LANDSCAPE EVOLUTION OF EAGLE FLAT AND RED LIGHT BASINS, CHIHUAHUAN DESERT, SOUTH-CENTRAL TRANS-PECOS TEXAS

by

R. P. Langford

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Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78713-7508

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EXECUTIVE SUMMARY

This report documents the development of the landscape near the site proposed for the Texas low-level radioactive waste repository, located in southern Hudspeth County, Texas. It documents the geomorphic, depositional, and erosional features in the area. The Texas Legislature designated an approximately 400 mi^2 (1,035 km^2) area as the Eagle Flat Study Area, within which the site was to be selected. The study area consists of six U.S. Geological Survey 7.5-minute topographic quadrangles between the towns of Sierra Blanca and Van Horn, Texas. The six-quadrangle Eagle Flat Study Area contains a large part of Eagle Flat Basin and a smaller area in Red Light Draw.

The Eagle Flat Study Area contains parts of the Bolson and Sacramento subsections of the Mexican Highlands section in the Basin and Range physiographic province. The Bolson subsection is characterized by broad, internally drained alluvial basins, interrupted by rugged, discontinuous fault-block mountains. The mountains are composed of Cretaceous and Permian carbonate rocks with scattered areas of Tertiary intrusives and volcanics, older Paleozoic strata, and Precambrian metamorphic rocks. In the Bolson subsection, the uplands make up about one-fifth of the area, whereas uplands make up 27 percent of the entire Eagle Flat Study Area. The Eagle Flat and Red Light Draw Basins, in the Bolson subsection, are floored by Pliocene and Pleistocene alluvial sands and muds. The Sacramento subsection is represented by the Diablo Plateau in the northern part of the study area. This plateau is an upland area of Cretaceous hills separated by broad alluvial valleys with thin sedimentary cover.

The Eagle Flat Study Area contains the four geomorphic regimes characteristic of the bolson subsection, mountain (mapped with upland), upland, piedmont, and basin floor. The proposed repository site is on the basin floor, which is a relict alluvial flat sloping gently south at 0.0043 (23 ft/mi), into which the dendritic drainage system of Blanca Draw has incised. At the proposed repository site, the relict alluvial flat has been covered by a 0- to-4-ft-thick

(0 to 1.3 m) veneer of eolian sand, forming a vegetated eolian sand sheet. The vegetated sand sheet exhibits eolian erosional and depositional features and is a dynamic geomorphic surface, meaning that it is being actively reshaped. The eolian sand sheet is undated, but some features are modern. Other features may date back as much as several thousand years. The lack of soil development precludes earlier deposition of the eolian sand.

Underlying the eolian sand at the proposed repository site is a relict geomorphic surface that predates the incision of the current Blanca Draw. This stable geomorphic surface is termed the Arispe Surface. The sediment beneath the Arispe Surface was deposited as an alluvial flat on the basin floor. Alluvial flats are low-relief and low-gradient areas of the basin floor on which sediment is deposited by axial channels and the surrounding alluvial fans. The channel-fills lie everywhere a few feet (5 to 20 ft; 1.5 to 6 m) beneath the Arispe Surface, except where they are exposed along the eroded flanks of Blanca Draw or in borrow pits. Because the low-gradient Arispe alluvial flat surface can be projected across the entire basin floor, the channels probably are buried to the same approximate depths throughout the basin. A radiocarbon sample from just north of the repository site is radiocarbon dead (<2.5% ^{14}C), indicating that the relict alluvial flat strata are older than 30,470 yr. The accumulation of calcium carbonate in the soil below the Arispe Surface indicates that, in the area of the proposed repository site, the Arispe Surface probably stabilized and began to form a soil between 150,000 and 300,000 yr ago.

There are no karst features or features caused by mass wasting, slumping, or landslides on the Eagle Flat Basin floor. The most extensive modification of the Arispe Surface was the incision, and subsequent partial refilling, of the Blanca Draw drainage system. The drainage was incised as much as 35 ft (10.7 m) below the level of the Arispe Surface. Wash floors are 200 to 1,650 ft (60 to 500 m) wide and average 950 ft (290 m) wide. Wash floors are 7 to 35 ft (2.1 to 10 m) below adjacent interfluvial flats. Wash floors have gradients of 0.0053 (28 ft/mi) in the northwestern part of the Faskin Ranch area. The incised wash has refilled with distinctive, silty wash-fill deposits (Q_w). Currently the floor of Blanca Draw is slowly aggrading, but depositional features are not evident.

The other landforms of the Eagle Flat Study Area include playas and axial drainageways. The major playa is Grayton Lake, an approximately 1 mi^2 (2.6 km^2) playa that is the terminus of drainages in the northwest Eagle Flat Basin. Incised drainages are rare in northwest Eagle Flat but common in Red Light Draw and in the southeastern part of southeast Eagle Flat, where Eagle Flat Draw passes through a constriction between piedmonts of the Eagle and Carrizo Mountains.

The piedmont areas of northern Faskin Ranch are composed of alluvial fan and bajada landforms. Two alluvial fan landform styles are evident: fan lobe aggradation and inset lobes and valley fills. In fan lobe aggradation, younger fan lobes were deposited onto the smooth, older surface of the fan. The resulting deposits form thin finger-shaped mounds that splay down the surface of the fan. Inset lobes and valley fills form where the surface of the fan is dissected and the more recent fan deposition fills previously carved valleys in the older fan surface.

An older set of alluvial fan and bajada deposits is defined by a series of poorly dated and uncorrelatable geomorphic surfaces. All of these surfaces exhibit stage III or stage IV calcic soil horizons and are assumed to have been formed over a long period of time, predating and in part coincident with the formation of the Arispe Surface.

Two generations of younger fans are present in the Faskin Ranch area, occurring both as aggradational lobes and as inset lobes and valley fills. The older generation of fans is less widespread and has provided one minimum radiocarbon age of 9,400 yr. The second generation of fans spreads much farther from the mountain fronts and has provided four radiocarbon dates that range from 1,510 to 3,700 yr.

No erosional landforms are present on the proposed repository site. Erosion on the proposed repository site is confined to wind erosion of the thin eolian sandsheet that forms the upper 0 to 6 ft (0 to 2 m) of the proposed repository surface. Where the surface is disturbed, as happens with the roads crossing the proposed site, erosional rates exceed 1.5 inches/yr (3.75 cm/yr), but the underlying basin fill deposits and soils of the Arispe Surface are not eroded. Elsewhere on Faskin Ranch, gullies are found in proximal alluvial fans and in

Blanca Draw. The wash-flank slopes along Blanca Draw exhibit rills and scarplets. The erosional areas along the wash have a maximum relief of 2.5 ft (0.77 m) and have existed in their present location without significant expansion during the last 40 yr.

Erosion is associated with cultural features in all geomorphic regimes and surficial deposits. Estimates of erosion associated with roads and fences in basin-fill sediments that underlie the proposed repository site, range from 0 to 1.5 inches/yr (0 to 3.75 cm/yr), as inferred from a 40-yr record of aerial photographs. Twenty-inch-deep (50 cm) gullies associated with roads exhibit the deepest erosion in basin-fill strata. Borrow pits along Interstate Highway 10 exhibit rills up to 16 inches (40 cm) deep, formed during the last 29 yr, providing a 0.5 inch/yr (1.3 cm/yr) estimated rate of erosion. In wash-fill deposits, erosion is much faster. Steep borrow pit walls in wash-fill strata have receded 30 ft (10 m) laterally and have been lowered 2 ft (0.6 m), relative to the adjacent walls cut into basin-fill strata. Three gullies have been cut into the wash-fill deposits next to the Hoover borrow pit. The largest extends 460 ft (140 m) from the borrow pit and is cut 16 ft (4.9 m) deep into the wash-fill. Relatively rapid gullying (2 inches/yr; 5 cm/yr) has occurred in the proximal parts of the alluvial fans that are fed by larger drainages. However, no gullying has been encountered in the lower, distal part of the piedmont or on alluvial fans with smaller catchments.

PURPOSE AND SCOPE

This report describes the investigations of geomorphology and surficial geology conducted for the Texas Low-Level Radioactive Waste Disposal Authority (TLLRWDA) as part of the evaluation of the site proposed for the location of the Texas low-level radioactive waste repository. This report documents the development of the landscape near the proposed repository site and characterizes the geomorphic, depositional, and erosional features in the area. Data derived from these studies provide estimates of the stability of the proposed repository site and locate areas of potential erosion or deposition.

LOCATION

The Texas Legislature designated an approximately 400 mi^2 (1,035 km^2) area as the Eagle Flat Study Area, within which the TLLRWDA is to select a site for disposal of low-level radioactive waste (fig. 1). This area, the Eagle Flat Study Area, consists of six U.S. Geological Survey 7.5-minute topographic quadrangles in southern Hudspeth County in Trans-Pecos Texas (fig. 1). The town of Sierra Blanca lies near the west edge of the study area, and the area is traversed by Interstate Highway 10. The six-quadrangle Eagle Flat Study Area contains a large part of the northwest and southeast Eagle Flat Basins and a smaller part of northern Red Light Draw.

The TLLRWDA proposed a site for the Texas low-level radioactive waste repository within this area located on the northern part of the Faskin Ranch (fig. 2). This site lies approximately 5.5 mi (8.9 km) southeast of the town of Sierra Blanca and is located between Interstate Highway 10 and the Southern Pacific Railroad track within northwest Eagle Flat Basin. Northwest Eagle Flat is a closed basin drained by Blanca Draw, which runs to the south of the proposed site and terminates in Grayton Lake (fig. 2).

Studies for this report were conducted at various scales. Detailed studies were conducted in the area of the proposed repository site, north of the Southern Pacific Railroad track (plate 1). Other studies were conducted across the area of northern Faskin Ranch (fig. 3). This is an area that includes the northern and central parts of Faskin Ranch and extends from Sand Mountain in the northwest to Grayton Lake in the southeast. In addition, surficial deposits and general geomorphology were mapped across the entire Eagle Flat Study Area (fig. 4 [in pocket]).

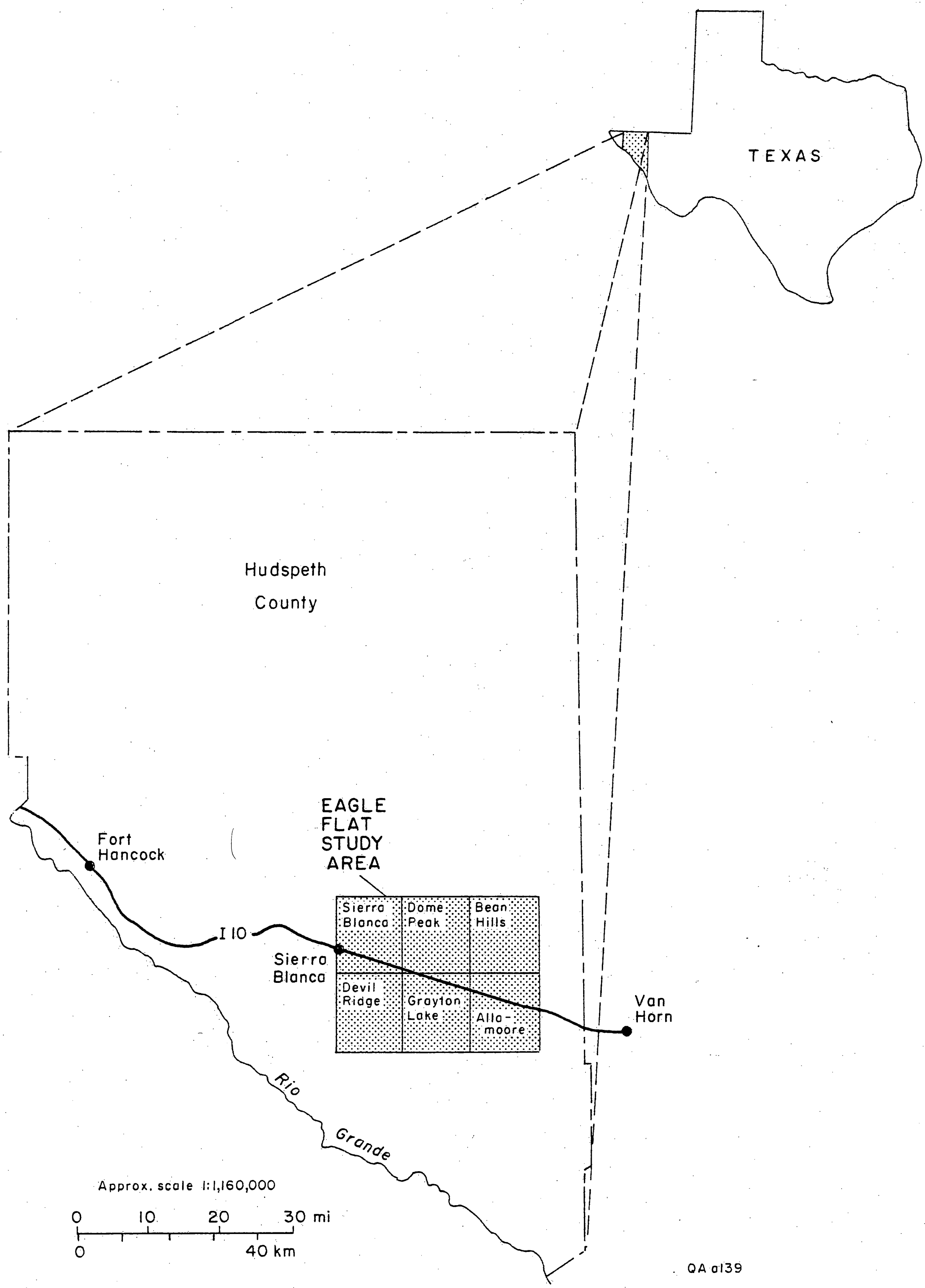

Figure 1. Map showing the location of the six U.S. Geological Survey quadrangles designated by the Texas Legislature as the Eagle Flat Study Area, Hudspeth County, Texas.

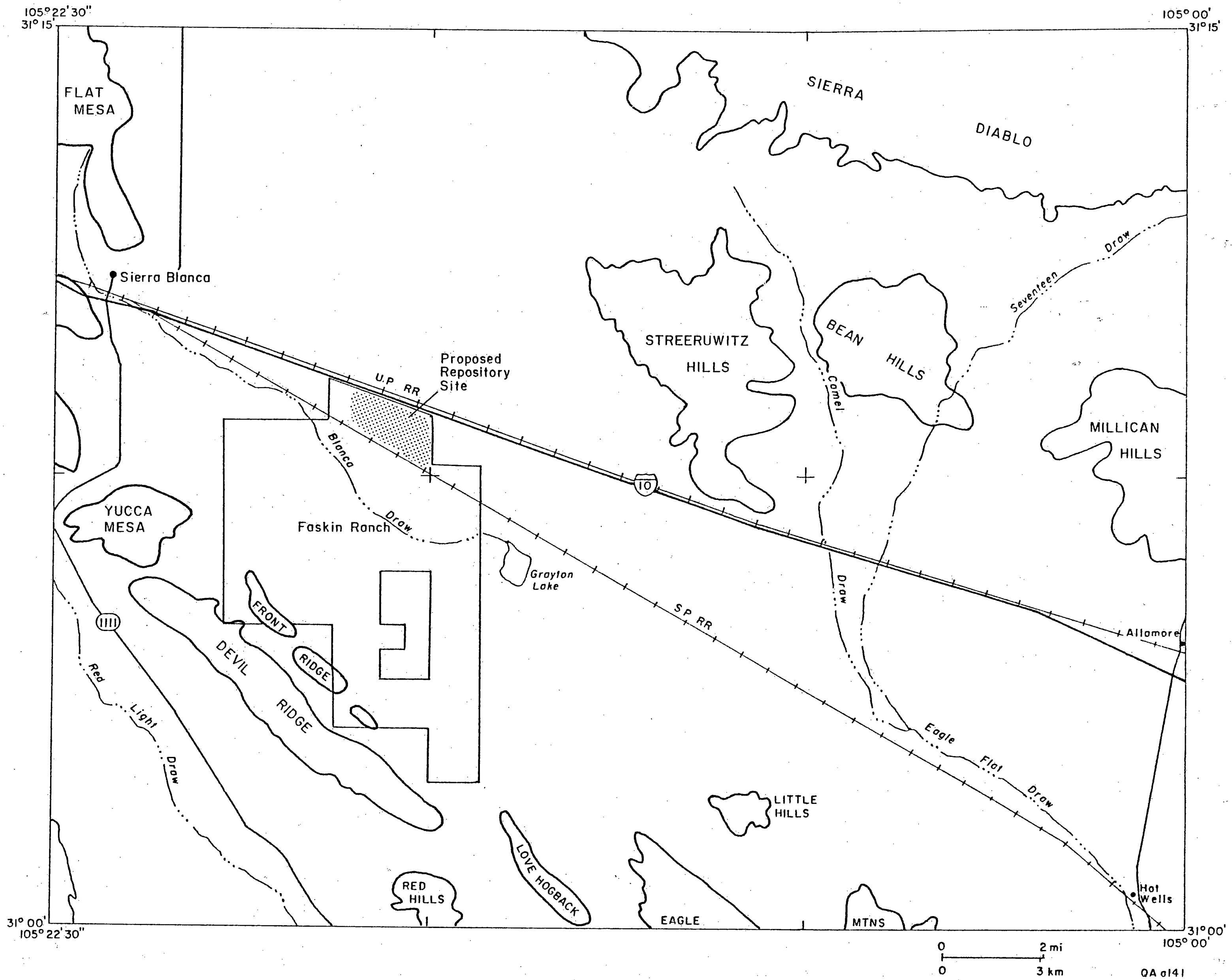

Figure 2. Map of the Eagle Flat Study Area showing major physiographic and cultural features, the approximate boundary of Faskin Ranch, and the proposed repository site.

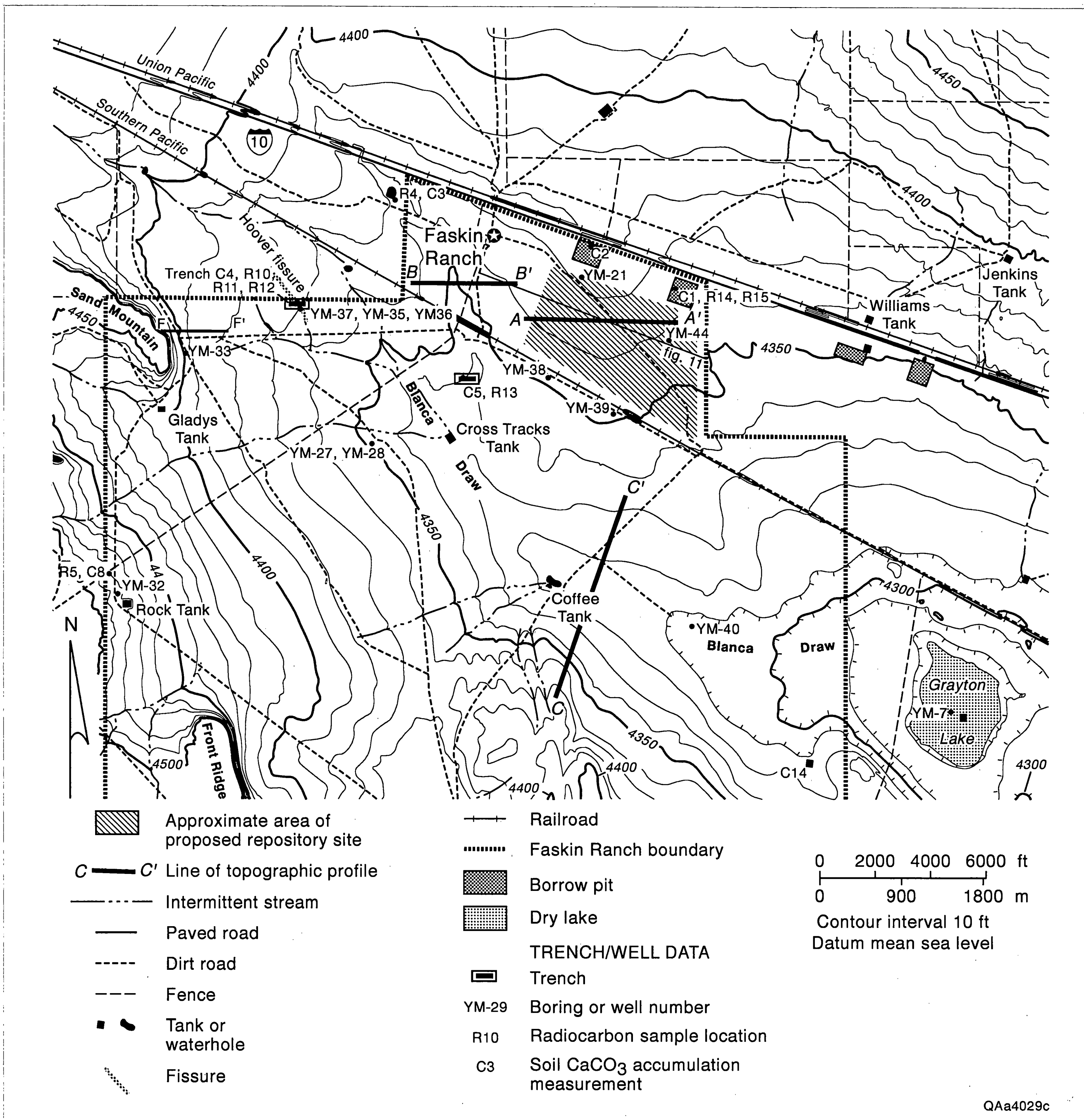

Figure 3. Map of northern Faskin Ranch showing the proposed repository site and cultural and natural features mentioned in the text. Locations of samples for radiocarbon dating and calcic soil (cS) measurements taken in the ranch area are also shown. The long northwest- to southeast-trending seismic line is the location of figure 11. A–A′ is the location of figure 21. B–B′ is the location of figure 10.

SETTING

Physiographic Setting

The Eagle Flat Study Area lies in the Mexican Highlands and Sacramento sections of the Basin and Range physiographic province (Fenneman, 1931; Thornbury, 1965; Gile and others, 1981) (fig. 5). The Eagle Flat Basin part of the Mexican Highlands has been referred to as the Bolson subsection (fig. 5), the type locality of the bolson landform (Hill, 1900), and is characterized by broad internally drained basins, interrupted by rugged, discontinuous fault-block mountains (Hawley, 1969). The mountains make up about one-fifth of the land surface area in the bolson subsection (Hawley, 1969). The mountains in the Eagle Flat Study Area are characteristic of those of the subsection in that they are composed of Cretaceous and Permian carbonate rocks with local areas of Tertiary intrusives and volcanics, older Paleozoic strata, and Precambrian metamorphic rocks (Raney and Collins, 1993). In the Eagle Flat Study Area, uplands (mountains, hills, and the Diablo Plateau) compose 27 percent of the surface area. The Bureau of Economic Geology borings from Eagle Flat Basin have cored as much as 715 ft (218 m) of Pliocene and Pleistocene basin-fill strata before penetrating Cretaceous bedrock (Jackson and others, 1993).

To the west of the Eagle Flat Study Area, the flat floor of the Hueco Basin was the site of playa and fluvial deposition as part of the terminal Rio Grande during the Pliocene. However, the Rio Grande was integrated through the Indio and Quitman Mountains during the late Pliocene (Gustavson, 1991). As the Rio Grande incised, a series of terraces developed. The terraces were graded to different elevations of the Rio Grande floodplain as it incised (Gile and others, 1981). Today, the Rio Grande is the only throughgoing drainage in the area. It lies in valley floors, well below the elevations of adjacent closed basins such as Eagle Flat. The Rio Grande floodplain is at 3,400 ft (1,035 m) at the southern end of the Hueco Basin (fig. 6).

Figure 5 shows the study area with the major features and the subsections of the Mexican Highlands section, and figure 6 shows the major physiographic features in the study area. The

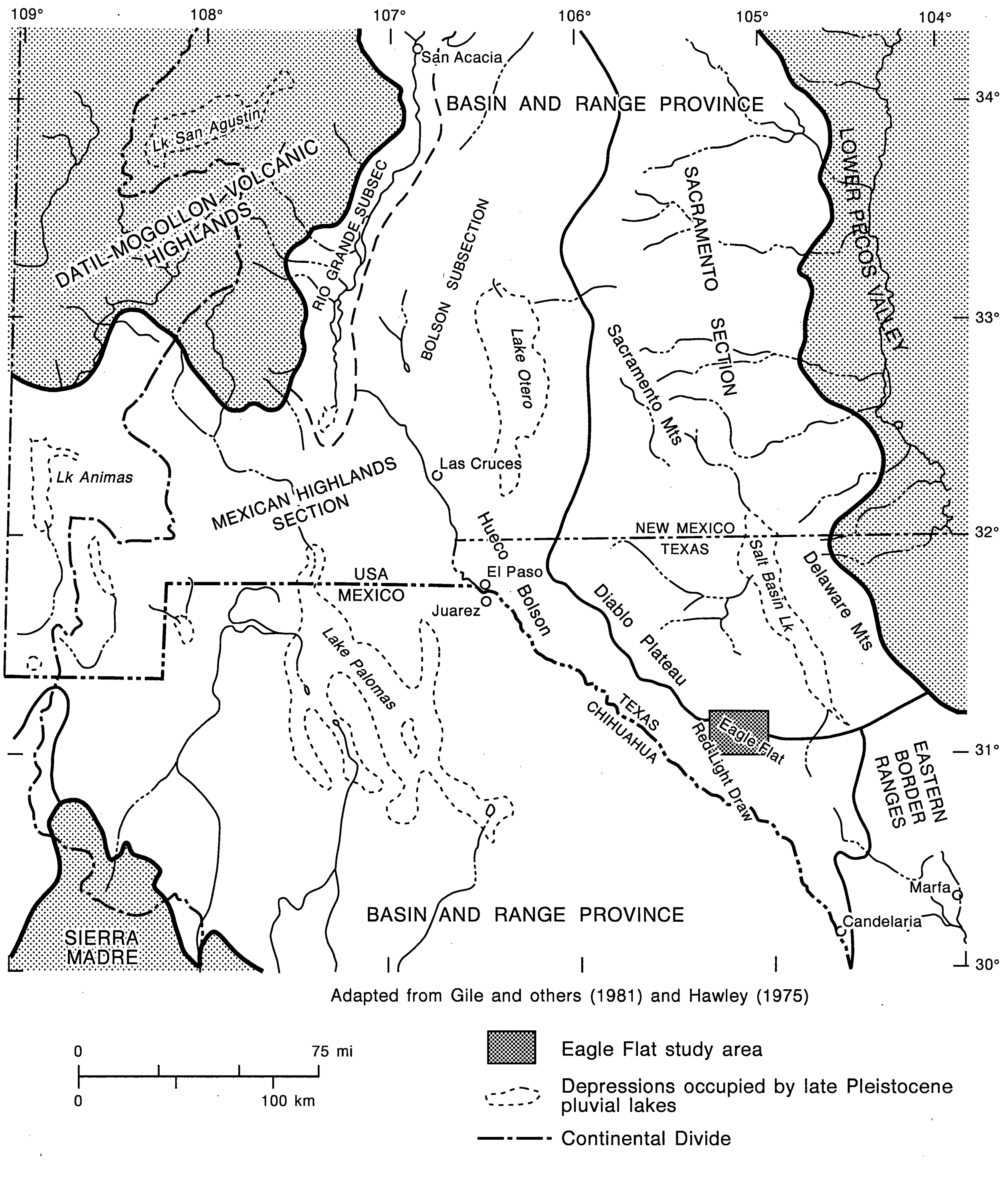

Figure 5. Physiographic subdivisions of West Texas and southern New Mexico, showing the Eagle Flat Study Area in relation to major river systems, lake basins, and dune fields (adapted from Hawley, 1975, and Gile and others, 1981).

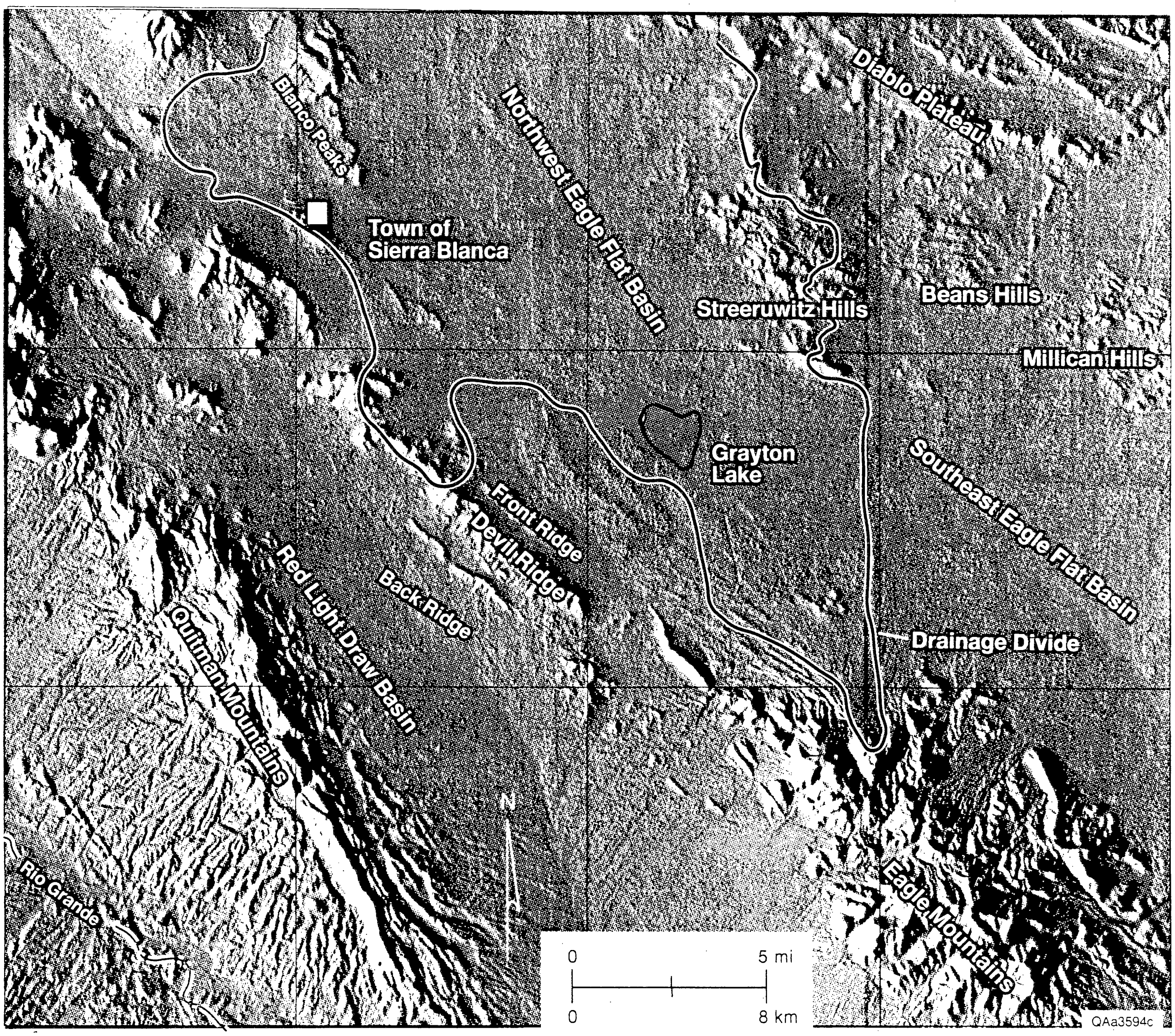

Figure 6. Physiographic features of the study area, shown on a shaded relief image made from USGS digital elevation models of 12 7.5-minute quadrangles in and near the study area showing physiographic elements. The Eagle Flat Study Area is the upper right set of six quadrangles. The drainage divides separating northwest Eagle Flat Basin from southeast Eagle Flat Basin and Red Light Draw are shown as lines.

northern part of the study area lies in the Diablo Plateau of the Sacramento section. The Diablo Plateau is a low-relief upland that slopes gently to the north from a drainage divide along the southern escarpment of the Plateau. The escarpment also forms a ground-water divide, with water flowing north or northeast beneath the Plateau. Hills of Cretaceous limestone and rolling eolian sand sheets are drained by wide shallow valleys. The bedrock is usually covered with thin colluvium and soil vegetated by grasses with scattered mesquite and juniper. The land drops from the southern rim of the plateau to a fringe of low hills of Precambrian metamorphic rocks and Permian and Cretaceous limestones and sandstones. Together, the Bean Hills, Millican Hills, and Streeruwitz Hills are an irregular shelf formed by gradual erosional retreat of the Diablo Plateau (fig. 6).

Between and to the south of the hills lie two northwest–southeast-trending basins. The two basins are the Eagle Flat Basin and the Red Light Draw Basin, also known as Quitman Canyon or Quitman Arroyo. Immediately south of the Millican, Bean, and Streeruwitz Hills and west of the Blanca Peaks is the Eagle Flat Basin. Eagle Flat Basin can be further subdivided into two topographic subbasins. Northwest Eagle Flat Basin forms a closed topographic depression that drains through the ephemeral Blanca Draw into Grayton Lake in its southeastern end (fig. 6). Coalescent alluvial fans compose a low drainage divide, 4.5 mi (7.2 km) east and 90 ft (27 m) above the floor of Grayton Lake. The northwest Eagle Flat Basin is approximately 200 mi^2 (518 km^2) (Wermund, 1992). Seventy-seven percent of the streams drain to the south and east (Wermund, 1992). Southeast Eagle Flat Basin is drained by the ephemeral Eagle Flat Draw, which flows between the Eagle Mountains (figs. 2 and 6) and the southern end of the Carrizo Mountains and into Lobo Valley.

The Eagle Flat Basins are bounded on their southwestern sides by the high volcanic massif of the Eagle Mountains and the lower limestone spines of Devil Ridge. These divide Eagle Flat Basin from Red Light Draw Basin to the southwest. To the northeast, southeast Eagle Flat Basin is flanked by the more subdued heights of the Precambrian rocks of the Carrizo Mountains.

Red Light Draw is an elongate drainage, with a straight and incised axial stream. The basin is straighter and narrower than the Eagle Flat Basins and is bounded by steep mountains along most of its length. Red Light Draw is an ephemeral tributary of the Rio Grande. Therefore, of the three topographic basins, Red Light Draw is graded to the floodplain of the incised throughgoing Rio Grande drainage. Southeast Eagle Flat is graded to its rocky outlet into Lobo Valley and northwest Eagle Flat is graded to the gradually aggrading surface of Grayton Lake.

Red Light Draw Basin is flanked to the southwest by the rugged limestone, sandstone, and volcanic Quitman Mountains. These are extended to the north by the Blanca Peaks, comprising the conical Sierra Blanca and its subsidiary peaks. The Blanca Peaks also form the northwest border of northwest Eagle Flat Basin. The overall relief in the Eagle Flat Study Area is approximately 3,200 ft (975 m), with elevations ranging from 7,424 ft (2,261 m) in the Eagle Mountains to 4,250 ft (1,295 m) at Hot Wells on Eagle Flat Draw.

Geomorphic Regimes

The landscapes in the Eagle Flat Study Area can be grouped into four geomorphic regimes (plate 2): mountains, uplands, alluvial fans, and basin floors. Mountains make up the highest relief and highest elevation areas around Sierra Blanca. Mountain areas include the Blanca Peaks, Devil Ridge, Eagle Mountains, and Quitman Mountains (fig. 6). Mountains are underlain by bedrock, with generally very shallow soils. In some of the volcanic and intrusive mountain areas, most notably the Eagle Mountains, water is encountered at shallow depths (Hibbs and Darling, 1993). These areas are included with upland areas on plate 2.

Uplands are areas underlain by bedrock but lower in relief and elevation than mountains, with peaks generally below 5,500 ft (1,675 m). Upland areas include the Diablo Plateau, Devil Ridge, and the Streeruwitz, Bean, and Millican Hills. Upland areas have thin soils underlain by bedrock. Vegetation is mostly cactus and desert shrubs, including creosote, tarbrush, mesquite, and Flourensia. The upland areas described in the rest of this report include both the true upland areas and the higher Eagle and Quitman Mountains.

Piedmont slopes lie between the mountains and uplands and the basin floors. The piedmonts consist of alluvial fans and *bajadas* or coalescent alluvial fans. Well-defined alluvial fans spread from the mouths of the larger canyons that drain the bigger catchments. The alluvial fans are underlain by gravels and sandstones deposited by streams flowing out of the highlands. These deposits may be thick or very thin. In general, the upper parts of alluvial fans are composed of relict surfaces and are incised.

The basin floors are generally flat areas that form the centers of the Eagle Flat and Red Light Draw Basins. These are generally gently sloping areas graded to the surface of the axial drainages. Basin floors are underlain by generally fine-grained materials of varying thickness. The basin floors vary in width, depending on the width of the basins and the width of the basin floors relative to the adjoining piedmont. Wider basin floors with graded surfaces are termed *alluvial flats* (Gile and others, 1981). Other basin floors, particularly in Red Light Basin, and the southeastern part of southeast Eagle Flat Basin are *drainageways* (Gile and others, 1981), in which the toes of opposing alluvial fans are separated by only a few hundred feet by the axial drainage of the basin.

Playa areas are ephemeral lakes into which the piedmont and axial drainages of the basin terminate. The inhabitants have recounted that Grayton Lake playa floods only once every few years; it was last flooded during the late summer of 1993.

Geologic Setting

Precambrian to Miocene

This section of the report describes the geologic phenomena that relate to the geomorphology and surficial strata of the Eagle Flat and Red Light Draw Basins. The regional geology is more fully discussed in Raney and Collins (1993). The stratigraphy of the Pliocene to Recent bolson sediments in Eagle Flat Basin is discussed in Jackson and others (1993).

Beginning in the Late Cretaceous, thick Cretaceous sediments of the Chihuahua Trough were thrust northeastward onto the stable Diablo Platform, which is composed of Precambrian metamorphics and covered with a relatively thin sheath of Permian and Cretaceous limestones and sandstones (Raney and Collins, 1993). The limit of thrusting lay on a line running southeast from Sierra Blanca along the front of Devil Ridge and Eagle Mountains. Southwest of this line, in the present-day Devil Ridge and Eagle and Quitman Mountains, the bedrock is dominated by highly deformed upper Cretaceous limestones and sandstones. Northeast of the thrust front are large areas of exposed Precambrian metamorphics and upper Cretaceous Cox Sandstone, exposed by erosion of the thin uppermost Cretaceous cover.

During the Late Eocene and Early Oligocene, volcanism constructed mountainous edifices built of tuffs and flows and associated intrusive complexes, in the northern Quitman Mountains and Eagle Mountains. The Blanca Peaks were constructed by the intrusive deformation of laccoliths and sills. Today these volcanic and intrusive edifices remain as the highest mountains in the area.

Starting approximately 24 m.y.a., Basin and Range deformation began, defining the present-day mountains of the area. The Quitman, Eagle, and Carrizo Mountains and Devil Ridge were uplifted, and Red Light Draw and Eagle Flat Basins subsided. During the early Basin and Range deformation, the basins were probably each closed and internally drained. Along with Basin and Range deformation, deposition of basin-filling sediments began in the lowest parts of the basins.

