MORPHOMETRY OF MAJOR ARROYOS IN THE VICINITY OF LOW-LEVEL RADIOACTIVE WASTE STUDY AREA, HUDSPETH COUNTY, TEXAS

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ABSTRACT

The area in Hudspeth County under consideration for disposal of low-level radioactive waste lies within the drainage divides of two watersheds: Alamo and Camp Rice Arroyos. The recent geomorphic history of these arroyos has been dominated by incision. Downcutting on the major arroyos caused upslope expansion of drainage networks and an increase in drainage density where clayey sediments of the Fort Hancock Formation crop out. However, alluvium fills the upper reaches of some tributaries and extends upslope onto the alluvial slope where drainage density values are relatively low.

INTRODUCTION

Attempting to predict future geomorphic conditions of a specific part of the Earth's surface is a difficult undertaking. Reliable historical records usually cover a much shorter period than the future timespan in question. In this study of an area in Hudspeth County, Texas, 500 yr is the minimum timeframe for which site characteristics of a low-level radioactive waste facility must be evaluated (U. S. Nuclear Regulatory Commission, 1988). Data on climate, vegetation, land use changes, and geomorphic conditions that existed in the recent geologic past are of limited use in describing possible future conditions. Nevertheless, the record preserved in existing landforms does provide information about past conditions that extends beyond the reach of extrapolation from historical records. This report presents a brief account of early arroyo development in the study area and cites evidence of recent geomorphic activity there.

GENERAL DESCRIPTION

Until about 600,000 yr ago the Hueco Bolson, a Basin and Range graben, was filling with fine-grained sediment that composes the Fort Hancock Formation and with coarser sediment of the Camp Rice Formation. The date of the end of basin-filling is based on the age of a volcanic ash that has been identified as Lava Creek B ash (formerly called Pearlette Type O) based on physical and chemical analyses (Izett and Wilcox, 1982). The ash deposit is found near the top of the Camp Rice Formation at Selden and El Paso Canyons, New Mexico (Gile and others, 1981). Since the end of Camp Rice deposition in middle Pleistocene time, the Rio Grande has incised the bolson-fill, possibly in response to drop in base level due to climatic changes related to global glacial cycles (Gile and others, 1981). The evidence of cyclic incision on the Rio Grande is the "stepped sequence of graded surfaces located between the valley floors and the...piedmont slopes" in southern New Mexico (Gile and others, 1981, p. 48). In the study area, surfaces equivalent to those described in southern New Mexico are found within the valleys of the major arroyos (E. W. Collins, personal communication, 1989). Thus, these arroyo basins began to develop soon after the first cycle of incision on the Rio Grande.

During this period of cyclic downcutting on the Rio Grande, the Campo Grande fault was undergoing normal fault movement. The Campo Grande fault is subparallel to the Rio Grande valley axis and is approximately perpendicular to the axes of the major arroyos that drain the northeastern side of the bolson in the study area (fig. 1).

These two processes, incision on the Rio Grande and movement on the Campo Grande fault, would have enhanced downcutting in these arroyos. Dropping base level on the Rio Grande or at the fault would have caused episodes of incision in the arroyos, reestablishing new profiles on the arroyos that were graded to the new, lower base level. The amount of incision on the arroyos that can be attributed specifically either to fault movement or to downcutting on the Rio Grande is not known. Because the correlative surfaces along the arroyos are present on the footwalls and hanging walls of the fault, it is more likely that downcutting on the Rio Grande is the dominant process controlling major episodes of incision on the arroyos.

EVIDENCE OF RECENT GEOMORPHIC ACTIVITY

Erosion and deposition are the principal geomorphic processes in the study area that might affect a shallow burial facility. These two categories can be subdivided into more specific processes such as denudation, downcutting, nickpoint advance, and valley filling. Other processes, such as stream capture, meander cutoff, and base-level change can enhance or inhibit erosion or deposition in the study area, depending on where they occur. For a site located on the drainage divide between Alamo and Camp Rice Arroyos (fig. 1), the most critical geomorphic process is probably nickpoint advance along shallow drainageways and valley-side gullies that cross or extend toward the proposed site.

