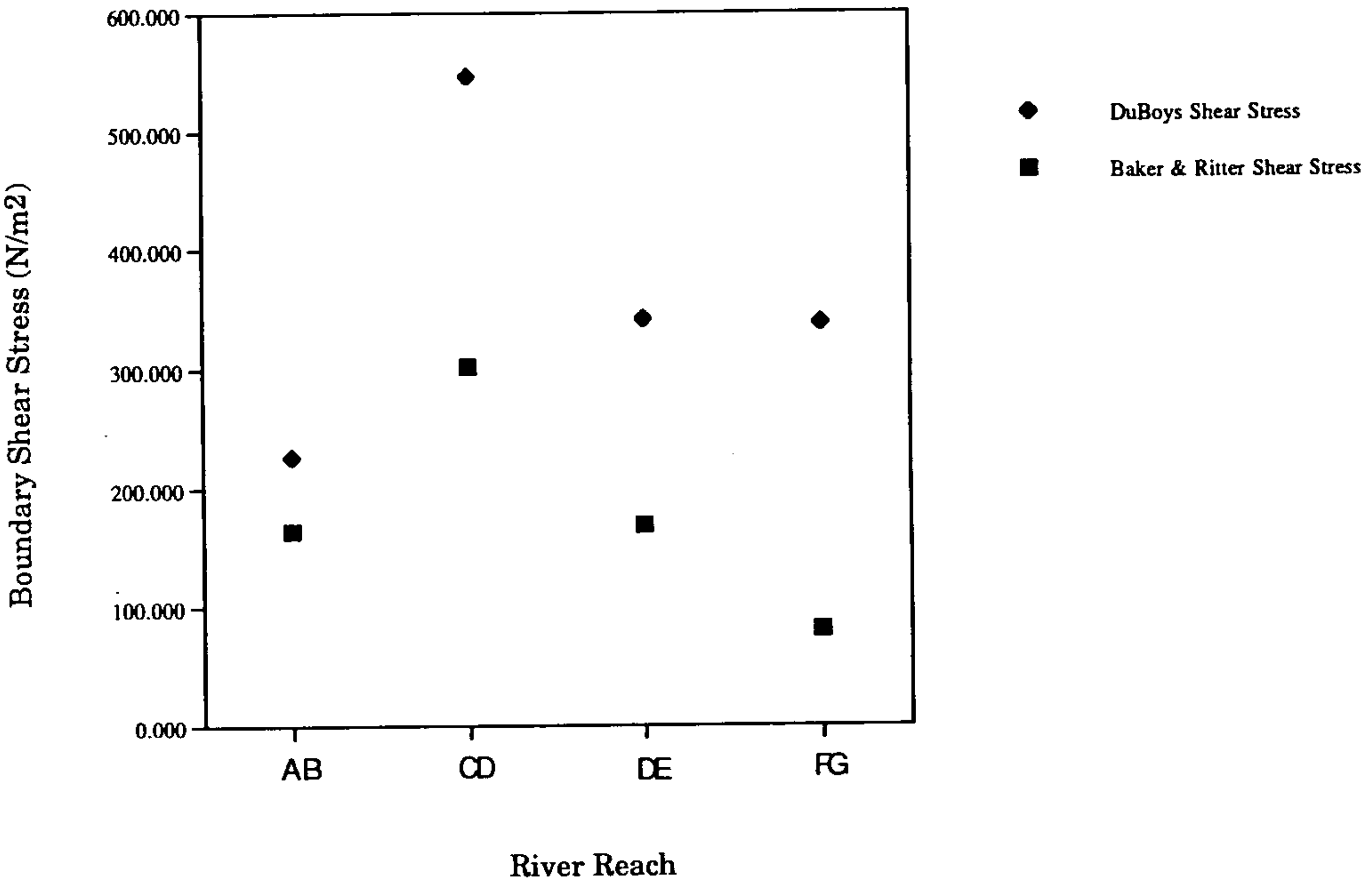
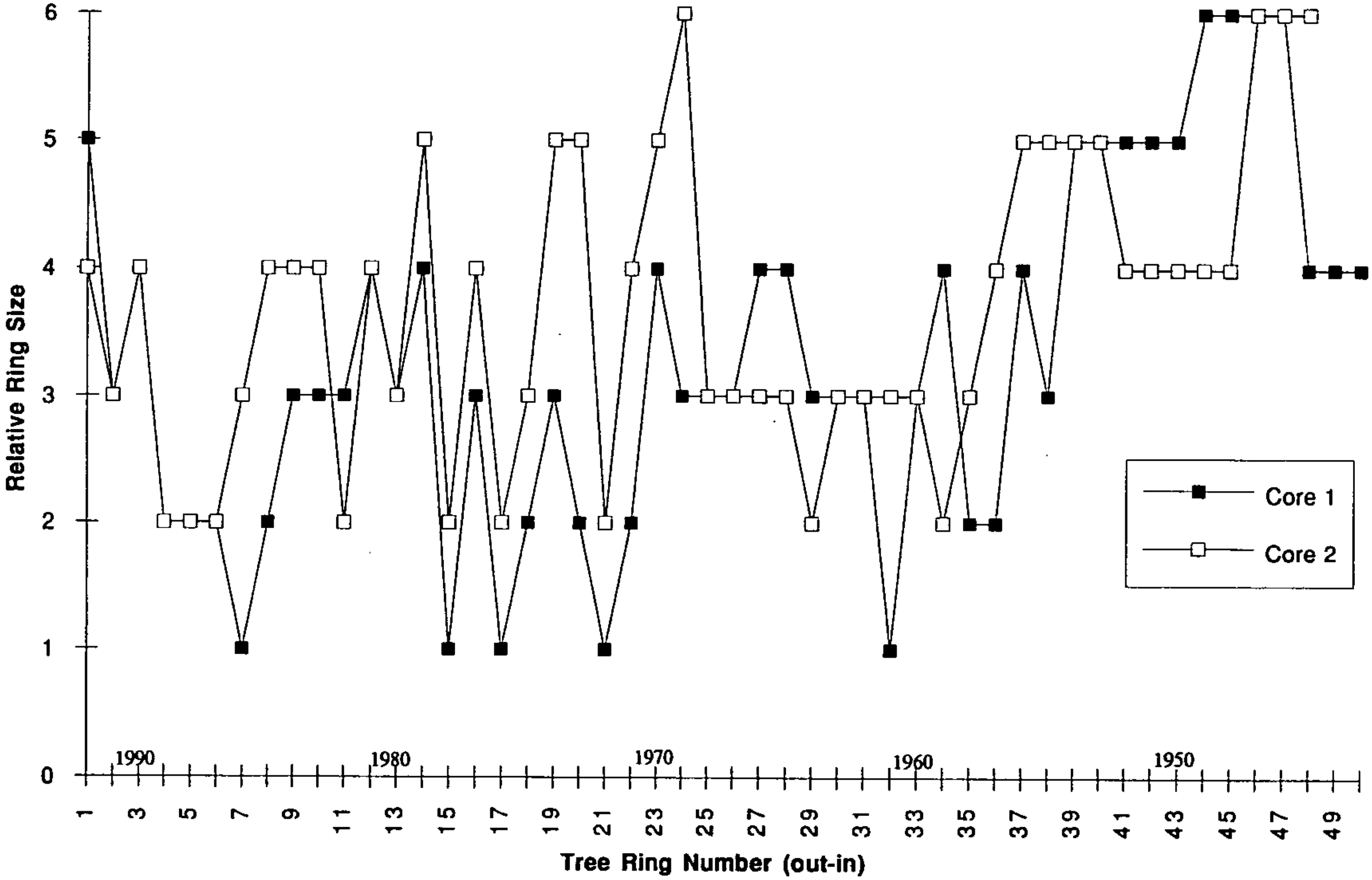