Miocene to Middle Pleistocene

Hueco Basin and Lower Red Light Draw

The basal, Miocene and early Pliocene, basin-fill sediments in the Hueco, Red Light, and Eagle Flat Basins are nowhere exposed, and their ages and depositional environments are uncertain. The oldest exposed sediments in the region are along the incised valley of the Rio Grande and its tributaries in the Hueco Basin and southern Red Light Draw (fig. 7). These strata date from the late Pliocene and are termed the Fort Hancock Formation in the Hueco Basin (Strain, 1966), and the Bramblett Formation in Red Light Draw (Akersten, 1967; Strain, 1980). During deposition of the Fort Hancock, the Hueco Basin had no outlet and served as the terminal drainage of the upper Rio Grande (Kottlowski, 1958). The Fort Hancock contains alluvial fan, fluvial, and playa depositional facies deposited in a closed basin with extensive alluvial plains and smaller playas and ephemeral lakes (Strain, 1966; Gustavson, 1991). The Bramblett Formation is similar in lithology and depositional facies to the Fort Hancock, except that the lateral extent of the depositional facies is more restricted due to the narrower geometry of Red Light Draw (Akersten, 1967).

Progressive filling of the basins and incision of the surrounding uplands has gradually integrated the Basin and Range fault-block basins into larger drainage systems. Integration of the Rio Grande system continued through the Pliocene. The Rio Grande incised through the southern Indio and Quitman Mountains by approximately 2.25 m.y.a. (Gustavson, 1991), integrating Red Light Draw with the Hueco Basin and the lower Rio Grande. Integration of the Rio Grande eroded a relatively shallow valley into the southern Quitman Mountains and in the Hueco Basin and southern Red Light Draw.

Filling this eroded valley and covering the Fort Hancock Formation were a series of sediments deposited by the throughflowing Rio Grande, and its tributaries flowing from the margins of the Hueco and Red Light Basins. These sediments, known as the Love Formation and Camp Rice Formation, contain alluvial fan gravels and sandstones derived from the tributary

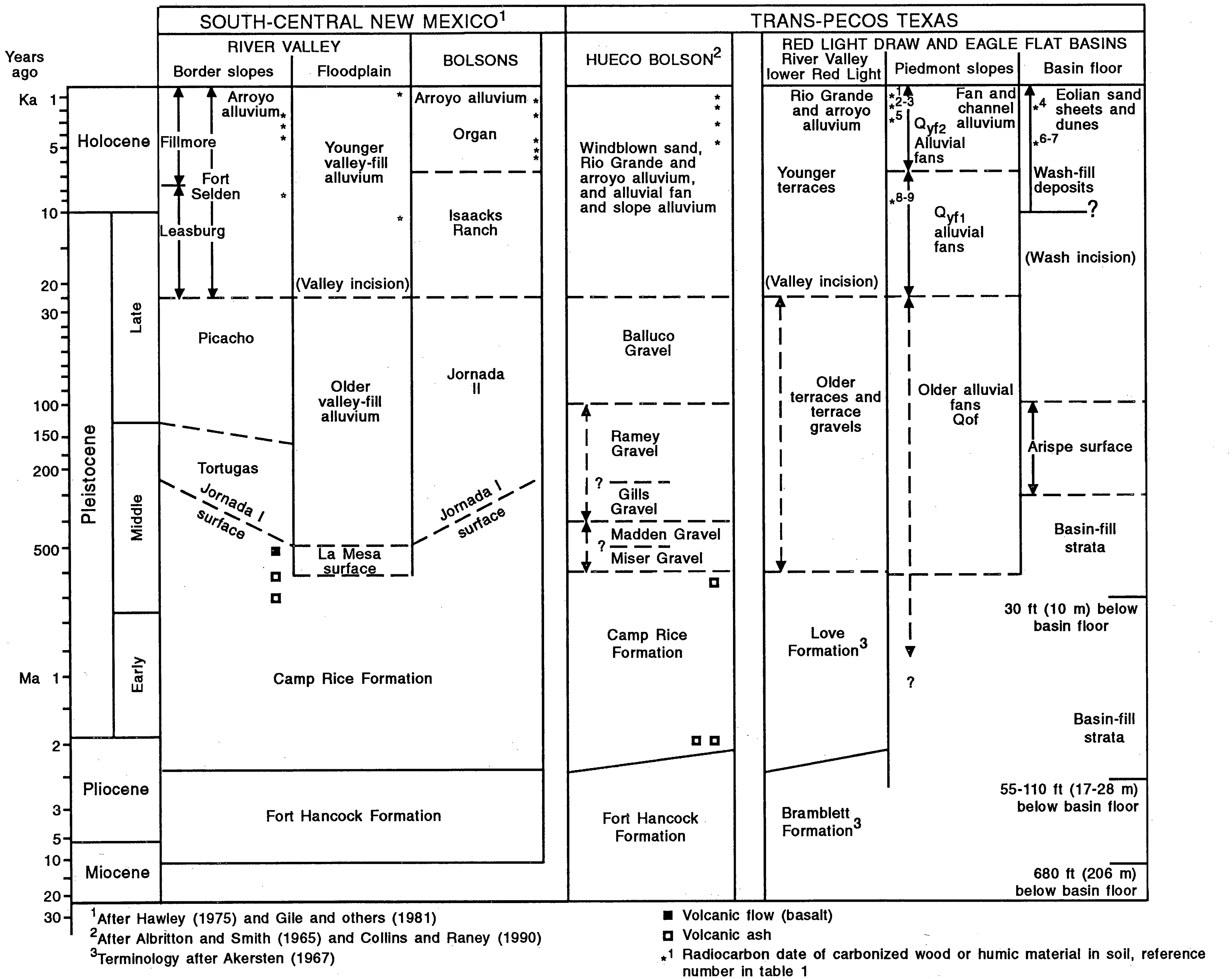

Figure 7. Stratigraphic correlation chart illustrating the Late Pliocene to Recent units in southern New Mexico and West Texas. Adapted from Gile and others (1981) and Collins and Raney (1990).

drainages, along with sandstones, shales, and mudstones deposited by the throughflowing Rio Grande (Gustavson, 1991) (fig. 7). In the Hueco Basin, the Camp Rice Formation rests everywhere on an unconformity (Albritton and Smith, 1965). In lower Red Light Basin, Akersten (1967) reports that at least at some locations, the Bramblett and Love Formations are conformable. The earliest Camp Rice sediments are believed to have been deposited prior to 2.1 m.y.a., and deposition ceased between 700,000 and 600,000 yr ago (Albritton and Smith, 1965; Gile and others, 1981; Gustavson, 1991). The Camp Rice and Love Formation strata are sandier, lighter colored, and more laterally varied than the underlying Bramblett and Fort Hancock strata. The climate in the Hueco Basin during Camp Rice deposition is inferred to have been semiarid to arid, hosting diverse depositional environments (Gustavson, 1991). The Rio Grande was a braided river, fed by smaller, ephemeral braided streams flowing from the Quitman Mountains and Diablo Plateau. The streams were flanked by eolian dunes and loess blankets that stored sand and silt to the east-northeast of the Rio Grande. Small saline playa lakes flanked the Rio Grande floodplain.

Upper Red Light Draw and Eagle Flat

The Love and Bramblett Formations are exposed only in the southeastern one-third of Red Light Draw. Little is known about the northwestern two-thirds of the basin due to lack of exposure or cored wells. One well in the middle of Red Light Draw penetrated 3,000 ft (1,000 m) of basin fill strata before encountering Oligocene volcanics (Gates and White, 1976).

Similarly, older basin-filling strata are not exposed in the Eagle Flat Basin. However, cores from borings in the Faskin Ranch provide much more data about the nature of the basin-filling strata (Jackson and others, 1993). Cores taken from Faskin Ranch have penetrated sediments as old as 12 Ma at a depth of 715 ft (218 m). I infer that the upper Red Light Basin contains Neogene fill similar to that of the Eagle Flat Basin because of its proximity, its current similarity in morphology, and the similarity in source terrain.

The Eagle Flat basin-filling strata do not exhibit the changes in lithology and appearance that characterize the Camp Rice and Love Formations. Likewise, there is no evidence of an erosion surface at the 2.0 to 2.5 m.y.a. interval that separates the Fort Hancock from the Camp Rice (described by Gustavson, 1991) and the Bramblett from the Love Formation. The 2.0 to 2.5 m.y.a. timespan lies at a depth of 50 to 100 ft (30 to 60 m) below the present-day Eagle Flat Basin floor, within an interval that apparently was undergoing slow episodic deposition.

Furthermore, the Eagle Flat Basin sediments are like neither Camp Rice nor Fort Hancock sediments. Eagle Flat sediments are a uniform brown, instead of the variegated colors of the Hueco Basin and Red Light Draw sediments. The Eagle Flat basin-fill mudstones are much more silt and sand rich than the Fort Hancock mudstones (compare Jackson and others, 1993; and Gustavson, 1991), and they contain much less sand and gravel than does the Camp Rice (Strain, 1966; Gustavson, 1991).

As is described below, deposition was influenced by the geomorphology of the basins. Only local deposition occurred in the upland areas forming the rims of the basins. Deposition was concentrated in the two other regimes, the piedmont slopes and the basin floor. Gravels, with intervening shales and sandstones, were deposited in alluvial fans and bajadas on the piedmont slopes. The sources of the gravels were local catchments, and the gravels are usually poorly sorted and monomictic. On the basin floor, larger axial drainages built extensive alluvial flats, consisting of channels surrounded by muds deposited both by floods in the axial drainage and floods extending from the surrounding alluvial fans.

If the Pliocene–Pleistocene northwest Eagle Flat Basin resembled the present basin, then the axial drainages terminated in a relatively small ephemeral lake. This interpretation is supported by the lack of identifiable lacustrine sediments recovered in cores from the Faskin Ranch area. However, it should be noted that the cores cover a very small part of the area of the present-day basin. Unlike the Hueco Basin and lower Red Light Draw, which are topographically lower than the Eagle Flat Basins, no saline playa facies are present in cores of Eagle Flat Basin sediments. Because saline playas only form where the ground-water table is near the surface, they will form only in the topographically lowest basins, the ground-water discharge areas. In the far Trans-Pecos region, these conditions are satisfied in the Salt Basin, into which subsurface waters of a large region are focused, and in the Hueco and Red Light Basins, along small depressions adjacent to the Rio Grande floodplain. The highest elevation of exposed basin-floor playa facies in the Fort Hancock Formation in the Hueco Basin lie at a 4,050 ft (1,234 m) elevation (Gustavson, 1991). At the end of Fort Hancock deposition, the floor of Eagle Flat Basin, as determined by paleomagnetic analysis (Jackson and others, 1993), was at approximately 4,200 ft (1,280 m). Although the geometry of the Pliocene northwest Eagle Flat Basin is uncertain, it is probable that the basin floor was at a higher elevation than the floor of the Hueco and Red Light Basins and therefore had no saline playas.

Today, northwest Eagle Flat Basin is topographically enclosed southeast of Grayton Lake by converging alluvial fans. There is no evidence as to whether northwest Eagle Flat Basin has been closed throughout its history or has been episodically open so that streams flowed into southeast Eagle Flat Basin. Regardless of whether it was open or closed, the deposits maintained a remarkable homogeneity throughout the Pliocene and Pleistocene.

Eagle Flat has filled in the manner of a shallow bowl being filled with liquid. As the basin floor aggraded, it covered a larger area, burying part of the former rim of the bowl. The basin floor has expanded because the upland areas in arid regions are the site of only local deposition. Alluvium eroded from the uplands is deposited on the piedmont slopes and on the basin floor. Therefore, as the basin floor and piedmont aggrade, they bury the flanks of the surrounding upland areas. This burial of upland areas has continued within the Mexican Highlands physiographic province, so that today only 20 percent of the land surface is mountain and upland areas (Hawley, 1969). In much of Eagle Flat Basin, the basin floor has also aggraded more rapidly than the piedmont and has gradually expanded to cover areas of piedmont and upland deposition.

The oldest Eagle Flat basin-fill sediments, as dated by paleomagnetic analysis, were encountered in the northernmost well on Faskin Ranch (Jackson and others, 1993). These sediments were deposited 12.3 m.y.a., when most of northern Faskin Ranch was an exposed upland hillslope of Cretaceous limestone and sandstone. The basin center lay to the north or northwest (Jackson and others, 1993). The northernmost part of the ranch was an alluvial fan that sloped to the north.

By 4.8 m.y.a., the piedmont slope had covered most of the upland area across most of the proposed repository site. Basin-floor sediments were being deposited beneath the northern part of Faskin Ranch. The deep basin floor had aggraded by deposition of about 500 ft (150 m) of sediment, to 180 to 210 ft (55 to 64 m) below the present-day land surface. By 2.6 m.y.a., the north-sloping piedmont was restricted to the area south of the Southern Pacific Railroad tracks and the basin-fill had aggraded to a level 55 to 110 ft (17 to 34 m) below the present-day surface. Alluvial fan sedimentation began beneath what is now the floor of Grayton Lake about 3 m.y.a.

The present-day landscape of the Eagle Flat Basins was beginning to take shape by 780,000 yr ago, at the end of the Early Pleistocene. The basin floor beneath the proposed repository site had aggraded to within 20 to 30 ft (7 to 10 m) of the present-day surface. Large-scale alluvial fan deposition had probably ceased, and stable geomorphic surfaces had formed in the larger alluvial fans draining the Eagle and Quitman Mountains. The evolution of this landscape during the Middle and Late Pleistocene is the subject of this report.

Climate

Present Climate

The climate at Sierra Blanca is subtropical-arid (Larkin and Bomar, 1983). The average rainfall at Sierra Blanca from 1961 to 1990 was 12 inches (31 cm) (Owenby and Ezell, 1992). The average annual temperature is 62°F (17°C), the average summer high is 92°F (33°C), and the average winter low is 28°F (–2°C) (Owenby and Ezell, 1992). Evaporation exceeds average precipitation throughout the year, with winter evaporation rates averaging 3.25 inches per month (8.3 cm) and summer rates averaging 10.25 inches (26 cm) per month.

Rainfall is concentrated between July and October and largely occurs as convective thunderstorms. For this reason, precipitation probably increases with elevation, as has been demonstrated elsewhere in this region (Gile and others, 1981). On the uppermost alluvial fans and protected canyons of the Eagle and Quitman Mountains, at just over 5,000 ft (1,651 m) elevation, soils are darker and appear to have a higher organic content. The change in soils coincides with an increase in vegetation and the appearance of numerous juniper trees in protected locations. Similar changes in soil and vegetation have been used to infer a vertical change from arid to semiarid climates in this region (Gile and others, 1981).

Climatic History

There is general agreement about the Late Pleistocene climatic history of the desert Southwest, but there are discrepancies in the detailed dates presented due to uncertainties in dating and stratigraphy and to local and regional paleoclimatic differences. The climate in southern New Mexico and Trans-Pecos Texas has been relatively arid since at least the late Pliocene. Bedded gypsum in ephemeral lake and saline playa deposits in both the Fort Hancock and Camp Rice Formations indicate an arid to semiarid climate during deposition of these units (Gustavson, 1991). Alternatively, Axelrod and Bailey (1976) and Wells and others (1982) reported that desert pollen was absent from the southern Basin and Range province and inferred that an arid climate did not develop until 8,000 to 10,000 yr ago. Gustavson (1991) reconciles these observations with an interpretation of a semiarid (dry grassland or woodland, but not desert) to subhumid climate.

During the early Pleistocene, the climate of the southwestern United States was cooler and more moist than that of the present (Hall, 1985). The Late Wisconsinan glacial period from 25,000 to 14,000 yr B.P. was a time of moist and cooler climate throughout the southwestern

United States (Wells and others, 1982; Hall, 1985). At the end of the Wisconsinan, 14,000 to 10,000 yr BP, the climate became warmer and drier, although still cooler and more moist than that of the present, and there was a gradual transition from glacial to post-glacial vegetation (Wells and others, 1982; Hall, 1985). Dry woodlands of juniper lasted in the deserts of the southwest until 8,000 to 10,000 yr ago (Axelrod and Bailey, 1976; Van Devender and Spaulding, 1979; Wells and others, 1982). Juniper woodlands persisted in the Hueco Basin, immediately to the west of Eagle Flat, until 8,000 to 4,000 yr ago, when they were replaced by grasses (Horowitz and others, 1981). Because the Eagle Flat and Red Light Draw Basins lie at generally higher elevations than floor of the Hueco Basin, and therefore would have had higher rainfall, woodlands should have persisted as long as in the Hueco Basin. To the north, wetter climatic regimes with woodlands persisted even longer, to about 5,000 yr B.P. in the San Augustin Plains of New Mexico (Markgraf and others, 1984), and to about 5,800 yr B.P. in Chaco Canyon (Hall, 1977).

A long-lasting hot and dry period is recorded in much of the Southwest from approximately 8,000 to 5,000 yr ago (Antevs, 1948; Hall, 1985). After the drying that occurred from 8,000 to 5,000 yr ago, desert shrubs and grasslands alternated as the climate alternated between wetter and drier periods (Freeman, 1972; Horowitz and others, 1981; Hall, 1985). The climate was drier from 8,000 to about 4,000 to 3,000 yr ago, and from 2,200 yr ago to the present (Freeman, 1972; Van Devender and Spaulding, 1979; Horowitz and others, 1981; Hall, 1985). The climate was wetter from about 2,500 to 2,200 yr ago (Bryant and Holloway, 1985). Within the current arid climatic regime, short periods of slightly more moist conditions have prevailed. Horowitz and others (1981) describe a wetter period from 1,000 to 500 yr ago and then a brief moist period from 1,610 to 1,660 yr ago.

PREVIOUS WORK

There has been no previous detailed study of the Quaternary strata in the Eagle Flat Study Area. However, several authors have mapped the Quaternary strata as part of general studies and produced somewhat conflicting maps of parts of the Eagle Flat Study Area. Underwood's (1963) study of the Eagle Mountains included the southern part of the Eagle Flat Study Area. Most of the basin floor and piedmont areas of the Eagle Flat and Red Light Basins were mapped as Quaternary alluvium. However, some of the oldest and some of the youngest alluvial fan deposits, including the young fan deposits in the Faskin Ranch area (see below), were mapped separately as an older terrace gravel deposit.

Albritton and Smith (1965) mapped the Quaternary strata in the Hueco Basin and adjoining areas in the Red Light Draw and northwest Eagle Flat Basin, near the Blanca Peaks. They divided the Quaternary strata in the Hueco Basin into five gravel units based on the correlation of terraces adjoining the Rio Grande. In the Eagle Flat Study Area, Albritton and Smith (1965) mapped an undifferentiated older colluvium along the flanks of Sierra Blanca. Elsewhere in the study area, the Quaternary strata were mapped as either undifferentiated alluvium and colluvium or as alluvium. The only exceptions are large areas mapped as the Balluca Gravel near the Blanca Peaks and in patches on alluvial fans near the town of Sierra Blanca and nearby Bluff and Yucca Mesas and Devil Ridge. The Balluca Gravel has since been correlated with the 25,000- to 100,000-yr-old Picacho gravels and 25,000- to 500,000-yr-old Jornada II strata near Las Cruces, New Mexico (Gile and others, 1981). Albritton and Smith (1965) also described large areas of windblown sand in the Hueco Basin and adjoining Diablo Plateau. They described two episodes of dune formation, the present active dunes, and a set of older, vegetated deposits of unknown ages.

King (1965) included part of the Eagle Flat Study Area, extending east and north from Grayton Lake playa, in his study of the Sierra Diablo region (see figs. 2 and 4 for location). Quaternary deposits were mapped by depositional environment and morphology rather than stratigraphy. All the Quaternary strata were mapped as undifferentiated Quaternary alluvium. Grayton Lake was mistakenly classified as an alkali flat. Small areas of older pediment gravels were identified along the southern rim of the Diablo Plateau and in the Bean and Millican Hills. These are included with the older fan deposits in this report. King (1965) noted the difficulty of subdividing Quaternary strata in the Eagle Flat Basin due to its slow sedimentation rates and tectonic stability.

Jones and Reaser (1970) studied the southwestern corner of the Eagle Flat Study Area, in the area southwest of Red Light Draw (fig. 2). They separated the wash fill deposits in Red Light Draw, and some of the active channels and fan lobes (see Q_W, Fa, and Ca below). Some areas mapped as younger fans and other areas mapped as older fans in this report were mapped tentatively by Jones and Reaser (1970) as older terrace gravels along the piedmont southwest of Red Light Draw. They mapped the rest of the piedmont areas as Quaternary and Tertiary bolson fill and grouped these deposits with the Camp Rice, Fort Hancock, Love, and Bramblett Formations.

CONCEPTS AND TERMINOLOGY

The following section describes the conceptual basis for the conclusions reached in this investigation and describes the more important terms. I acknowledge a debt to Gile and Grossman (1979) and Gile and others (1981), who developed many of the concepts and established the framework I have followed in mapping the surficial deposits in the Eagle Flat Study Area. For a thorough explanation of these concepts, read Gile and others (1981).

Landforms

Landforms are recognizable forms or features of the Earth's surface that have characteristic shapes and are produced by natural processes (Bates and Jackson, 1980). The major landforms in the Eagle Flat Study Area are the fault-block mountains and basins formed by tectonic and volcanic processes. These features have controlled the geometry of the resulting deposition and erosion since the Miocene, including the filling of the Hueco, Red Light, Mesilla, and Eagle Flat Basins. The next largest feature in the region is the incised valley of the Rio Grande, formed by over 2 Ma of erosion by the river. The Rio Grande valley is superimposed on the tectonic and older depositional features in the region and flows through a valley incised through the southern Quitman Mountains about 15 mi (24 km) southwest of the Eagle Flat Study Area. Smaller landforms in the Eagle Flat Study Area date from the latest Tertiary and the Pleistocene. They formed through erosion and deposition by running water and wind action. The most common landforms in the study area are alluvial fans, bajadas, eolian sand sheets and dunes, alluvial flats, axial drainageways, playas, erosional valleys (washes), gullies, and upland areas. The landforms characteristically occupy well-defined positions within the landscape (fig. 8). For example, playa lakes are restricted to the basin floors of the closed northwestern Eagle Flat Basin. Figure 8 illustrates the relationships between the various landforms in the study area.

Geomorphic Surfaces and Morphostratigraphic Units

Ruhe (1962, 1964) and Gile and Grossman (1979) pioneered the concepts of geomorphic surfaces and morphostratigraphic units within the desert Southwest. *Geomorphic surfaces* are mappable landforms or groups of landforms that formed at or near the same time and are related by their similar age and soil development (Gile and others, 1981). Episodes of erosion and deposition, which modify the landscape, create new erosional and depositional landforms. After its development, the landscape undergoes a period of stability, during which soils develop in the material underlying the geomorphic surface. Note that while depositional and erosional episodes may last for a long period of time, *it is the period of stability and soil formation following deposition and erosion that defines the geomorphic surface.*

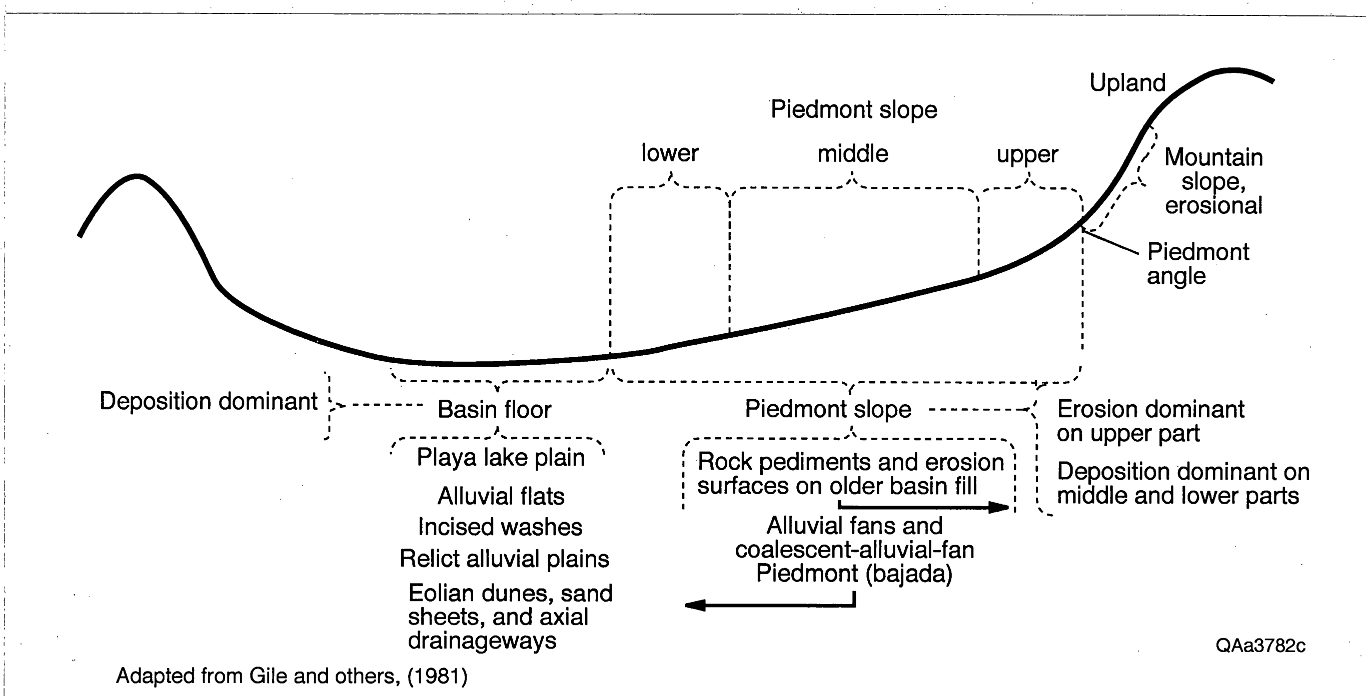

Figure 8. Diagrammatic profile across a Basin and Range basin illustrating the relative locations of the common landforms in the study area (adapted from Gile and others, their figure 4).

Morphostratigraphic units are genetically related sediments laid down during the depositional episode that creates a geomorphic surface (Gile and others, 1981). Therefore, they are related by their landform morphology, their depositional environment, and their similar age of formation. Morphostratigraphic units may be laid down over long time periods and may represent several periods of erosion and deposition, as long as they are capped by the same correlatable geomorphic surface. Again, *it is the period of stability and soil formation following deposition of a recognizable landform* that defines a morphostratigraphic unit.

Landscape Stability

Geomorphic surfaces may be further classified by the processes that have affected them since deposition. *Stable surfaces* are areas in which no recognizable active drainageways or areas of deposition are evident (Ruhe, 1965). This concept can be expanded to include areas of eolian deflation or deposition. In contrast, *dynamic surfaces* are being actively modified by wind or water, and surficial materials are being moved over a time scale of several decades or less. Examples of dynamic surfaces in the Eagle Flat Study Area are Grayton Lake playa, the eolian sand deposits, and the active channels in the arroyos on the alluvial fans.

Geomorphic surfaces and their associated soils may be *buried* by younger deposits. Having been buried, they may be *exhumed* and reexposed at the surface. Buried surfaces are common in the Eagle Flat Study Area where recent eolian deposits and Holocene and Late Pleistocene alluvial fans have buried older surfaces and soils. In contrast, *relict* landforms are features that formed as part of a preexisting landscape and have remained relatively unmodified by erosion or burial, to persist as part of the present-day landscape. A geomorphic surface and its associated soils are relict when they display the effects of geomorphic or soil-forming processes that are no longer active on the surface.

GEOMORPHOLOGY OF NORTHERN FASKIN RANCH

Methods

The proposed repository site is located on a portion of the basin floor of northwest Eagle Flat Basin. The following section describes the landforms evident on the basin floor and piedmont slopes near the proposed repository site. Geomorphic elements and surficial deposits of northern Faskin Ranch, in and around the proposed repository footprint, were mapped from aerial photographs and checked by field observation. Shape features and slopes for each geomorphic element in the immediate area were quantified using topographic maps with a 2-ft (0.6 m) contour interval. Shapes of features farther away from the proposed site were quantified using 1:24,000-scale USGS topographic quadrangle maps with 10- and 20-ft (3.05 and 6.1 m) contour intervals.

Landforms of the Basin Floor

Figure 9 illustrates the landforms on northern Faskin Ranch, shown in relationship to the proposed repository site. The northern Faskin Ranch area can generally be divided into three geomorphic regimes. (1) The wide and flat floored *washes* of Blanca Draw and its tributaries form a dendritic network trending east, southeast, and south through the area (fig. 9). (2) The washes terminate in the small playa floor of Grayton Lake. (3) Between the washes are *interfluvial flats*, a dissected, low-relief, generally south-southeast sloping surface.

Grayton Lake Playa

Blanca Draw terminates in Grayton Lake approximately 2 mi (3.2 km) from the proposed repository site. It is an approximately 1 mi^2 (2.6 km^2) playa that floods ephemerally following exceptional local precipitation (figs. 3 and 6). The lake flooded during August 1993. When not flooded, the playa is usually sparsely vegetated with ephemeral herbs. A dirt stock tank in the

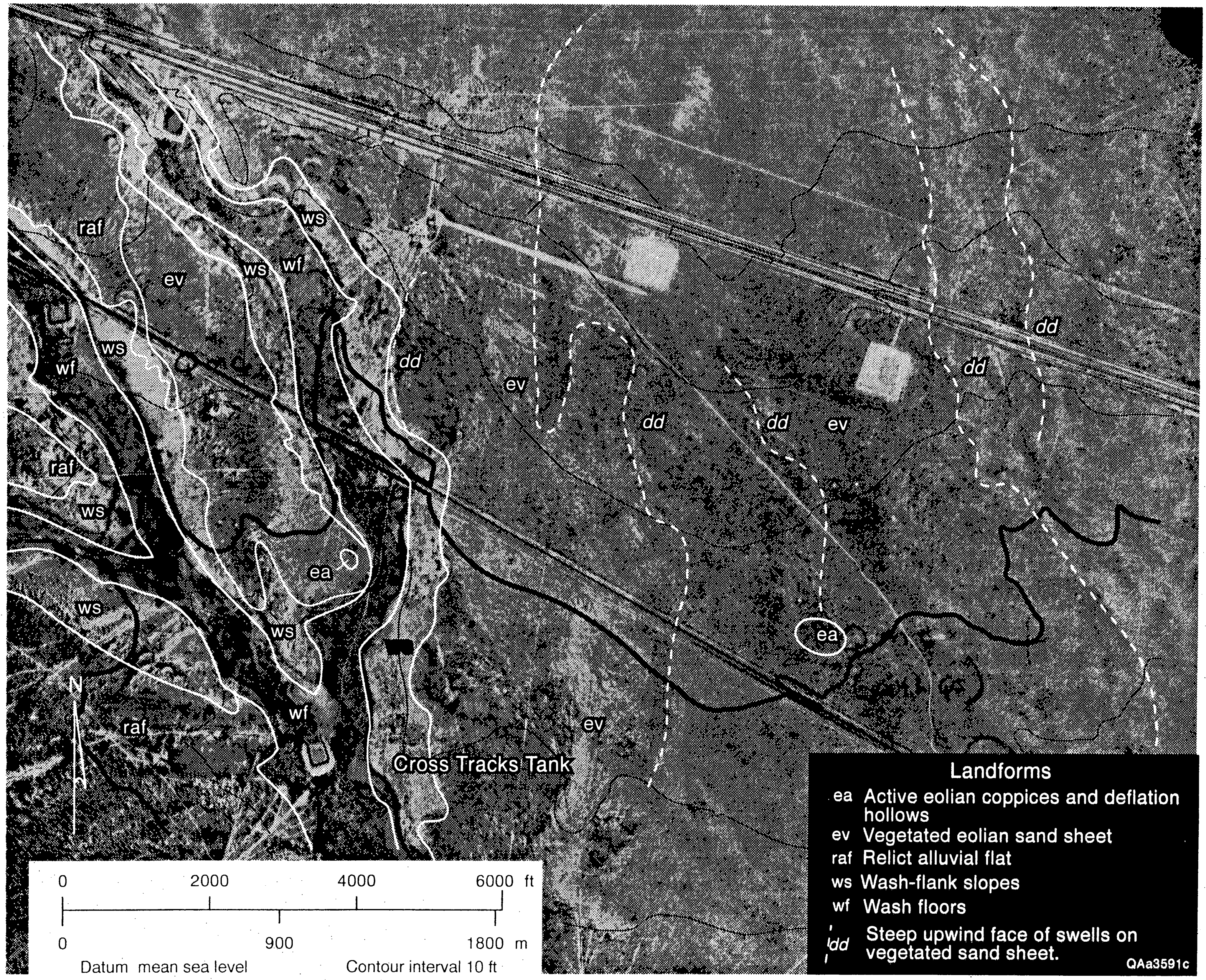

Figure 9. Aerial photograph of the area of the proposed repository site in northern Faskin Ranch, with the landforms of the area outlined. Location shown in figure 4.

center of the playa floor is currently kept filled by a well drilled nearby. To the east, the playa merges with the wash floor of Blanca Draw. The floor of the playa is a silt and clay flat exhibiting mud cracks and a well-developed microgilgai topography resulting from soil shrink and swell.

Washes

Washes contain two types of landforms, *wash floors* in the center of the washes and *wash-flank slopes* that separate the washes from the adjacent interfluvial flats (figs. 9 and 10). Figure 10 is a profile across one wash showing the relationship between wash floor and wash-flank slope. Wash floors in the north Faskin Ranch area are 200 to 1,650 ft (60 to 500 m) wide and average 950 ft (290 m) wide (fig. 9). Wash floors are 7 to 35 ft (2.1 to 10 m) below adjacent interfluvial flats. Wash floors have gradients of 0.0053 (28 ft/mi) in the northwestern part of the north Faskin Ranch area to 0.0019 (10 ft/mi) near Coffee tank. Wash floors are vegetated and rarely exhibit channels or other erosional or depositional features resulting from fluvial or alluvial activity. One wash floor northwest of Cross Tracks tank is gullied for a short distance, emphasizing the lack of erosional or depositional forms in the rest of the Blanca Draw drainage.

It is difficult to classify the wash floors as either stable or dynamically aggrading. The lack of depositional or erosional features would suggest a stable surface, as would 2,350-yr-old radiocarbon ages from wash-fill strata within 4 ft (1.3 m) of the present-day wash floor (sample RCFR1 in table 1; fig. 3). Alternatively, the topographically low position and active small-scale erosion of many of the wash-flank slopes suggest that sediment is being episodically deposited on the wash floors, albeit slowly.

Wash floors can be subdivided into three areas defined by distinct vegetation types: (1) mesquite bosques, with scattered to dense mesquite thickets interspersed with grasses and other shrubs; (2) grass flats with dense patches of grass, most commonly *Tobosa* grass; and (3) grass flats covered with more scattered grasses. Mesquite bosques are wider and more common

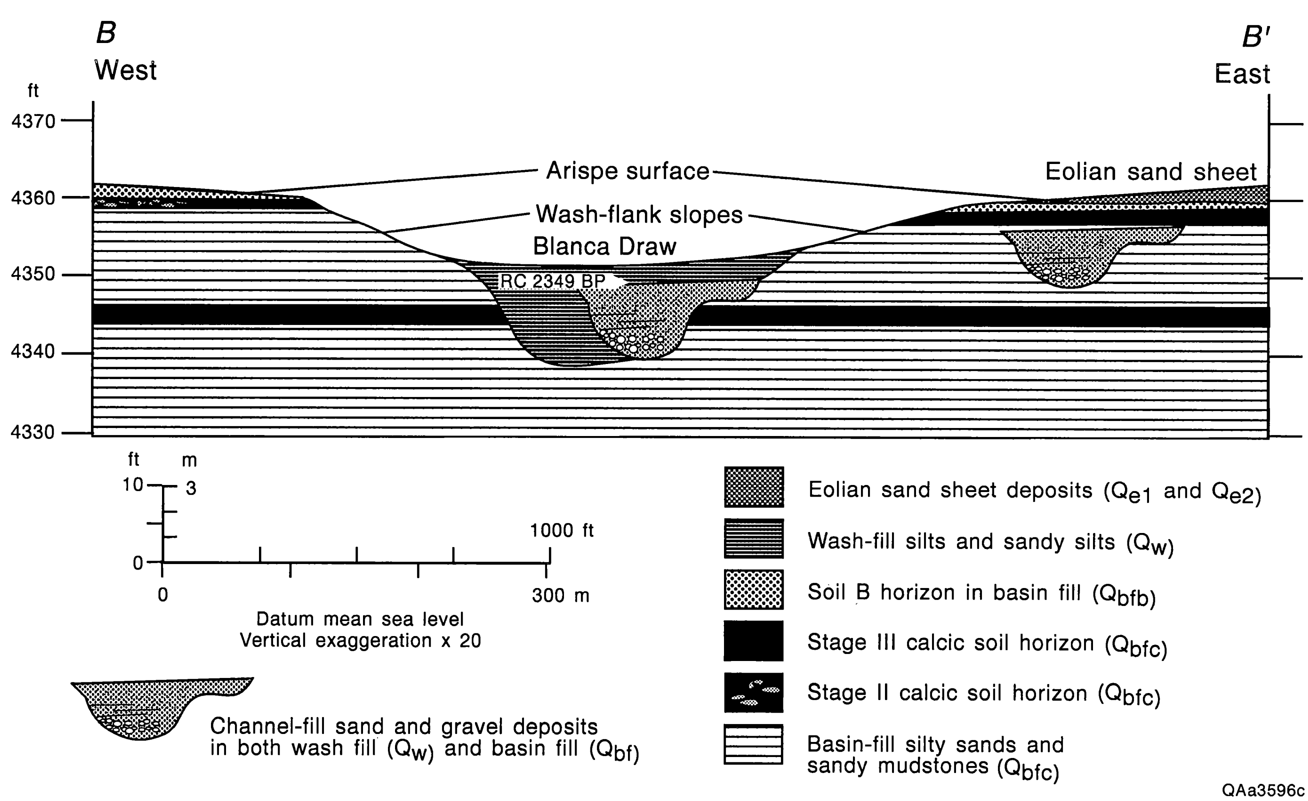

Figure 10. Profile B–B′ across Blanca Draw, showing wash floor and wash-flank slope areas, and the stratigraphic relations of the surficial deposits in the washes and adjacent interfluvial flats. The profile is located in figure 3 and plate 1. RC indicates projected location of radiocarbon sample RCFR1 (sample 4 in table 1). Sample is located in figure 3.

in the lower reaches of Blanca Draw, in the southeastern part of the area. The thickly vegetated grass flats form isolated patches along the margins of the wash floors. Thickly vegetated grass flats are also common, farther from the proposed repository site in lower Blanca Draw, near Grayton Lake, where the wash floor is wide and has a low gradient.

Wash flank slopes are defined by their relatively steep slopes down from the interfluvial flats into the wash floors (fig. 10). The slopes are well defined on contour maps and in many places are visible on aerial photographs (fig. 9). Wash-flank slopes average 790 ft (240 m) wide and have gradients averaging 0.013 (99 ft/mi). Vegetation is generally similar to the interfluvial flats, but less dense. Locally the slopes are dynamically eroding. The characteristic erosional features are "scarplets." Scarplets consist of crescentic erosional scarps, 0.3 to 1 ft (0.1 to 0.3 m) high that open down slope and enclose a poorly vegetated or nonvegetated fan-shaped area in which erosional features such as rills are evident. Sediment is evidently sapped from the scarp face, washed across the barren, fan-shaped area, and deposited in grassy areas at the toes of the scarplets. Sediment derived from the scarplets is being deposited within the adjacent parts of the wash floors.