According to Gile and others (1981, p. 48), the evolution of the Rio Grande valley in southern New Mexico and western Texas includes the following stages: (1) excavation of the axial valley and at least the lower segments of tributary valleys during waxing and full-glacial intervals; (2) deposition during waning glacial and early interglacial times; and (3) relative stability during the remainder of a given interglacial interval. According to this scenario, the area is now in a period of relative stability, which should persist until the onset of a climatic change to wetter conditions when valley excavation will recur and the arroyos will probably incise again. However, within that context of relative stability the arroyos may undergo geomorphic processes that are unrelated to base-level change on the Rio Grande or to faulting. Natural processes of meander cutoff, stream capture, and oversteepening due to deposition can cause changes in erosion and deposition. Furthermore, dam construction or destruction and changes in land use and sediment yield affect stream behavior. The record of some of these processes is partially preserved in the terrace deposits along the arroyos. These deposits and channel networks, evidence of past geomorphic activity, will be described next.

Erosion and Deposition in Arroyos

There are three major arroyos near the proposed site on the northeast side of the Rio Grande (fig. 1). In general, the recent history of the arroyos upstream from Campo Grande fault has been one of continual downcutting interrupted by short periods of alluviation, as evidenced by (1) preservation of unpaired, low terraces along the arroyos; (2) exposure of the Fort Hancock Formation in the floor of Alamo Arroyo upstream from the fault; and (3) ongoing removal of alluvial fill in the upper reaches of Alamo and Camp Rice Arroyos by upstream migration of headcuts.

A cross-profile from Alamo Arroyo upstream from the Campo Grande fault (fig. 2) depicts three unpaired, low terraces. All three are relatively young, based on their height above the stream and the absence of well-developed calcic horizons that are found in higher, older terraces. The three terrace levels are at unequal heights (unpaired) above the present stream. The fluvially deposited sediments are less than 6 ft (2 m) thick and lie unconformably on top of the Fort Hancock Formation. This arrangement of relatively thin sediments over much older bolson sediments at heights that alternate across the stream probably is the result of downcutting by the stream as it meandered several times across its valley, leaving overbank and channel deposits behind. This is significant because it suggests that during the recent geologic past downcutting has been the dominant stream process here, a conclusion that is supported by two other processes, exposure of Fort Hancock strata and removal of alluvial fill. The Fort Hancock Formation is exposed locally in the channel floor of Alamo Arroyo upstream from the Campo Grande fault. No thick layer of alluvial fill exists underneath the channel for most of its length, which indicates that the channel is at its lowest level of incision. In the upper reaches of Alamo and Camp Rice Arroyos and in some valley-side gullies, where alluvial fill is present, the fill is now being eroded.

A recent period of alluviation in the arroyos ended less than about 900 to 1,300 yr ago, based on the ^{14}C ages of organic material in low terraces along tributaries of Alamo Arroyo. Carbonized wood from a 5.7-ft- (1.75-m-) high terrace (fig. 3) has been radiocarbon-dated at 920±70 yr B.P. The alluvial fill in the arroyo west of the proposed site (fig. 3) has been radiocarbon-dated at 1,330±60 yr B.P., age-corrected for $\delta^{13}C$. The date was obtained on a sandy, silty, clayey organic horizon from a terrace 7.7 ft (2.35 m) high. The humic acid fraction of the organic humates was dated using a technique described by White and Valastro (1984) and Haas and others (1986). This date is the mean residence time of organic matter in the soil, and indicates that organic matter in this deposit began to accumulate at least 1,300 yr ago. The organic horizon is part of the alluvial fill, 5 ft (1.5 m) thick locally, which unconformably overlies older bolson (probably Fort Hancock Formation) sediments. At present, the organic horizon is exposed upstream and downstream for a total distance of about 130 ft (40 m) on both sides of the incised channel. The organic horizon accumulated on a relatively flat, gently sloping surface within the arroyo valley, which at this location is about 260 ft (80 m) wide.

In this arroyo, as in others, alluvial deposits can be traced upstream along the arroyo axis onto the low-relief alluvial slope between the main arroyo valleys. There, the alluvial fill covers the bottoms of shallow swales where ephemeral streams flow across the alluvial slope. The alluvium probably was once a continuous deposit, extending from the alluvial slope down into the arroyo at an angle slightly greater than that of the present arroyo slope. Now this alluvial package is being excavated near the upper end of the arroyo where a 10-ft- (3-m-) high nickpoint marks the eroding edge of the alluvial fill.