Figure 8. Boundary Shear Stress estimates using DuBoys Eqn. ($T=\rho gRS$) and Baker and Ritter's Relationship ($T=(D.65)_{1.85}$)
(Figure 4.8)

Figure 4.9

Figure 9. Dendrochronological Correlatio



*Cores from 2 sycamores; vertical axis values are relative, core-specific ring size classes.

5.0 DISCUSSION

5.1 Upper Santa Ana River Site

The upper Santa Ana River Wash is comprised of a mosaic of different ages of geomorphic surfaces that have probably resulted from combined movement along the San Andreas Fault and episodic, climatically-induced alluvial deposition. Correlating the degree of soil development determined by soil augering to other regional soils allows the preliminary assignment of a mid- to late-Holocene age to surface Qf4, an estimate of 3,000 to 10,000 years. This age is supported by field observations of the loss of bar and swale topography on the surface and observed weathering of surface cobbles including lichens of 8 inch diameters. This Qf4 surface is higher and older than the spineflower surface. With no datable material, a minimum age is difficult to establish for the spineflower surface. However, the degree of soil development observed by augering of the spineflower surface indicates that this surface also has antiquity and is probably older than 100 years.

The age of these surfaces should effect run-off during intense storm events. That is, although these surfaces are not altered by the primary channel of the Santa Ana River during flooding events, they may experience significant movement of water over their surfaces through overland flow. Overland flow during flood events can move fine sediments (and even gravels and cobbles) on these surfaces. Such run-off will be enhanced on older surfaces due to their lowered permeability. A reduction in permeability can be caused by the incorporation of aeolian silt into the soil or chemical weathering of primary deposits to finer-grained material.

5.2 Upper San Jacinto River Wash Site

The reach of the San Jacinto River which contains spineflower habitat is geomorphically simpler than the mosaic of surfaces found in the Santa Ana River Wash. The soil pedon description (Table 3.2) indicates through correlation to other regional soil studies that this surface may be late to mid-Holocene in age -- that is, on the order of thousands of years old. The age of this topographically higher deposit is supported by a radiocarbon date obtained from charcoal in a topographically lower terrace across the channel indicating that the age is historic. This terrace is both lower topographically and inset stratigraphically against the higher terrace which hosts the spineflower. Thus, the lower terrace is younger than the spineflower terrace. A minimum age for the dated terrace can be considered by comparing its potential age range to major historic storm events. This terrace could be as young as 1927 when a peak discharge of 45,000 cfs was recorded at a nearby gauging station. It is estimated that the 100 year flood stage for this station would be 47,000 cfs. Alternately, this terrace could be as old as 526 years.