Interfluvial Flats

Interfluvial flats contain most of the area of northern Faskin Ranch (fig. 9). The flats are low-relief, grass, mesquite, and yucca savannas that slope gently south across the northern part of the ranch. The flats are stable, vegetated landforms that do not exhibit channels or erosional or depositional features resulting from fluvial or alluvial activity. The overall southerly gradient on the flats is 0.0043 (23 ft/mi). Three landforms can be recognized on interfluvial flats, *relict alluvial flats*, *large-scale forms of the vegetated eolian sand sheet*, and *coppices and associated hollows* in active eolian areas.

Relict alluvial flats are common west of the north–south-trending tributary of Blanca Draw but are rare east of Blanca Draw, near the proposed repository site (fig. 9). Relict alluvial flats are distinguished from the eolian flats by their smooth and low-relief topography and silty, well-developed soils. The surfaces are smoother than the eolian flats, with only very wide, subtle swales that slope southeast toward the Blanca Draw tributaries. No depositional features are evident. The only erosional features are very scattered and poorly developed scarplets that occur as patches scattered across most of the exposed flats. Relict alluvial flats are vegetated with scattered short bunch grasses and small *Tobosa* grass patches. Shrubs are much rarer, and the overall vegetation is less dense than that of the adjacent eolian flats.

The vegetated eolian sand sheet is characterized by a very irregular microtopography consisting of 4- to 8-inch (10 to 20 cm) hummocks and swales. This microtopography is superimposed onto larger scale eolian bedforms formed in a sand-sheet setting. High-resolution topographic profiles, acquired for the seismic survey, reveal a gently rolling topography with three north–south-elongate swells, 3 to 6 ft (1 to 2 m) high, and intervening swales (fig. 11). These are visible on aerial photographs and can be traced on the 2-ft (0.6 m) contour map of the proposed repository site (*dd* on fig. 9). The swells are oriented generally transverse to the predominant present-day west-southwest effective wind direction and have steep upwind slopes, (0.0042 to 0.0057; 22 to 30 ft/mi) and gentle downwind slopes, (0.0011 to 0.0052; 6 to 27 ft/mi). The sand sheets are composed of loose, well-sorted, fine-grained sand and are densely vegetated compared to the relict alluvial flats and the active eolian areas. Black gramma and other grasses are dense and common, along with soaptree yucca and mesquite.

Active eolian landforms make up a very small proportion of the interfluvial flat surface and consist of small, topographically high areas of bare sand that include small, poorly defined coppice dunes and associated swales. Active eolian landforms are found only within the vegetated sand sheet. They are characteristically vegetated by condelia shrubs and soaptree yucca and have patches of bare mobile sand between the shrubs. The coppice mounds and swales are usually only a few meters wide, and this local topography is much greater than that found on the vegetated sand sheets. One area of active dunes is found on the southeastern

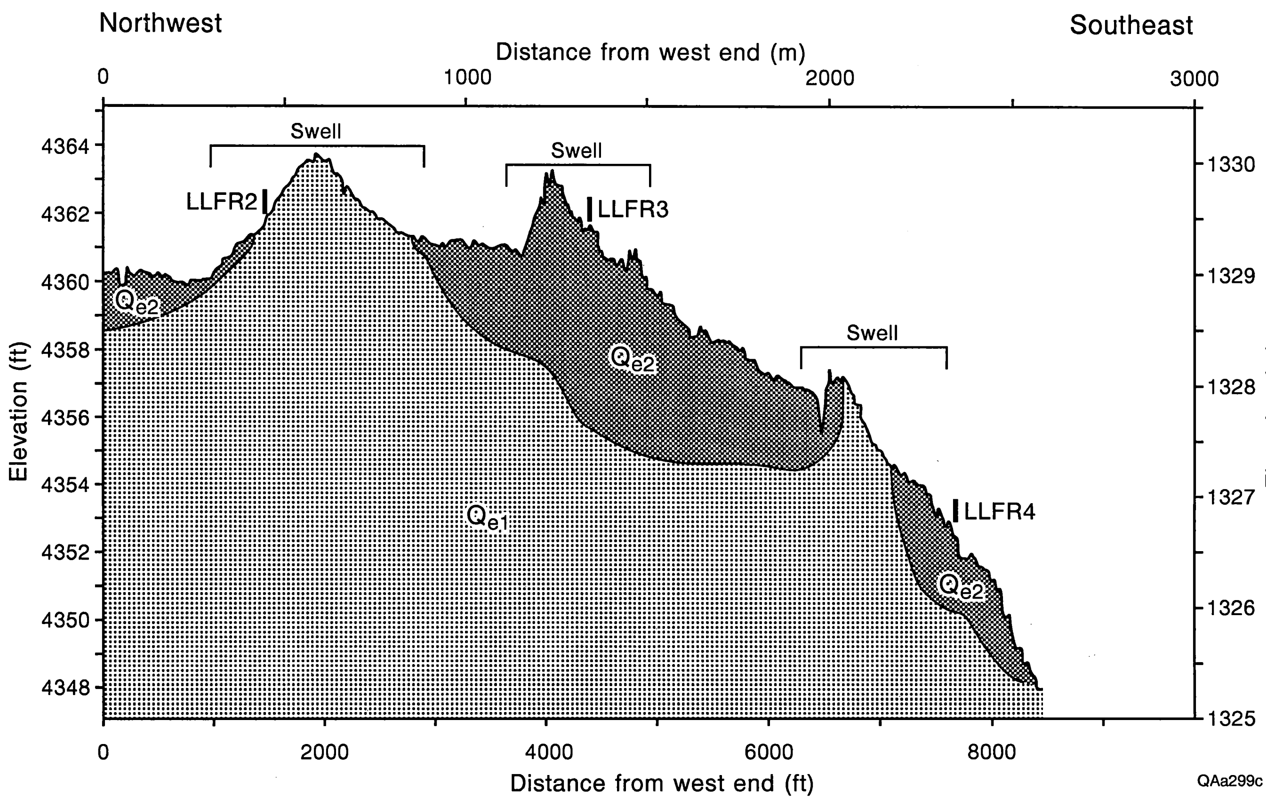

Figure 11. Topographic profile along the northwest-to-southeast seismic line across the proposed repository footprint showing the asymmetrical swells in the eolian sand sheet. The location of the seismic line is shown in plates 1 and 3. QE_1 is the older eolian sand, QE_2 is the younger eolian sand. Underlying strata are not shown.

part of the proposed repository site (fig. 9). Another occurs between the branches of Blanca Draw, southwest of the proposed repository site.

Landforms of the Piedmont Slopes

The piedmont (plate 2) slopes form regularly sloping areas that can be separated from the basin floor and upland areas by marked changes in slope angle. Below the piedmont slopes, the basin floor, north of Blanca Draw, slopes gently to the south and southwest, toward Blanca Draw and Grayton Lake, except along the margins, where it slopes gently away from the piedmont and uplands. The piedmont slopes away from adjacent upland areas. They usually slope more steeply in the proximal piedmont areas near the uplands, and slope more gently in the distal piedmont areas near the basin floor (fig. 8). The nature of the piedmont is controlled by the character of the adjacent upland areas. The upland areas can be divided into (1) *low-relief upland areas*, (2) *high-relief uplands without canyons*, (3) *high-relief uplands with small canyons*, and (4) *high-relief uplands with large canyons*. The corresponding piedmonts are (1) *no piedmont*, (2) *small bajadas*, (3) *small alluvial fans*, and (4) *large alluvial fans*. The small and large alluvial fans are end-members of a spectrum of fans. Most fans contain some features of both large and small fans. Between alluvial fans lie poorly defined *interfan valleys*.

The vegetation in the different piedmont areas is generally similar, changing with local topography, rather than the overall landform. Open areas are vegetated with creosote, with scattered mesquite and broad-leaf yucca. Commonly, there is a band of mesquite at the toe of the piedmont, where alluvial fan gravels merge into basin-fill muds and sands. This contact probably reflects an increase in moisture coincident with the slope and sediment transition. Protected areas and gullies on dissected alluvial fans are more thickly vegetated by mesquite, cat-claw acacia, sumac, and other shrubs. In the higher elevation alluvial fan gullies in the Eagle and Quitman Mountains, juniper and other trees can be found.

Areas without Piedmonts

In low-relief upland areas, sediment production is slow enough that piedmonts have not formed. Upland slopes have been buried by the more rapidly aggrading basin floor or piedmont slopes from adjacent upland areas. In the Faskin Ranch area, low-relief upland areas are found along the southern edge of Blanca Draw, extending west from Grayton Lake and south of Coffee tank.

Small Bajadas

High-relief uplands without canyons are characterized by small *bajadas*, or alluvial aprons without distinct fans. Because there are no well-defined point sources for sediment, alluvial fans have not formed. Sediment production rates are slow enough that depositional features such as active channels are rare. No areas of active deposition were mapped on the bajadas adjacent to the uplands without canyons in the Faskin Ranch area. Bajadas of this type are found around Sand Mountain and along most of Front Ridge (figs. 3 and 12 [in pocket). The bajada around Sand Mountain has well-defined boundaries (fig. 13). A profile across this bajada displays the smooth slope and sharp change in slope angle between the basin floor and the bajada (fig. 14). The small bajadas are covered with well-developed pavements of rounded cobbles and pebbles. Rills and other erosional features are rare.

Alluvial Fans

Alluvial fans are highly variable in size, ranging from small gully-mouth fans, 1 acre (4,046 m^2) in area and less than 30 ft (10 m) thick, to the large fans along the front of the Eagle and Quitman Mountains that cover nearly 30 mi^2 (78 km^2) and probably compose a substantial part of the underlying basin fill. Along the northeastern flank of the Quitman Mountains, in

Figure 13. Aerial photograph of Sand Mountain area with topographic contours and locations of selected landforms and erosional features. The sites of erosional measurements of roads (R2 through R8) and fences (F1, F2a, F2b) are numbered as they are in table 5. F–F′ shows the location of figure 14. Location shown in figure 4.

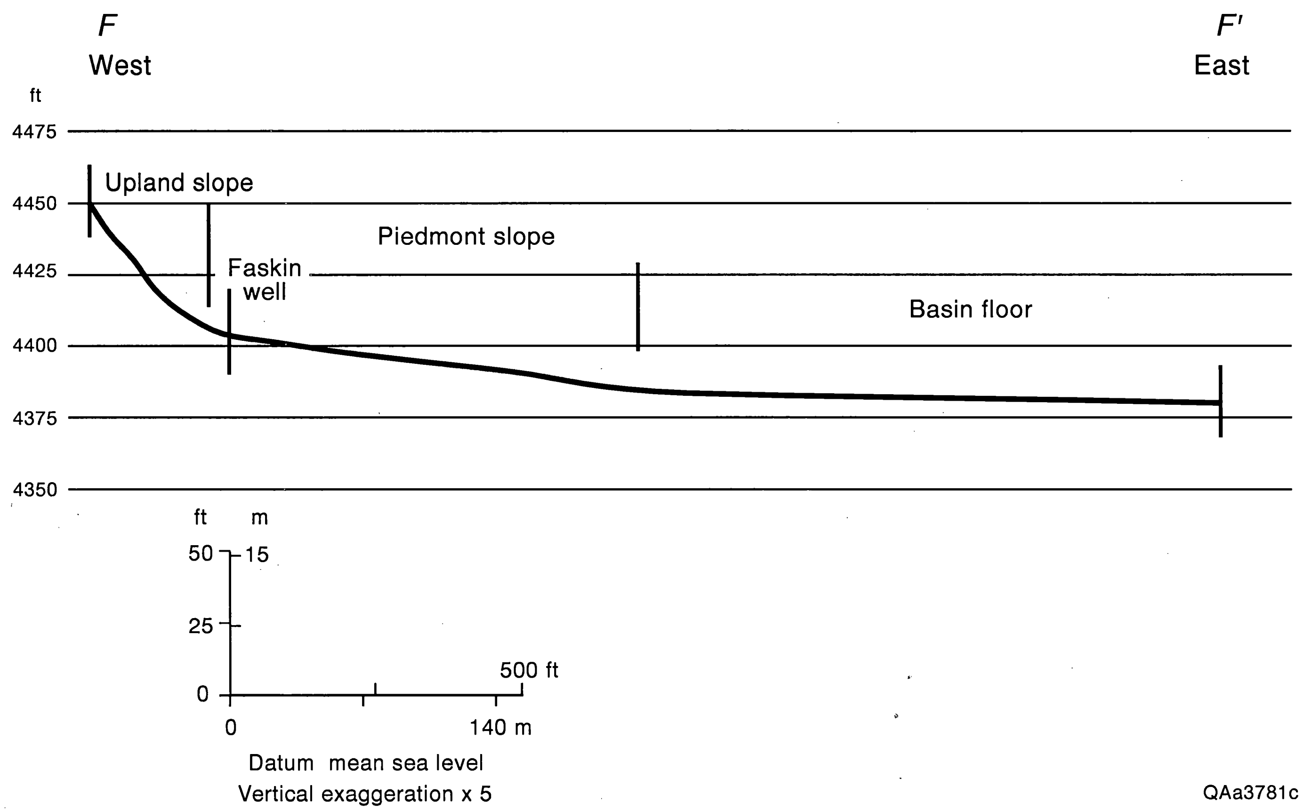

Figure 14. Topographic profile F–F′ across the bajada east of Sand Mountain and the adjacent basin floor. The profile is located in figure 13.

Red Light Draw, the fans have coalesced into a large bajada, similar in overall geometry to the small bajadas described above, but with processes and landforms similar to the alluvial fans.

The alluvial fans can be divided into proximal and distal regimes, with intertonguing and gradational contacts. The proximal parts of alluvial fans are primarily erosional in nature. Large areas are formed by older, stable alluvial fan surfaces underlain by well-developed stage IV calcic soils. The upper fan surfaces may be incised by a *fan-head trench*, that extends from the source canyon to where it debouches in the distal part of the fan. Other *secondary gullies* dissect the older, proximal parts of the fan. Within the proximal fan landscape, one or more fan surfaces are evident. These are usually not distinct fan segments; they can be distinguished by differences in degree of dissection, tonal variations on aerial photographs, and vegetation differences. The largest secondary gullies and fan-head trenches may contain active channels, which have flooded in the recent past and contain an unvegetated stream bed of mobile sand and gravel. Fan-head trenches are best expressed in the large Goat Canyon and Carpenter Canyon alluvial fans in the Eagle Mountains in the southeastern part of the Eagle Flat Study Area.

The fan-head trenches and the larger secondary gullies feed *fan lobes* on the lower surfaces of the fans. Lobes are depositional features, formed when the fan growth is concentrated in one segment. The fan lobes are areas of currently active deposition in which numerous uprooted plants, gravel bars, and other erosional and depositional features are evident. Older fan lobes are also distinguishable through vegetation differences.

Two styles of alluvial fan deposition are evident in the Eagle Flat Study Area. The first is termed *fan lobe aggradation*, in which younger fan lobes have been deposited onto the smooth, older surface of the fan (fig. 15). The resulting deposits form thin mounds up to 3 ft (1 m) above the older fan surface that are shaped similarly to fingers, splayed and spreading down the surface of the fan. Closer examination reveals that each finger-shaped fan deposit is composed of one or more teardrop-shaped lobes that branch alternately to the right and left of a central feeder channel.

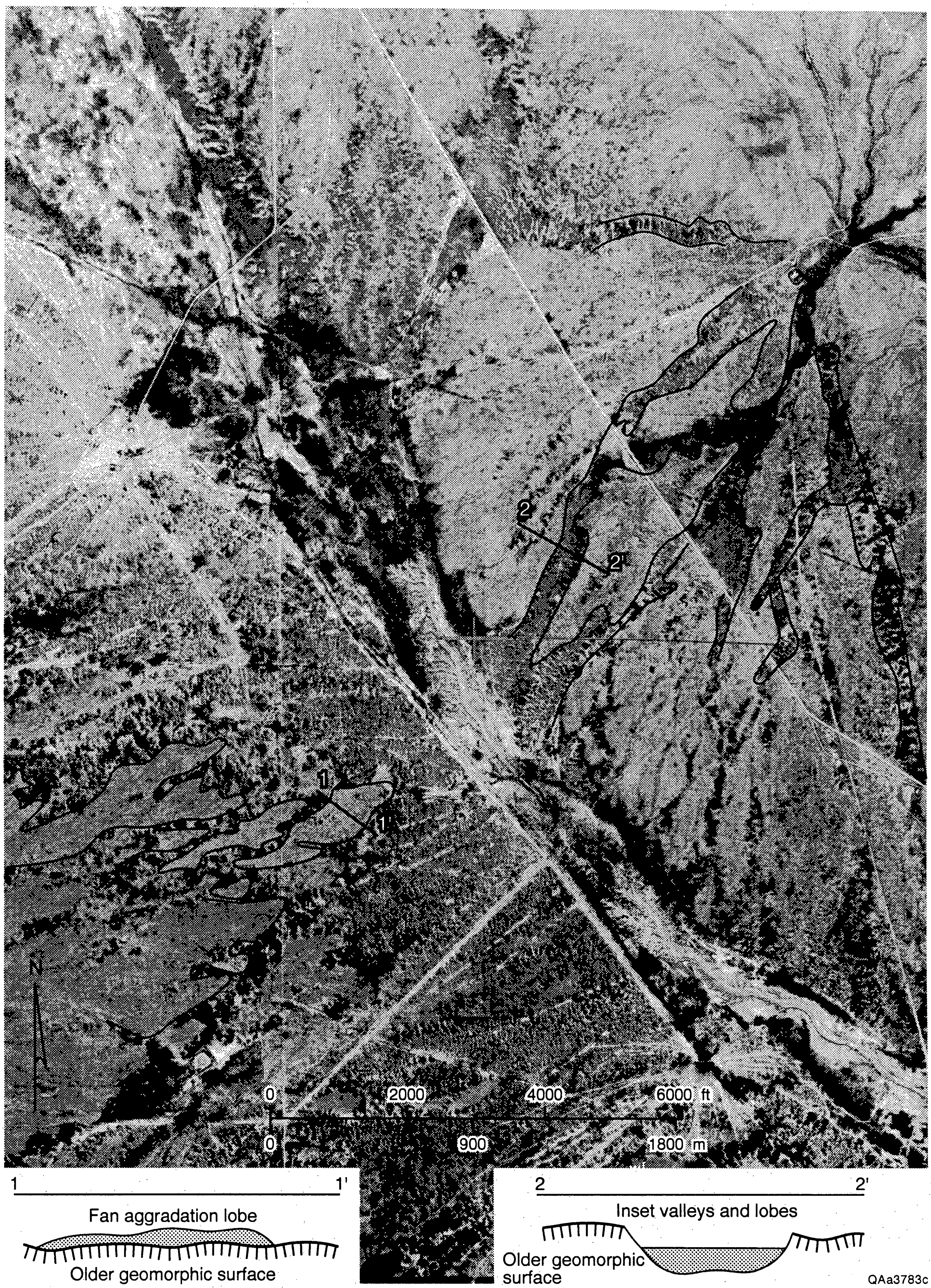

Figure 15. Aerial photograph of Red Light Draw showing the fan aggradation and inset valleys and lobes styles of deposition. Location is shown in figure 4.

The second style of fan deposition is that of *inset lobes and valley fills*, which form where the surface of the fan is dissected to form a series of down-fan elongate valleys (fig. 15). More recent fan deposition is filling the valleys. Therefore, younger fan deposits are confined to the valleys until they reach the toes of the fan and debauch into the washes or basin floors.

Small Alluvial Fans

Small alluvial fans are characterized not by specific areal dimensions but by the nature of their catchments. Small alluvial fans have small catchment areas that do not flood regularly under present-day conditions. Therefore, no active fan lobes or active channels are present. The landscape of the small alluvial fans is dominated by a relatively undissected stable surface, underlain by a well-developed soil. Fan-head trenches may be absent or are short and restricted to the uppermost part of the fans. Most deposition occurs as fan aggradation on the proximal and middle parts of the fan surface. In the Faskin Ranch area, several small alluvial fans are found along the northeastern flank of Devil Ridge, southwest of the proposed repository site.

Large Alluvial Fans

Large alluvial fans are more complex than small alluvial fans. Active fan lobes and active channels are commonly present, although they make up small proportions of the fan surface, usually in the more distal parts of the fan. These may terminate on the fan surface or they may merge into wash-fill or interfluvial flats on the basin floor. Fan-head trenches are well defined and extend across a substantial proportion of the width of the fan. The most proximal fan areas are deeply dissected, and may feed substantial secondary gullies that in turn feed active fan lobes in the distal fan. More than one stable older fan surface is present, marking different generations of fan deposition. Both the fan-head trench and secondary gullies may be partially filled with younger fan material, or may have terraces of younger fan deposits. Terraces (Q_t)

were correlated, but were not mapped separately on plate 3. Most deposition occurs as inset valleys and lobes, with fan aggradation lobes only found in the most distal parts of the fan.

The large fans contain both older and more stable surfaces as well as younger and more active channels and depositional lobes. This contrast results from two processes. (1) Incision of the proximal fan causes deposition to cease and allows stable older surfaces to form. (2) The more frequent floods from the larger catchments result in more common active channels and fan lobes. The only large fan near north Faskin Ranch occurs approximately 3 mi (4.8 km) to the northwest, north of Interstate Highway 10 (fig. 12). Active channels and fan lobes are draining toward Grayton Lake from a part of the southern Streeruwitz Hills and Eagle Flat Mountain to the north (see fig. 4 for locations). Other well-developed large fans are found bordering both the Red Light Draw and Eagle Flat flanks of the Eagle Mountains.

SURFICIAL DEPOSITS AND QUATERNARY STRATIGRAPHY OF NORTHERN FASKIN RANCH

Methods

Surficial Deposits

In the immediate area of the proposed repository site, surficial deposits were mapped along traverses spaced at 2,000 ft (600 m) to create a grid. Surficial deposits required detailed field mapping, because in places the different surficial deposits are similar in their appearance on aerial photographs. Samples of surficial deposits were collected from shallow pits at depths between the surface and 1.5 ft (0.5 m) below the surface. Outside of the immediate area of the proposed repository site, surficial deposits were mapped through loop traverses designed to cross all the map elements visible on aerial photographs. Samples were also collected from locations along these traverses. Grain size distributions were analyzed from 52 samples to quantify the range of textures in surficial deposits. In 12 pits, samples were collected from different depths to quantify textural and compositional changes with depth.

Quaternary Stratigraphy

The stratigraphy of the surficial deposits was established using both physical stratigraphic techniques and age dating. Physical stratigraphic techniques involve the study of strata in outcrop, wells, and trenches in order to determine the nature of the contacts between different units. For example, which units overlie other, and which are truncated by correlatable erosion surfaces. Three primary techniques were used to date Quaternary deposits in the Eagle Flat Study Area. (1) Paleomagnetics was used to date the older Quaternary deposits in cores and trenches. Paleomagnetics provides the primary chronological framework used to correlate the older basin-fill strata on the northern Faskin Ranch (Jackson and others, 1993). (2) Fifteen radiocarbon samples were collected from the younger surficial deposits in the Eagle Flat Study Area (table 1). (3) The accumulation of calcium carbonate in the soil was used to provide relative stratigraphic ages for Quaternary deposits.

Radiocarbon Dates

Three types of radiocarbon dates were collected. One sample (samples RCSB1, table 1) is from charcoal that was deposited by fluvial processes in the sediment. In these samples, the dated carbon is older than the deposit, and therefore provides a ***maximum*** age for the dated deposit. However, because charcoal is so fragile and labile, it usually does not predate the deposit by a long time. A second sample (sample RCFR7 in table 1) is from infaunal snail shells and provides a date from shortly after deposition, when the snails were alive. The rest of the radiocarbon samples are obtained from the humic material in the soil. These samples are dating the carbon that accumulated in the soil both during deposition and through subsequent biotic activity as part of the soil. Because biotic activity can contribute material from deposition to the present, radiocarbon dates of humic material provide ***minimum*** ages for the dated deposits (Gilet-Blein and others, 1980). However, Gile and others (1981) found that radiocarbon ages

Table 1. Radiocarbon samples showing collection localities, surficial deposits, and corrected ages.

Reference number on figures	Sample number	Uncorrected radiocarbon age B.P. (years before 1950)	Corrected age, B.P.	1s (years B.P.)	2s (years B.P.)	Calcic soil stage	Calcic soil accumulate d cS gm/cm^2	Location description
R1	RCEM2	1,600 ± 95	1,511	1,565 – 1,356	1,707 – 1,298		0.7	Stage II calcic soil in young wash deposit on west side of Carpenter Canyon Fan
R2	RCRL1	2,035 ± 125	1,984	2,140 – 1,835	2,329 – 1,703	Incip. II	1.7	Young alluvial fan sediment, Red Light Draw
R3	RCSB1	2,215 ± 115	2,301, 2,262, 2,156	2,343 – 1,927	2,466 – 1,927	I	1.3	Stage I calcic soil in Q_{yf2} alluvial fan deposit north of town of Sierra Blanca
R4	RCFR1*	2,360 ± 60	2,349	2,364 – 2,205	2,706 – 2,205	Org. Rich I or II	5.7	Younger Q_w wash-fill deposits in Hoover tank
R5	RCFR3	3,165 ± 105	3,372	3,470 – 3,262	3,626 – 3,081	Incip. II	1.82 to 4.98	Incipient stage II calcic soil in Q_{yf2} alluvial fan deposit north of Rock tank
R6	RCCD1	4,645 ± 65	5,321	5,456 – 5,299	5,575 – 5,064	Org. Rich I or II	> 1.53	Wash deposits in terrace 2 m above floor of Camel Draw
R7	RCCD2	4,875 ± 70	5,602	5,657 – 5,500	5,740 – 5,340	Org. Rich I or II	> 1.53	Wash deposits in terrace 2 m above floor of Camel Draw
R8	RCEM1	8,395 ± 210	9,428, 9,409, 9,391	9,524 – 9,044	9,869 – 8,727	II	8.7	From stage II calcic soil developed on terrace, 1.5 m above the active floor of Carpenter wash
R9	RCFR2	8,420 ± 195	9,434, 9,401, 9,399	9,527 – 9,058	9,866 – 8,955	II to incip. III	-------	Mature stage II calcic soil in Q_{yf1} deposit from south end of Front Ridge
R10	RCFR6	8,245 ± 220	9,216	9,448 – 8,955	9,644 – 8,519	---------	----------	Fill of fissure in upper part of trench 18 at Hoover fissure, at same horizon as RCFR5
R11	RCFR5	9,270 ± 245	10,286, 10,253, 10,214	10,781 – 9,986	10,973 – 9,688	Incip. III	8 – 19.3 in wells and trench	Q_{bf} below uppermost calcic horizon in upper part of trench 18 at Hoover fissure.
R12	RCFR4	10,160 ± 110	11,865	12,131 – 11,224	12,317 – 11,007	III	36.3	Charcoal sample from crack filling in lower part of trench 18 at Hoover fissure.

Table 1 (cont.)

Reference number on figures	Sample number	Uncorrected radiocarbon age B.P. (years before 1950)	Corrected age, B.P.	1s (years B.P.)	2s (years B.P.)	Calcic soil stage	Calcic soil accumulate d cS gm/cm^2	Location description
R13	RCFR7*	13,735 ± 170	16,467	16,696 – 16,229	16,971 – 15981	Org. Rich I or II		Snail shells from lower wash-fill sediments trench 2 in Blanca Wash
R14	RCFR8*	7,355 ± 85	8,125	8,174 – 8,000	8326 – 7,942	III	34.8	Trench 17 in east Borrow pit on Faskin Ranch in Q_{bf}
R15	RCFR9	>30,430	>30,430	----	-----	III	34.8	Trench 17 in east Borrow pit on Faskin Ranch in Q_{bf}

*Radiocarbon dates for these samples were obtained from the AMS radiocarbon facility at the University of Arizona. This laboratory was not approved according to the Bureau's quality assurance requirements. Therefore these dates have not been used in any measurements or calculations associated with the proposed repository site. However, the results are believed to be as accurate as the other radiocarbon dates and have been cited in the report in order to better explain the regional geologic history.

obtained from soil carbonate compared well with the true ages of geomorphic surfaces for soils up to 10,000 yr old.

Volatile humic material cycles rapidly through the soil and can cause radiocarbon age estimates to be significantly younger than the true age of the soil. Although the processes used to separate the volatile elements can vary in their effectiveness (Trumbore and others, 1989), pretreatment can improve age estimates (Trumbore and others, 1989). Therefore, samples were treated to remove mobile humic material. Also, wherever possible, samples were collected from horizons in which sedimentary structures are visible. Relict sedimentary structures are evidence that soil forming processes (e.g., root turbation) have not thoroughly mixed the soil and therefore have not acted over long time spans. Only samples RCFR5 and RCFR6 were collected from intervals in which sedimentary structures were not evident.

Radiocarbon dates were corrected to correspond to the radiocarbon true age calibration curve using the program Calib3 (Stuiver and Reimer, 1993). The resulting corrected ages and standard deviations are shown in table 1.

Soil Calcium Carbonate Accumulations

The procedures of Machette (1985) to determine the whole-profile index of secondary carbonate were used to compute the accumulated calcium carbonate in the soil. The secondary carbonate (cS) is determined by subtracting the amount of primary carbonate in materials underlying the soil (c_1) from the total carbonate present in the soil (cT).

$$cS = cT - c_1.$$

The resulting soil profiles and computed cS values are provided in appendix B and results are summarized in table 2.

For each soil, the primary calcium carbonate content (c_1) was estimated, either by measuring the calcium carbonate in underlying horizons of similar texture and composition or

Table 2. Accumulated calcium carbonate in the surficial strata in Eagle Flat Basin.

Referenc e number	Location figure	Location	Well or section	Soil stratigraphy	Carbonate stage	Accumulated $CaCO_3$ g/cm^2
YM-21	Plate 1	Arispe Surface at northern Faskin Ranch near repository site	Boring YM-21	A Soil	III	43.5
YM-38	Plate 1		Boring YM-38	A Soil	III	61
YM-39	Plate 1		Boring YM-39	A Soil	III	41
				B Soil	III	23.6
C1	Plate 1		Trench 17	A Soil	III	34.8
C2	Plate 1		West Borrow Pit	A Soil	III	70.1
C3	Plate 1		Hoover tank	B Soil	III	24.1
YM-29	Plate 1	Near YM-19	Boring YM-29	A Soil	II to III	17
YM-35	fig. 3	At Hoover fissure	Boring YM-35	A Soil	III	37
				B Soil	III	27.5
YM-36	fig. 3		Boring YM-36	A Soil	I to II	8
				B Soil	III	18
YM-37	fig. 3		Boring YM-37	A Soil	I to II	6
				B Soil	III	27
C4	fig. 3		Trench in Hoover fissure	A soil	III	35.6
				B Soil	III	39.3
YM-27	fig. 3	southwest of Blanca Wash	YM-27	A Soil	III	60
YM-28	fig. 3		YM-28	A Soil	II to III	47
YM-40	fig. 3		YM-40	B Soil?	III	>13
C5	Plate 1	In Blanca Wash	Trench 2	Surf. soil	I to incipient II	0? too small to measure
C3	Plate 1		Hoover tank			5.7
YM-40	fig. 3		YM-40	Surf. soil	I?, organic rich	6.16
C7	fig. 4	Camel Draw	Camel Draw	Surf. soil	I to II organic rich, hard to see	>1.53

Table 2 (cont.)

Referenc e number	Location figure	Location	Well or section	Soil stratigraphy	Carbonate stage	Accumulated $CaCO_3$ g/cm^2
C8	fig. 3	In alluvial fans	Q_{yf2} at Rock tank	Q_{yf2}	Incipient II	1.82 to 4.98
C9	fig. 4		Young fan in Red Light Draw	Q_{yf2}	Incipient II	1.7
C10	fig. 4		Young fan at trailer park north of Sierra Blanca	Q_{yf2}	I	1.3
C11	fig. 4		Hot Wells	Q_{yf1}?	II to incip. III	5.6
C12	fig. 4		Terrace above active channel at Carpenter Wells	Qt	II	8.7
C13	fig. 4		Q_{yf2} in upper Carpenter Fan	Q_{yf2}	II	0.72
YM-32	fig. 3		YM-32	A soil in OF	III to IV	32
YM-33	fig. 3		YM-33	A soil in OF	III to IV	30
C14	fig. 3		Tank SW of Grayton Lake	A soil in OF	III	23.4

where these were unavailable, by using the carbonate content of unweathered material from nearby locations in the same stratigraphic unit.

The secondary calcic horizon for each soil (Cs) was determined by:

$Cs = c_t \rho_t d_t - c_1 \rho_1 d_1$

where

c_t is the present total calcium carbonate content (g $CaCO_3$/100 g soil)

ρ_t is the dry bulk density of the soil (gm/cm^3)

d_t is the thickness of the sampled horizon

and

c_1 is the estimated initial calcium carbonate content, as discussed above

ρ_1 is the estimated initial dry bulk density of the soil

d_1 is the original thickness of the soil and was estimated by $d_1 = (\rho_1/\rho_t)d_t$.

Densities were measured by obtaining a volumetric sample of material, and drying the sample until the weight remained constant. Initial densities (ρ_1) were estimated to be similar to current densities in soils with low percentages of calcium carbonate. In areas of higher calcium carbonate content, initial densities (ρ_1) were obtained from density samples of underlying strata of similar composition. The Cs values for each horizon within a soil are added to determine the cS or total secondary carbonate, expressed in gm of pure calcium carbonate per cm^2.

Samples were collected from cores drilled in north Faskin Ranch along with samples from key exposures of surficial deposits, including locations from which radiocarbon samples were collected. Samples were collected from the upper two soil horizons in each well. The uppermost horizon is referred to as the *A soil* and the next lowest is referred to as the *B soil* (table 2). Before sampling, the cores and outcrops were described and divided into horizons with similar soil and textural properties. Samples were then collected from each horizon and the consequent Cs value was assigned to the entire thickness of the horizon. Core samples were collected from 0.1-ft-thick (3 cm) intervals. In thicker horizons, several samples were collected to detect changes within the horizons. Outcrop samples were collected from the entire width of the horizon or, from 6-in-thick (15 cm) intervals within the horizons.

Samples were homogenized through mixing and splitting and then oven dried and pulverized using a reciprocal shaker (shatter box). Samples were analyzed through acidification and coulometric titration of the evolved CO_2 using a *Coulometrics 5010 CO_2 Coulometer.* This instrument provided weight-percent inorganic carbon within the samples, which was converted to weight-percent $CaCO_3$ by multiplying by an atomic weight factor of 8.33. The analysis of every sixth sample was replicated twice, and the standard deviations of the three analytical results were determined. Standards were run daily to calibrate the machine. The maximum standard deviation was less than 1 percent of the weight percent calcium carbonate.

Calcic Horizons and Soil Ages

Because the accumulations of calcium carbonate in soils is an important tool in estimating the ages of geomorphic surfaces and surficial deposits in the Eagle Flat Study Area, it is important to describe all the factors that might influence age estimates. In noncalcareous parent materials, the morphologies of the calcic horizons and accumulated volumes of $CaCO_3$ are two of the tools used most commonly to estimate the ages of soils in the southwestern United States (Gile and others, 1966; Gile and others, 1981; Machette, 1985; Reheis and others, 1992). Gile and others (1966), Bachman and Machette (1977), and Machette (1985) defined six stages of development of calcic soil horizons (fig. 16). Initial deposition occurs as clast coatings on pebbles and as disseminated filaments in fine-grained sediments. Nodules develop in stage II, and coalesce into massive carbonate matrix in stage III. Stage IV is characterized by the development of a laminar structure at the top of the calcic horizon.

Some authors (see Leeder, 1975) have indicated that stages of calcic horizon development can be used to estimate the duration of calcic soil development. Machette (1985) and Wright (1990) noted that in southern New Mexico, stage III calcic soils have been found only in soils

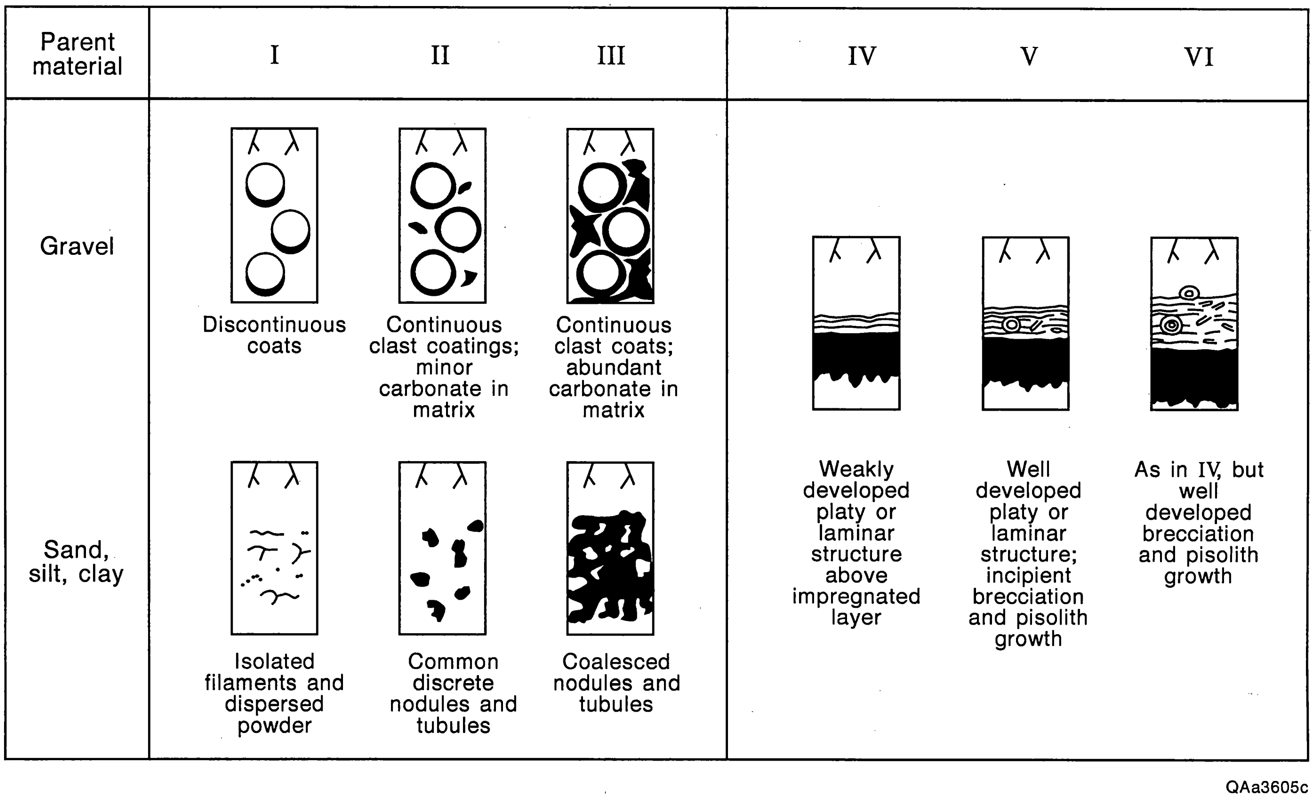

Figure 16. Diagram illustrating the morphological stages of calcic soil horizons.

older than Late Pleistocene. However, several complicating factors preclude more accurate age estimates from calcic stages alone in the Eagle Flat Study Area. Gile and others (1966) have shown that the time required to form different calcic stages varies with the texture of the soil. Fine-grained soils develop the stages much more slowly than coarse-grained soils, and visual determination of the stages of calcic soil development in fine-grained soils is somewhat difficult. This problem was avoided by using the amount of accumulated calcic material, as described above, rather than the stage of soil development. The rate of accumulation of calcic material is less dependent on soil texture (Machette, 1985).