This transition from deposition to erosion may have been caused by climate change or crossing of an intrinsic threshold, such as oversteepening of the stream profile due to accumulation of sediment in the channel (Schumm, 1977). Because alluvial fill throughout the study area is being incised by headward-advancing nickpoints, it seems more likely that climate is the cause of this widespread change from alluviation to incision.

Climate of the Hueco Bolson became increasingly drier beginning about 500 yr ago (Horowitz and others, 1981), and there is evidence in southern New Mexico of a strong, short-term drought that began about 500 yr ago and lasted about 50 yr (Hall, 1985). More recently, desert shrub vegetation expanded in the Hueco Bolson near El Paso between 1835 and 1905, reportedly as a result of drought and overgrazing (Horowitz and others, 1981). These shifts in climate may have induced erosion of the alluvial fill that had accumulated previously. It is not known whether livestock grazing in the study area has affected vegetation cover there.

Drainage Pattern Change

The Campo Grande fault has affected basin development (fig. 1). All three arroyos have an abrupt upslope expansion of their drainage networks at or near the Campo Grande fault. This expansion is a result of normal fault movement and readjustment of the drainage system in each arroyo. Nickpoints created at the fault in each arroyo would have migrated upstream until new profiles were established. This headward advancement of erosion up the drainage network would have eventually reached the lower-order streams and produced upslope extension of the drainage network.

Stream capture may have enlarged Alamo Arroyo basin upstream from the Campo Grande fault at the expense of Camp Rice Arroyo. Alamo Arroyo is the widest of the three basins and has the largest drainage area upstream from the fault (fig. 1). The width of Alamo Arroyo basin increases about 4.5 times at the fault from 0.9 to 4.0 mi (1.4 to 6.4 km). More than 75 percent of this expansion is toward Camp Rice Arroyo. The main channel of Camp Rice Arroyo flows very close to the drainage divide between the two arroyos, at one point less than 2,400 ft (730 m) away. This suggests that Pear Canyon, which is adjacent to Camp Rice Arroyo and now drains into Alamo Arroyo, previously may have been part of the Camp Rice Arroyo drainage system. The tributary from Pear Canyon that now flows into Alamo Arroyo makes an abrupt 55-degree change in direction from S42W to N83W within 2600 ft (790 m) of the drainage divide between the two arroyos. Further possible evidence of stream capture is furnished by short, relatively deep valleys between Alamo Arroyo and Camp Rice Arroyo (fig. 3). At present, they are unconnected, but in the past they may have carried overland flow into Camp Rice Arroyo from Pear Canyon or from the area that now lies between the two arroyos.

The width of the area between the arroyos is considerably different upslope and downslope from the fault (fig. 4). Upslope from the fault the width of the interfluves is much less than that downslope from the fault. Alamo Arroyo has cut the deepest valley at the fault, and more Fort Hancock Formation is exposed at the surface upstream from the fault due to headward migration of tributaries directly up the alluvial slope toward Diablo Plateau. Clay outcrops in the Fort Hancock Formation are practically unvegetated, and this leaves surface materials unprotected during high-intensity rainfall. The fine-grained sediments are more coherent than sandy sediments in the Camp Rice Formation; therefore, more rills can form per unit area where Fort Hancock Formation is exposed. These precursors to low-order streams collect runoff and expand the drainage network, narrowing the undissected interarroyo drainage divides. This process eventually leads to higher drainage density.

Drainage Network Differences

Drainage density is a measure of the length of stream channels per unit area of land (Horton, 1932). For this study, drainage density was measured on the extended blue-line network of streams shown on 1:24,000-scale U.S.G.S. topographic maps. The blue lines were extended upslope to the highest V-shaped topographic contour. The resulting network was then checked against larger-scale (1:12,000) aerial photos, and drainage density was determined using the line-intersection method described by Mark (1974). Because many variables affect drainage density, including climate, erodibility of substrate, basin relief, and vegetation cover (Gregory and Gardiner, 1975; Ritter, 1978), drainage density therefore encapsulates them.

A previous study showed that mean drainage density and total stream length in a basin were highly positively correlated ($r \geq .96$, $p \leq .02$) with various measures of discharge in intermittent streams in northwestern Texas and eastern New Mexico (Baumgardner, 1987). This suggests that, other conditions being equal, areas with higher drainage density will have higher discharge than areas with lower drainage density.