An age on the order of thousands of years is supported by the surface topography of the spineflower terrace. It has an unmeasurably low slope (~0%) with no remaining bar and swale topography. This microtopography could result from an erosional event of the terrace, but the soil description data does not support such an event (although it does not rule it out).

The soil described in Table 3.2 indicated that the surface horizons of the pedon exhibited hydrophobicity. Hydrophobic soils are water repellent, often due to biotic substances vaporized and reprecipitated during fire or due to dense fungal mycelial mats. Study in the chaparral of Southern California has shown that hydrophobicity slows infiltration rates, increases surface runoff and erosion rates, and can change the morphology and composition of soils (Servink, 1988; Chartres and Mucher, 1989; Brown, 1990). Hydrophobic mineral layers are generally water repellent over a period of 30 minutes resulting in overland flow (Brown, 1990). On the most water-repellent soils, a water droplet will remain on the surface until it evaporates (DeBano and Rice, 1973). Brown (1990) has suggested that increased sediment yields after fire may result from a combination of less vegetation cover and changes in soil hydrological characteristics.

Hydrophobicity usually occurs in the upper 10-15 cm and is usually related to organic substances produced by plants (including chaparral brush species) and microorganisms (Brown, 1990). After plant cover is burned, hydrophobic substances move downward into the soil as vapors and condense on soil particles (DeBano and Rice 1973). The depth and thickness of this layer probably depends on the type and amount of vegetation and litter present as well as the intensity of the fire. DeBano and Rice (1973) suggest that the texture of a soil affects its hydrophobicity. That is, coarse textured soils may have greater hydrophobicity because they have lower surface area on which the vaporized compounds can condense.

The hydrophobicity of the soil described in Table 3.2 would not prevent water penetration below the AB horizon because it is not severely water repellent. However, it should act to significantly slow water penetration below this layer and to increase surface sediment movement for those soils with a slope greater than 0%. These effects would conceivably be moderated by the intensity and duration of the rainfall effect. That is, infiltration during a short, intense precipitation event could be limited to the AB horizon; while that of a longer, gentle event (with the same amount of total rainfall) could infiltrate beneath the AB horizon. The hydrophobicity could also have an effect on the patch dynamics of this vegetative cover since burned and eroded soils have a lower potential as sites of germination, seed entrapment, and growth than do unburned sites (Chartres and Mucher, 1989). Additionally, Holzhey (1969) found that soils in the Box Springs area of Riverside were seasonally hydrophobic, depending on the moisture content of the soil. Holzhey (1969) also found that if soils were air dried, they were hydrophobic regardless of field moisture conditions. This could effect the phenology (seasonal development) of the component species of a vegetation, especially for annual species such as DOLE. He also found that the time for water penetration was dependent on the number of roots and percent organic carbon in the soils. Hydrophobicity is site specific (Holzhey, 1969) probably because of the dependence of fire intensity on the type of vegetation present, as well as the potential effect of slope position on the movement of water and ash.

5.3 Bautista Creek Site

The relative ages of the surfaces supporting spineflowers are indicated in Figure 3.4. Since the surfaces are of relatively the same height in the channel, it is more difficult to assess their relative ages. However, comparison of lichen growth patterns (the largest diameter lichens are used to indicate the older surfaces) and the relative silt content based on hand texturing of soils have been used to assign relative positions to these surfaces. The Qf1 surface supporting the DOLE populations is given the oldest relative age of the fluvial surfaces mapped.

The numerical age of this surface is given as 90 ± 70 years BP or 140 ± 70 years before 1996 (since BP is assigned a calendar date of 1950). It is of interest that a relatively old landform (as far as historical dates) still exists in this narrow channel. It appears to have not been eroded during the floods of 1938 or 1980. During the 1980 event, stream velocities were estimated in excess of those which can be calculated to have occurred during the original deposition of this surface. Based on the model of Costa (1988), these deposits reflect a stream velocity of ~ 8 feet/sec. Sciandrone et al. (1982) estimated a stream velocity of approximately 9.6 - 16 feet/sec during the February, 1980 event. Of additional interest is the preservation of a terrace of presumably early Holocene age in this narrow channel. Based on the occurrence of DOLE on Pleistocene surfaces in the vicinity of Arroyo Seco (Riverside County), it would perhaps be worthwhile to survey the surfaces of the older terrace deposits to the north and the south of the mapped channel for any future projects.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion 1

The sediments underlying the geomorphic surface that supports the spineflower populations are usually older than 100-year (or 20th century) deposits and may often be patchy remnants of late to mid-Holocene deposits.