Other factors can influence the accumulation rates of calcium carbonate in the soil. One factor is local geography (Gile and others, 1981), which can concentrate calcic material in some areas and disperse it from others. Furthermore, the absolute age of formation of each stage of development can vary regionally (Machette, 1985; Harden and others, 1991) or with elevation changes due to the correlative climatic changes (Machette, 1985; Reheis and others, 1992). Another factor is the parent material. Soils developed on carbonate clast gravels (Gile and others, 1981), or limestones (Machette, 1985; Rabenhorst and Wilding, 1986) may accumulate soil carbonate at faster rates than similar soils in noncalcareous parent materials.

I have addressed these problems by using multiple methods to estimate the soil ages in the Eagle Flat Study Area. First, the accumulated calcic material in the soil (cS) was compared to published values from nearby areas with similar climates and elevations. Table 3 provides carbonate accumulations and the estimated ages for soils in the southern New Mexico area that were compared to the results shown in table 2. As can be seen, carbonate accumulation rates are consistent between these areas. Comparison allows age estimates with ranges of several thousand years for the Holocene and Latest Pleistocene and within 100,000 yr for the middle Pleistocene.

In order to confirm the estimates made from analogy to nearby areas (table 3), $CaCO_3$ accumulations were measured at all but one of the radiocarbon sample locations. The corrected radiocarbon ages were correlated with the resulting Cs values and the results are shown in

Table 3. Calcic soil accumulations from Southern New Mexico and the Eagle Flat Study Area.

Area	Climate: Mean precip. (cm)	Climate: Mean temp. (°C)	Estimated soil age (yr)	Cs Accumulation (gm/cm^2)
Albuquerque*	20.5	13.1	500,000	110
			320,000[1]	70
			77,000[2]	17
San Acacia*	21.2	14.7	475,000	105
			250,000	55
			136,000	30
			82,000	18
Las Cruces*	20.4	15.5	560,000 to 705,000[3]	145–185
			500,000	129
			388,000[4]	100
			306,000[5]	79
			95,000[6]	25
			62,000	16
			25,000 to 31,000[7]	6.5 to 8
			8,000 to 15,000[8]	2.5 to 7.5
			2,000 to 4,000[8]	0.8 to 2
Eagle Flat	25.4	17	150,000 to 300,000	35–60
			9,400	8.7
			1,500 to 3,700	0.7 to 1.8

*Data from Gile and others (1981) and Machette (1985)
1 older than 190,000-yr-old K-Ar date
2 younger than 190,000-yr-old K-Ar date
3 older than 600,000-yr-old ash bed
4 older than 290,000-yr-old K-Ar date
5 younger than 290,000-yr-old K-Ar date
6 130,000-yr-old uranium-thorium date
7 C^{14} and uranium-thorium dates
8 C^{14} dates

figure 17. Several samples were not used in the calculation of calcium carbonate accumulation. Three samples were not used because the laboratory could not comply with the Bureau of Economic Geology's quality assurance procedures (table 1). A fourth sample (RCFR5 in table 1) was not used because it was collected very near the surface in the active root horizon (see above). A fifth sample (RCFR9 in table 1) was not included because it was an outlier and provided a spuriously high correlation coefficient. The remaining samples indicate a clear correlation between increasing age and greater accumulation of soil calcium carbonate. Gile and others (1981) note a similar degree of variation within the calcic accumulation on a given surface as that expressed in figure 17 and table 2. This variation is due to differences in rates of calcium carbonate due to local geographic and hydrologic effects at each site as well as to variation in the relationship between the age of the soil formation and the age of deposition of the substrate. Finally, additional variation is induced because different parts of a morpho-stratigraphic unit may have been deposited and stabilized at different times, and therefore soils beneath the associated geomorphic surface will have accumulated for different lengths of time.

Formation of Soil Carbonate

Calcium carbonate can accumulate in soils through a variety of processes (see Machette, 1985, for a discussion). In most of the samples collected in the Eagle Flat Study Area, the primary source of calcium is probably the gradual addition of airborne calcium to the soil. Carbonate clasts in sands and gravels probably have contributed additional carbonate to the coarse-grained samples. In order to obviate the problem of clast derived calcium carbonate, calcium percentages were compared to samples of similar composition from below the soil horizon and the primary, nonsoil carbonate was subtracted. Also, age estimates were only made from sand and finer grained materials so that comparisons were made between similarly textured soils. While carbonate accumulations were measured in gravels, these were not used to estimate ages of geomorphic surfaces. Samples were not collected from gully bottoms or relict

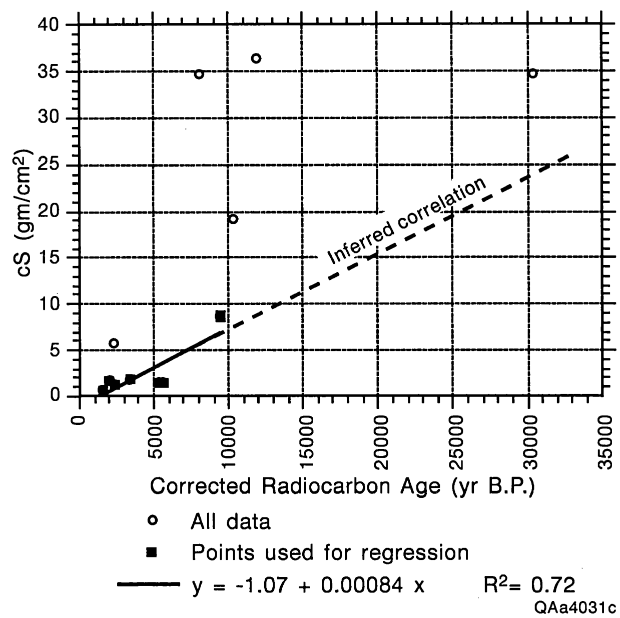

Figure 17. Plot of the correlation between corrected radiocarbon ages and measured cS values.

gully bottoms in which flowing water can precipitate carbonate. The approximate 800-ft (240-m) depth to the water table (Hibbs and Darling, 1993) and the presence of mobile sodium deeper in the sediment (Scanlon and Xiang, 1993) preclude additions of calcium to the soil through the capillary flow of groundwater. The occurrence of calcium carbonate in the soils supports this hypothesis. Carbonate soils of similar development are found over wide areas of the interfluvial flats on the basin floor but are poorly developed in washes and in the floor of Grayton Lake. Capillarity would be expected to operate most strongly in these low-lying settings.

Surficial Deposits of North Faskin Ranch

General

The surficial deposits in the area of Faskin Ranch, which includes portions of the Ranch lying up to about 4 mi (6.5 km) south of the Ranch house, are illustrated in figure 12. Explanations of the surficial deposit map units are in appendix A and table 4. The surficial deposits on the north Faskin Ranch area can be grouped into five textural categories, each associated with different landforms and geomorphic elements (fig. 18). Two generations of well-sorted, fine- to very fine grained sands are found on the surfaces of the vegetated sand sheets and active eolian area. The older generation is designated Q_{e1}, and the younger generation is designated Q_{e2}. The soil in the basin-floor deposits at the surface of the relict alluvial flat is composed of sandy silts and sandy clays (Q_{bf}). Similar sandy silts and clays are found where the alluvial flat has been eroded, exposing the underlying basin-fill strata (Q_{bfc}), particularly along the wash-flank slope. Silt with rare gravelly sands and silty sands of the wash-fill deposits (Q_w) form the finest-grained deposits on north Faskin Ranch and are restricted to the floors of Blanca Draw and its tributaries. Poorly sorted gravelly silty sands are found as residual soil (Q_{rs}) associated with the Cretaceous bedrock hills south and west of Blanca Draw. Interstratified beds

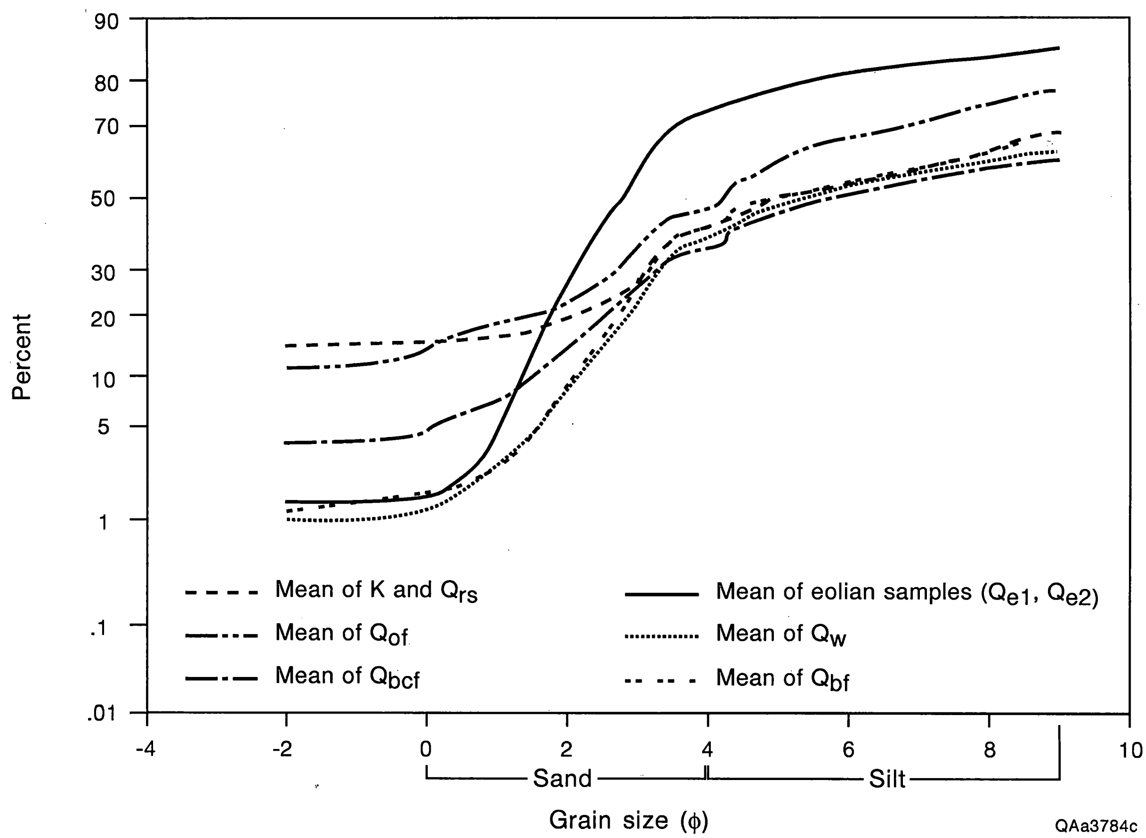

Figure 18. Cumulative probability plot of the mean grain size distribution of the major categories of surficial deposits. Samples and grain size data are presented in appendix C.

Table 4. Classes of surficial deposits in the six-quadrangle Eagle Flat Study Area. Detailed descriptions are found in appendix A.

Surficial deposits	Geomorphic setting	Sediment	Soil	Ages and relative ages (if any)	Vegetation	Other
Uplands						
K Bedrock	Slopes, crests and rugged topography in upland and mountain areas	Bedrock of Permian, and Cretaceous limestones and sandstones and Tertiary volcanics	Mostly without soil, scattered and thin colluvium and residual soil	>28 mya (volcanic rocks)	Cactus, desert shrubs	
Q_{rs} Residual soil on bedrock	Swales and slopes in upland areas	Gravelly silty sands and silty sands USC = SM	Silty B horizon on stage III to IV calcic horizon	--------	Grass, creosote bush, greasewood	Immediately underlain by bedrock. Same pavement as Sc. Calcic horizon locally exposed
Piedmont Slopes						
Ca Active channels		Sands and gravels USC = SP, SW and GW	None	Present day	Unvegetated floor with movable clasts, includes poorly vegetated terraces	On larger alluvial fans derived from the Eagle, Quitman, and Carrizo Mountains
Fa Active alluvial fans		Gravel bars, sand patches, USC = SP, SW and GW	None	Present day	Sparse, large unvegetated patches	Same as Ca

Table 4 (cont.)

Surficial deposits	Geomorphic setting	Sediment	Soil	Ages and relative ages (if any)	Vegetation	Other
Q_{yf} Young alluvial fan deposits	Piedmont slopes, bajadas, and alluvial fans	Alluvial sand and gravel, channel fills of gravel and gravelly sand, siltier than Q_{of} (USC = GW, GM, SW), in a matrix of silty sand and sandy silt (USC = SW, SM)	Absent to poorly developed B horizon and stage I to incipient stage III calcic horizon	Younger than the Arispe Surface, undated but similar to Q_{yf1} and Q_{yf2}	Creosote, cacti, sage, mesquite, grass	Poorly developed pavements, poor to moderate varnish. Well-expressed fan lobes and gully fills
Q_{yf2} Second generation of young fan deposits	Piedmont slopes, bajadas, and alluvial fans	Same as Q_{yf}	Stage I to incipient stage II calcic horizon	Possibly 1,000 to 6,000 yr. Radiocarbon dates range from 1,511 to 3,370 years B.P.	Same as Q_{yf}	Thin widespread on Q_{of} and Q_{bf}, more distal to mountains than Q_{yf1}, thinner than Q_{yf2}
Q_{yf1} First generation of young fan deposits	Piedmont slopes, bajadas, and alluvial fans	Same as Q_{yf}	Well-developed stage II to incipient stage III calcic horizon	Possibly 7,000 to 16,000 yr. Radiocarbon dates are 9,400 yr B.P.	Same as Q_{yf}	Closer to mountain front than Q_{yf2}, commonly incised to 7 ft, incised channels feed Q_{yf2}
Q_{of} Older alluvial fans includes Q_{of1} and Q_{of2}	Piedmont slopes, bajadas, and alluvial fans	Alluvial sand and gravel, soil is gravel, sand, or gravel pavement (USC = GW, GM, SW, and SM)	B horizon thick silty, well-developed stage III or IV calcic horizon	Varying, but most are as old as or older than the Arispe Surface (>100,000 to 300,000 yr)	Shrubs, including grass and creosote	Proximal well-developed pavement, distal poorly developed

Table 4 (cont.)

Surficial deposits	Geomorphic setting	Sediment	Soil	Ages and relative ages (if any)	Vegetation	Other
Basin Floors						
H Cultural	Basin floors and piemont slopes	-----------	------------	------------	------------	Disturbed by cultural activities, orignial surficial deposit removed or covered
Q_p Playa	Grayton Lake on the Basin floor	Silts (USC = ML and CL)	No soil horizons evident	Recent to (paleomag "dates") <780,000 yrs	Ephemeral Asteracae	Grazed by sheep, no topography or depositional features present
Q_{e2} Younger generation of eolian dunes and sand sheets	Basin floors and lower piedmont slopes	Well-sorted fine-grained sand at repository, coarse to medium east of Camel Draw (USC = SP with some SM)	Only incipient soil horizination	Unknown to present day, younger than Q_{e1}	Narrow leaf yucca, shrubby savannas, grassland less dense than washes, scattered mesquite	Cohesive surface horizon, few pebbles or calcic fragments in surface, locally overlies Q_{e1} with pebble layer at contact, areas of coppice dunes, and bare sand patches
Q_{e1} Older generation of eolian dunes and sand sheets	Basin floors and lower piedmont slopes	Well-sorted, very fine grained sand, well-sorted, loamy sand (USC = SP with some SM)	More cohesive, discernable B horizon, small (stage I) carbonate nodules	Unknown, probably younger than 2,000 yr	Same as Q_{e2}	Cohesive surface horizon, many pebbles and calcic fragments on surface, hard to tell from Q_{bf} in some areas
Q_w Wash-fill deposits	Basin floors and valleys in peidmont and upland areas	Finest grained sediment in northern Faskin Ranch, high silt and clay (USC = ML and CL, some SP)	Soil horizons not distinct	Radiocarbon dates from 2,300 to 5,600 yr B.P.	Vegetated, except gullies; mesquite, grass	Pseudofissures present, aggrading, has some gullies

Table 4 (cont.)

Surficial deposits	Geomorphic setting	Sediment	Soil	Ages and relative ages (if any)	Vegetation	Other
Q_{bf} Soil in basin-fill deposits	Relict alluvial plains on the basin floor	Silt, sandy silt, silty clay B horizon (USC = ML, CL, and SM)	Thick B horizon on stage III to IV on basin fill	Variable, older than washes, Arispe Surface estimated age 100,000 to 300,000 yr	Well vegetated; grass, shrub, and thickets	No pavement in grass, poor to moderate pavement in shrubs. Similar to Q_{rs} and Q_{e1}. Calcic horizon locally exposed
Q_{bfc} Basin-fill deposits	Eroded areas on the basin floor, most common along Blanca Draw	Disguised by calcic material (USC = ML and CL)	Calcic horizon exposed	———	Similar to that of Q_{bf}	Dynamically eroding, rills and scarplets common

of silty sands, sands, and gravels are found on the alluvial fans west and northeast of the proposed repository site (Q_{of} and Q_{yf}).

Surficial Deposits of the Interfluvial Flats

Vegetated Sand Sheet and Active Eolian Areas

Figure 19 illustrates the surface and near-surface stratigraphy on the interfluvial flat at the proposed repository site. The two deposits that make up the largest area on the vegetated sand sheet are well-sorted, fine to very fine grained sands (Q_{e1} and Q_{e2}) that form a thin sheet across much of the interfluvial flats (fig. 12). The good sorting (fig. 18), lack of intercalated muds and gravels, and irregular rolling topography indicate an eolian origin for these deposits. Where both are present, Q_{e1} always underlies Q_{e2}.

The two eolian sand deposits (Q_{e1} and Q_{e2}) cover almost the entirety of the proposed repository site, except for small hollows and flats in which the underlying soil in basin-floor deposits (Q_{bf}) is exposed. The largest exposure of soil in basin-floor deposits (Q_{bf}) near the proposed repository site is on the west side of the meteorological station (location shown on plate 1). Active eolian erosion and deposition are evident at two locations on northern Faskin Ranch (fig. 9). The surficial strata at these locations are identical to surrounding areas of the younger generation of vegetated eolian sand (Q_{e2}). As can be seen in figure 12, Q_{e2} is only locally present in some areas. In these areas, particularly just east of Blanca Draw, Q_{e2} occurs in such small patches that they could not be shown at the scale of the map. Similarly, the older generation of vegetated eolian sand (Q_{e1}) deposits were not encountered in all the pits dug through the younger generation Q_{e2} deposits, and may be only locally present beneath the areas mapped as younger generation of eolian sand (Q_{e2}) in figure 12.

The younger generation of eolian sand deposits (Q_{e2}) exhibits very little or no soil horizonation and contains very little silt- and clay-sized material. They are inferred to be very recent deposits in which soils have not had time to form. The older-generation eolian sand

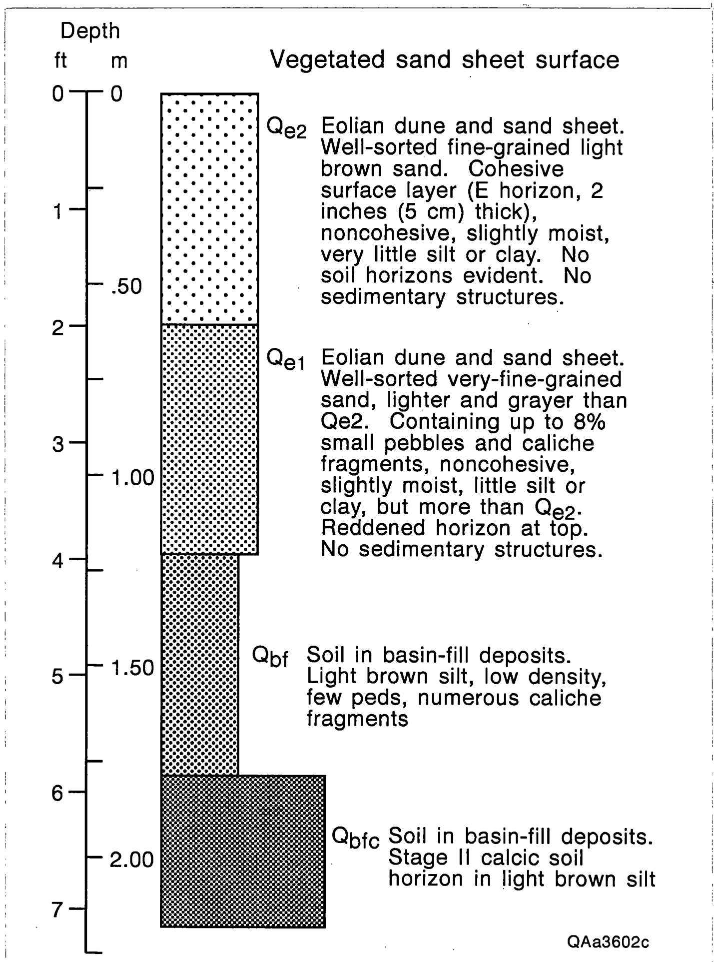

Figure 19. Stratigraphic log of boring YM-44 on the repository site, near the east end of topographic profile A–A′ illustrating the surficial deposits of the vegetated alluvial sand sheet setting. Q_{e1}, Q_{e2}, Q_{bf}, and Q_{bfc} are surficial deposits enumerated in table 4 and appendix A. The location is shown in figure 3 and plate 1.

deposits (Q_{e1}) are grayer and more clay rich and have slightly rubified B horizons. They also exhibit a litter of pebbles and fragments of caliche at the surface. These features are typical products of soil processes in sandy soils in arid regions (Gile and Grossman, 1979; Birkeland, 1984). Figure 20 illustrates the distribution of grain sizes in the Q_{e1} and Q_{e2} eolian deposits. The younger Q_{e2} sands almost everywhere have a coarser mean grain size than the older Q_{e1} sands. Q_{e2} sands contain fewer fines and also contain fewer granules and pebbles. Although both deposits are of eolian origin, the difference in grain size indicates different depositional episodes.

Figure 21 illustrates the overall distribution of the older generation Q_{e1} sands and the younger generation Q_{e2} sands, which form a thin mantle, locally absent, and never measured at more than 4 ft thick (1.3 m). The contact between the Q_{e1} and Q_{e2} deposits is sharp and commonly coincides with a layer of scattered pebbles similar to those exposed on the surface of the Q_{e1} deposits. Likewise, the contact at the base of the Q_{e1} and Q_{e2} deposits is sharp. In many pits on the proposed repository site these deposits rest on a stage II or stage III calcic horizon (Q_{bfc}). In others (fig. 19) a 1- to 2-ft-thick (0.3 to 0.6 m) brown silt or silty sand (Q_{bf}) was present at the base of the eolian deposits. This silt and silty sand (Q_{bf}) is interpreted to be the B horizon of the soil onto which the eolian sands were deposited (fig. 19). It indicates a period of landscape stability before deposition of the Q_{e1} and Q_{e2} eolian sands, and the local absence of this horizon indicates an episode of shallow erosion prior to deposition of the eolian sands. Because the calcic horizon is always present, the erosion was confined to the upper 2 ft (60 cm) of the present-day landscape.

Relict Alluvial Flats

On the relict alluvial flat surfaces, largely occurring southwest of Blanca Draw, the surficial deposits are consistently a light brown to grayish silty clay or clayey sand termed Q_{bf} (for basin floor). Figures 22 and 23 show the appearance of the Q_{bf} surficial strata underlying the relict

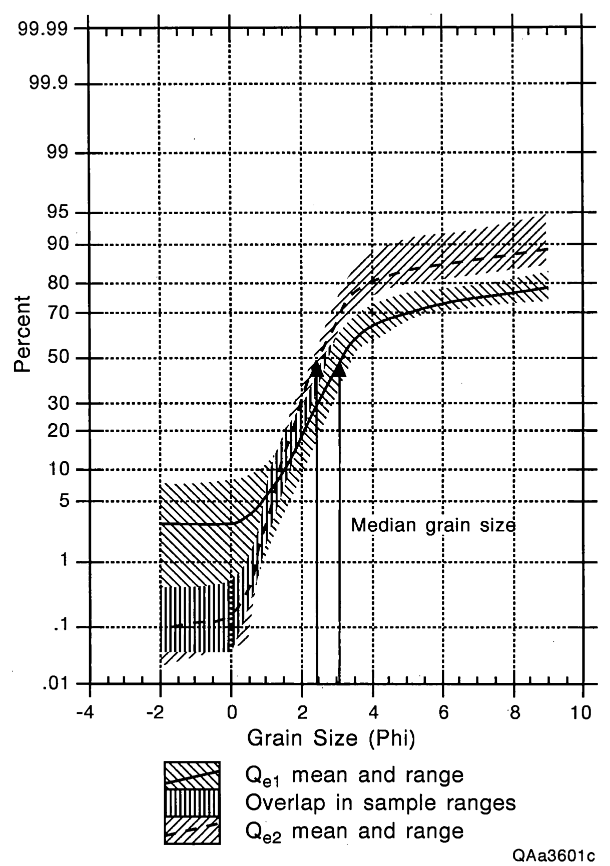

Figure 20. Cumulative probability plot of the grain size distribution of samples of older ($Q_{e}1$) and younger ($Q_{e}2$) eolian sand deposits. Samples and grain size data are presented in appendix C.

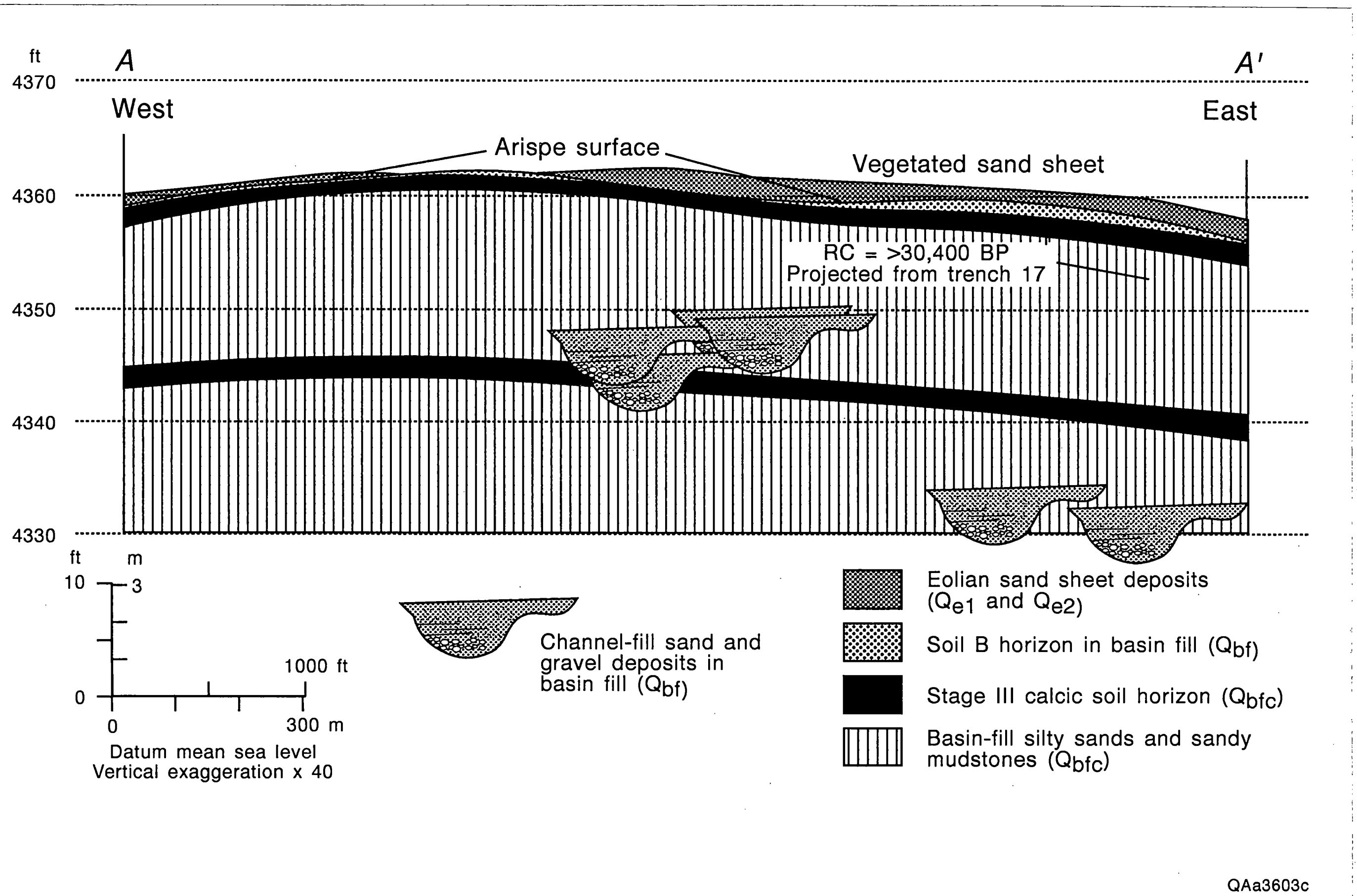

Figure 21. Topographic profile A–A′ on the interfluvial flat, illustrating the surficial stratigraphy of the vegetated sand sheet at the proposed repository site. The location is shown in plate 1 and figure 3.

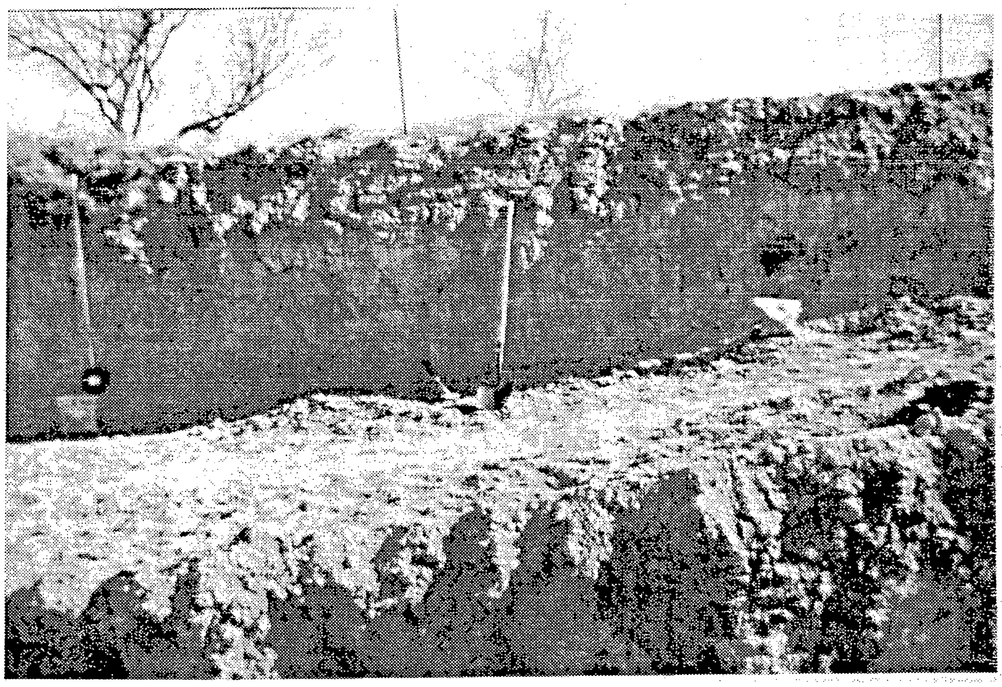

Figure 22. Photograph of trench 18 at Hoover fissure showing the surficial deposits of the relict alluvial flat and the typical appearance of the soil in basin floor deposits (Q_{bf}), showing the thin B soil horizon (Q_{bfb}) and the underlying, well-developed calcic horizon (Q_{bfc}). Q_{bf} and Q_{bfc} are surficial deposits enumerated in table 4 and appendix A. Location shown in figure 3 and plate 1.

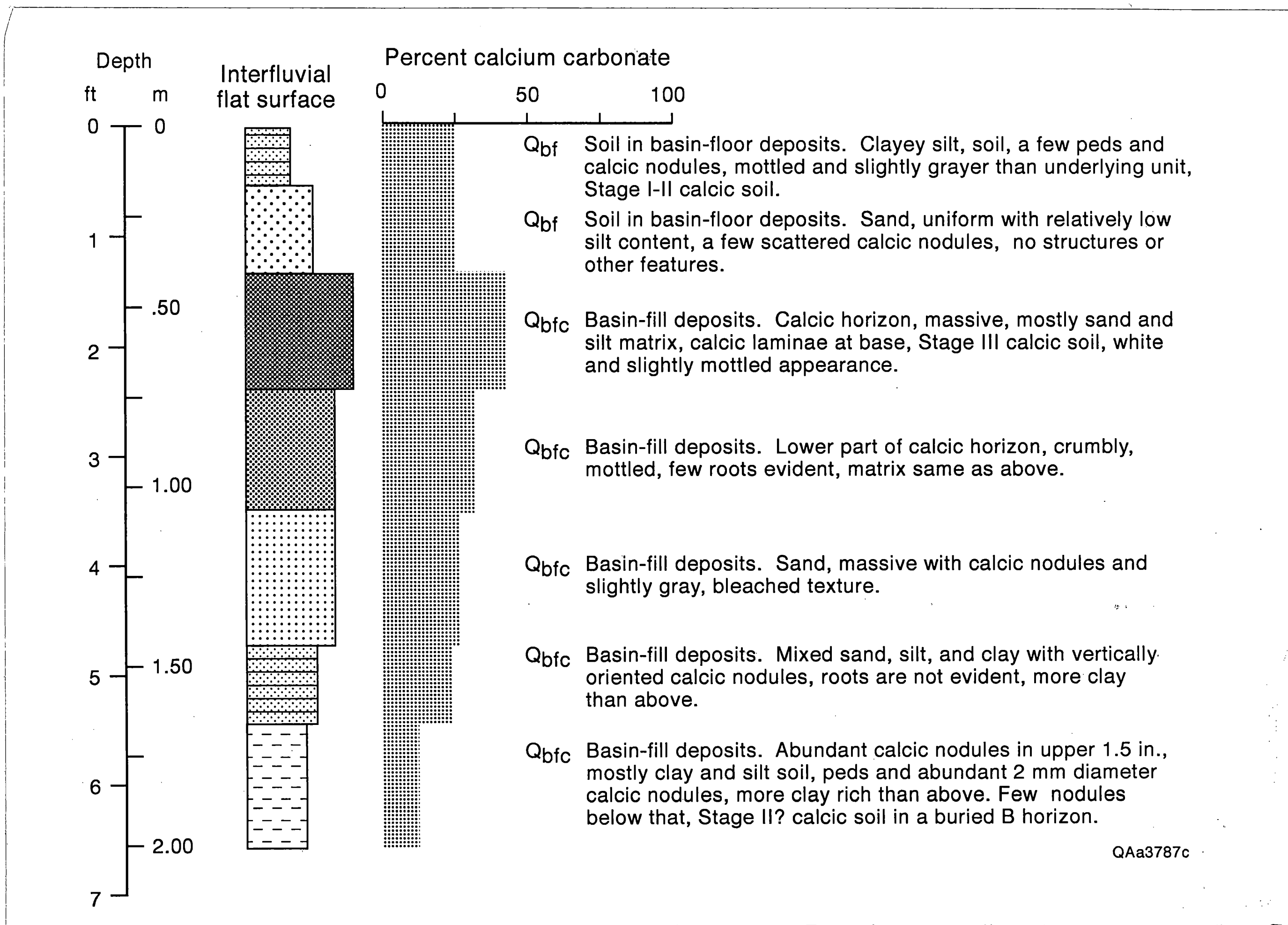

Figure 23. Stratigraphic log of boring YM-35 near Hoover fissure, illustrating the surficial deposits of the relict alluvial flat. Q_{bf} and Q_{bfc} are surficial deposits enumerated in table 4 and appendix A. The location is shown in figure 3.

alluvial flat. Samples of the surficial strata collected from the surface to depths of 12 inches (30 cm) ranged from 60 percent sand, 20 percent silt, 20 percent clay to 20 percent sand, 30 percent silt, 50 percent clay. The deposit contains numerous roots and tubules. Peds are evident in clayey samples. The B soil horizons are weakly expressed, but this is typical even of older soils developed on sediment mainly derived from calcareous bedrock, as is the Q_{bf} (Gile and Grossman, 1979; Gile and others, 1981).

Immediately underlying the soil in basin floor unit (Q_{bf}) is a well-developed stage II or stage III calcic soil horizon (Q_{bfc}) (figs. 22 and 23). This soil has been correlated from cores and borrow pits across the area of the repository site and is termed the *A soil* in table 2. The Q_{bfc} unit includes the calcic soil and underlying basin-fill strata below the B (Q_{bf}) soil horizon. The Q_{bfc} calcic soil and Q_{bf} units are similar to those on the vegetated sand flats east of Blanca Draw and are developed in a similar variety of sands, muddy silts and clays (fig. 23). I infer that this well-developed soil developed beneath an alluvial flat in the basin floor that was traversed by axial trunk drainages that carried sediment from the Diablo Plateau and Streeruwitz Hills to the north and from the Blanca Peaks to the northwest. A second calcic soil can also be correlated in cores and in deep trenches across the area of the repository site and is termed the *B soil* in table 2. West and south of Blanca Draw, only a single calcic soil is found in the uppermost basin-fill deposits (Jackson and others, 1993).

Channel fills exposed in the Hoover and West borrow pits, as well as in other pits in the Eagle Flat Basin (see plate 1 for location), are approximately 150 ft (50 m) wide and 3 to 4.5 ft (1 to 1.5 m) thick. The channels contain coarse- to fine-grained sands and pebble and cobble gravels. The pebbles and cobbles are of polymictic composition, resulting from a large and diverse source area and indicating an axial drainage as opposed to alluvial fans. The channels are well defined and are set within a matrix of muds and muddy sandstones containing calcic soil nodules, root tubules, and other features indicative of soil processes (Jackson and others, 1993). Well-expressed, stage II and stage III calcic soil horizons are present at approximately 15 ft (5 m) stratigraphic intervals within the muds and muddy sands (Jackson and others, 1993). The buried calcic soil horizons are not evident within the channel fills, indicating that the channels may have been incised into these horizons, during or after their formation. The present-day Blanca Draw contains channel fills of similar dimensions and compositions (see below).

Channel-fill sandstones and conglomerates are present throughout the basin-fill strata (Q_{bfc}), including the uppermost calcic horizon shown in figures 22 and 23, but pebbles are not found within the upper soil horizons (Q_{bf}). In areas of the basin-floor and channel margins underlain by channel-fill gravels, pavements of pebbles and cobbles are found on the surface of the relict alluvial flat. These pavements trend north to south and northwest to southeast, parallel with the present-day Blanca Draw drainage system.