The arroyo basins can be divided into five zones based on drainage density (fig. 5, table 1): from lowest to highest drainage density, these are Diablo Plateau, alluvial slope, scarp, area below the fault, and dissected surface above the fault. Drainage density varies from a low value of 2.9 mi/mi^2 (1.8 km/km^2) to a high value of 19.7 mi/mi^2 (12.3 km/km^2). Because higher discharge is expected from areas with higher values of drainage density, siting of a proposed facility should take into account the drainage density of upstream drainage areas.

The proposed site is on the alluvial slope that lies between the Campo Grande fault and Diablo Plateau (fig. 3). The surface at the site slopes away from the Diablo Plateau at about 55-65 ft/mi (10-12 m/km). The surface is slightly convex in a downslope direction. Convex slopes tend to disperse overland flow, rather than concentrate it into channels, and as a result, drainage density is relatively low on these surfaces. Drainage density values on the alluvial slope are lower than anywhere else in the study area except on top of Diablo Plateau (fig. 5).

SUMMARY

Recent geomorphic history of the study area has been dominated by incision on the major arroyos. The most recent period of alluviation ended less than about 900 to 1,300 yr ago. Base-level lowering on the Rio Grande is the major control of incision on these arroyos, although movement on the Campo Grande fault can lower base level locally. Climate change may cause some changes in erosion and deposition.

Faulting may have led to stream capture by Alamo Arroyo of its Pear Canyon tributary from Camp Rice Arroyo. The proposed site is located in an area of relatively low drainage density.