6.2 Conclusion 2

Populations of spineflowers in the Santa Ana and San Jacinto River washes are clearly found on geomorphic surfaces which are estimated to be mid- to late-Holocene in age (i.e., on the order of one to 5,000 thousand years). Thus, historic extreme flood events do not appear: (1) to deposit any significant layer of sediments upon which the spineflowers grow; or (2) to geomorphologically alter the surfaces upon which spineflowers are found.

6.3 Conclusion 3

Populations occur in shallow depressions on relatively flat (0-2% slopes) surfaces. Movement of fine sediment into these depressions may occur primarily by local overland flow during rain events. Thus, hydrologic processes related to localized runoff appear to be more influential on the geomorphic surfaces of sites with spineflowers than extreme overbank events related to the master nearby stream channels.

6.4 Recommendations

It is recommended that:

- Preservation of older, stable surfaces in these washes should be of primary concern in the protection of this plant species. These surfaces will have increased probability of development as flood control construction is completed. The older land surfaces containing these populations is also supported by herbaria records of past populations. Many of these populations are listed as being on 'mesas and plains' (Reveal, 1988), descriptive terms which usually describe higher (and probably older), stable geomorphic surfaces. Additionally, observations have been made of DOLE on pre-Holocene surfaces in the Arroyo Seco (Dripping Springs) drainage.

- Given the fact that field evidence indicates fine sediment is transported by overland flow near the DOLE populations during rain events, research into the role of overland flow as a dispersive agent of spineflower seed should be undertaken.
- Most of these spineflower populations occur near windgaps apparently related to geomorphic responses to active fault systems. Such windgaps can allow the movement of fine-grained eolian (windblown) sediment to be funneled into local regions and deposited on geomorphic surfaces. Thus, it would be beneficial to investigate the importance of eolian deposition of fine-grained material into these older soils. If a high percentage of grains are of eolian origin, it might be worthwhile considering the wind as a dispersive agent for these spineflowers.
- Solid waste that has been disposed at the Orange/Boulder Avenue site in the Santa Ana River could be used as datable cultural artifacts in order to provide historic dates to disturbances on the geomorphic surfaces. Determination of the vintage of the solid waste along with a measurement of the depth of its burial could yield a rate of fine sediment infilling into depressions supporting DOLE. Such rates might be used to elucidate the magnitude and frequency of local surficial processes modifying the surfaces supporting spineflowers.

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8.0 LIST OF FIGURES

Section 3

Fig. 3.1 Geomorphic surfaces from aerial photo-mapping of Santa Ana River Wash. Surfaces are numbered Qa1 through Qf5, with Qa1 being older surfaces.

Fig. 3.2 Geomorphic surfaces delineated from aerial photo-mapping of San Jacinto River Wash. Surfaces are numbered Qa1 through Qa4, with Qa1 being older surfaces. Qa1 supports spineflower populations.

Fig. 3.3 Generalized cross-section of terraces in reach of San Jacinto River Wash supporting spineflower. Location of terrace where charred wood sample was taken for ^{14}C dating and spineflower terrace are indicated.

Fig. 3.4 Geomorphic surfaces from aerial photo-mapping of Bautista Creek in upper reach.

Section 4

Fig. 4.1 Index map showing location of study area.

Fig. 4.2 Sketch map of streams in Arroyo Seco study area as determined from 1990 aerial photographs. Terrace riser retreat measured in field.

Fig. 4.3 Schematic geologic map of the Arroyo Seco area, San Diego County California. Geology derived from Santa Ana Sheet, California Division of Mines and Geology (1966; scale = 1:250,000).

Fig. 4.4 Longitudinal profile of Arroyo Seco Creek, showing locations of transverse profiles 1, A-G. Water slope is shown as extrapolated between the measurements derived from the transverse profiles.

Fig. 4.5 Velocity estimates by the Manning Equation and the Costa Equation. Error bars (25%) shown for the Costa Equation.

Fig. 4.6 Relationships between calculated values of discharge, velocity and shear strength using different methods.

Fig. 4.7 Comparison of discharge estimates using Q = AV (Manning V) and Riggs Equation ($Q = 3.39A^{1.3}S^{.32}$).

Fig. 4.8 Boundary Shear Stress estimates using DuBoys Equation (t = rgRS) and Baker and Ritter's Relationship ($t = (D.65)^{1.85}$).

Fig. 4.9 Dendrochronologic correlations; Very small, small, medium, large, very large, and very-very large were the terms used and were correlated numerically 1-6, respectively.

FOOTNOTES

*Migmatitic gneiss and local quartzite, calc-silicate rocks, marble, metaconglomerate, phyllite, and amphibolite, locally intruded by gabbro, granite pegmatite, quartz monzonite, granodiorite, and quartz diorite (along San Jacinto Fault zone). Mixed rocks consisting of strongly foliated migmatites.