The contours in figure 9 illustrate the topography of the surface of the relict alluvial flat, and the gentle slopes on which the Q_{bf} soil has formed. The Q_{bf} silts and clays form a continuous coverage over a large area of the Eagle Flat Study Area (fig. 12; plate 3). Erosion only locally exposes the underlying basin fill and calcic horizons (Q_{bfc})(fig. 12, plate 3). Erosion into the soil on the relict alluvial flat surface (Q_{bf}) is concentrated along Blanca Draw and its tributaries and elsewhere is associated with cultural features such as cattle trails, roads, and fences (see below).

The relict alluvial flat is interpreted as a depositional surface, produced by muds and channel-fill sandstones and gravels deposited by axial streams flowing across the basin floor from the Diablo Plateau, Streeruwitz Hills, and Blanca Peaks areas. The basin-fill deposit (Q_{bfc}) channel-fill sands and gravels were deposited by sandy braided streams, flowing through channels, incised less than 5 ft (1.5 m) below the adjacent floodplain. The muds and muddy sandstones that compose the majority of the basin-fill strata were deposited both as overbank deposits from the axial braided stream channels and as sediment from depositional events that spread across the basin floor from the toes of alluvial fans. Similar muds and muddy sands can be found today, both in the fill of the present-day Blanca Draw and at the toes of the active alluvial fans along the northeastern front of the Eagle Mountains (plate 3). During deposition of the basin-fill deposits (Q_{bfc}) underlying the relict alluvial flat, there was no extensive incision of the basin floor. The lateral extent of the gravels, muds, and muddy sands of the basin-fill (Q_{bfc}) deposits suggests that the alluvial channels must have flowed across a gentle, unincised south and southwest sloping surface. The present-day drainage of Blanca Draw must have been incised after deposition of the basin-fill deposits (Q_{bfc}). Furthermore, the similarities of strata underlying eolian sands (Q_{e1} and Q_{e2}) indicate that the vegetated sand sheets form a thin mantle that covers large areas of relict alluvial flat on the basin floor.

The soil that forms the surface below the eolian sand sheet and the surface of the relict alluvial flat (Q_{bf}) is interpreted to be the uppermost E and B horizons of a soil developed on the alluvial flat between the time of deposition and the present day (see Birkeland, 1984, for soil terminology). The soil predates the incision of Blanca Draw. The surface is assumed to be stable because the relict alluvial flat surface exhibits no depositional features, and very few erosional features penetrate the thin Q_{bf} soil. Corrected radiocarbon dates from basin-fill deposits (Q_{bfc}) immediately underlying the surface of the relict alluvial flat range from 8,120 yr old (sample R14 in table 1) to radiocarbon-dead (sample R15 in table 1), indicating an age greater than 30,470 years before present. Because these samples were collected from humic material near to the surface, and because organic material is constantly added to these horizons, these dates represent minimum ages for the relict alluvial flat and its associated soil (Q_{bf}) (table 1). Assuming carbonate accumulates at rates comparable to the Mesilla Basin (at comparable elevations, 150 mi (240 km) northwest) the accumulated soil carbonates in the uppermost basin-fill soil horizon (Q_{bfc}), indicate ages for the onset of stability and soil accumulation ranging from local minimums of 10,000 yr B.P. in wells YM-36 and YM-37 near the Hoover fissure (see figure 3 for location), to 150,000–300,000 yr in the wells and pits surrounding the proposed repository site (table 2, appendix B). Well YM-35 (fig. 23) and soil carbonate profiles in trench 18 at Hoover fissure provide additional age estimates of 70,000 to 130,000 yr old for this area (fig. 13). Therefore, the Arispe surface, in the vicinity of the repository site, was probably largely stabilized 150,000 to 300,000 yr ago. Local erosion and deposition may have continued on the relict alluvial flat west of the repository and Blanca

Draw to as late as 10,000 yr ago. However, the 10,000 yr age, coming from soil humates in an active soil may be very young estimates. The 70,000- to 130,000-yr-old dates are probably better estimates of the age of stabilization in this area.

Surficial Deposits of the Wash Floors

Figures 10 and 24 illustrate the stratigraphic relationship between the wash-fill deposits (Q_w) and the basin-fill (Q_{bfc}). The western and northwestern parts of the Blanca Draw drainage system are incised 7 to 35 ft (2.1 to 10 m) below the adjacent alluvial flats (fig. 10). However, in the southern and southeastern parts of the drainage, the interfluvial flats and uplands slope beneath the wash floor (fig. 24) with no apparent incision. At one time the Blanca Draw drainage was deeper than at present. The edges of this more deeply incised drainage can be traced beneath the wash floors from the current eroded edges of the Blanca Draw drainage system. In the incised valleys to the north, the eroded margins of the wash-flank slopes continue below the wash floors to define the original deeper valley in which the wash flowed (fig. 10). Below the eroded surface are basin-filling strata similar to the (Q_{bfc}) strata exposed in the wash flanks and beneath the interfluvial flats. In the south, where Blanca Draw does not flow through an incised valley, wash-fill strata (Q_w) overlie the soil horizons Q_{bf} and Q_{rs} at the margins of the washes. In the center of the wash the more deeply incised drainage is evident. This relationship is displayed in the walls of Coffee tank, where the soil Q_{bf} and Q_{bfc} extend halfway across the tank walls beneath the present-day wash floor (as shown in fig. 24).

Wash-fill deposits postdate the incision of the present-day Blanca Draw drainage. A radiocarbon date from the upper part of a channel-fill sand in the wash-fill deposits (Q_w), 4 ft (1.3 m) below the wash floor in Hoover tank, provides a minimum age of 2,350 yr (sample RCFR1, table 1). The uppermost wash-fill strata (Q_w) from 16 inches (40 cm) below an incised wash floor in upper Camel Draw provided radiocarbon dates of approximately 5,300 to 5,600 yr (samples RCCD1 and RCCD2 in table 1; fig. 4 for location).

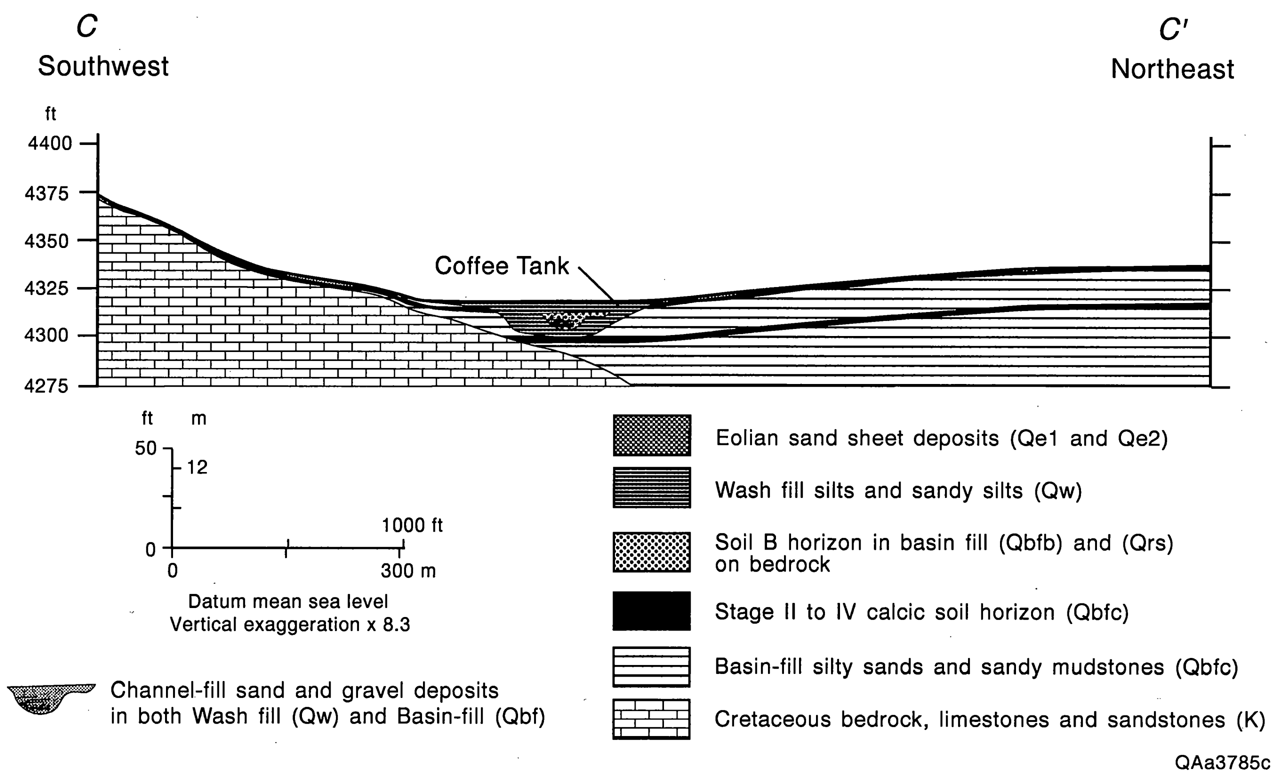

Figure 24. Profile C–C′ across Blanca Draw, showing topography of the wash floor and the stratigraphic relations of the surficial deposits in the washes and adjacent alluvial flats and upland areas. Location shown in figure 3.

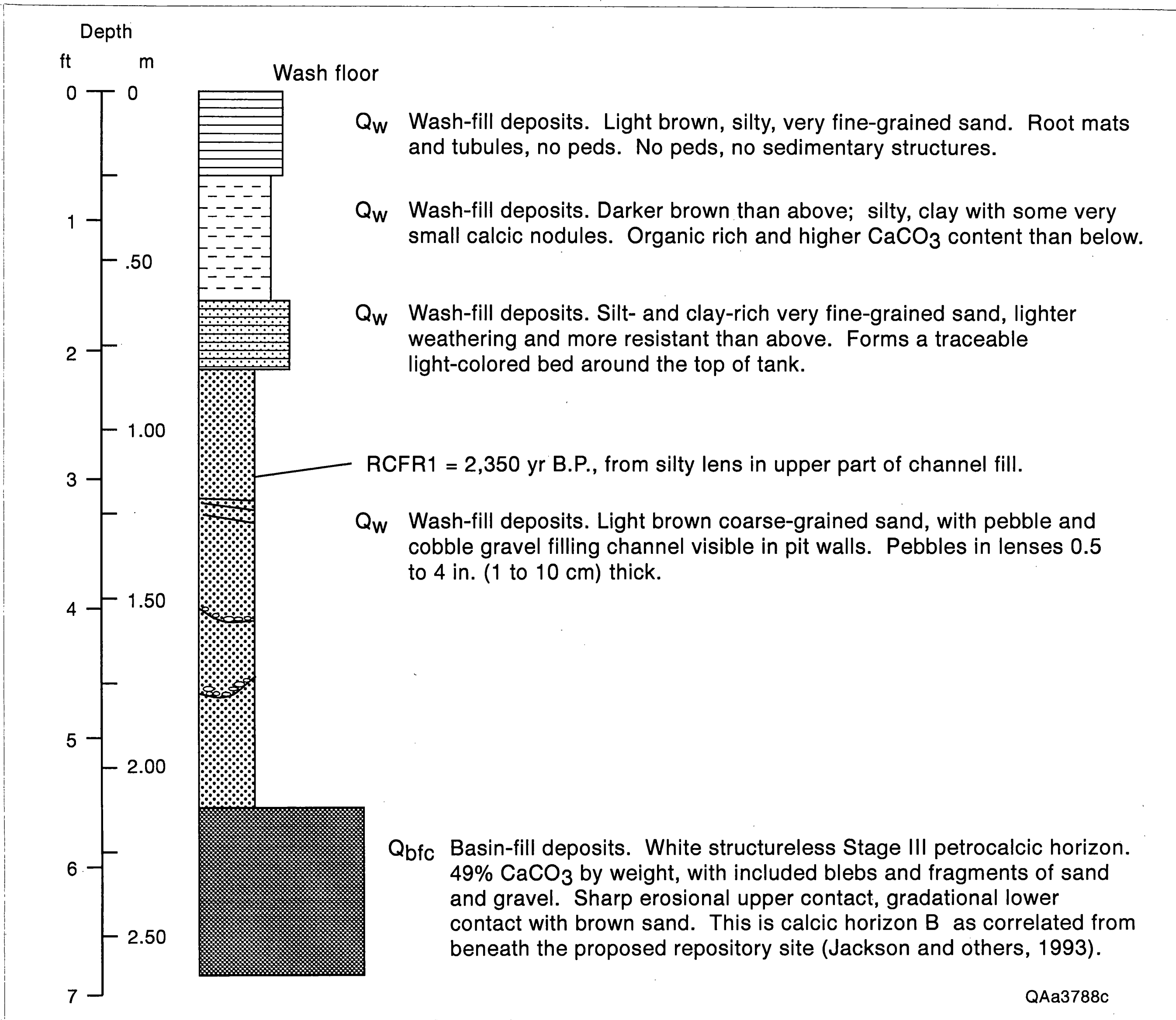

Figure 25. Log of stratigraphic section in the south wall of Hoover tank showing the wash-fill deposits (Q_w). The location of radiocarbon sample RCFR1 is also shown. The section is located in plate 1 and figure 3.

Above the erosion surface and beneath the present-day wash floors are two different types of wash fill (Q_w) (fig. 25). Most of the fill is silty clays and clayey silts. Wash-fill deposits (Q_w) are on average, the finest grained surficial sediment at Faskin Ranch (fig. 18), with samples averaging 40 percent clay and 25 percent silt. Gravels and gravelly sands occur as well-defined channels within the wash-fill strata (Q_w). These are best exposed at Hoover tank, where a 3.6-ft to 6.5-ft-thick (1.1 to 1.7 m) channel within the Q_w wash-fill strata cuts across the tank from the northwest to the south. Similar coarse-grained wash-fill strata are rarely encountered in borings into the wash floor (Jackson and others, 1993).

Wash-fill clays and silts are light gray and low-density (Jackson and others, 1993). The clays and silts are always the uppermost fill in wash; and the uppermost horizons and wash floor have no gravel clasts evident. They only rarely exhibit internal stratification or other sedimentary structures. The typical stratification is illustrated in figures 25 and 26. Rarely, channel or gully fills are evident in the clays and silts due to color differences, but there are typically no textural differences across the clay and silt channel boundaries. The soil stratification evident in the wash-fills (Q_w) is also shown in figure 26. A dark organic-rich zone, 0.5-to-1-ft- thick (15 to 30 cm) thick, forms the uppermost layer, immediately under the wash-floor. Beneath this is a whitened horizon, 1- to 2-ft-thick (30–60 cm) (figs. 25 and 26). The whitened horizon was originally thought to result from the accumulation of calcium carbonate. However, analysis of soil carbonate content indicates that the highest concentrations of carbonate are in the darker upper horizon. The dark upper horizon has similar carbonate similar to that of the underlying strata (see appendix B).

The coarse-grained channel-fill strata exhibit upward-fining beds of pebbles and sand, subhorizontal laminae, and trough-cross-stratification (fig. 25). They contain little clay or silt (e.g., sample RL13B, appendix B), and contain gravel clasts up to 5.9 inches (15 cm) in diameter. The overall geometry and clast composition are similar to that described for the channel fills in the basin-fill strata (Q_{bfc}).

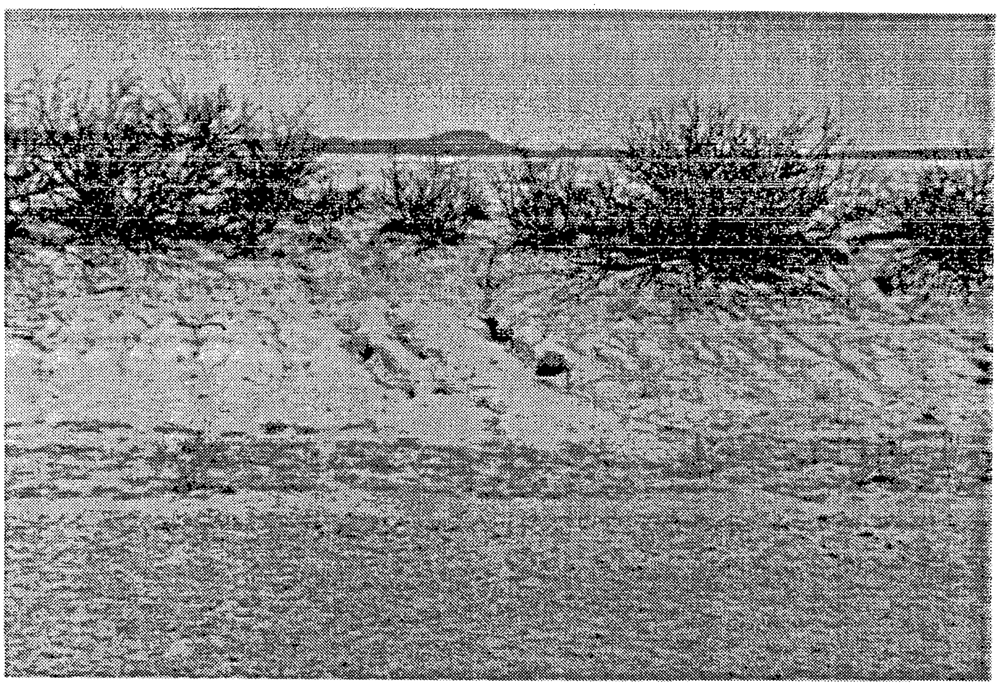

Figure 26. Photograph of north wall of Coffee Tank showing the stratification evident in the wash-fill strata (Q_w). Pack on ground in center of photo is 40 cm wide.

Surficial Deposits of the Playa Floor

At its southeastern end, Blanca Draw terminates into a small 1 mi^2 (2.6 km^2) playa known as Grayton Lake (fig. 3 and 12). The floor of the playa is flat, with less than 2 ft (0.6 m) of topographic relief. Depositional features are confined to the western and northern margins of the playa, where a small, flat terrace above the playa floor may be a relict shoreline formed during a flooding event. The terrace is well-sorted fine-grained sand. The floor of the playa (Q_p) is a silt and clay flat, exhibiting few mudcracks but with a well-developed microgilgai topography resulting from soil shrink and swell. A well drilled in the center of the playa (YM-7, fig. 3), pierced 27 ft (9 m) of silts, similar to those of the playa floor (Q_p) (Jackson and others, 1993). The oldest playa muds coincide with the Brunhes-Matuyama magnetic reversal (Jackson and others, 1993). Therefore, Grayton Lake playa appeared in its current location approximately 780,000 yr ago.

To the west, the playa merges with the wash fill deposits (Q_w) in lower Blanca Draw (fig. 12). To the south, bedrock and associated soils of an upland area dip beneath the playa floor (fig. 12). At the southern margin of the playa, the residual soil on the bedrock (Q_{rs}) is encountered at shallow depths. The northerly slope of the bedrock must continue beneath the lake. Near the center of the playa, bedrock is encountered 109 ft (33 m) below the basin floor. Along its northern margin, there is a thick vegetated eolian sand mound that is probably a degraded dune formed by sand blown from lower Blanca Draw and the Grayton Lake surface (fig. 12). The eolian sand rests on a relict alluvial flat that is truncated along the northern margin of the lake, exposing the basin-fill strata (Q_{bfc}) (fig. 12). To the east, a similar relict alluvial flat (Q_{bf}) slopes beneath the lake surface.

Surficial Deposits of the Piedmont Slopes

Old Fan Deposits Q_{of}

Old fan deposits (Q_{of}) are characterized by well-developed pavements of pebbles and cobbles with well-developed varnishes and soils with stage III and stage IV calcic horizons. The old fans represent deposition over a long time, during which a succession of stable surfaces developed on the alluvial fans. On fans where several generations of geomorphic surfaces were readily identifiable, the old fan deposits were assigned relative stratigraphic names, with Q_{of1} being the deposits underlying the oldest geomorphic surface on a given fan and Q_{of2} and Q_{of3} representing deposits associated with successively younger geomorphic surfaces. Because the alluvial fans have developed at different rates, Q_{of1} and similar units may not be correlatable between adjacent fans. A deeply dissected surface on some fans was found to contain calcic soils similar to those found on undissected, and apparently younger, surfaces of adjacent fans. Therefore, the Q_{of1} and Q_{of2} designations are purely for reference within individual fans.

Because they cannot be correlated, the old fan subdivisions (Q_{of}) do not represent stratigraphic subdivisions correlative to established time intervals. However, the using comparison with the calcic soil stages derived from Machette (1985) and Gile and others (1981), all of the old fans (Q_{of}) are at least as old as the Arispe Surface in the basin floor (150,000–300,000 yr old). Some of the old fan deposits may be much older. The soils in the proximal parts of some fans in the Eagle Mountains are highly rubified. In these areas, the geomorphic surfaces may be as old as Pliocene or early Pleistocene.

The surfaces of the old fan deposits are loose pavements of pebbles and cobbles. Pebbles become smaller toward the toes of the fans and bajadas and abruptly disappear at the edge of the basin floor. The pavements are underlain by a loose, light gray silty sand. The upper 4 inches (10 cm) of these sediments is lighter colored and contains abundant small pebbles and caliche fragments. The lower part, extending to 2 ft (60 cm) below the surface, is darker and loamier. Below this is a stage III to IV calcic soil horizon within a coarse gravel. The typical gravels are moderately sorted and contain clasts as large as boulders. Beds are up to 3 ft (1 m) thick, and in some fans, gravel channels are inset into finer grained sand and muds.

The old fan deposits in the north Faskin Ranch area are found in the small bajada at Sand Mountain and the small alluvial fans along Front Ridge (fig. 13). Older fan deposits (Q_{of}) are also found in the large alluvial fan northwest of the repository site. The small bajadas near the proposed repository site are typified by the bajada surrounding Sand Mountain. The calcic horizon and gravel are exposed by bulldozing just south of Faskin Well (near YM-33 on fig. 3; fig. 13) and have been cored in several Bureau boreholes (Jackson and others, 1993).

Young Fan Deposits Q_{yf}

Young fan deposits are thin, rarely more than 9 ft (3 m) thick. Young fan deposits contain a high proportion of silt. Gravels in young fan deposits occur as well-defined channels and thin beds set within beds of silty sand and silt. Pavements are poorly developed, commonly with only a scatter of clasts on the surface that exhibit poor to moderate desert varnishes. Young fan surfaces are typically irregular, with many small rills and other surface wash features, and there is much evidence of recent local deposition and erosion. Soils are poorly developed, ranging from stage I calcic soils to incipient stage III calcic soils.

Unlike older fan deposits (Q_{of}), the younger fan deposits occur as well-defined landforms, and different episodes of younger fan (Q_{yf}) sedimentation are readily differentiable. Younger fans occur as both fan aggradation lobes, with well-defined feeder channels and teardrop-shaped lobes and also as inset valley fills and lobes, partially filling valleys incised into the older fan surfaces.

The young fans have been divided into two generations, based on the soil developed in the fan deposits, the stratigraphic relationships with other young fan deposits, and radiocarbon dates. Unlike the older fan deposits, the different generations of younger fan deposits have stratigraphic implications and are correlatable from fan to fan. It should be reemphasized that a generation of fan development may span a long time and is not defined by the dates of the fans themselves but by the establishment of a stable geomorphic surface on the aggregate deposits.

Units mapped as Q_{yf} are fans that were mapped only from aerial photographs; the degree of calcic soil development is uncertain. Also, Q_{yf} deposits include fans that could not be unambiguously related to either Q_{yf1} or Q_{yf2} deposits and that contained calcic soils that could occur in either generation of fans. Fans mapped as Q_{yf} due to lack of access are found northeast of the proposed site, partially filling a valley in the older fan surface north of the Interstate Highway (fig. 12).

First Generation of Young Fan Deposits Q_{yf1}

Typically the first-generation younger fans (Q_{yf1}) have steeper slopes and are nearer to the mountain fronts than associated second-generation fan deposits (Q_{yf2}). They are commonly more incised than Q_{yf2} fans, up to 7 ft (2.1 m), exposing the underlying older fan deposits (Q_{of}). Incised channels in first-generation fans (Q_{yf1}) feed lobes of second-generation fans (Q_{yf2}). Calcic soils in Q_{yf1} fans range from well-developed stage II to incipient stage III in which small areas of the matrix between clasts are massive calcium carbonate. In general, the silts and sands are darker and grayer than Q_{yf2} deposits. First-generation fans (Q_{yf1}) near the proposed repository site are found along Front Ridge, south of Rock tank (fig. 12). One radiocarbon date has been collected from a first-generation (Q_{yf1}) deposit at the southern end of Front Ridge, which has provided a minimum age of 9,400 yr for these deposits (sample RCFR2 in table 1; fig. 4 for location).

Second Generation of Young Fan Deposits Q_{yf2}

Second-generation fans (Q_{yf2}) are thinner and more widespread than first-generation fans (Q_{yf1}). Some of these second-generation fans (Q_{yf2}) are the best examples of fan aggradation lobes, separated from each other by exposures of underlying older fan and Q_{bf} deposits. The fans rest on older alluvial-fan deposits (Q_{of}) and basin-fill deposits (Q_{bf}), and at their proximal ends on first-generation alluvial fans (Q_{yf1}). Gravels form a patchy pavement within a matrix of sandy and silty deposits. In gullies and trenches, the gravels exist as 3-ft-deep (1 m) and 18-ft-wide (6 m) channels encased in finer younger alluvial fan (Q_{yf}) material. Gravels mantle lobes that form topographic highs within the fan deposits. No exposures have revealed second-generation fans (Q_{yf2}) to be more than 6 ft (2 m) thick. Second-generation fans (Q_{yf2}) exhibit stage I to incipient stage II calcic soil development.

Four radiocarbon dates were collected from second-generation fan deposits (Q_{yf2}) in the Eagle Flat Study Area, providing minimum ages ranging from 1,510 to 3,370 yr ago (samples RCEM2, RCRL1, RCSB1, and RCFR3 in table 1; see plate 1 and figs. 3 and 4 for locations). In the Faskin Ranch area, second-generation fans (Q_{yf2}) fans are found along Front Ridge, extending for about 1.5 mi (2.4 km) north and south of Rock tank (fig. 12).

Active Channel Deposits

These are deposits of active stream channels in which the sediment is mobile enough that vegetation is not well established. The active channel deposits (Ca) typically form in confined channels with steep eroded banks in which ephemeral streams are intermittently transporting and depositing sediment. These deposits include low, poorly vegetated terraces immediately above the active bed and unvegetated bars within the active bed of the channels. There are no active channel deposits in the immediate vicinity of the north Faskin Ranch. Active channels are most common on the large alluvial fans on either side of the Eagle Mountains (plate 3).

Active Fan Deposits

These are areas fed from active channels that contain poorly vegetated gravel bars, sand patches, and small rills (Fa). Lack of vegetation and soil cover are evidence of recent activity, as are dislodged and buried shrubs. These areas are distinguished from active channels by the lack of well-defined channels that confine flow. Numerous small, branching channels feed the depositional lobes in active fans. In the immediate area of the repository site, active fan lobes are found northwest of the Faskin Ranch, within the same incised drainage as the younger generation alluvial fans (Q_{yf}) (fig. 12).

Surficial Deposits of the Upland Areas

Much of the upland areas consist of bedrock, or bedrock covered by thin patches of regolith and residual soil. The most extensive areas of residual soil (Q_{rs}) in the uplands are found on areas of low relief, overlying easily eroded Cretaceous or Precambrian strata. The residual soil near the repository site is a thin to thick gray porous soil, with poorly expressed soil horizons. Residual soil (Q_{rs}) is light gray, consists of a gray sandy silt or silty clay in the soil B horizon, and covers a stage III to IV calcic soil horizon. The thin to thick, stage III to IV calcic soil horizon is locally exposed at the surface by erosion. The B soil horizon is thick, but as is typical of soils formed on calcic materials, is poorly developed. The soil is coarse grained and very poorly sorted, containing up to 30 percent granules, pebbles, and cobbles of residuum and caliche, and 20 percent silt and clay. There is no pavement in grass-covered areas and a poorly to moderately developed pavement in shrub-covered areas. In deeply eroded areas, the underlying calcic soil is exposed. A poor to moderately developed pavement, composed of angular monolithologic fragments, is present in patches. Areas of residual soil (Q_{rs}) are covered with diverse vegetation—grasses, creosote bush, and *Flourensia* are common.

Distribution of Surficial Deposits

Figure 12 shows the surficial deposits in the area of northern Faskin Ranch and the proposed repository site. The repository site itself sits on a broad relict alluvial flat, extending across the interstate to the north. To the southwest of Blanca Draw, this plain is floored by basin-fill strata (Q_{bf}). To the northeast of Blanca Draw, and including the area of the proposed repository site, are large areas of eolian sands (Q_{e1} and Q_{e2}). The slightly coarser grained younger generation eolian sands (Q_{e2}) are more prevalent farther east, away from Blanca Draw. The prevailing effective winds are from the west-southwest, and all of the eolian deposits are east-northeast of Blanca Draw, making Blanca Draw the most likely source for the Q_{e1} and Q_{e2} eolian sand. Erosion has exposed basin-fill deposits (Q_{bfc}) along Blanca Draw.

Wash-fill deposits are found in two drainage systems in the area of north Faskin Ranch. First is the Blanca Draw set of washes, which includes the fill of a subtle swale that extends from near Rock tank northeast to Blanca Draw. This swale is included with the more typical wash-fill deposits because of the similarity of its texture and the similar vegetation. The second drainage system runs along the eastern edge of the Streeruwitz Hills, surrounding several islands of old alluvial fan deposits. The wash-fill deposits eventually disappear near Williams tank, where it is buried beneath the encroaching younger generation eolian deposits (Q_{e2}). The eolian sand appears to have drifted across the wash, filling it with an irregular topography and creating an effective dam. A more substantial dam is the interstate, which diverts several drainages in the area of Williams tank. One small area of thin, newly deposited wash-fill (Q_w) has been formed by the diversion of surface wash into a culvert southeast of the tank. A second area of probable wash-fill deposits has been formed by diversion through culverts beneath the interstate, just east of the eastern fence-line of Faskin Ranch and just south of the interstate (fig. 12).

Bedrock is exposed along the low hills south of Blanca Draw, and at Front Ridge and Sand Mountain along the western edge of the map (fig. 12, plate 3). A large area of residual soil (Q_{rs}) occurs south of Blanca Draw because of the easily eroded Cretaceous Espy and Buda strata that underlie this area.

Old alluvial fans are found at Sand Mountain, and along Devil Ridge, but the largest area of older alluvial fans (Q_{of}) is the large alluvial fan northeast of Faskin Ranch. Two generations are evident in this area. An older geomorphic surface defines a set of deeply incised fans near the

Streeruwitz Hills and Eagle Flat Mountain, off the eastern edge of figure 12 (plate 3). The second set of alluvial fans (Q_{of2}) extends across the interstate toward Grayton Lake along the eastern edge of figure 12. The fan surface contains a set of shallow longitudinal valleys, cut into the depositional surface of the older fan and these are partially filled with younger alluvial fan (Q_{yf}) and active fan (Fa) deposits. The thin younger alluvial fan deposits (Q_{yf}) cannot be traced across the interstate. Either the deposits are absent here or the interstate has so influenced surface wash and the resulting vegetation that the deposits are not recognizable on aerial photographs.

Erosional Features and Rates of Erosion

Introduction

Scales and Processes of Erosion

Describing erosion and aggradation is complicated because the effects of different erosional and aggradational processes that occur at various rates may be superimposed. For example, at a given location on an alluvial fan, a period of aggradation lasting millions of years may be punctuated by periods of erosion lasting 10,000 to 100,000 yr. In turn, the erosional periods may be interrupted by periods of deposition lasting hundreds to thousands of years. Even shorter periods of erosion and deposition may be superimposed onto the above-described pattern. Additionally, different landforms may experience different processes and therefore exhibit different rates and patterns of erosion. Areas that aggrade during moderate precipitation events may be eroded during more intense events. For example, Lehre (1982) discovered that within one small basin near San Francisco, sediment was eroded from high-relief areas during dry years but was stored in low-relief areas, which underwent aggradation. High-precipitation events, however, resulted in erosion along the main channel and throughout the basin.

The erosional processes that may affect a waste repository with an anticipated life of 500 yr are those in which the total erosion would be enough to influence the integrity of the disposal facility. Total erosion is defined as the duration of the erosional episode multiplied by the average rate of erosion during this time. Erosion can also pose engineering problems during construction due to gullying of the trench walls and resulting sedimentation on the trench floors while a trench is exposed. Therefore, even a high rate of denudation will not produce significant erosion when the duration of erosion events is very short, unless several of these events are superimposed so that the erosion is additive. Alternatively, a slower rate of erosion that continues for a long time may produce a significant amount of total erosion.

Erosional Processes

Erosional processes in arid regions such as Eagle Flat Basin can be divided into three classes, (1) eolian (wind) erosion, (2) processes associated with unchannelized flow, and (3) processes associated with channelized flow.

On a typical hill, different types of erosion are restricted to different parts (Gilbert, 1877; Horton, 1945). At the top of a hill, the slope is convex, and erosion occurs through *rainsplash* and sheetwash runoff (Horton, 1945; Schumm, 1956; Ritter, 1978). Rainsplash is the movement of soil particles by impacting rain drops (Ritter, 1978). Farther down the slope, runoff is channelized into *rills*, which are small channels only a few centimeters wide and deep that carry runoff down the slope (Young, 1972). Rill erosion is initiated when accumulated runoff volume and slope angle exceed a critical value. This location is marked by a change from a convex slope to a concave slope (Dunne, 1980). Rill erosion is most common on slopes with limited soil development and sparse vegetation, such as those in arid and semiarid environments (Ritter, 1978) like the Eagle Flat Basin. Left alone, rills will progressively deepen and enlarge through headward erosion (Ritter, 1978). Deeper and wider rills develop on the longest slopes and will eventually merge into gullies and small streams (Ritter, 1978).

Gullies are narrow channels in soft rock or unconsolidated material through which water runs only following precipitation events (Bates and Jackson, 1980). Gully and rill erosion take place though three primary processes, (1) headward erosion, (2) gully (or rill) deepening, and (3) gully widening and lateral migration. Gullying is an important type of erosion in the southwestern United States because relatively deep erosion may occur relatively rapidly (Schumm, 1977). Schumm (1977) has demonstrated that gullies are initiated only where the slope exceeds a critical value.

Many factors may affect the resistance of the surficial sediment to erosion. The most important of these are (1) composition and grain size of the surficial material, (2) vegetation, and (3) human activity. Because runoff is initiated when rainfall exceeds infiltration capacity, erosion is greater on clayey or silty soils where infiltration capacities are lower (Hadley and Schumm, 1961). Vegetation resists erosion because it interferes with runoff flow and binds sediment with roots. Human activity is known to significantly increase erosion (Judson, 1968) through removal of protective vegetative cover and through modification of runoff characteristics (Ritter, 1978).

Erosional Features at Faskin Ranch

The Arispe Surface and Erosion of the Blanca Draw Drainage System

The modern floor and piedmont slopes of Eagle Flat Basin are largely composed of the relict depositional surfaces that formed during the middle and late Quaternary. The piedmont surface is dominated by several surfaces beneath which stage III or stage IV calcic soils have developed. The basin floor is largely the *Arispe Surface*. At Faskin Ranch, a soil has developed on the Arispe Surface that contains a stage II to III carbonate horizon. This is in sharp contrast to upland areas in which exposed bedrock and only small patches of soil predominate. Erosion in the upland areas generally exceeds the rate of soil formation, whereas in the basin floor and piedmont, the rate of soil formation exceeds, or is in balance with, the rate of erosion.

One radiocarbon date from 6.2 ft (1.9 m) below the Arispe Surface in trench 17 is radiocarbon dead and indicates that the Arispe Surface and its soil have minimum ages of 30,400 yr (sample RCFR9 in table 1, location on plate 1 and fig. 3). The most significant erosion of the Arispe Surface has been the incision of the dendritic network of Blanca Draw (figs. 10 and 12). Borings, borrow pits, and tanks within the washes provide exposures and supporting data that indicate that the washes were incised from 10 to 25 ft (3 to 7.6 m) into the Arispe Surface. Following incision, the washes were refilled with 0 to 20 ft (0 to 6.1 m) of wash-filling deposits. Radiocarbon dates from the uppermost wash-fill deposits indicate that the wash floors had aggraded to almost their present level prior to 2,000 to 4,000 yr ago (samples RCFR1, RCCD1, and RCCD2 in table 1).

Outside of the Blanca Draw Drainage System, the Arispe Surface shows little evidence of fluvial erosional processes. No channels, rills, or other fluvial erosional features are evident on the surface (fig. 27). We conclude that little erosion has occurred since stabilization of the Arispe Surface on the interfluvial flats because the calcic soil horizon has required more than 30,400 yr to form (sample RCFR9 on table 1) and probably formed 150,000 to 300,000 yr ago (see tables 2 and 3), and because the soil and included carbonate horizons were encountered at shallow depths in every core (Jackson and others, 1993) and in every trench on the interfluvial flat.

Active Erosional Features

As opposed to the relict erosional features of Blanca Draw, the only active erosional processes in the Eagle Flat Study Area are (1) incision of gullies on alluvial fans in the upper piedmont, (2) erosion of gullies within the wash-fill deposits, (3) erosion of wash-flank slopes forming rills, scarplets, and small gullies, (4) eolian erosion of the eolian deposits (Q_{e1} and Q_{e2}), and (5) erosion associated with artificial features. Of these features, the gullies on alluvial fans are restricted to the upper parts of alluvial fans, and the gully erosion in the washes and eolian

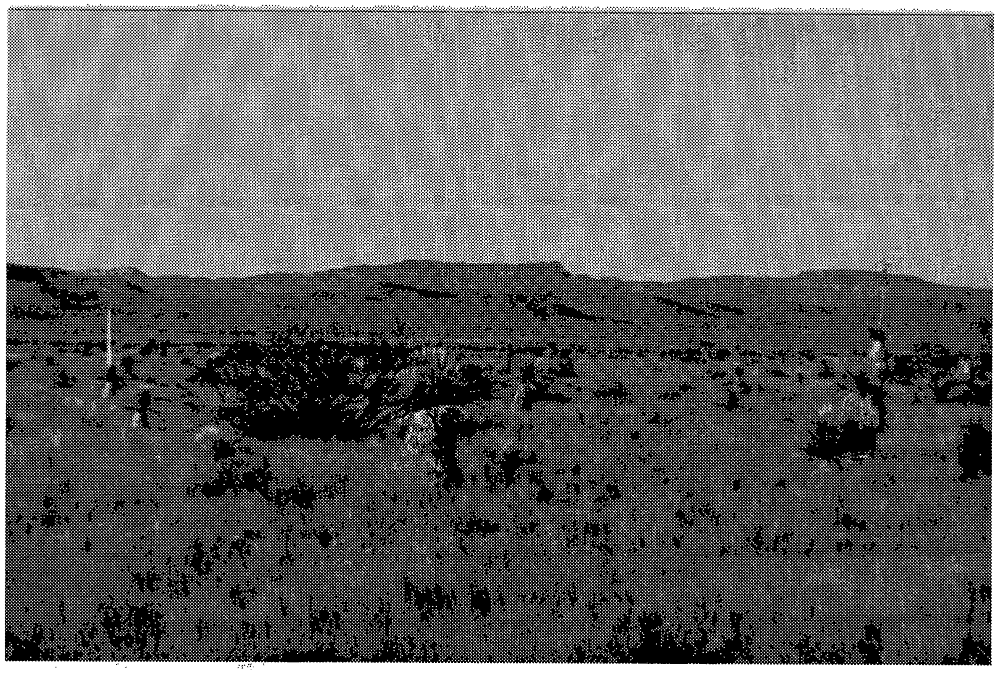

Figure 27. Photograph showing the appearance of the Arispe Surface at the repository site looking west. For location of Ranch boundary, compare with figure 9.

erosion is restricted to their respective units and does not penetrate the Arispe Surface or underlying sediments. Figures 28 and 13 show the locations of erosional features in the northern part of Faskin Ranch.