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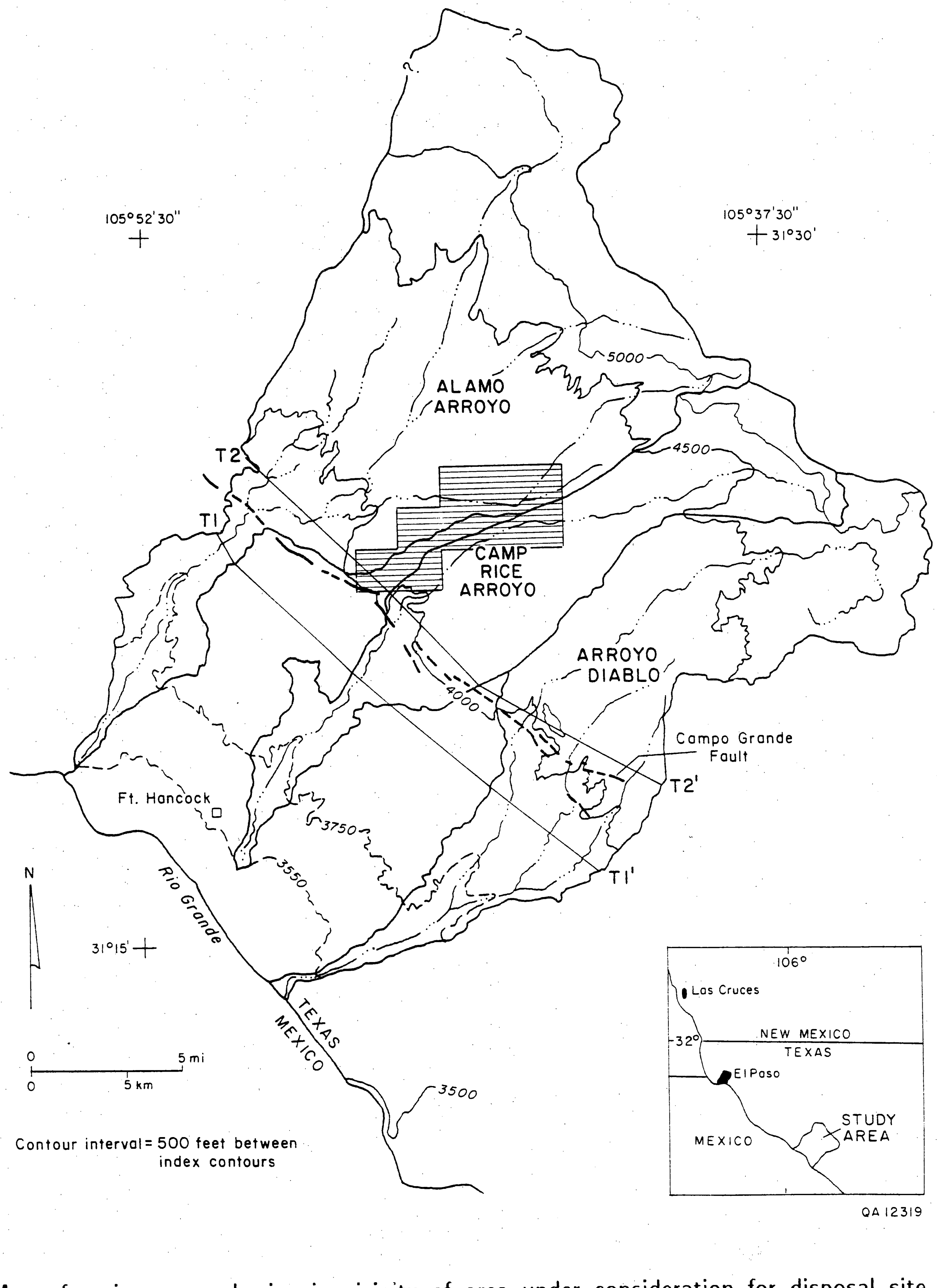
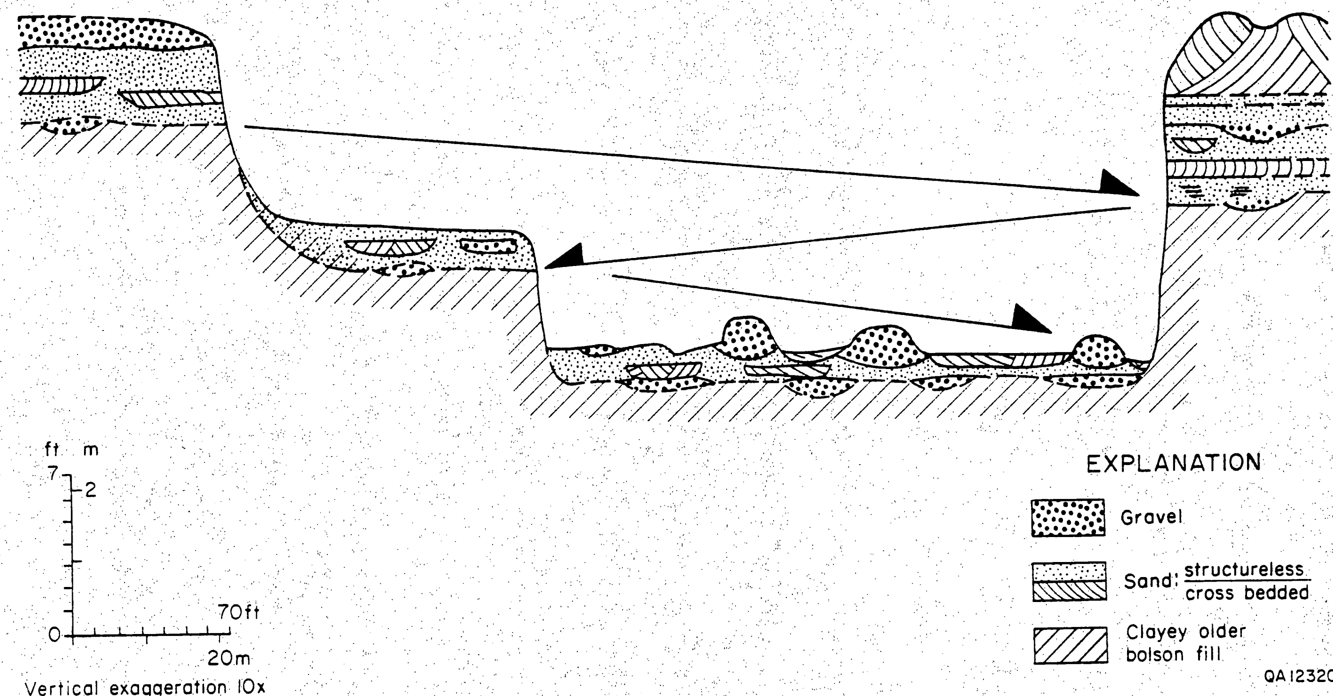
Table 1. Values of drainage density (mi/mi^2) for geomorphic zones in arroyo drainage basins. Geomorphic zones are listed upstream from the basin mouth to the Diablo Plateau. See figure 5 for boundaries between geomorphic zones.