**The two sigma calibrated result (95% probability) is that the age of the wood lies between 46 and 526 years old.

APPENDIX A

BETA ANALYTIC INC.
RADIOCARBON DATING SERVICES

Dr. MURRY A. TAMERS
Mr. DARDEN G. HOOD
Directors

RONALD E. HATFIELD
Laboratory Manager

CHRISTOPHER PATRICK
TERESA A. ZILKO-MILLER
Associate Managers

ANALYTICAL PROCEDURES AND FINAL REPORT

FINAL REPORT

This package includes the final date report, this statement outlining our analytical procedures, a glossary of pretreatment terms, calendar calibration information, billing documents (containing balance/credit information and the number of samples submitted within the yearly discount period), and peripheral items to use with future submittals. The final report includes the individual analysis method, the delivery basis, the material type and the individual pretreatments applied. Please recall any correspondences or communications we may have had regarding sample integrity, size, special considerations or conversions from one analytical technique to another (e.g. radiometric to AMS). The final report has also been sent by fax or e-mail, where available.

PRETREATMENT

Results were obtained on the portion of suitable carbon remaining after any necessary chemical and mechanical pretreatments of the submitted material. Pretreatments were applied, where necessary, to isolate ^{14}C which may best represent the time event of interest. Individual pretreatments are listed on the report next to each result and are defined in the enclosed glossary. When interpreting the results, it is important to consider the pretreatments. Some samples cannot be fully pretreated making their ^{14}C ages more subjective than samples which can be fully pretreated. Some materials receive no pretreatments. Please read the pretreatment glossary.

ANALYSIS

Materials measured by the radiometric technique were analyzed by synthesizing sample carbon to benzene (92% C), measuring for ^{14}C content in a scintillation spectrometer, and then calculating for radiocarbon age. If the Extended Counting Service was used, the ^{14}C content was measured for a greatly extended period of time. AMS results were derived from reduction of sample carbon to graphite (100 %C), along with standards and backgrounds. The graphite was then sent for ^{14}C measurement in an accelerator-mass-spectrometer located at one of three collaborating laboratories; Lawrence Livermore National Laboratory (CAMS) in California, Eidgenössische Technische Hochschule University (ETH) in Zürich, or Oxford University (Ox) in Oxford, England.

CALENDAR CALIBRATION

The "Conventional C14 Age (*)" is the result after applying C13/C12 corrections to the measured age and is the most appropriate radiocarbon age (the "*" is discussed at the bottom of the final report). Applicable calendar calibrations are included for organic materials and fresh water carbonates between 0 and 10,000 BP and for marine carbonates between 0 and 8,300 BP. If certain calibrations are not included with this report, the results were either too young, too old, or inappropriate for calibration. It is important to read the calibration explanation sheet before interpreting the results (especially for calcareous materials).

PRETREATMENT GLOSSARY

Pretreatment of submitted materials is required to eliminate secondary carbon components. These components, if not eliminated, could result in a radiocarbon date which is too young or too old. Pretreatment does not ensure that the radiocarbon date will represent the time event of interest. This is determined by the sample integrity. The old wood effect, burned intrusive roots, bioturbation, secondary deposition, secondary biogenic activity incorporating recent carbon (bacteria) and the analysis of multiple components of differing age are just some examples of potential problems. The pretreatment philosophy is to reduce the sample to a single component, where possible, to minimize the added subjectivity associated with these types of problems.

"acid/alkali/acid"

The sample was first gently crushed/dispersed in deionized water. It was then given hot HCl acid washes to eliminate carbonates and alkali washes (NaOH) to remove secondary organic acids. The alkali washes were followed by a final acid rinse to neutralize the solution prior to drying. Chemical concentrations, temperatures, exposure times, and number of repetitions, were applied accordingly with the uniqueness of the sample. Each chemical solution was neutralized prior to application of the next. During these serial rinses, mechanical contaminants such as associated sediments and rootlets were eliminated. This type of pretreatment is considered a "full pretreatment". On occasion the report will list the pretreatment as "acid/alkali/acid - insolubles" to specify which fraction of the sample was analyzed. This is done on occasion with sediments (See "acid/alkali/acid - solubles"

Typically applied to: charcoal, wood, some peats, some sediments, textiles

"acid washes"

Surface area was increased as much a possible. Solid chunks were crushed, fibrous materials were shredded, and sediments were dispersed. Acid (HCl) was applied repeatedly to ensure the absence of carbonates. Chemical concentrations, temperatures, exposure times, and number of repetitions, were applied accordingly with the uniqueness of each sample. The sample, for a number of reasons, could not be subjected to alkali washes to ensure the absence of secondary organic acids. The most common reason is that the primary carbon is soluble in the alkali. Dating results reflect the total organic content of the analyzed material. Their accuracy depends on the researcher's ability to subjectively eliminate potential contaminants based on contextual facts.