Gullies on Alluvial Fans

By far the largest part of the piedmont areas in northwest Eagle Flat and on Faskin Ranch are uneroded and exhibit no gullies. Small drainages, such as those on the slopes of Sand Mountain, have produced no erosion, and the piedmont surface is underlain by a soil containing a well-developed calcic horizon. Alluvial fans fed by larger drainages, such as those that drain longitudinal valleys in Devil Ridge, exhibit gullies in their proximal portions. Erosion has not penetrated the soil developed on the Arispe Surface except in the higher, proximal parts of the alluvial fans.

Figure 13 shows the locations of gullies on north Faskin Ranch. The most prominent gullies on the ranch are north and west of Rock tank (fig. 13) and west of Mac and New tanks (fig. 29). The gullies west of Rock tank are as much as 6 ft (2 m) deep and penetrate the top of the stage IV calcic soil horizon associated with the Sand Mountain piedmont surface. The gullies are also incised into the second generation of younger alluvial fan deposits (Q_{yf2}), which in this area overlie the older alluvial fan (Q_{of}) surface. The Q_{yf2} deposits in this area are at least 3,372 yr old (corrected age; see table 1), providing an estimate of the maximum age for initiation of the gullying. Some of the gullies in this area are associated with fences constructed before 1953. These culturally induced gullies are likely 40 yr old or younger. If a 40 yr age can be assumed for initiation of the gullying along the fences, then the rate of incision is 2 inches (5 cm) per year. Because gullying may not have initiated until some time after fence construction, this should serve as a minimum erosion rate.

West of Mac and New tanks is another area with gullies. Gullies here are incised up to 7.6 ft (2.5 m) into first-generation younger alluvial fans (Q_{yf1}) and up to 2.46 ft (0.75 m) into

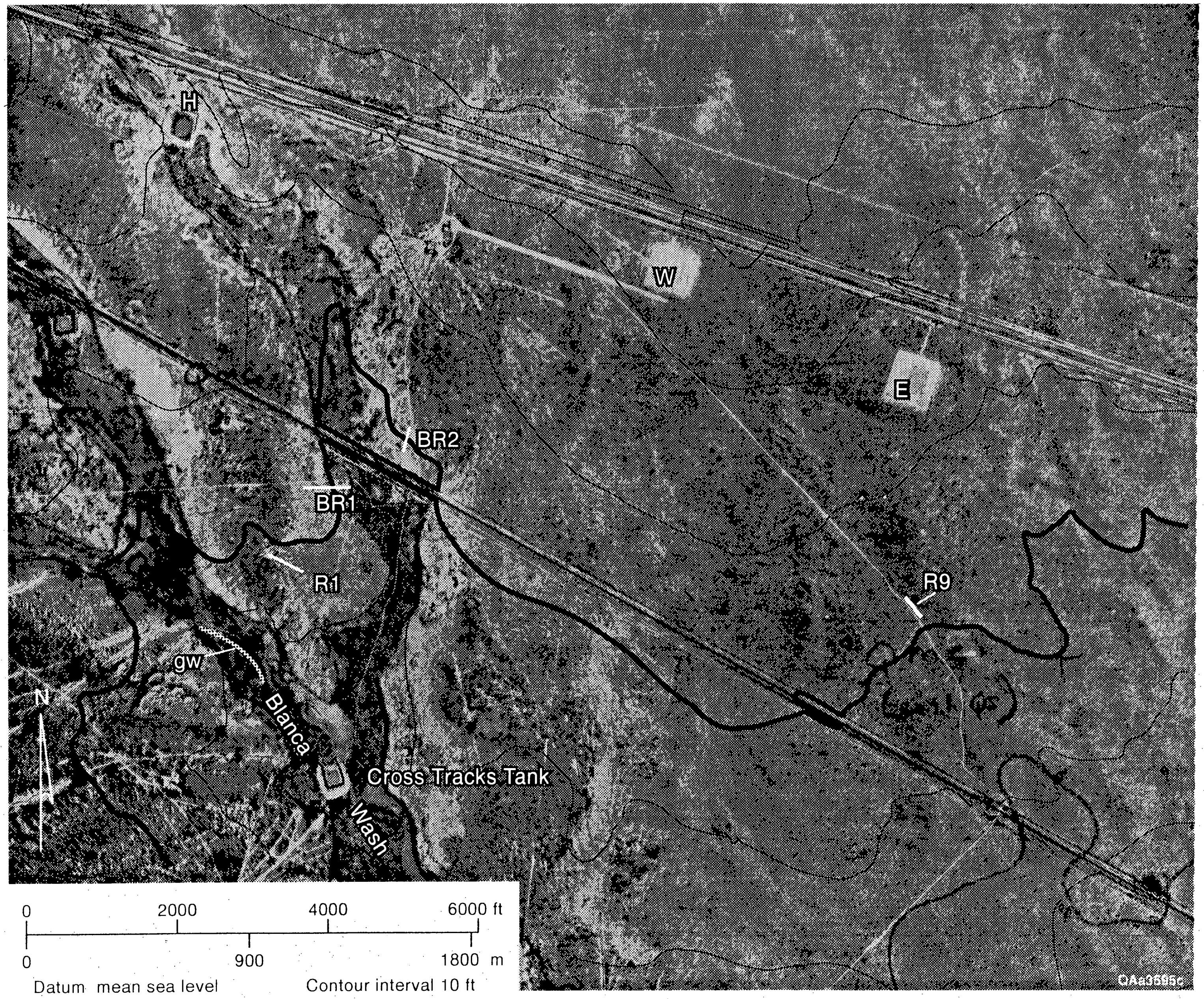

Figure 28. Aerial photograph of proposed repository site with topographic contours and locations of erosional features. The gully in the bottom of Blanca Wash is shown as (gw). The Hoover (H), West (W), and East (E) borrow pits are shown. The sites of erosional measurements of roads are shown as R1 and R9, as they are labeled in table 5. BR1 and BR2 show where erosion on the roads has penetrated the calcic soil horizon. The location of the figure is shown in figure 4.

Figure 29. Aerial photograph of southern Faskin Ranch showing Mac and New tanks. The circles outline areas in which gullies are found in Red Hills Arroyo and in proximal alluvial fans along Front Ridge. The location of the figure is shown in figure 4.

second-generation fans (Q_{yf2}). The gullies extend to bedrock and into the top 12 inches (30 cm) of the thick calcic soil underlying the Sand Mountain surface. These gullies are not associated with fences or roads and therefore their ages are poorly constrained. A radiocarbon age of approximately 9,400 yr ago in the first-generation younger fan deposits (Q_{yf1}) provides a maximum age for initiation of the gullying (RCFR2 in table 1). Tongues of second generation of younger fans (Q_{yf2}) radiate from the gully mouths in the first-generation fans (Q_{yf1}). These gullies have obviously served as feeders for the Q_{yf2} deposits and therefore must have been at least partly incised by at least 1,000 to 4,000 yr ago, the minimum age of the second-generation fans (Q_{yf2}) (RCEM2 in table 1). The second-generation fan deposits (Q_{yf2}) are in turn incised, indicating that undated gully erosion has continued, probably episodically to the present.

In summary, relatively rapid gullying has occurred in the proximal parts of the alluvial fans that are fed by larger drainages. Gullying rates of at least 2 inches/yr (5 cm/yr) are possible in these areas. However, no gullying has been encountered in the lower, distal part of the piedmont or on alluvial fans with smaller catchments.

Gullies in Wash-Fill Deposits

One gully is present in the wash-fill deposits of Blanca Draw on Faskin Ranch, northwest of Cross Tracks tank (gw, fig. 28). Figure 30 illustrates the dimensions of the gully, which is 605 ft (184 m) long and averages 42 ft (12.7 m) wide. The gully is formed entirely within the fine-grained wash-fill deposits and consists of dendritic tributary gullies feeding a sinuous axial gully that eventually decreases in depth and delivers water back onto the flat wash floor. Analyses of aerial photographs indicate that while gullies are commonly present in this part of the draw, individual gullies are somewhat ephemeral. Different parts of the draw are gullied in 1991, 1980, and 1953, aerial photographs (fig. 31). Additional gullies are present in washes, associated with tanks and borrow pits. These will be discussed below in the section on erosion associated with cultural features.

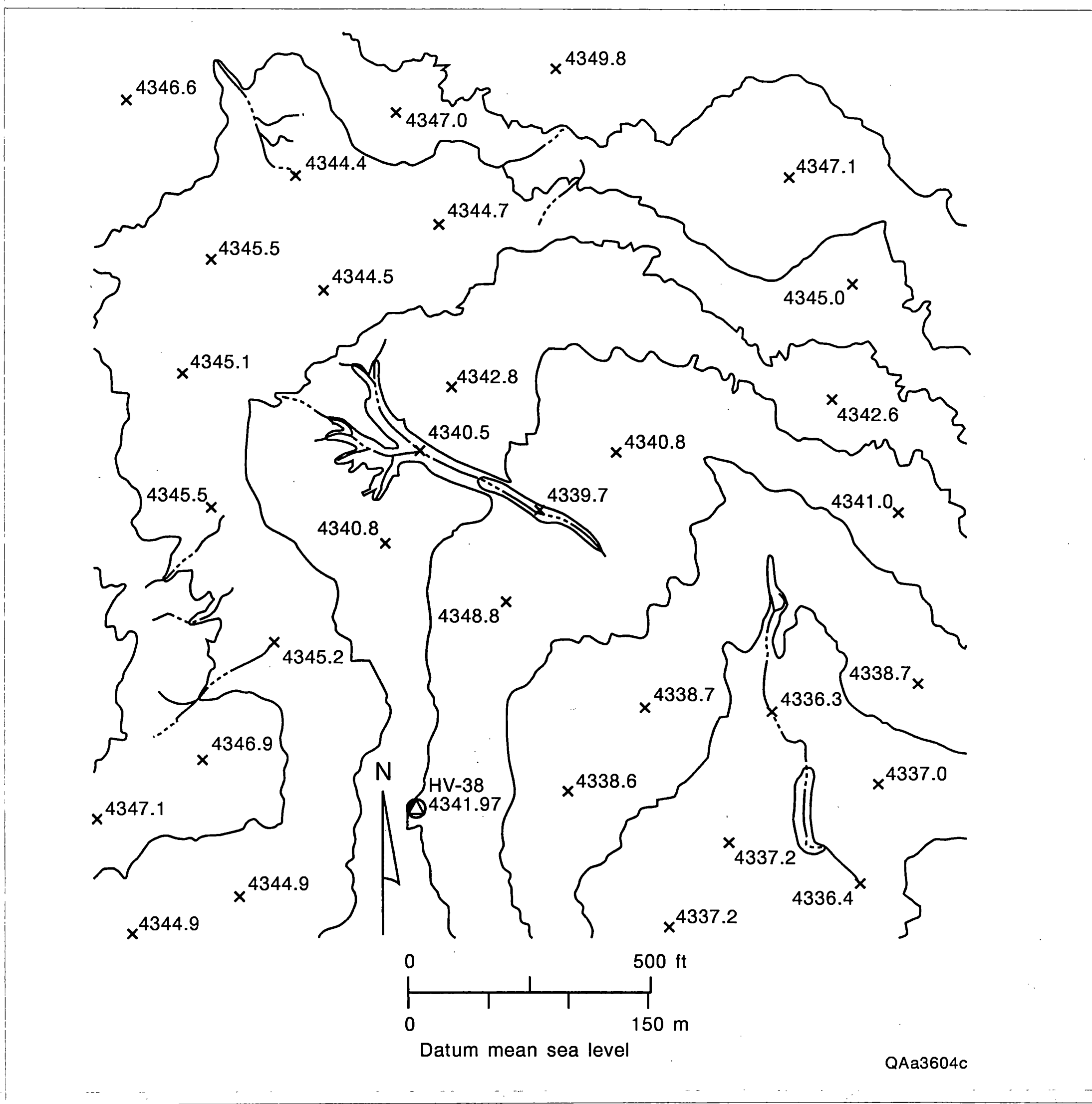

Figure 30. Detail of the 2 ft (0.6 m) topographic contour map of Faskin Ranch showing the gully present in Blanca Draw northwest of Cross Tracks tank. The location is shown in figure 28 and plate 1.

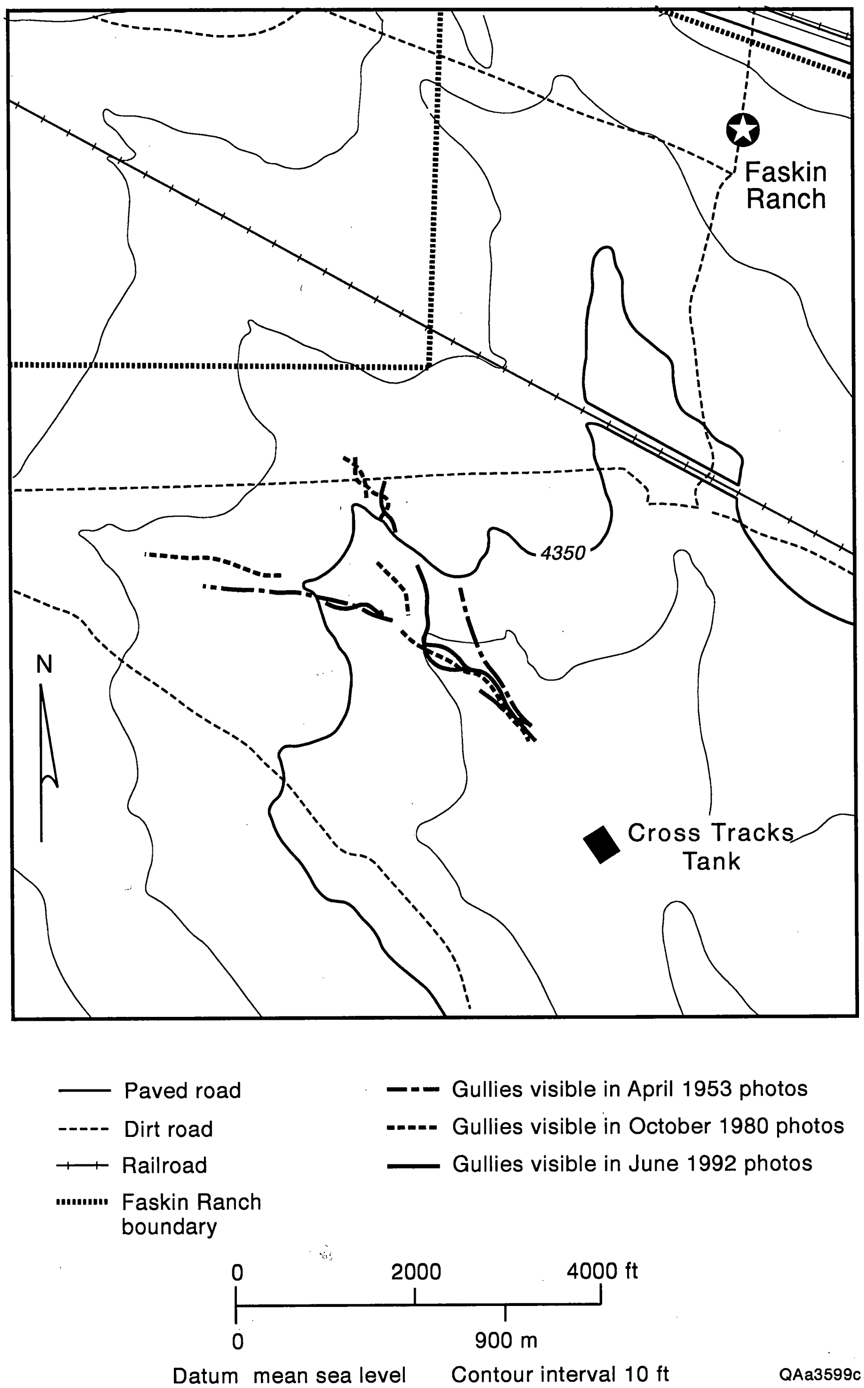

Figure 31. Detail of the 10 ft (3 m) topographic contour map of Faskin Ranch illustrating the gullies visible on the 1991, 1980, and 1953 aerial photographs. The location is shown in plate 1.

Erosion on Wash-Flank Slopes

Erosion on wash-flank slopes occurs as well-defined areas containing rills and scarplets. A few short gullies occur where cultural features, roads, or cattle paths cross the wash-flank slopes. The following section describes the erosion on the wash-flank slopes and describes the scarplets, which are unusual erosional features.

Scarplets

Scarplets consist of crescentic erosional scarps, 4 to 12 inches (10 to 30 cm) high, that open downslope and enclose a poorly vegetated or unvegetated fan-shaped area in which erosional features such as rills are evident. I refer to the poorly vegetated area of the scarplet as the *glacis*. I have not yet determined the processes that initiate scarplet erosion, but sediment is evidently sapped from the scarplet face washed across the barren, fan-shaped area and deposited in grassy areas at the toes of the glacises. Sediment derived from the scarplets is being deposited within the adjacent parts of the washes. Pebbles and cobbles litter the surface of the glacis. These are believed to be residual lags resulting from erosion of the pebbly sediment underlying the glacis. In some areas the glacises are covered by cobble pavements. In these areas, the glacises were found to be underlain by gravel-rich sediment.

The lengths, widths, and depths of 21 scarplets were measured, 7 in each of 3 scarplet areas. Width was defined as the widest point within the scarp crescent. The length is defined as the longest distance from the scarp to the cord along which the width was measured. Depth was measured by stretching a line along the uneroded slope above the scarplet to determine the normal slope. The depth was measured by extending the line across the scarp and finding the deepest point beneath the line. Therefore, the depth measured is not the lowest topographic point in the scarplet but the greatest depth of erosion from the normal slope.

Most scarplets open in a downhill direction and are oriented perpendicular to the local slope. Scarplets have hyperbolic size distribution, with many more small scarplets than large ones. The geometric mean of the scarplet widths is 11 ft (3.4 m), and the geometric mean of the lengths is 8.1 ft (2.5 m). The largest scarplet we measured is 107 ft wide (32.6 m) and 51 ft long (15.5 m), and the smallest scarplets are 6 ft wide (1.8 m) and 4.8 ft (1.5 m) long. The ratio of width to length is consistent throughout the entire size range with widths approximately 1.5 times the lengths. The scarplets are only shallowly eroded, with depths ranging from 0.5 ft (15 cm) to 2.5 ft (77 cm). The average depth of erosion was 1.4 ft (43 cm).

Scarplets are restricted to the basin floors. Within Faskin Ranch, scarplets are restricted to the wash-flank slopes, and similar slopes flanking Grayton Lake. In aerial photographs taken in 1953, 1980, and 1992, areas with scarplets are visible (fig. 32). The visible areas are almost identical in all three photographs, indicating that the areas in which scarplets occur have not changed in the last 40 yr. Earlier maps of scarplets are not available, but their current restriction to wash-flank slopes indicates that there is a geomorphic control on scarplet formation.

Rills are associated with the scarplets in some areas, predominantly in areas in which there has been some cultural disturbance by humans or cattle of the wash-flank slopes. The rills are shallow (less than 12 inches [30 cm] deep) and cut through the associated scarplets. Some scarplet orientations seem to be controlled by the rills. The scarplets appear to open obliquely toward the rills rather than directly downslope.

Eolian Erosion

Areas of bare sand, wind ripples, and roots exposed below plants from which sand has been moved are evidence of eolian erosion. Significant eolian erosion is confined to the eolian sand sheet and dunes of the eolian sand (Q_{e1} and Q_{e2}) surficial deposits. Figure 33 shows the appearance of one typical site of eolian erosion. Several small locations on Faskin Ranch exhibit features associated with eolian erosion. The more prominent of these sites are located in figure 28. The proposed repository site is covered with a sheet of eolian sands (Q_{e1} and Q_{e2}) that is 0 to 6 ft (0 to 2 m) thick. One of the areas exhibiting eolian erosion is found on the

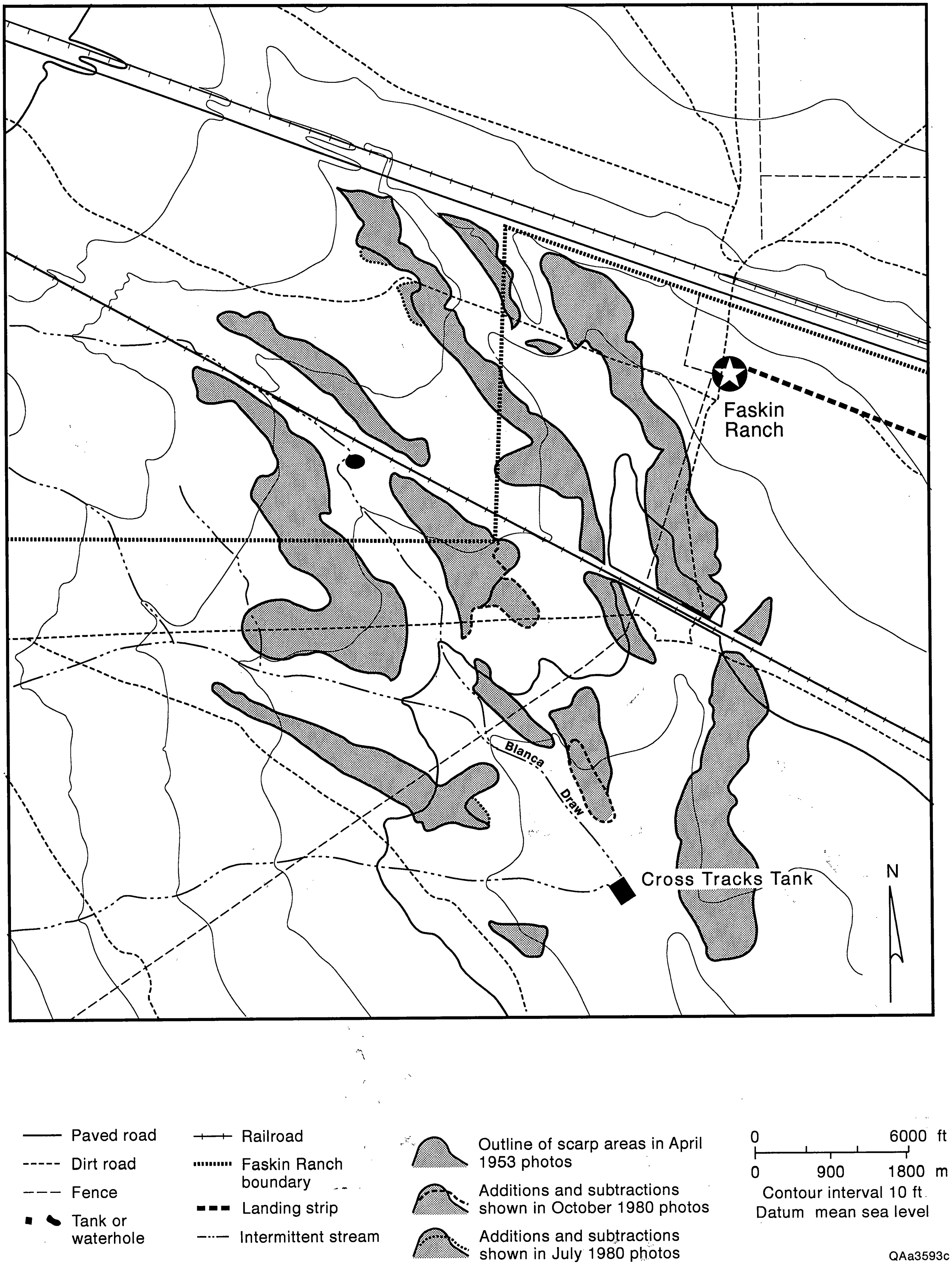

Figure 32. Map showing the distribution of scarplets in the areas nearest the proposed repository site, along with the changes in these areas between 1953, 1980, and 1992.

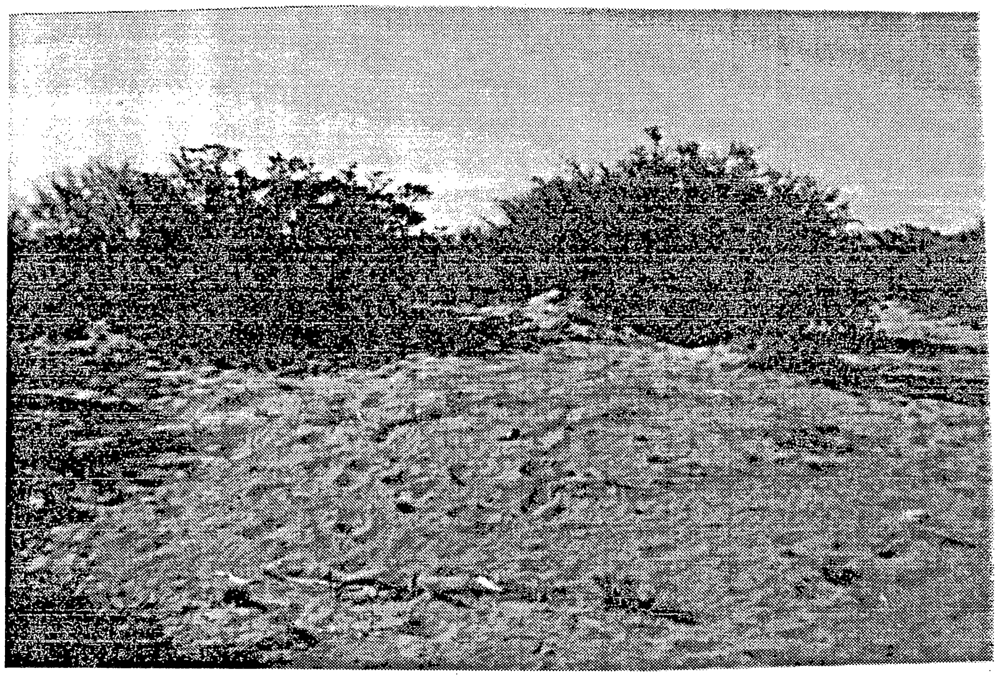

Figure 33. Photograph showing the surface characteristics at an area of eolian erosion.

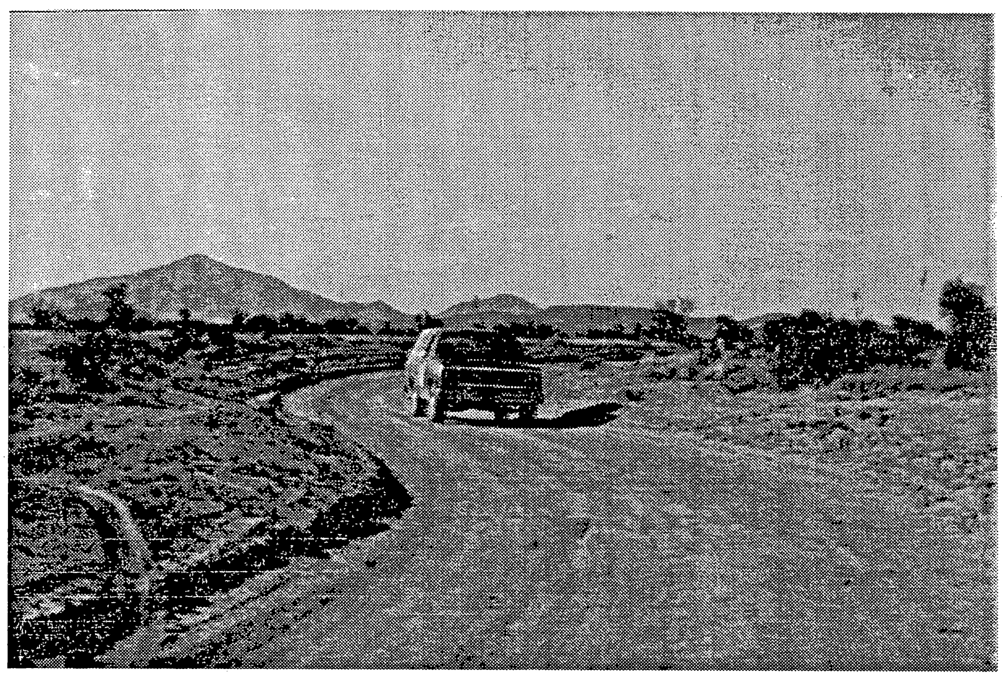

Figure 34. Photograph showing 5 ft (1.5 m) of eolian erosion along Road 9 through the proposed repository site. Location is shown in figure 28 (R9).

southeast corner of the proposed repository site (fig. 28; road 9 on table 5). It proved impossible to quantify the eolian erosion of these sites, because they do not lie much further below the rest of the vegetated eolian sand sheet surface (Q_{e1} and Q_{e2}). In fact, eolian erosion seems to be significant only in areas of recent eolian deposition where coppice dunes have produced topographic highs and the eolian deposits are poorly vegetated. Much deeper eolian erosion can occur where the surface of the eolian sand sheet has been disturbed by cultural activities. When the vegetation that binds the eolian sand together and protects it from erosion is removed, the eolian sand deposits (Q_{e1} and Q_{e2}) may be quickly reworked by the wind. The eolian surficial deposits (Q_{e1} and Q_{e2}) have locally been removed from the main road that crosses the proposed repository site (fig. 34). At one location this has resulted in erosion up to 5 ft (1.5 m) deep into Q_{e2} deposits. No erosion below the base of the eolian sand deposits (Q_{e1} and Q_{e2}) was observed on these roads.

Erosion Associated with Cultural Features

Within the Chihuahuan Desert, construction of roads, fences, embankments and pits is commonly associated with erosional features. The surface of the desert is fragile, and when it is disturbed by human activity, an episode of erosion may be initiated. When the vegetation is removed, the soil, no longer bound by roots, is subject to erosion down to the indurated calcic horizon. Disturbing the surface in areas where a desert pavement has developed may also remove the layer of pebbles that protects the underlying soil from erosion. When steep slopes are created through digging pits or building embankments, slope wash or slope failure may occur. The desert surface may be disturbed when fences are constructed. The desert is also disturbed along fence lines where cattle create paths. Erosion is also commonly associated with roads, which in some parts of the desert may be deeply gullied.

Table 5. Erosional features on northern Faskin Ranch.

Road no.	Depth of erosion (cm)	Surficial deposit	Year of oldest map or photograph on which road appears	Maximum average rate of erosion (cm/yr)
1	37	Q_{bfc}	1953	0.925
2	49	Q_{bf}	1953	1.225
3	20	Q_{bf}	1980	1.538
4	10	Q_{bf}	1980	0.769
5	0	Q_{bf}	1980	0
6	50	Q_{bf}	1980	3.846
7	15	Q_{of}	1980	1.154
8	20	Q_{of}	1953	0.500
9	150	Eolian (Q_{e2})	1953	3.75

Fence no.	Depth of erosion (cm)	Surficial deposit	Year of oldest map or photograph on which fence appears	Maximum average rate of erosion (cm/yr)
1	0	Q_{bf}	1953	0
2a	0	Q_{of}	1953	0
2b	150	Q_{yf}	1953	3.75

Borrow pits	Depth of erosion (cm)	Surficial deposit	Year of oldest map or photograph on which borrow pit appears	Maximum average rate of erosion (cm/yr)
Hoover Pit*	40	Q_{bfc}	1964	1.3
Hoover Pit*	900	Q_w	1964	31.0
West Pit*	40	Q_{bfc}	1964	1.3
East Pit*	40	Q_{bfc}	1964	1.3
	Length and depth of gully (m)			
Gullies in Hoover Pit*	150 × 3 ft	Q_w	1964	
	73 × 2.7	Q_w		
	67 × 2	Q_w		

* Depth estimated from 2-ft (0.6 cm) contour map

Erosion Associated with Roads and Fences

Nine roads and two fences within the boundaries of Faskin Ranch were studied for erosion. The most deeply eroded areas on each road were selected in order to obtain maximum erosion rates for each road or fence. The depth of erosion was measured at 10 locations in the deepest gullies, with erosion measured from the closest vegetated and undisturbed surface; averages of the 10 measured depths of erosion for each road are presented in table 5. Erosion of the basin-fill material at the Arispe Surface ranged from 0 to 18 inches (0 to 50 cm). Erosion of eolian sand and alluvial fan sediments was much greater but was restricted to proximal fan areas and areas of eolian sand cover (Q_{e1} and Q_{e2}). There was no significant difference between the depth of erosion of older roads, such as the road to Faskin Well (Road 1, fig. 28), and the erosion of newer roads. The only places where the calcic soil of the Arispe Surface was penetrated were where roads crossed the wash-flank slopes of Blanca Draw in the area of the Southern Pacific Railroad (BR1 and BR2, fig. 28).

Erosion in Borrow Pits

Two borrow pits were constructed on Faskin Ranch between 1961 and 1964. An additional pit was constructed on the Hoover property to the west of Faskin Ranch. We have informally designated these pits the East, West, and Hoover pits (E, W, and H, fig. 28). The East and West pits were cut through the eolian sand sheet (Q_{e1} and Q_{e2}), through the Arispe Surface and soil (Q_{bf}), and into the underlying basin-fill deposits (Q_{bfc}). The Hoover pit lies partly in Blanca Draw and was cut partly through the Arispe Surface and basin-fill deposits, and partly through the wash-fill deposits in the draw. The East and West pits are 5 to 10 ft (1.5 to 3 m) deep, depending on the elevation of the surrounding terrain, and the walls have slopes with gradients of 0.08 to 0.05 (2.9 to 4.5 degrees). The Hoover pit is deeper (14 to 18 ft; 4.2 to 5.5 m) and the walls are steeper, with gradients of 0.12 to 0.16 (6.8 to 9.1 degrees).

All the pit walls excavated into basin fill material exhibit little erosion. Rills or small gullies, up to 1 ft (0.3 m) deep extend down the pit walls, but erosion has not significantly widened the pits (plate 1). In contrast, those portions of the Hoover Pit walls that are cut into wash-fill deposits have undergone extensive erosion. The north pit wall has receded approximately 30 ft (10 m), and three gullies, the largest 460 ft long (140 m) and up to 16 ft deep (4.9 m), are incised into the walls of the pit. The largest gully is located where the flow from upper Blanca Draw is focused into the pit, providing impetus for erosion.

Landscape Development in the Faskin Ranch Area

The landscape in the vicinity of the Faskin Ranch is a composite formed by the gradual aggradation and expansion of the basin floor. At different times different portions of the landscape stabilized and were preserved as recognizable suites of landforms beneath geomorphic surfaces. Because of the slow rates of deposition and erosion in this area, few distinct geomorphic surfaces are evident, and we have recognized only the Arispe Surface, in the basin floor of northwest Eagle Flat Basin. Deposits younger than the Arispe Surface have been mapped and can be recognized throughout the Eagle Flat Study Area. The deposits as old as or older than the Arispe Surface have been grouped as older deposits, although these deposits formed over a long span of time and, in fact, probably contain elements of many geomorphic surfaces.

The oldest parts of the landscape in the area of the Faskin Ranch are the Cretaceous bedrock hills south of Blanca Draw and in Devil Ridge (fig. 12, plate 3). These represent remnants of bedrock highs that once formed the margin of a smaller basin floor located in the northern part of Faskin Ranch and north of the interstate (Jackson and others, 1993). Gradual aggradation during the last 12 m.y. has stranded bedrock hills such as Sand Mountain within the basin floor. A thick residual soil (Q_{rs}) has formed on the lower relief parts of the bedrock highs (fig. 12).

During the Pliocene and Pleistocene, the basin floor and alluvial fans episodically aggraded. Because deposition was more rapid on the basin floors than piedmonts, the level of the floors gradually rose, burying distal piedmont slopes and bedrock highs (Jackson and others, 1993). Approximately 780,000 yr ago Grayton Lake was established in its present location. Before 780,000 yr ago, Grayton Lake was probably located north or west of its present location, still within the northwest Eagle Flat Basin. Deposition in the north part of northwest Eagle Flat has created a south-sloping basin floor. Gradual aggradation of the basin floor would shift the lowest elevation in the floor to the south (fig. 12, plate 3).

Alluvial fans and bajadas, shed from the bedrock highs, are probably the next youngest features in the area (fig. 12). The exposures of thick stage IV calcic soils suggest stabilization of parts of the aggrading alluvial fans, at some time before stabilization of the basin floor. Over a period of time, the bajadas and alluvial fans along Sand Mountain and Front Ridge, as well as the large fan extending north from Williams tank, were stabilized. At some time after deposition ceased, shallow valleys were incised in the large fan near Williams tank. No valleys were excavated on the alluvial fans fronting Sand Mountain and Front Ridge.

As deposition slowed and the alluvial fans stabilized, the basin floor continued to aggrade through the accumulation of axial channel sands and floodplain muds deposited on the alluvial flats. Deposition continued until some time between 150,000 to 300,000 yr ago when deposition ceased and the Arispe Surface formed over much of the basin floor as it stabilized. The timing of the formation of the Arispe Surface is based on assumed rates of calcium carbonate accumulation (table 2). By 300,000 yr ago the floor of Grayton Lake was approximately 10 ft (3 m) below its present level, and a large unincised alluvial flat occupied most of the basin floor (Jackson and others, 1993).

At some time, after 150,000–300,000 yr ago and before 16,480 yr ago, the Arispe Surface was incised, creating the dendritic Blanca Draw drainage network. Incision created valleys up to 35 ft (10.7 m) below the surface of the alluvial flats. The alluvial flats, however, were left largely uneroded as a relict landform, and subsequent fluvial deposition was concentrated in the wash valleys and Grayton Lake playa. The washes were gradually filled with coarse-grained sediment from the Blanca Draw drainage and fine-grained sediment derived both down Blanca Draw and the adjacent alluvial flats. A radiocarbon sample taken from snail shells from the lower parts of the wash-fill deposits provides an approximate age of 16,480 yr ago (sample RCFR7 in table 1; location in plate 1 and fig. 3). Radiocarbon dates from the upper part of the wash-fill in Hoover tank (sample RCFR1 in table 1; location in plate 1 and fig. 3) indicate that the washes were largely filled by 2,350 yr ago.

On the piedmont slopes, small alluvial fans were deposited along Front Ridge before 9,400 yr ago. The older fans and the soil developed on the stable older fan surface were buried by the younger fans (Q_{yf1}). The fans were stabilized, and a soil began to develop in the fan sediment. A second, more widely distributed generation of alluvial fans was deposited on both the older fan surface and on the first generation of alluvial fans (Q_{yf2}). These fans are found west of Blanca Draw, north and south of Rock tank, and form a thin veneer on the basin-fill sediment (Q_{bf}) and on the older alluvial fan surface (Q_{of}). During either or both of these piedmont depositional episodes, similar young alluvial fans were deposited northwest of Faskin Ranch in shallow valleys cut into the older fan surface.