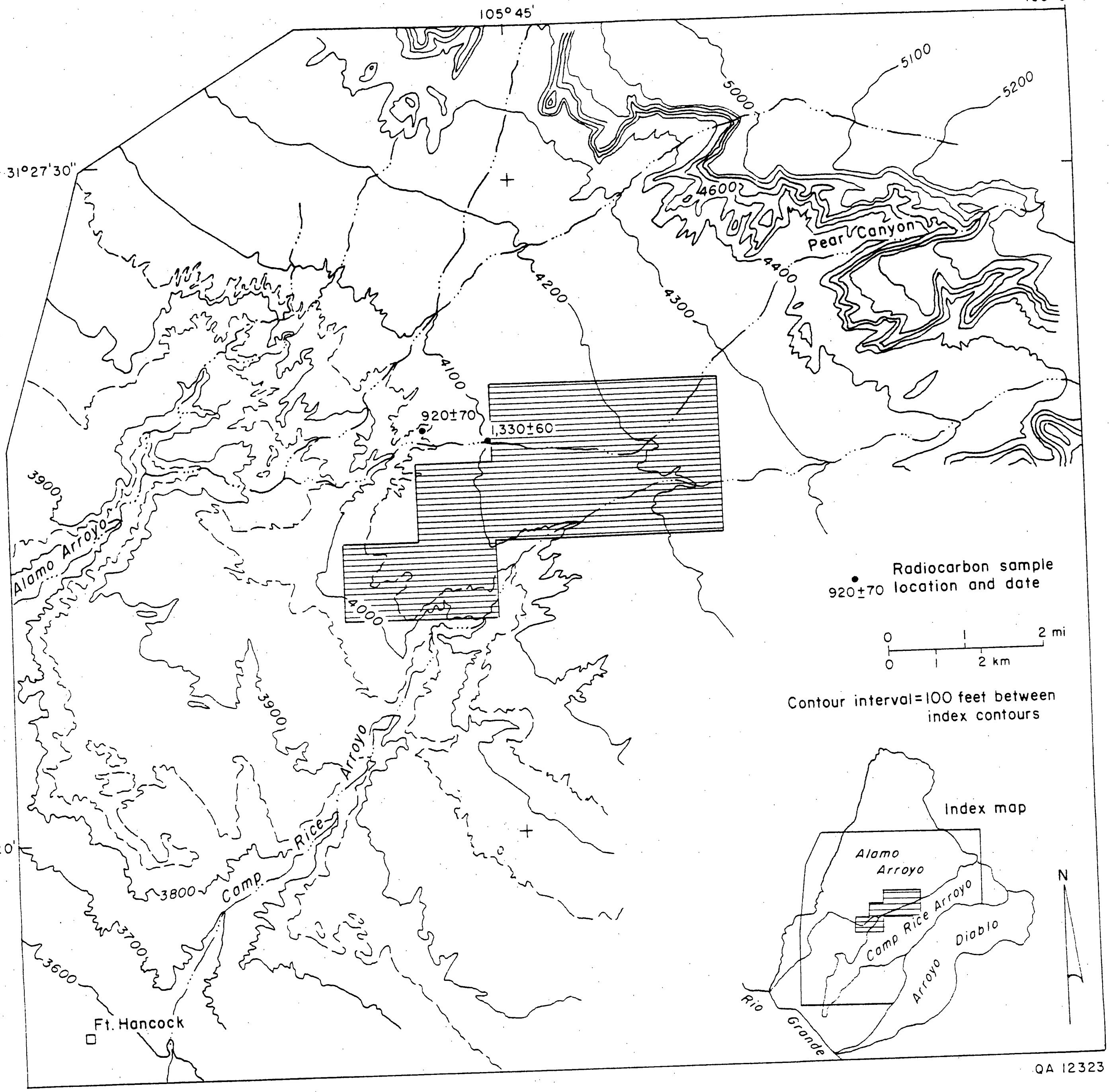
	Geomorphic Zone of Arroyo Basin				
Arroyo Name	Downstream from fault	Dissected zone	Alluvial Slope	Escarp-ment	Diablo Plateau
Alamo	16.1	19.3	11.0	15.3	4.9
Camp Rice	16.3	19.9	10.8	15.6	5.9
Diablo	12.2	14.6	11.1	13.8	2.9