Typically applied to: organic sediments, some peats, small wood or charcoal, special cases

EXPLANATION OF THE BETA ANALYTIC DENDRO-CALIBRATION PRINTOUT

CALIBRATION OF RADICARBON AGE TO CALENDAR YEARS

Laboratory Number: Beta-12345

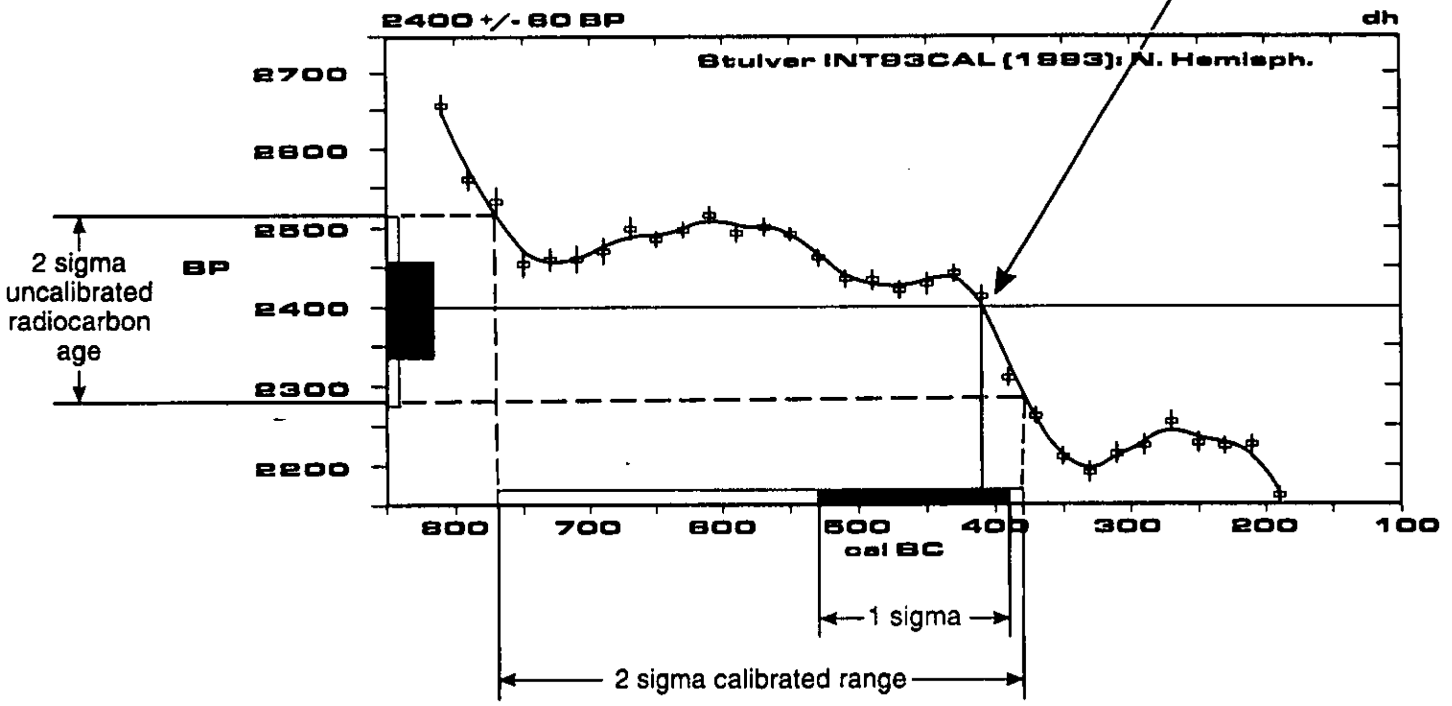
Radiocarbon age: **2400 +/- 60 BP** ← The uncalibrated radiocarbon age (± 1 sigma)

The recommended calibration age range to be used for interpretation → **Calibrated result: (2 sigma, 95% probability)** **cal BC 770 to 380**

Intercept data:

Intercept of radiocarbon age with calibration curve: cal BC 410 ← The intercept between the radiocarbon age & the calibrated calendar time scale curve

The calibration result of the radiocarbon age ± 1 sigma → 1 sigma calibrated result: (68% probability) cal BC 530 to 390



References:

Vogel, J. C., Fuls, A., Visser, E. and Becker, B., 1993, Radiocarbon 33(1), p73-86
Talma, A. S. and Vogel, J. C., 1993, Radiocarbon 35(2), p317-322
Stuiver, M., Long, A., Kra, R. S. and Devine, J. M., 1993, Radiocarbon 35(1)

Results prepared by:

Beta Analytic, Inc., 4985 S.W. 74th Court, Miami, Florida 33155

Reporting results (recommended):

1. List the radiocarbon age with its associated 1 sigma standard deviation in a table and designate it as such.
2. Discussion of ages in the text should focus on the 2 sigma calibrated range.

Calibrations of radiocarbon age determinations are applied to convert BP results to calendar years. The short term difference between the two is caused by fluctuations in the heliomagnetic modulation of the galactic cosmic radiation and, recently, large scale burning of fossil fuels and nuclear devices testing. Geomagnetic variations are the probable cause of longer term differences.

The parameters used for the corrections have been obtained through precise analyses of hundreds of samples taken from known-age tree rings of oak, sequoia, and fir up to 7,200 BP. The parameters for older samples, up to 22,000 BP, as well as for all marine samples, have been inferred from other evidence. Calibrations are presently provided for terrestrial samples to about 10,000 BP and marine samples to about 8,300 BP.