The most recent depositional event is the development of eolian sand sheets and dunes on the relict Arispe Surface, northeast of Blanca Draw. Two eolian deposits have accumulated, defined by a soil developed in the older eolian sand deposit (Q_{e1}). These deposits are undated but are assumed to be no older than a few thousand years because of the poorly developed soils. Additionally, active eolian deposition and erosion continue on the younger Q_{e2} eolian sand sheet surface, demonstrating that it is at least in part a recent deposit. The sediment in the wash floors must be, in part, due to continuous deposition through the present. Additional active areas of deposition are found in the active fan area (Fa) northwest of Faskin Ranch.

SURFICIAL DEPOSITS OF THE EAGLE FLAT STUDY AREA

Outside the immediate area of north Faskin Ranch and the proposed repository site are numerous features that illustrate aspects of the landscape evolution in the Eagle Flat Study Area. The surficial deposits of the Eagle Flat Study Area are presented in plate 2 and explained in table 2 and appendix A.

Northwest Eagle Flat Basin

Northwest Eagle Flat Basin is characterized by a wide, north-northwest elongate, basin floor. Piedmont areas are restricted to alluvial fans along Flat Mountain, the Blanca Peaks, Sand Mountain, the southern Streeruwitz Hills, and Devil Ridge. There are no piedmonts developed along the Diablo Plateau and the northern Streeruwitz Hills. Extensive uplands are evident to the south of the basin, along the drainage divide between the Eagle Mountains and Devil Ridge.

The basin floor is dominated by three surficial deposits. The largest part of the basin floor is an extensive relict alluvial flat (Q_{bf}) covering the northern and western parts of the basin. Two branches of Blanca Draw are incised into the basin floor. One extends through the town of Sierra Blanca and drains the southern Blanca Peaks along with the Bluff Mesa–Sand Mountain area. This wash is incised all the way to its head. A second branch drains the northern part of the northwest Eagle Flat Basin. This wash drains the northern Streeruwitz Hills, the Diablo Plateau, and the northern Blanca Peaks area. The northern branch is not incised in its upper reaches. It forms part of what may be an actively aggrading alluvial flat in the northern part of the basin.

Large areas along the western branch of Blanca Draw have been too disturbed by cultural activities to determine what were the original surficial deposits. Interstate 10 extends across the entirety of the Eagle Flat Study Area. Because of the extensive grading associated with the interstate, and because it has obstructed and diverted drainage, it has affected the relatively thin surficial deposits. Some surficial deposits do not cross the interstate. Along the western branch of Blanca Draw is the town of Sierra Blanca. Another large disturbed area extending to the north is a proposed development and golf course.

West of the northern branch of Blanca Draw is a relatively extensive set of alluvial fans that separates the basin floor from Flat Mountain and the northern Blanca Peaks. The alluvial fans show few recent depositional lobes, except in the northern end, where large canyons cut through the ridge north of Flat Mountain. The largest of these fans is centered just north of the Eagle Flat Study Area. A radiocarbon date of wood ash from the upper deposits in this fan has provided a maximum age of 2,150–2,300 yr ago (sample RCSB1 in table 1; location in fig. 4). This fan has recently (during the last several hundred years) deposited an active lobe of sediment, just north of the Eagle Flat Study Area.

East of the northern branch of Blanca Draw, the extensive upland area of the northern Streeruwitz Hills merges with the basin floor with no intervening piedmont. Upland areas are largely covered by a thick residual soil (Q_{rs}). Cretaceous Cox Sandstone and Finlay Limestone are exposed only on isolated hill crests. The contact between the residual soil and the basin-fill strata of the basin floor is obscure and difficult to map. However, the residual soil can be observed in one quarry to dip beneath the thicker deposits of the basin floor. Several areas of thin wash-fill deposits are found in the bottoms of shallow valleys in the uplands. Some of the wash-fill deposits terminate at or near the edge of the basin floor. This is inferred to result from the lack of confinement in the basin floor, which has prevented discrete wash-fill deposits from forming.

Two playas of ambiguous origin are found within this upland area. They have not formed as eolian deflation hollows because the sides of the depressions are resistant Cox Sandstone and residual soil. The playas may have formed through damming of a shallow valley by the aggrading basin floor. Or they may have formed through dissolution or subsidence beneath the playa floors. Dissolution is not as likely within the Cox Sandstone as within the overlying and underlying limestones, which do not exhibit playas. On the other hand, the morphology of the depressions containing the playas is not obviously that of a dammed alluvial valley.

South of the northern Streeruwitz Hills is an extensive area of eolian sand (Q_{e1} and Q_{e2}) occurring both as dunes and as vegetated sand sheets. The area of eolian sand extends without interruption to north of Grayton Lake. The morphology and deposits of the vegetated sand sheets have been discussed in detail in the north Faskin Ranch section. The eolian deposits occur almost entirely northeast of the Blanca Draw, which is presumed to be a major source for the eolian sand. The eolian deposits are vegetated sand sheets to the west and are increasingly less vegetated to the east, with increasing development of transverse and coppice dunes. Many more unvegetated dunes are evident on aerial photographs taken in 1953 and 1980 than are present today. These dunes, although well vegetated, are evident beneath a recent cover of creosote, mesquite, and grasses.

Several large drainages flowing along the east side of the eolian sand sheet are diverted and obstructed by the eolian sand. In the area of the interstate, the eolian sand fills the wash floor and has effectively dammed surface flow within the drainage. Wash-fill deposits in this drainage, south of the interstate and north of Grayton Lake are buried beneath the eolian sand. Several other buried drainages are evident in the area of the repository site (note relict wash defined by the contours on the east side of the repository in plate 1). These drainages are evidence of the disorganization of drainage during the recent past. Three primary processes have resulted in disorganization of the drainages. (1) The washes have filled, spreading and slowing the flow of flood waters. (2) Eolian sand has formed effective dams that have ponded flow in the upstream areas of drainages. (3) Construction, primarily of stock tanks and the interstate, created dams and has restricted the flow of water from the north to the south side of the interstate.

West of the eolian sand deposits are the Blanca Draw drainage and the relict alluvial flat described in the north Faskin Ranch section. South of the Blanca Draw drainage and Grayton Lake is an upland area consisting predominantly of residual soils up to 4 ft thick with scattered outcrops of Cretaceous limestones and sandstones. The uplands form a broad ridge that connects Devil Ridge with the Eagle Mountains and divides the drainage of northwest Eagle Flat Basin from that of Red Light Draw. The drainage divide continues across an area of relict basin floor and piedmont between Front Ridge and the broad upland ridge. Front Ridge itself consists of three discontinuous steep and rugged ridges separated from Devil Ridge by narrow strike valleys. South of the basin-floor drainage divide are the headwaters of Red Hill Arroyo, which drains around the southeast end of Devil Ridge into Red Light Draw. North of the drainage divide is a broad basin floor–piedmont extending to the northernmost segment of Front Ridge. This area is geomorphically ambiguous, having aspects of both a basin floor and a piedmont alluvial fan. There is no well-defined break between the alluvial fan and piedmont, and the slope is more gentle than that of other piedmont alluvial fans. The surficial strata are similar to those of the relict alluvial flat. However, several younger alluvial fan aggradation lobes (Q_{yf}) are distributed across this basin floor–piedmont and cover the basin floor deposits (Q_{bf}). The basin floor–piedmont extends to Yucca Mesa, where there is a well-expressed piedmont. A second area of thick residual soils (Q_{rs}) and scattered bedrock outcrops is found between Yucca Mesa and the west flank of Sand Mountain, forming the drainage divide between northwest Eagle Flat and the upper Red Light Draw drainage.

Southeast Eagle Flat Basin

The southeast Eagle Flat Basin is an open basin that drains through Eagle Flat Draw into Lobo Valley to the east. The basin is strongly influenced by its contrasting uplands to the north and south. To the north, Camel Draw, Seventeen Draw, and other unnamed washes have extensive catchments in the Diablo Plateau and the Millican and Bean Hills. These streams have built extensive, gently sloping alluvial fans and pediments that merge imperceptibly into the basin floor. To the south, the high Eagle Mountains have created a steep piedmont that intersects the basin floor with a well-defined change in slope.

The floor of southeast Eagle Flat Basin can be divided into two areas. The westernmost area is a continuation of the wide basin floor of the northwest Eagle Flat Basin. This area extends to where Seventeen Draw crosses the basin floor. Seventeen Draw and other draws to the east have created an extensive piedmont that reduces the basin floor to a narrower band 2 to 3 mi (3.2 to 4.8 km) wide. Farther to the east the basin floor narrows to an axial drainageway, only 164 to 329 ft (50 to 100 m) wide, sandwiched between piedmont fans of the Eagle and Carrizo Mountains.

A large portion of the basin floor is covered with eolian dunes. These are sinuous transverse dunes that extend up to 0.5 mi (0.8 km) at right angles to the west-southwesterly effective wind direction. These dunes are up to 9 ft (3 m) high and are now almost entirely vegetated by creosote. Between the dunes are interdune corridors that lack eolian sand. Because the dunes are oriented obliquely across the slope, they have dammed flow in the basin floor. Each dune has an area of silt and clay on its upslope (eastern) side that was strained out of the flowing water by the eolian sand. The water reemerges on the downhill sides of the dunes and erodes the basin fill sediment, leaving an erosional scarp and pebble lags.

The Bean and Millican Hills are extensive islands within the northern piedmont surface. Complicated patterns of alluvial fan drainages have formed in the northeastern part of the basin, where an extensive older alluvial fan surface has been dissected. Young fan and wash deposits have formed on the older fan as the incised valleys have partially refilled. Tributary drainages incised through the Bean Hills, have captured some of these younger streams. Washes extend for a long distance up this piedmont surface. Along the interstate, young wash-fill deposits have formed in some areas where the interstate has obstructed the flow in Seventeen and Camel Draws.

The southern piedmont, extending from the peaks of the Eagle Mountains to the basin floor, is characterized by very well defined alluvial fans, each fed from one of the larger canyons in the Eagle Mountains. The two largest fans that extend into the Eagle Flat Study Area are the Goat Canyon Fan and the Carpenter Canyon Fan. The fans adjacent to the Eagle

Mountains are characterized by numerous well-defined geomorphic surfaces. Several generations of deeply incised older fans are evident, each inset into older steeper surfaces set higher on the fan. Stage IV calcic horizons are found on the fan surface all the way to the toes of the fans. Young fan deposits (Q_{yf}) and active fan lobes (Fa) are found as thin deposits near the toes of the fans and as inset lobes and valley-fills that fill incised valleys that radiate down from the entrenched proximal fan. These fans emerge from the inset valleys only near the toes of the fans. A similar fan slopes westward off of the Carrizo Mountains and forms the southwestern corner of the Study Area, just north of Hot Wells.

Red Light Draw Basin

Red Light Draw Basin is a narrow basin, approximately 4 mi wide (6.4 km) in the study area, confined between the Quitman Mountains and Devil Ridge. The basin can be divided into two drainages, Red Hills Arroyo, that flows between Devil Ridge and the drainage divide south of Grayton Lake, and Red Light Draw drainage that flows down the axis of Red Light Draw Basin.

The Red Hills Arroyo drainage is different from drainages in other basins of the Eagle Flat Study Area. Although it is floored by similar wash-fill deposits as the other drainages, it does not flow across a basin floor, but through a network of valleys incised into an upland of Cretaceous limestones and sandstones. The arroyo floor is lower than the floor of northwest Eagle Flat Basin and with continued erosion and headward incision it is assumed that over geologic time it will eventually capture the upper Blanca Draw drainage. Middle Pleistocene fan surfaces (Collins and Raney, 1993) near the Red Hills Arroyo have been little incised, and with similar rates of erosion, the Eagle Flat drainage will not be captured for hundreds of thousands to millions of years. Young fan deposits cover a large portion of the narrow piedmont between Front Ridge and this drainage. The fans are almost entirely fan aggradation deposits.

Red Light Draw lies in a straight valley incised in the center of the basin. In contrast to the northwest and southeast Eagle Flat Basins, the basin floor of Red Light Draw is a narrow drainageway, 500 to 2,000 ft (152 to 609 m) wide, confined between wide piedmont slopes. The drainageway is floored almost entirely with wash-fill deposits (Q_w), except at the southern margin of the Eagle Flat Study Area, where there is a sand-floored braided stream (Ca) that extends to the Rio Grande.

Old fan deposits cover a much greater proportion of the basin than in the Eagle Flat Basins. The opposite sides of the basin are characterized by different styles of alluvial fan deposition. The fans on the southwest side of the basin are relatively unincised. Most young fan deposits on this side of the basin are fan aggradation lobes. There is one area of active fan and channel deposition in the southwestern corner of the study area. The northeast side of the basin is incised farther up the basin from the Rio Grande, north of the northwestern end of Back Ridge. Young fan deposits in this part of the basin occur as inset lobes and valley fills. Fans derived from the southwestern side of Yucca Mesa are fan aggradation deposits.

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Appendices

APPENDIX A. LIST OF SURFICIAL DEPOSIT MAP UNITS

Surficial Deposit Map Units

Geomorphic Regimes	Map Units: Map of Eagle Flat Study Area	Map Units: Detailed Map of North Faskin Ranch	Descriptions
Uplands	K	K	*Bedrock Areas*. Areas of exposed bedrock and bedrock with thin soil cover. Some areas southeast and northeast of Grayton lake may have patches of eolian sand cover. Drainages may have thin covers of alluvial material, either alluvial fan sands and gravely sands or wash-fill silts. On Devil Ridge and Love Hogback, the bedrock is predominantly Cretaceous limestone and calcareous sandstone that supports thin gravely and clayey soils and gravely colluvium on steep slopes. The topography ranges from rugged mountains with a stair step topography of cliffs and steep slopes on Devil Ridge to subdued rolling hills on the slopes south of Grayton Lake. The hills and other areas of thicker soil are covered largely with creosote bush and grasses. The more rugged mountains are covered with the typical shrub and cacti of the Chihuahuan desert, Lechuguilla, Sotol, broad leaf yucca, Ocotillo, and various cacti.
Uplands	K	Q_{rs}	*Bedrock covered with thin to thick soil*. Areas with no exposed bedrock, but immediately underlain by bedrock. Q_{rs} is a residual soil, light gray, and consists of a gray sandy silt, or silty clay in the soil B horizon, covering a stage III to IV calcic soil (K) horizon. The thin to thick, stage III to IV calcic soil horizon is locally exposed at the surface through erosion. The B soil horizon is thick, but typical of soils formed on calcic materials, is poorly developed. The soil is coarse grained and very poorly sorted, containing up to 30 percent granules, pebbles and cobbles of residuum and caliche, and 20 percent silt and clay. This soil is classified as SM under the United Soil Classification. There is no pavement in grass-covered areas and a poorly to moderately developed pavement in shrub-covered areas. In deeply eroded areas, the underlying calcic soil is exposed. A poor to moderately developed pavement, composed of angular monolithologic fragments, is present in patches. Areas of Q_{rs} are covered with diverse vegetation -- grasses, creosote bush, and greasewood are common.
Piedmont Alluvial Fans and Bajadas	C_a	C_a	*Active Channel deposits.* Areas in confined channels in which ephemeral streams are intermittently transporting and depositing sediment. These include low, poorly vegetated terraces immediately above the active bed and unvegetated bars within the active bed of the channels. Active channels are filled with poorly sorted sands and gravels. These deposits are largely classified as SW, SP, and GW under the United Soil Classification.

Piedmont Alluvial Fans and Bajadas	F_a	F_a	_Active Fan deposits._ Areas of active aggradation on alluvial fans and bajadas. These are areas, fed from active channels that contain poorly vegetated gravel bars, sand patches and small rills. Lack of vegetation and soil cover are evidence for recent activity, as are dislodged and buried shrubs. These are distinguished from active channels by the lack of a well-defined channel to confine flow. Numerous small, branching channels feed the depositional lobes in active fans. These deposits are largely classified as SW, SP, and GW under the United Soil Classification.
Piedmont Alluvial Fans and Bajadas	Qyf	Qyf	_Younger Alluvial Fan Deposits,_ alluvial fan gravels sands and silts that do not contain well-developed soils. Calcic soils are stage I or stage II. Younger fan deposits fill drainages incised into older fan deposits and form lobes on fan surfaces. The lobes are generally well defined and visible on aerial photographs. Q_{yf} deposits are covered by a combination of creosote, sage, cacti, mesquite, and grasses and have bare areas and rills due to active erosion. Younger fans have poorly developed pavements. Most young alluvial fan deposits are classified as SM, SW, SP, and GW under the United Soil Classification.
Piedmont Alluvial Fans and Bajadas	Qyf	Qyf2	_Second Generation of Younger Alluvial Fan Deposits._ Thin widespread alluvial fan deposits on top of the older fan deposits and the Q_{bf} deposits. The fans exhibit well-defined lobes, separated by exposures of underlying older fan and Q_{bf} deposits and by intervening younger Q_w deposits. Q_{yf2} units extend farther from the mountain front and are thinner than Q_{yf1} deposits. Gravels form a patchy pavement within a matrix of sandy and silty deposits. In gullies and trenches, the gravels are revealed to exist as 3 ft (1 m) deep, and 18 ft (6 m) wide channels encased in finer Q_{yf} material. Gravels mantle lobes that form topographic highs within the fan deposits.
Piedmont Alluvial Fans and Bajadas	Qyf	Qyf1	_First Generation of Younger Alluvial Fan Deposits._ Darker, grayer deposits making fans. Typically Q_{yf1} fans have steeper faces and are nearer to the mountain fronts than associated Q_{yf2} deposits. They are commonly incised up to 7 ft (2.1 m), exposing the underlying older fan deposits. Q_{yf1} deposits consist of sands with gravels in channels, and layers. No soil horizonation is evident, except for small calcic nodules. Incised channels in $Q_{yf}1$ fans feed lobes of (Q_{yf2}) fan deposits.

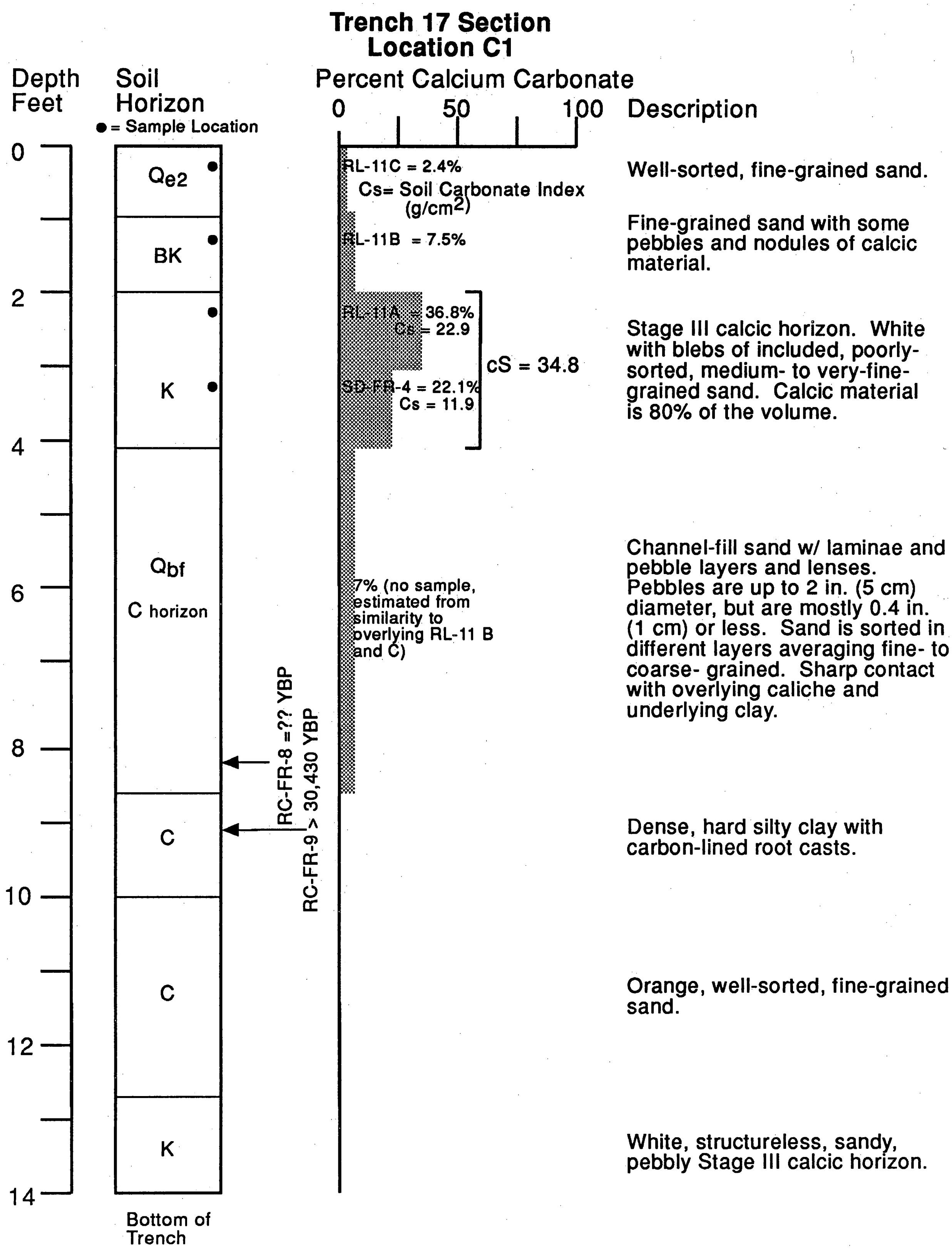
Piedmont Alluvial Fans and Bajadas	Q_{of}	Q_{of} Q_{of2} Q_{of1}	*Older Alluvial Fan and Bajada Gravels*. Alluvial gravels and sands containing well-developed soils, typically exhibiting stage III or stage IV calcic soil horizons. The uppermost soil horizon is a gravelly sand or gravel pavement. The B horizon is thick, when not eroded, and well developed as a silty horizon beneath the gravel. The calcic horizon is most commonly a stage IV. The deposits consist of gravelly sands and sandy gravels (United Soil Classification = GW, GM, SW, and SM). Some fans exhibit little surficial dissection, whereas others exhibit dissection through the calcic soil. This may be a fundamental difference in genesis or may simply represent differences in exposure to erosion. Q_{of} areas have well-developed pavements of gravels that become more poorly developed at the toes of the fans, where the Q_{of} units grade into the basinal soil Q_{bf} unit. Incised drainages may contain local younger alluvial fan deposits and older alluvium is exposed in the eroded banks of the drainages. Many incised channels have unvegetated beds and are ephemerally active after rainfall or snowfall. The vegetation is a combination of shrubs including grasses and creosote. Older fan surfaces are widely varying in age. Some may have formed in the Tertiary. Where distinctly different ages of fans were evident, they were labeled according to their apparent relative ages, with Q_{of1} being the oldest deposits on a particular fan and Q_{of2} and Q_{of3} representing younger fan surfaces. These assigned ages are only relative to the units on the same fan and do not imply correlative ages with Q_{of1} and Q_{of2} units on adjacent fans. Fans with similar appearance (e.g., degree of incision), may have markedly different ages, and correlation of the older fan surfaces should not be attempted without careful field mapping.
Basin Floor	H	H	*Areas disturbed by human activities* or covered by human structures so that the original surficial deposits cannot be determined. This includes some excavated areas and areas where fill has been added.
Basin Floor	Q_p	Q_p	*Playa deposits*. The largest area of these deposits is on the floor of Grayton Lake. Other small playas are in the northern end of northwest Eagle Flat. The surface of the lake is very flat, with a total relief of less than 2 ft. Vegetation is restricted to a few varieties of ephemeral herbs. The surface of the playa is underlain by about 2 ft of structureless sandy silt, which grades down into a mixed silt and clay mud. Playa deposits are classified as ML, CL, or CH under the United Soil Classification.

Basin Floor	Q_{e2}	Q_{e2}	<u>Younger Fine-grained Sand</u> occurs on *interfluvial flats* and on *slopes flanking washes*. This facies consists of light brown fine-grained to very fine-grained, well-sorted loamy sand. It includes the youngest Quaternary eolian deposits as well as areas of active eolian erosion and deposition. Small patches of included Q_{e1} and Qbf are mapped within this unit. Active coppice dunes and lines of coppice dunes occur perpendicular to the primary effective wind. These are patches fine-grained sand, unvegetated except by the large anchoring shrubs. The topography is irregular mound and deflation hollows, each a few feet in diameter, and usually less than 3 ft (1 m) high. The largest coppices are less than 8 ft (2.5 m) high. Shrubs may be partially buried, or their roots may be exposed by migrating sand. Horizonation is very poorly developed. A slightly more cohesive surface horizon is developed in patches. This horizon may be absent or may be well developed and 2 to 4 in (5-10 cm) thick. A slightly more clayey (B) horizon is very poorly developed. In some pits, a zone extending down from 6 to 10 in (15-25 cm) below the surface is slightly more cohesive and may be more clay-rich. Pebbles and fragments of pedogenic calcrete (caliche) are entirely absent except where brought to the surface and scattered by burrowing animals. These fragments occur in isolated patches, commonly surrounding an active burrow. No sedimentary structures are evident. In some pits, Q_{e2} is overlies Q_{e1} with a sharp contact marked by a layer of pebbles and pedogenic calcrete fragments. The topography underlain by Q_{e2} is of low relief, rolling sandy flats. Q_{e2} deposits are classified as SP under the United Soil Classification.
Basin Floor	Q_{e1}	Q_{e1}	<u>Older Fine-grained Sand</u> occurs on *interfluvial flats* and on *slopes flanking washes*. This facies consists of light brown fine-grained to very fine-grained, well-sorted loamy sand. Small patches of Q_{e2} and Qbf are included within this unit. Contains up to 5% pebbles and granules worked from underlying gravels and calcic horizons. This unit is finer grained and contains more silt and clay than does Q_{e2}. Soil horizonation is better developed than in Q_{e2}. The cohesive surficial horizon is developed similar to Q_{e2}. A better developed more cohesive (B) horizon begins 0 to 11 in (0-30 cm) below the surface and is up to 16 in (40 cm) thick. There is an increase in clay content in this horizon. Fragments of pedogenic calcrete and/or pebbles are scattered widely across surfaces underlain by Q_{e1}, and are scattered through out the Q_{e1} deposit. A stage I to II carbonate horizon is developed in isolated areas, and imparts a grayish color to the lower parts of the Q_{e1} deposit. In some pits, Q_{e1} is observed to underlie Q_{e2} with a sharp contact marked by a layer of pebbles or pedogenic calcrete fragments. Note Q_{bf} may have been mapped as Q_{e1} in some places as these may be difficult to discriminate when Q_{bf} is sandy. Both Q_{e2} and Q_{e1} exhibit the same general vegetation patterns. They are shrubby savannas, grasslands with scattered mesquite, narrow-leaf yucca, and diverse other shrubs. Grasses are generally less dense than in wash bottoms. Q_{e1} deposits are classified as SP or SM under the United Soil Classification.

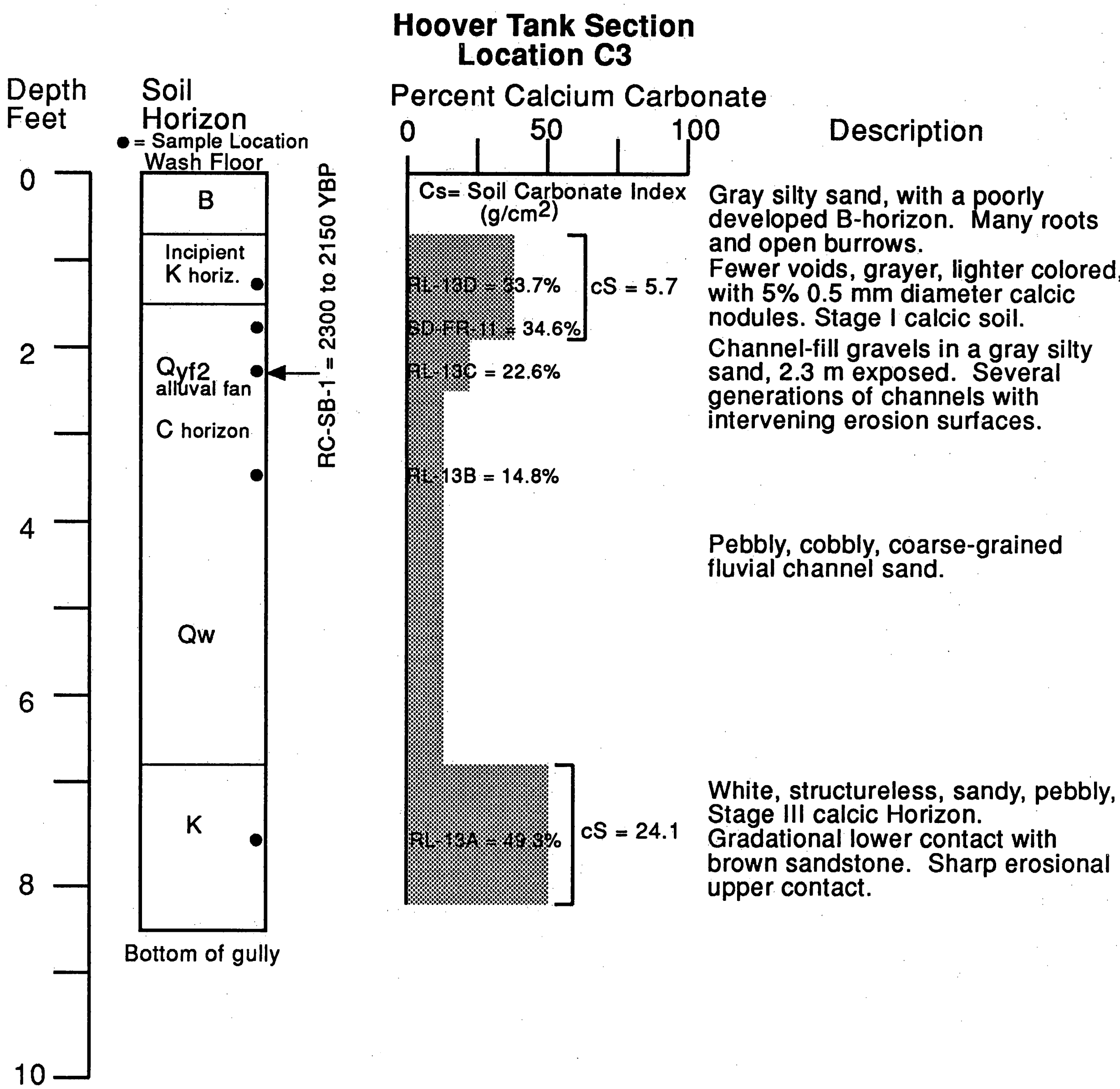
Basin Floor	Qw	Qw	*Wash-Fill Deposits* Silts and silty clays, occurring entirely in wash bottoms. Wash channels are observed to truncate the soil horizons of the Q_{bf} unit. The deposits are cohesive and support a steeper trench wall than other facies due to a higher silt and clay content. Pebbles are scattered, or occur as isolated lenses throughout the deposit. Internal horizonation is not commonly evident. Surface morphology is extremely low relief and flat. Small fans extend from the slopes on the flanks of the washes to merge with the wash facies. This facies is presumed to be currently aggrading. The facies thins to a zero-edge at the margins of the washes and thickens to at least 1.5 ft (0.5 m) thick within the rest of the washes. Most wash-fill deposits are classified as ML, CL, MC under the United Soil Classification. The channel-fills are classified as SW and GW. Washes are covered by several distinct vegetation types: (1) Mesquite thickets, with scattered to dense mesquite thickets interspersed with grasses and other shrubs. (2) Grass flats with dense patches of grass. Most common are patches of grass with a silvery colored, twisting curly leaf. (3) Grass flats covered with more scattered grasses. Buffalo grass is most common. Washes are distinguished from active channels because they lack an unvegetated channel floor containing movable clasts. The only unvegetated areas are gullies, that only exhibit erosion. Deposition in fan gullies is confined to thin fans extending from rills and pipes in the gully walls.
Basin Floor	Qbf	Qbf	*Soil on Basin-Fill Deposits* Q_{bf} is a soil developed on lower piedmont slopes and basin floors. It consists of a thick silt, sandy silt, and silty clay B horizon, covering a stage III to IV calcic soil horizon, which grades into underlying basin-fill sediment and buried soils. B soil horizon is thin to thick and is light gray in color. The calcic soil horizon is most commonly 12 to 18 in (30 to 50 cm) thick, with a sharp upper contact and a gradational lower contact as the massive calcrete changes into nodules. Q_{bf} is usually well vegetated with grasses or thickets of diverse shrubs. There is no pavement in grass-covered areas and a poorly to moderately developed pavement in shrub-covered areas. In places, this deposit is difficult to segregate from Q_{rs} or Q_{e1} deposits. In deeply eroded areas, the calcic soil horizon is exposed. Areas of concentrated erosion include old pipelines, cattle trails, fence lines, and roads. Q_{bf} is classified as ML, CL, or SM under the United Soil Classification.
Basin Floor	Qbf	Qgr	*Gravel mounds.* Low mounds, no more than 8 ft (2.5 m) above the present day piedmont and basin floor. The mounds are covered by a well-developed pavement of pebbles to large cobbles.
Basin Floor	Qbfc	Qbfc	*Areas of erosion exposing the lower parts of the Q_{bf} soil and underlying basin-fill deposits.* These areas are marked by exposure of the calcic soil horizon of the Q_{bf} unit. The units are variable in texture, ranging from silty clays to poorly sorted gravels. This erosion is concentrated in gullies and erosional scarps flanking the major washes and along the slopes and alluvial fans on the western side of Eagle Flat Basin. Q_{bfc} is classified as ML, CL, or SM under the United Soil Classification. The channel-fills are classified as SW and GW.

APPENDIX B.
PROFILES OF SECTIONS USED TO DETERMINE CALCIC SOIL ACCUMULATION IN THE EAGLE FLAT STUDY AREA

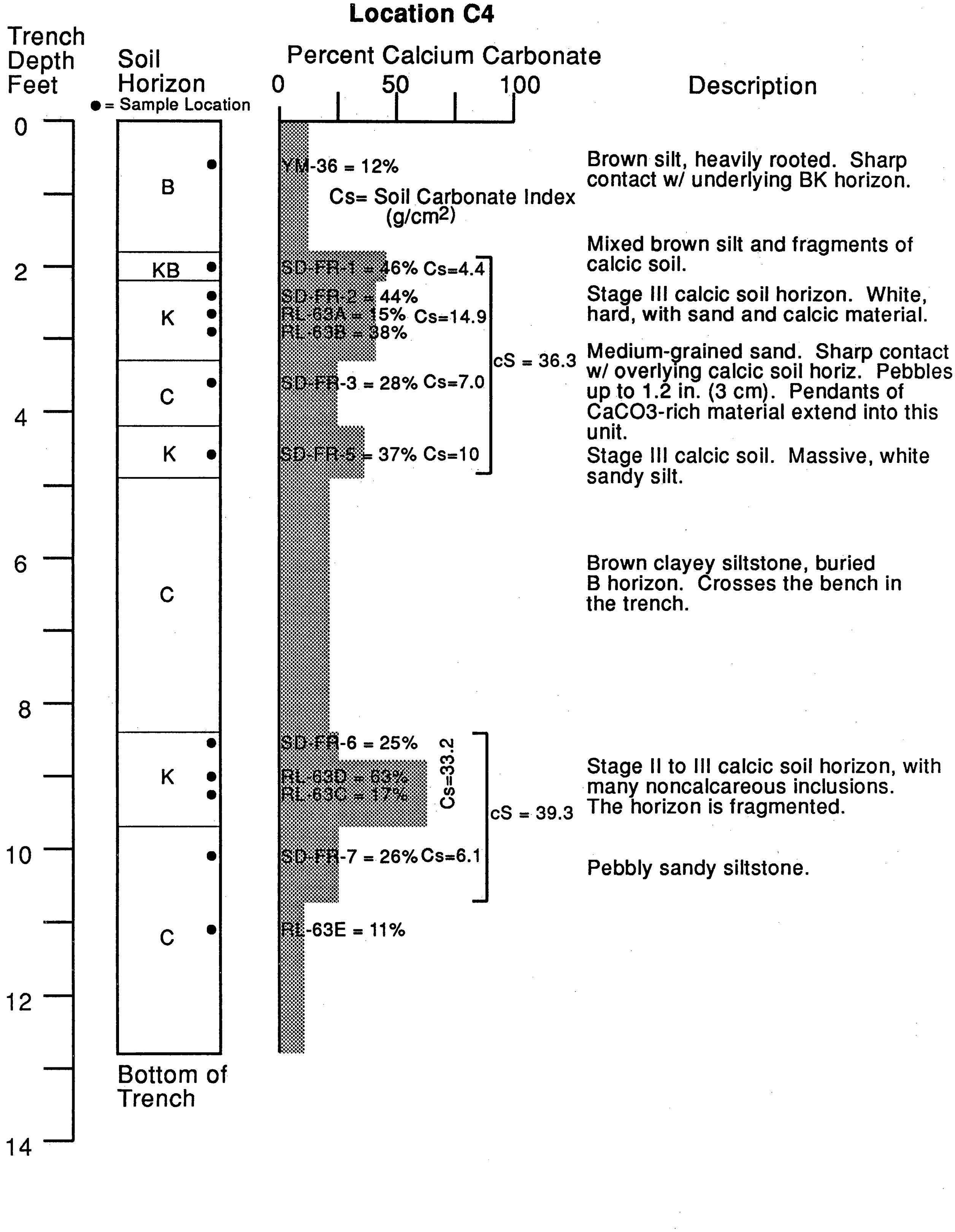
The figures in this appendix illustrate graphically the calcium carbonate profiles measured in cores, trenches, and outcrops. Sample numbers are shown on the trench and outcrop profiles to allow correlation of sample numbers with locations and depths. This was not necessary in the core profiles as the samples were numbered according to core and depth. Dots indicate sample locations in the profiles. Cs = calcium carbonate accumulation for individual horizons. cS = total calcium carbonate accumulation for the soil.