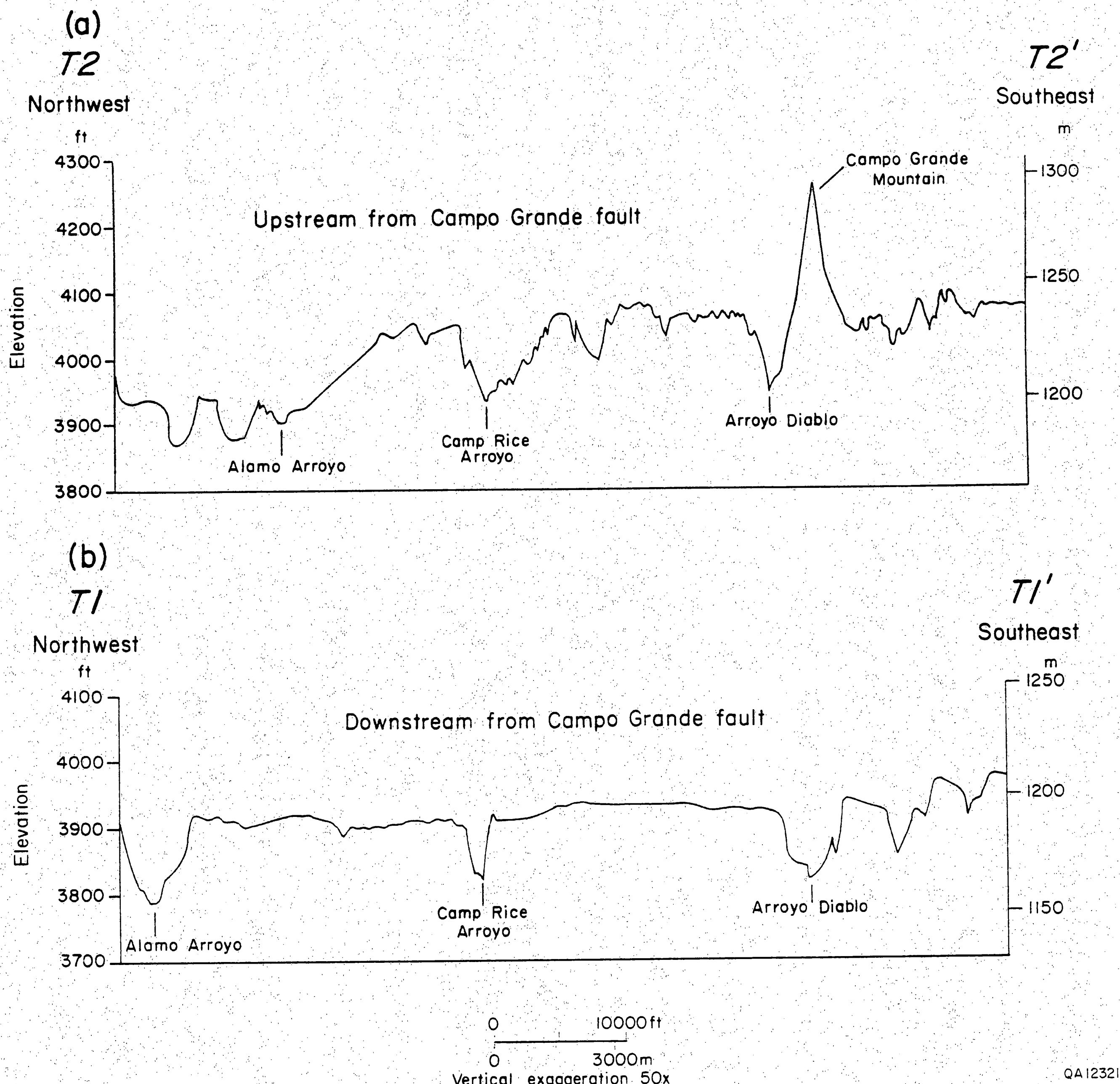
1. Map of major arroyo basins in vicinity of area under consideration for disposal site (shaded area), Hudspeth County, Texas.