The Pretoria Calibration Procedure program has been chosen for these dendrocalibrations. It uses splines through the tree-ring data as calibration curves, which eliminates a large part of the statistical scatter of the actual data points. The spline calibration allows adjustment of the average curve by a quantified closeness-of-fit parameter to the measured data points. On the following calibration curves, the solid bars represent one sigma statistics (68% probability) and the hollow bars represent two sigma statistics (95% probability). Marine carbonate samples that have been corrected for $\delta^{13/12}C$, have also been corrected for both global and local geographic reservoir effects (as published in Radiocarbon, Volume 35, Number 1, 1993) prior to the calibration. Marine carbonates that have not been corrected for $\delta^{13/12}C$, have been adjusted by an assumed value of 0 ‰ in addition to the reservoir corrections. Reservoir corrections for fresh water carbonates are usually unknown and are generally not accounted for in those calibrations. In the absence of measured $\delta^{13/12}C$ ratios, a typical value of -5 ‰ was assumed for freshwater carbonates. There are separate calibration data for the Northern and Southern Hemisphere. Variables used in each calibration are listed below the title of each calibration page.

(Caveat: the calibrations assume that the material dated was living for exactly ten or twenty years (e.g. a collection of 10 or 20 individual tree rings taken from the outer portion of a tree that was cut down to produce the sample in the feature dated). For other materials, the maximum and minimum calibrated age ranges given by the computer program are uncertain. The possibility of an "old wood effect" must also be considered, as well as the potential inclusion of some younger material in the total sample. Since the vast majority of samples dated probably will not fulfill the ten/twenty-year-criterium and, in addition, an old wood effect or young carbon inclusion might not be excludable, these dendrocalibration results should be used only for illustrative purposes. In the case of carbonates, reservoir correction is theoretical and the local variations are real, highly variable and dependant on provenience. The age ranges and, especially, the intercept ages generated by the program must be considered as approximations.)

BETA ANALYTIC INC.

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REPORT OF RADIOCARBON DATING ANALYSES

FOR: Ms. Yvonne A. Katzenstein
University of California

DATE RECEIVED: February 16, 1996
DATE REPORTED: March 22, 1996

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-90763	230 +/- 80 BP	-23.9 o/oo	240 +/- 80 BP

SAMPLE #: SJRW-1
ANALYSIS: radiometric-standard
MATERIAL/PRETREATMENT:(wood): acid/alkali/acid

NOTE: It is important to read the calendar calibration information and to use the calendar calibrated results (reported separately) when interpreting these results in AD/BC terms.

NOTE: Sample BC-YK1 is being analyzed by AMS and will be reported separately. Portions 2, 3, and 4 of sample SJRW were not necessary to complete the analysis and are being returned under separate cover.

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By international convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:C13/C12=-23.9:lab mult.=1)

Laboratory Number: Beta-90763

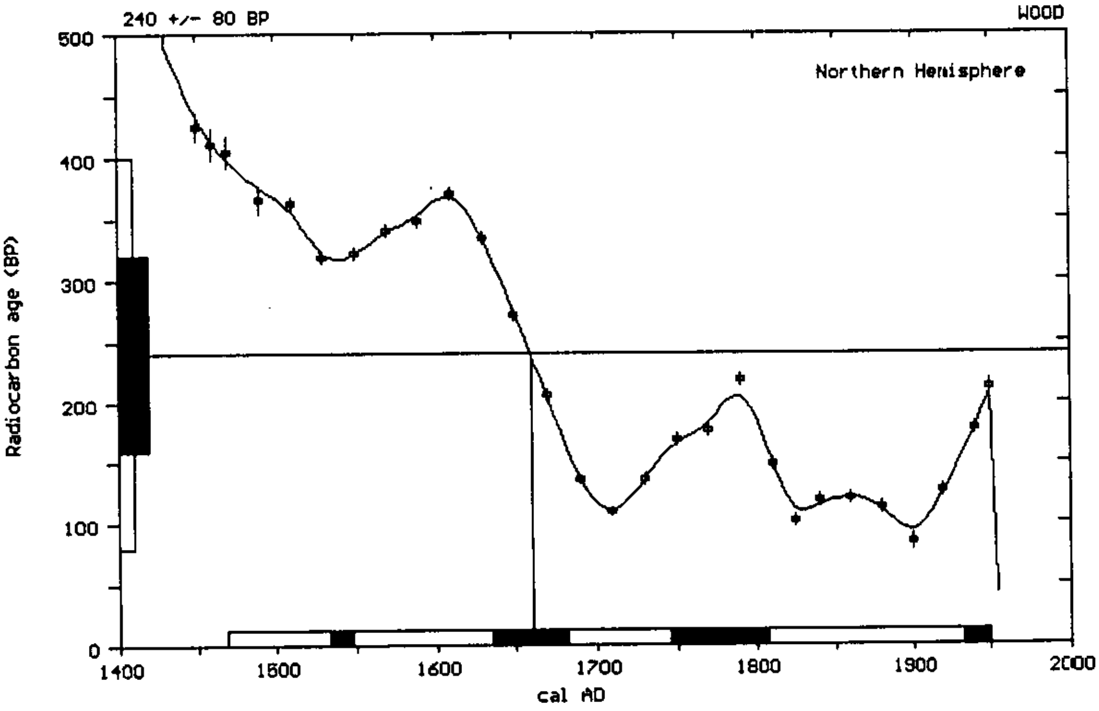
Conventional radiocarbon age: 240 +/- 80 BP

Calibrated results: cal AD 1470 to 1950
(2 sigma, 95% probability)

Intercept data:

Intercept of radiocarbon age with calibration curve: cal AD 1660

1 sigma calibrated results: cal AD 1535 to 1545 and
(68% probability) cal AD 1635 to 1680 and
cal AD 1745 to 1805 and
cal AD 1935 to 1950



References:

Pretoria Calibration Curve for Short Lived Samples
Vogel, J. C., Fuls, A., Visser, E. and Becker, B., 1993, Radiocarbon 35(1), p73-86
A Simplified Approach to Calibrating C14 Dates
Talma, A. S. and Vogel, J. C., 1993, Radiocarbon 35(2), p317-322
Calibration - 1993
Stuiver, M., Long, A., Kra, R. S. and Devine, J. M., 1993, Radiocarbon 35(1)

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REPORT OF RADIOCARBON DATING ANALYSES

FOR: Ms. Yvonne A. Katzenstein
University of California

DATE RECEIVED: Auth. Feb. 29, 1996
DATE REPORTED: May 1, 1996

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-90762	90 +/- 70 BP	-24.9 o/oo	90 +/- 70 BP

SAMPLE #: BC-YK1
ANALYSIS: AMS(New Zealand)
MATERIAL/PRETREATMENT:(charred material): acid/alkali/acid

NOTE: It is important to read the calendar calibration information and to use the calendar calibrated results (reported separately) when interpreting these results in AD/BC terms.

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By International convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

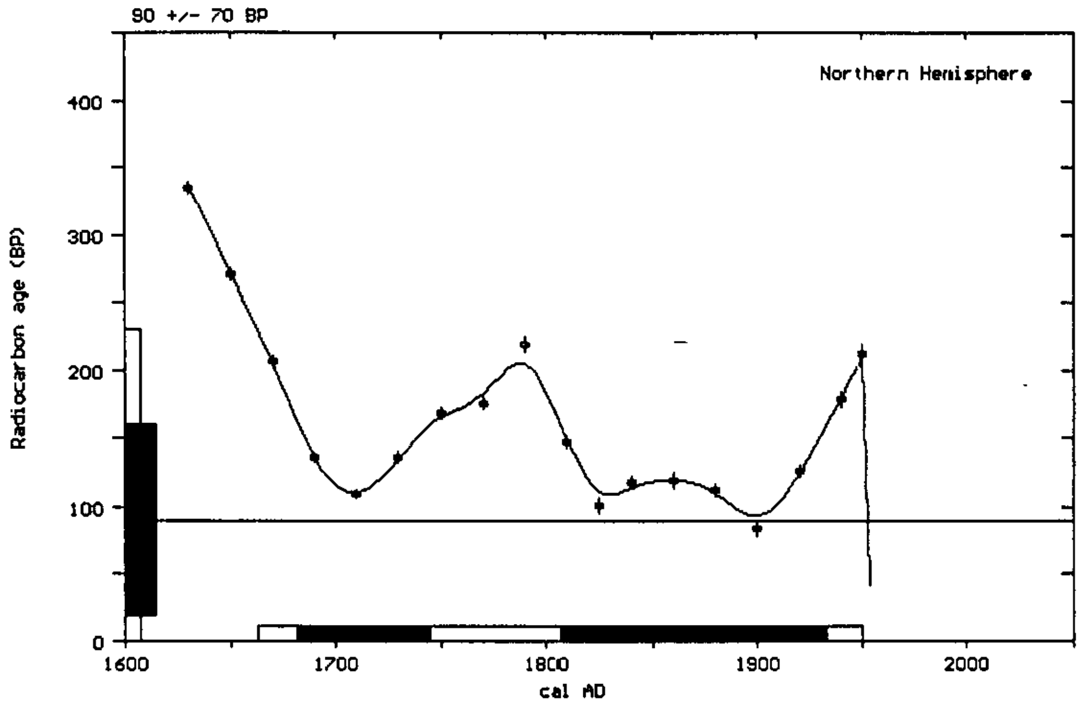
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:C13/C12=-24.9:lab mult.=1)

Laboratory Number:	Beta-90762
Conventional radiocarbon age:	**90 +/- 70 BP**
Calibrated results: (2 sigma, 95% probability)	**cal AD 1665 to 1950**

Intercept data:

Intercepts of radiocarbon age with calibration curve:	NO INTERCEPTS
1 sigma calibrated results: (68% probability)	cal AD 1680 to 1745 and cal AD 1805 to 1935



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Calibration - 1993

Stuiver, M., Long, A., Kra, R. S. and Devine, J. M., 1993, Radiocarbon 35(1)