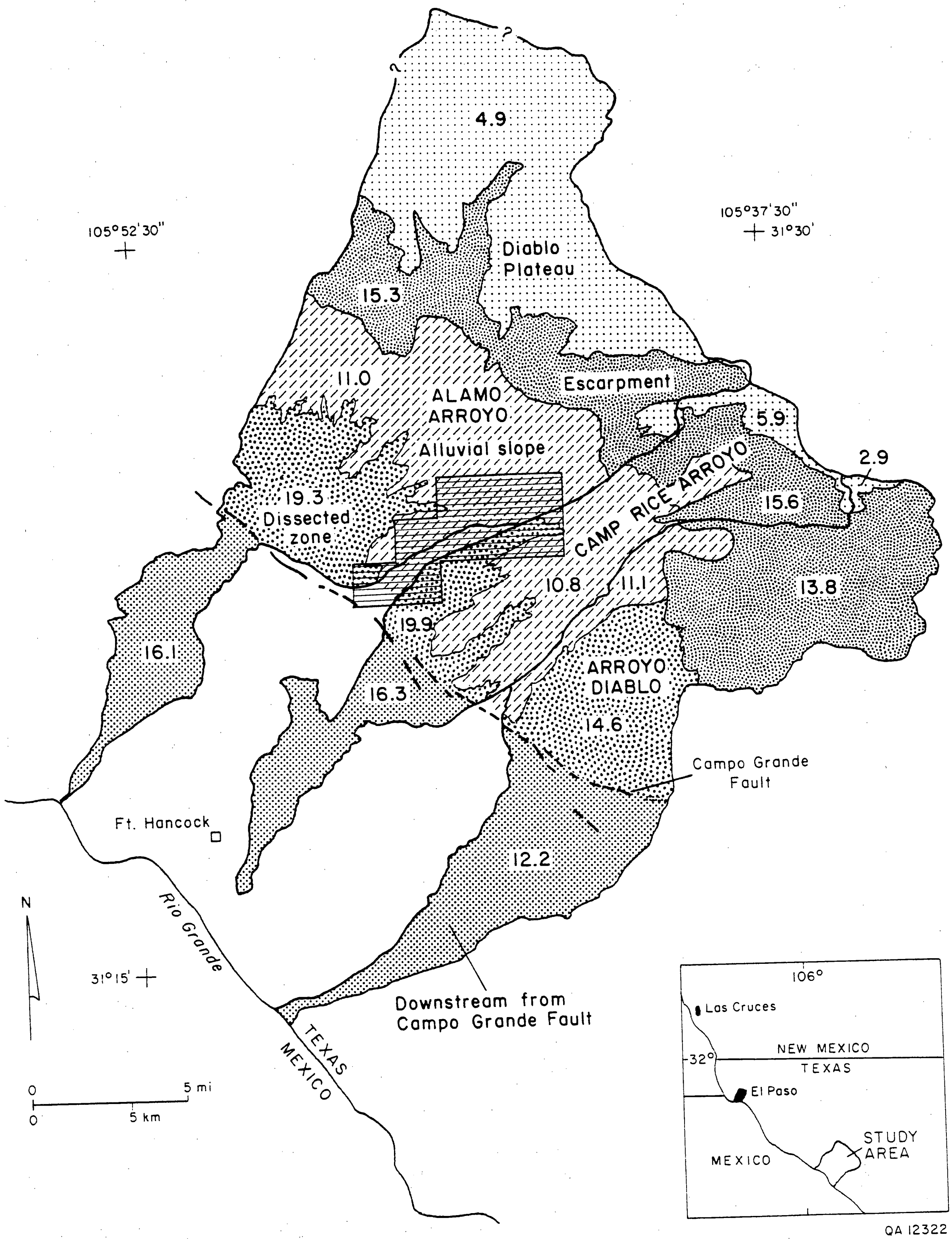
2. Terraces on Alamo Arroyo, upstream from Campo Grande Fault. Terrace heights alternate across the arroyo, indicating continual downcutting by the stream as it meandered across its valley. Arrows indicate direction of lateral movement by meandering stream during incision.



3. Map of vicinity of proposed site, showing sampling locations of radiocarbon-dated materials. Shaded area is under consideration for disposal site.



4. Transverse topographic profiles across major arroyo basins (a) upstream and (b) downstream from the Campo Grande fault. Location of profiles shown on figure 1.



5. Geomorphic zones in major arroyo basins, with values of drainage density (mi/mi^2) shown. Shaded area is under consideration for disposal site.