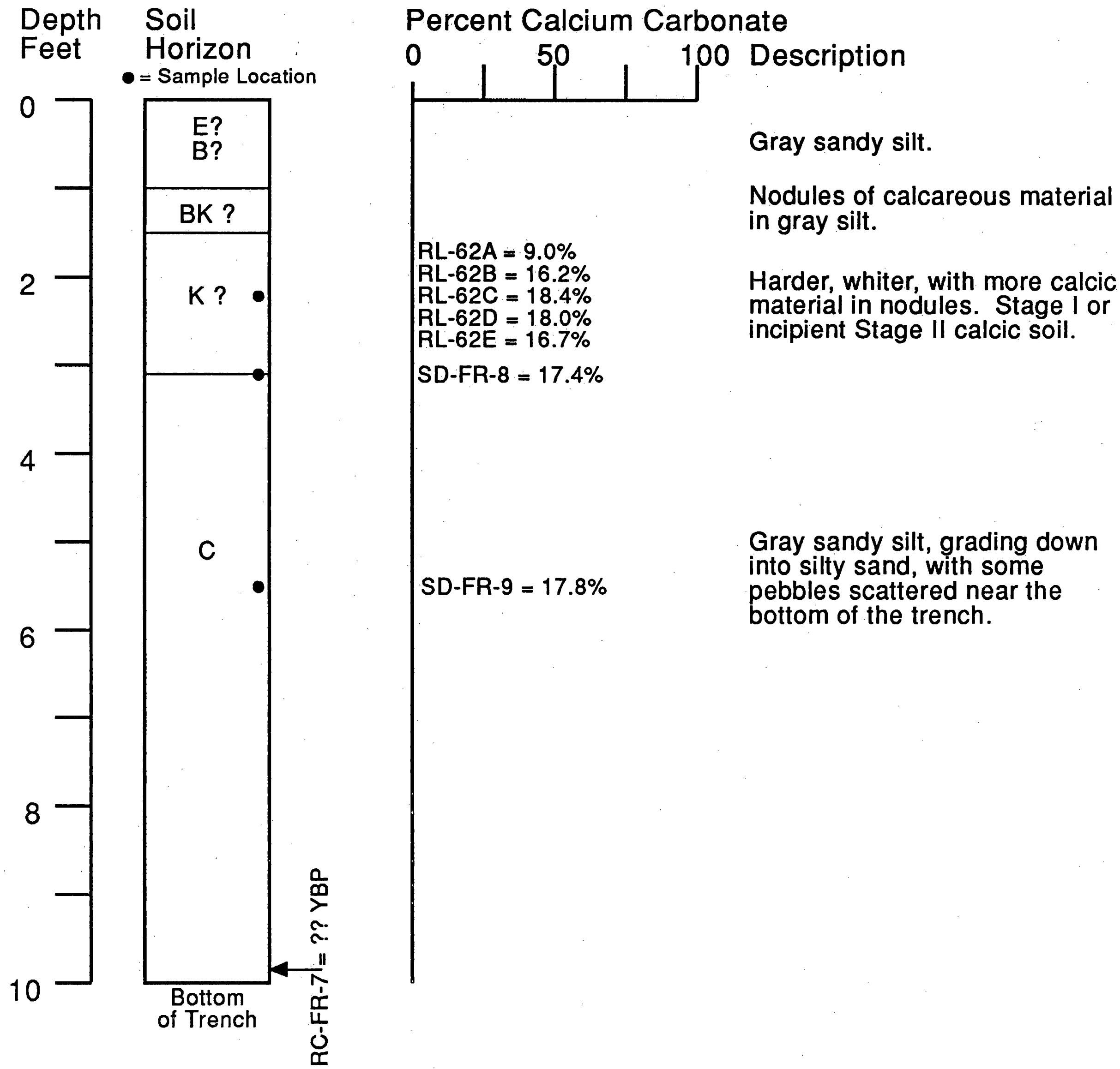
Trench 17 Section
Location C1
Depth Feet
Soil Horizon
● = Sample Location
Percent Calcium Carbonate
0
50
100
Description
0
2
4
6
8
10
12
14
Qe2
BK
K
Qbf
C horizon
C
C
K
Bottom of Trench
RL-11C = 2.4%
Cs= Soil Carbonate Index (g/cm2)
RL-11B = 7.5%
RL-11A = 36.8%
Cs = 22.9
SD-FR-4 = 22.1%
Cs = 11.9
cS = 34.8
7% (no sample, estimated from similarity to overlying RL-11 B and C)
RC-FR-8 =?? YBP
RC-FR-9 > 30,430 YBP
Well-sorted, fine-grained sand.
Fine-grained sand with some pebbles and nodules of calcic material.
Stage III calcic horizon. White with blebs of included, poorly-sorted, medium- to very-fine-grained sand. Calcic material is 80% of the volume.
Channel-fill sand w/ laminae and pebble layers and lenses. Pebbles are up to 2 in. (5 cm) diameter, but are mostly 0.4 in. (1 cm) or less. Sand is sorted in different layers averaging fine- to coarse- grained. Sharp contact with overlying caliche and underlying clay.
Dense, hard silty clay with carbon-lined root casts.
Orange, well-sorted, fine-grained sand.
White, structureless, sandy, pebbly Stage III calcic horizon.

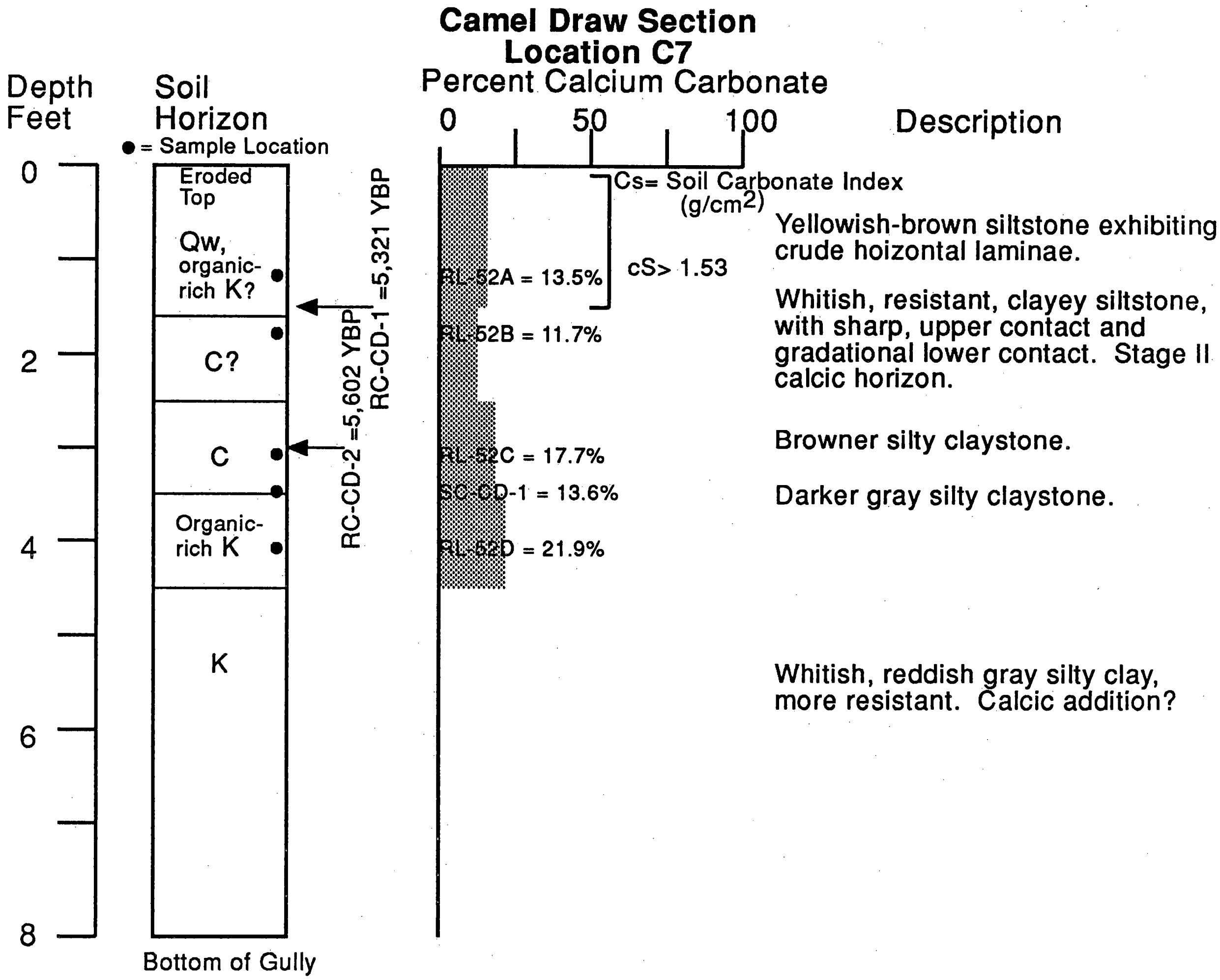

Hoover Tank Section
Location C3
Depth Feet
Soil Horizon
● = Sample Location
Wash Floor
Percent Calcium Carbonate
0
50
100
Description
Cs= Soil Carbonate Index (g/cm2)
B
Incipient K horiz.
Qyf2 alluvial fan
C horizon
Qw
K
Bottom of gully
RC-SB-1 = 2300 to 2150 YBP
RL-13D = 33.7%
SD-FR-11 = 34.6%
cS = 5.7
RL-13C = 22.6%
RL-13B = 14.8%
RL-13A = 49.3%
cS = 24.1
0
2
4
6
8
10
Gray silty sand, with a poorly developed B-horizon. Many roots and open burrows.
Fewer voids, grayer, lighter colored, with 5% 0.5 mm diameter calcic nodules. Stage I calcic soil.
Channel-fill gravels in a gray silty sand, 2.3 m exposed. Several generations of channels with intervening erosion surfaces.
Pebbly, cobbly, coarse-grained fluvial channel sand.
White, structureless, sandy, pebbly, Stage III calcic Horizon. Gradational lower contact with brown sandstone. Sharp erosional upper contact.

Trench at Hoover Fissure Location C4

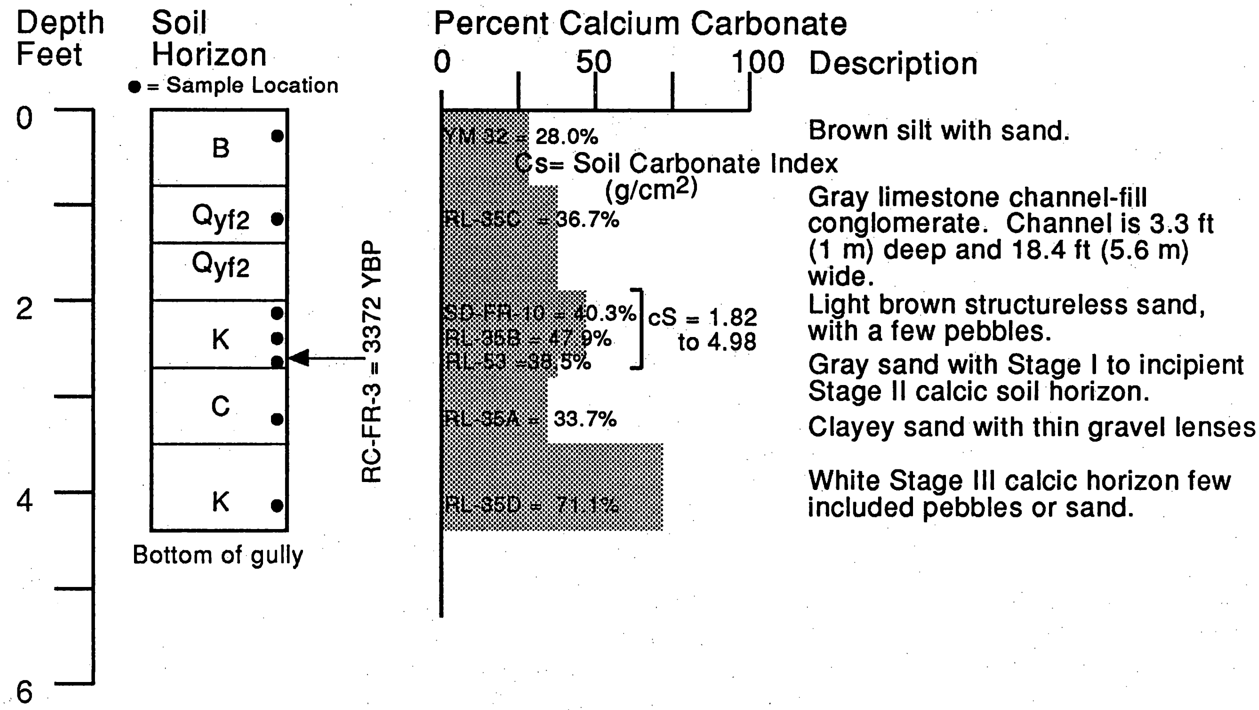


Trench 2 Section
Location C5

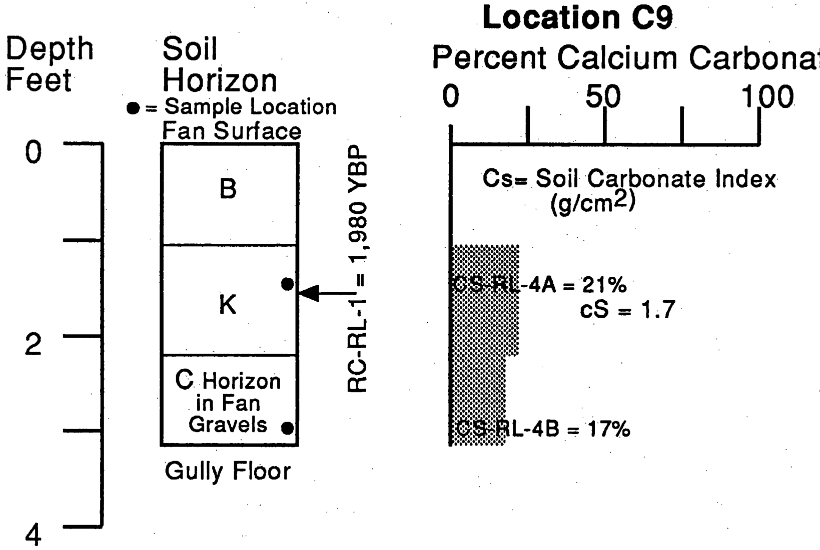



Camel Draw Section
Location C7
Depth
Feet
Soil
Horizon
● = Sample Location
Percent Calcium Carbonate
0
50
100
Description
Eroded
Top
Qw,
organic-
rich K?
C?
C
Organic-
rich K
K
Bottom of Gully
RC-CD-1 =5,321 YBP
RC-CD-2 =5,602 YBP
Cs= Soil Carbonate Index
(g/cm2)
cS> 1.53
RL-52A = 13.5%
RL-52B = 11.7%
RL-52C = 17.7%
SC-CD-1 = 13.6%
RL-52D = 21.9%
Yellowish-brown siltstone exhibiting
crude hoizontal laminae.
Whitish, resistant, clayey siltstone,
with sharp, upper contact and
gradational lower contact. Stage II
calcic horizon.
Browner silty claystone.
Darker gray silty claystone.
Whitish, reddish gray silty clay,
more resistant. Calcic addition?
0
2
4
6
8

Rock Tank Section
Location C8



RC-RL-1 Section
Location C9



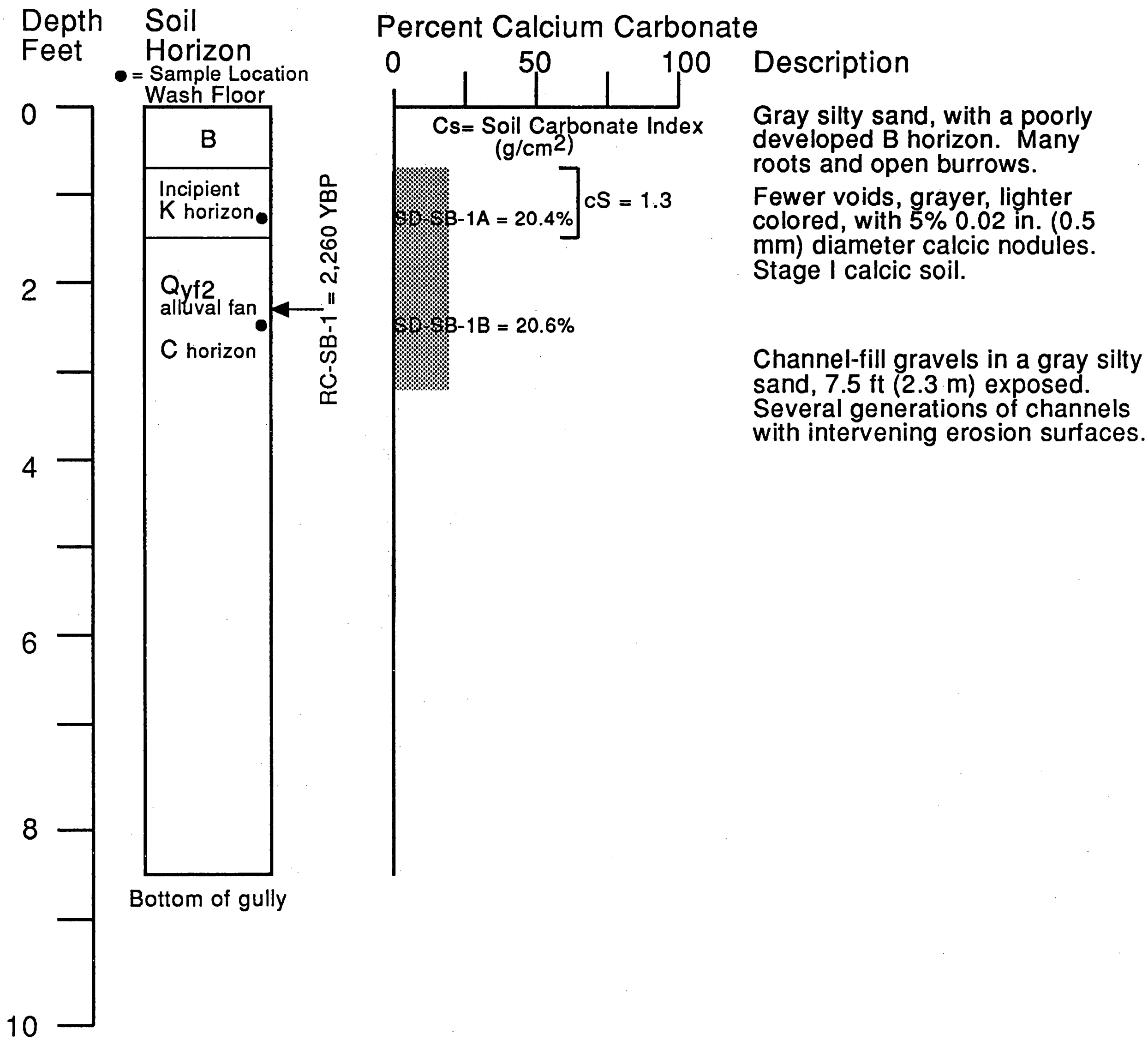
Description

Moderately to poorly developed B horizon. Slightly siltier and darker than below.

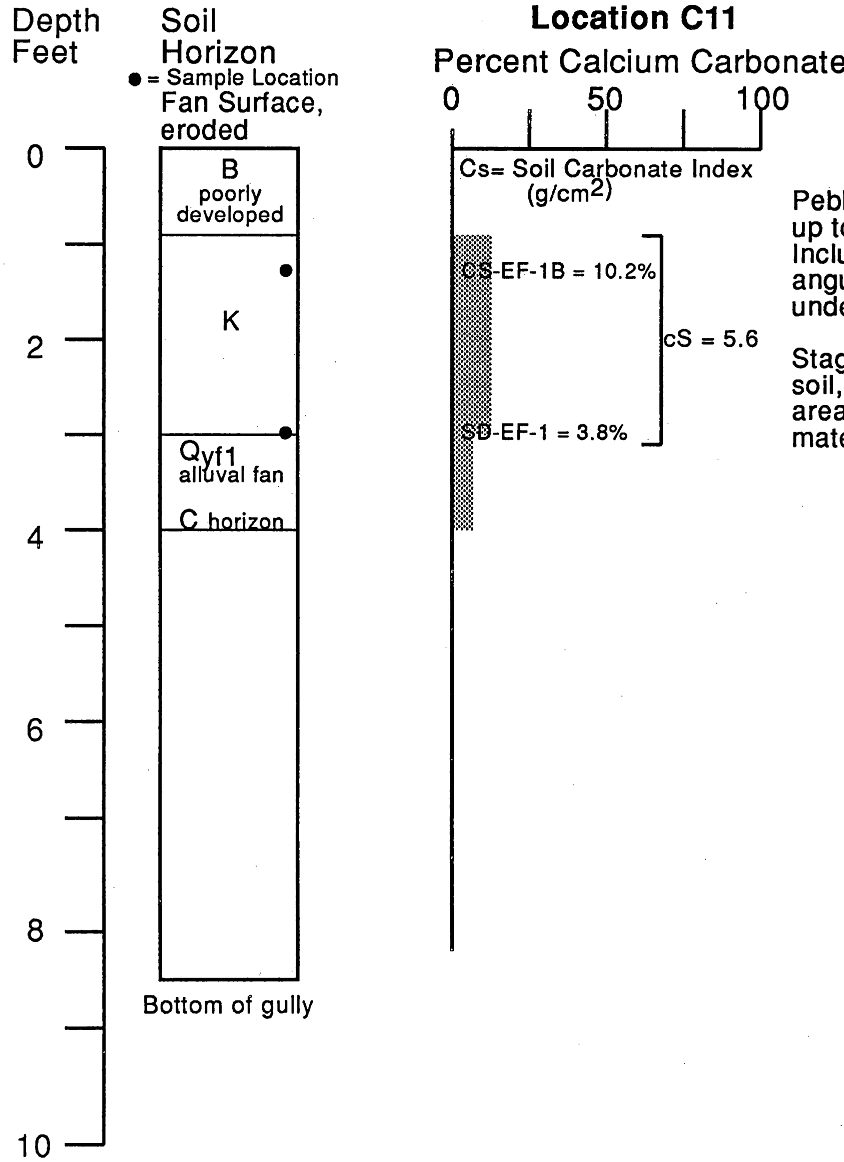
Stage II calcic soil. Pebbles are completely coated. Horizon is slightly whitened.

Alluvial fan gravels filling shallow incised valley near Red Hills. Generally silty, gravelly sands; much siltier than older gravels.

RC-SB-1 Section
Location C10



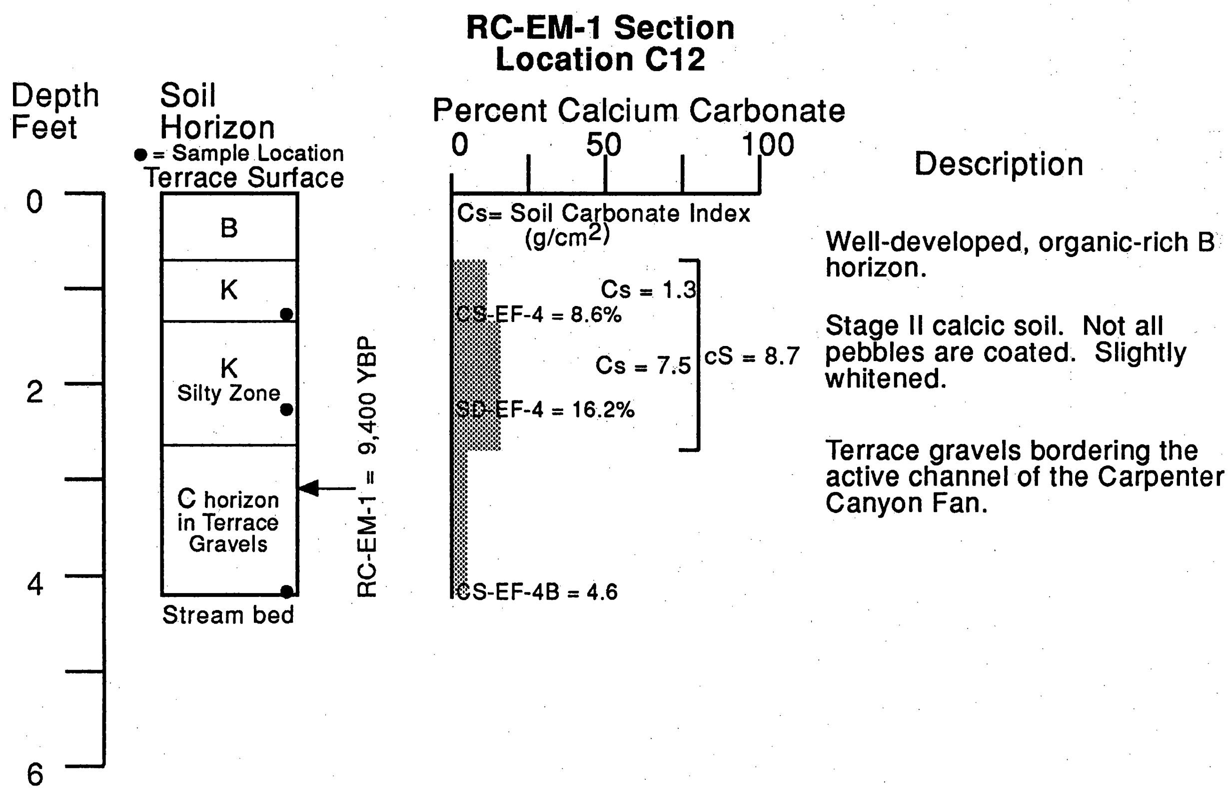
Hot Wells Section
Location C11



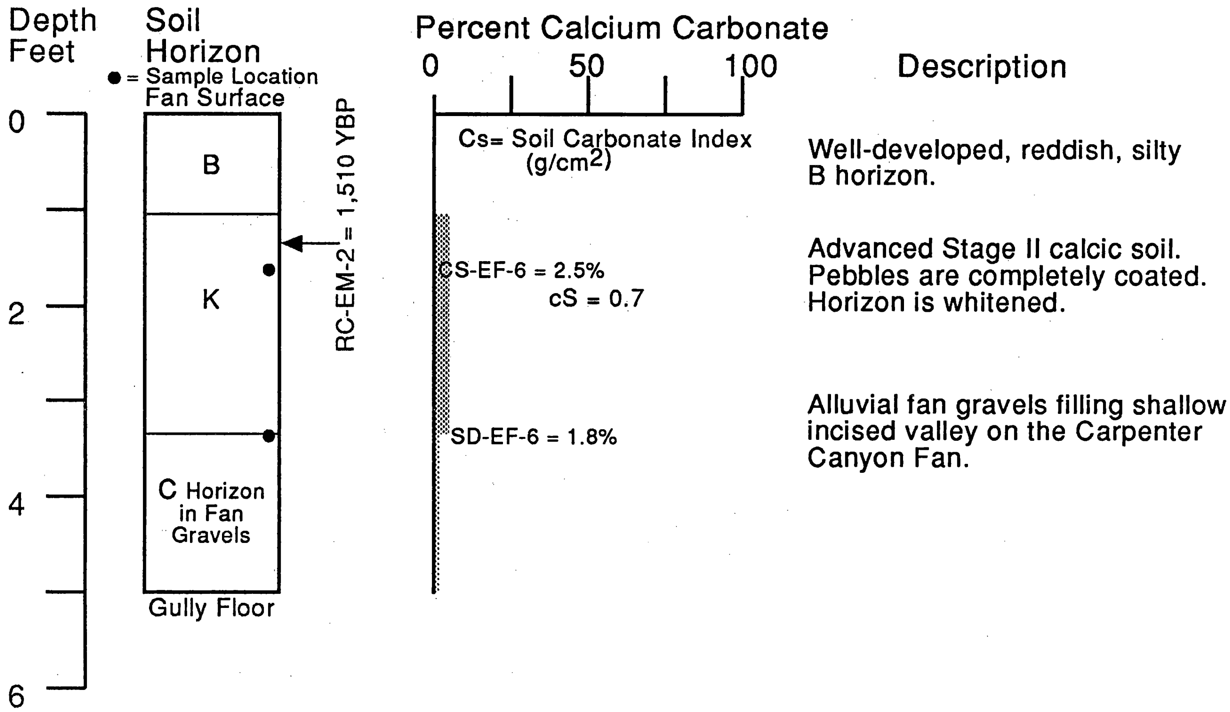
Description

Pebbly fanglomerate, w/ pebbles up to 4.7 in. (12 cm) diam. Includes soil described below, in angular unconformity with underlying basin fill strata.

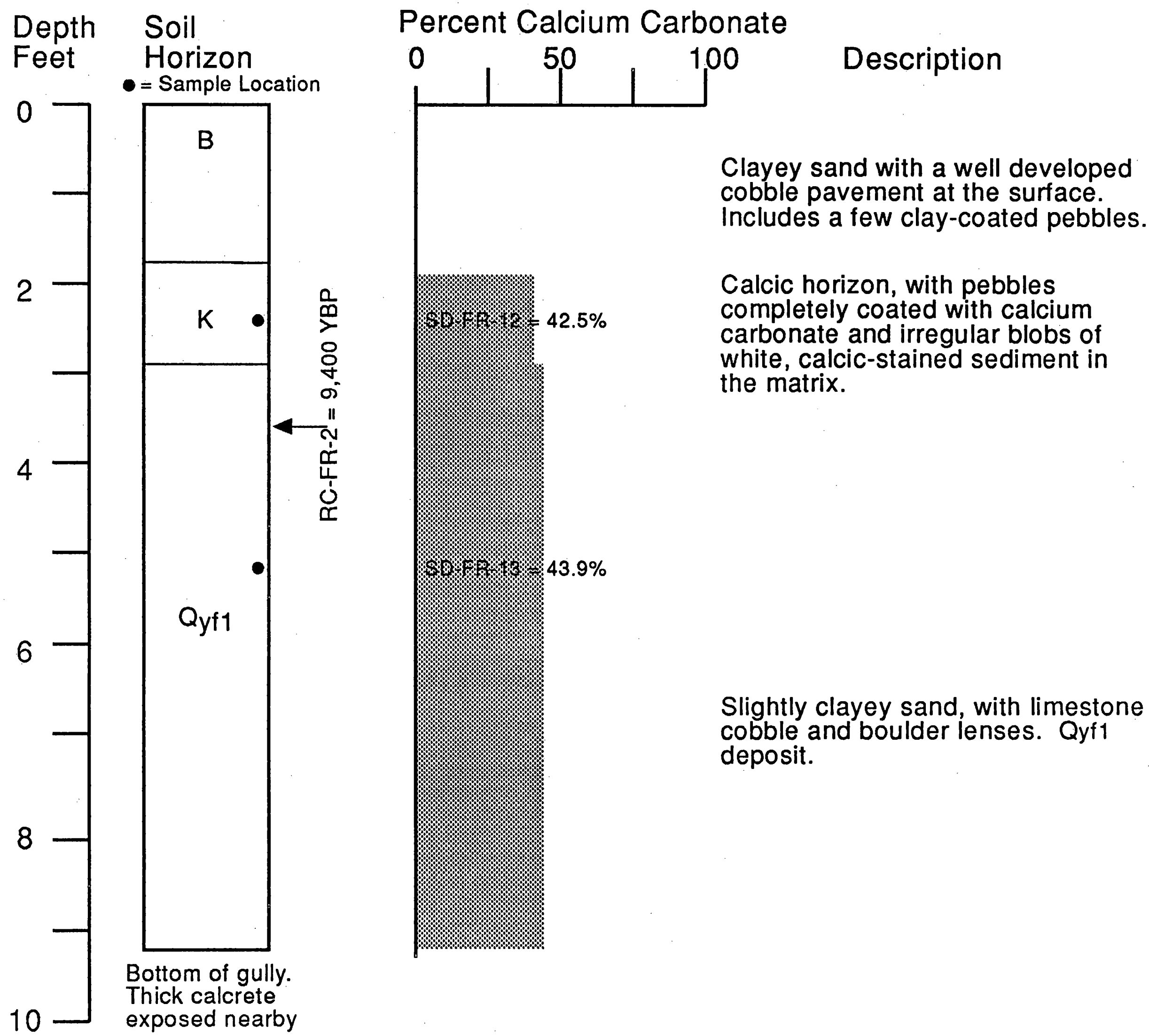
Stage II to incipient Stage III calcic soil, with coated pebbles and some areas of whitish, massive calcic material.

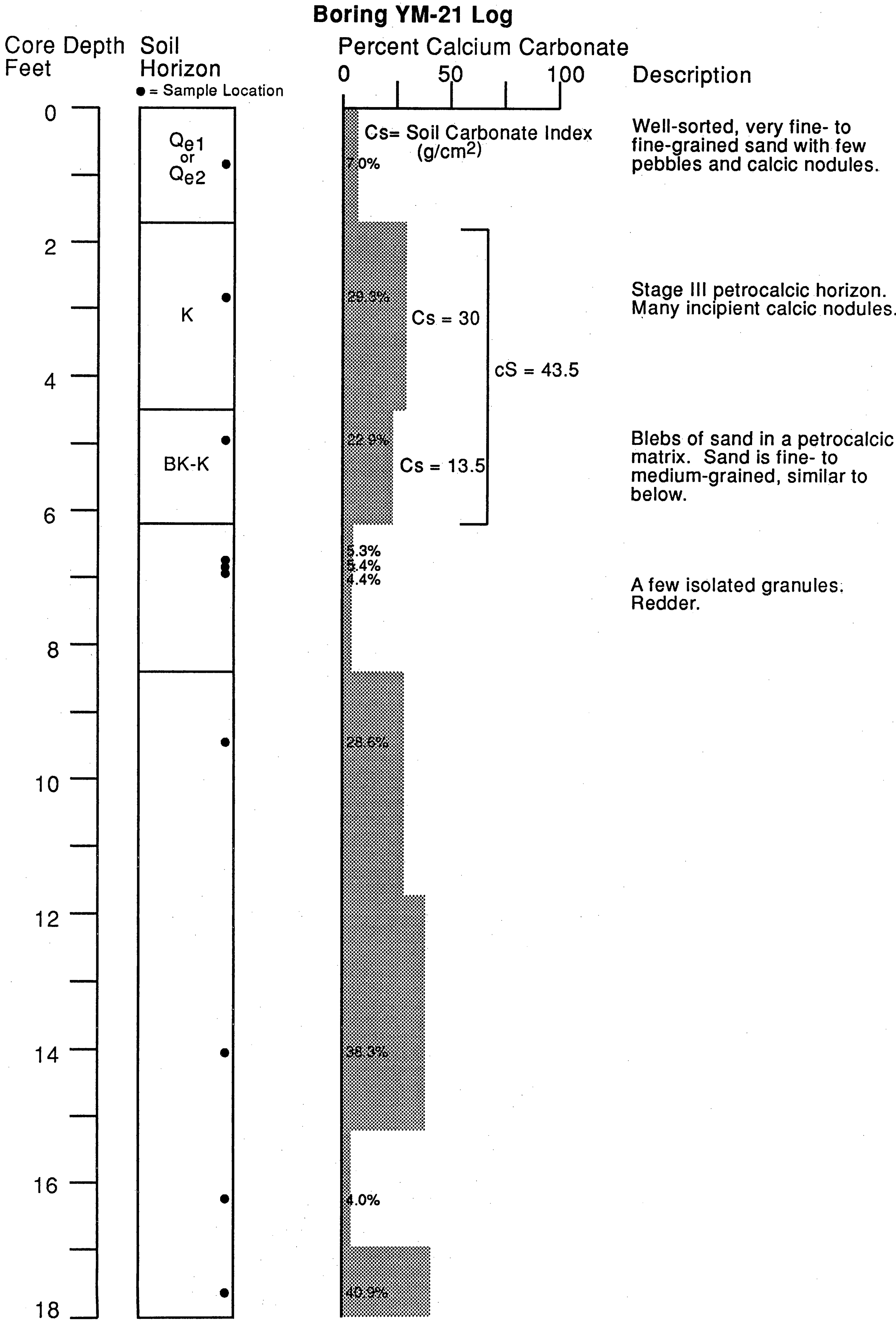

RC-EM-1 Section
Location C12
Depth Feet
0
2
4
6
Soil Horizon
● = Sample Location
Terrace Surface
B
K
K
Silty Zone
C horizon in Terrace Gravels
Stream bed
RC-EM-1 = 9,400 YBP
Percent Calcium Carbonate
0
50
100
Cs= Soil Carbonate Index (g/cm2)
Cs = 1.3
CS-EF-4 = 8.6%
Cs = 7.5
cS = 8.7
SD-EF-4 = 16.2%
CS-EF-4B = 4.6
Description
Well-developed, organic-rich B horizon.
Stage II calcic soil. Not all pebbles are coated. Slightly whitened.
Terrace gravels bordering the active channel of the Carpenter Canyon Fan.

RC-EM-2 Section
Location C13



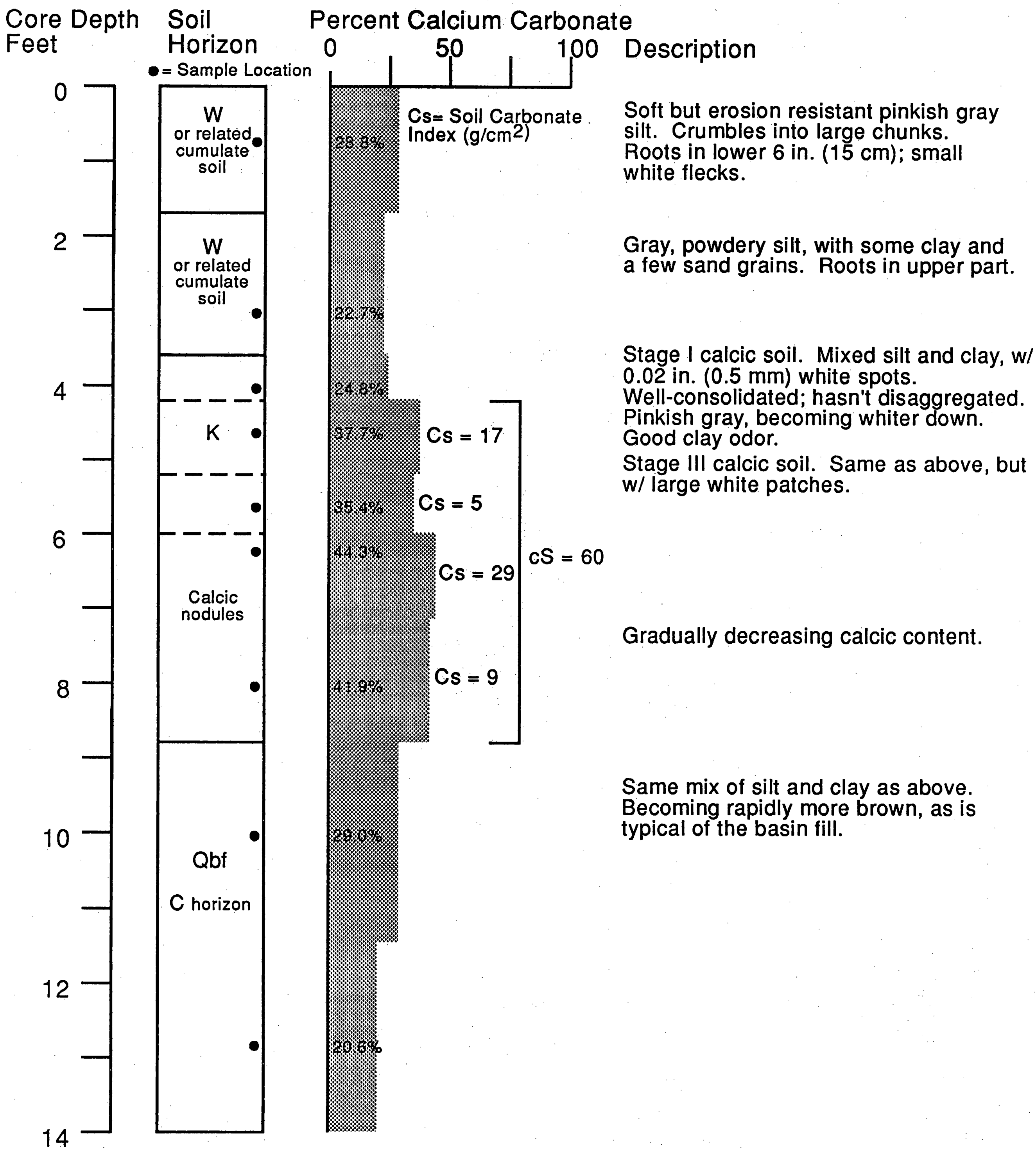
Front Ridge Section
Location C15



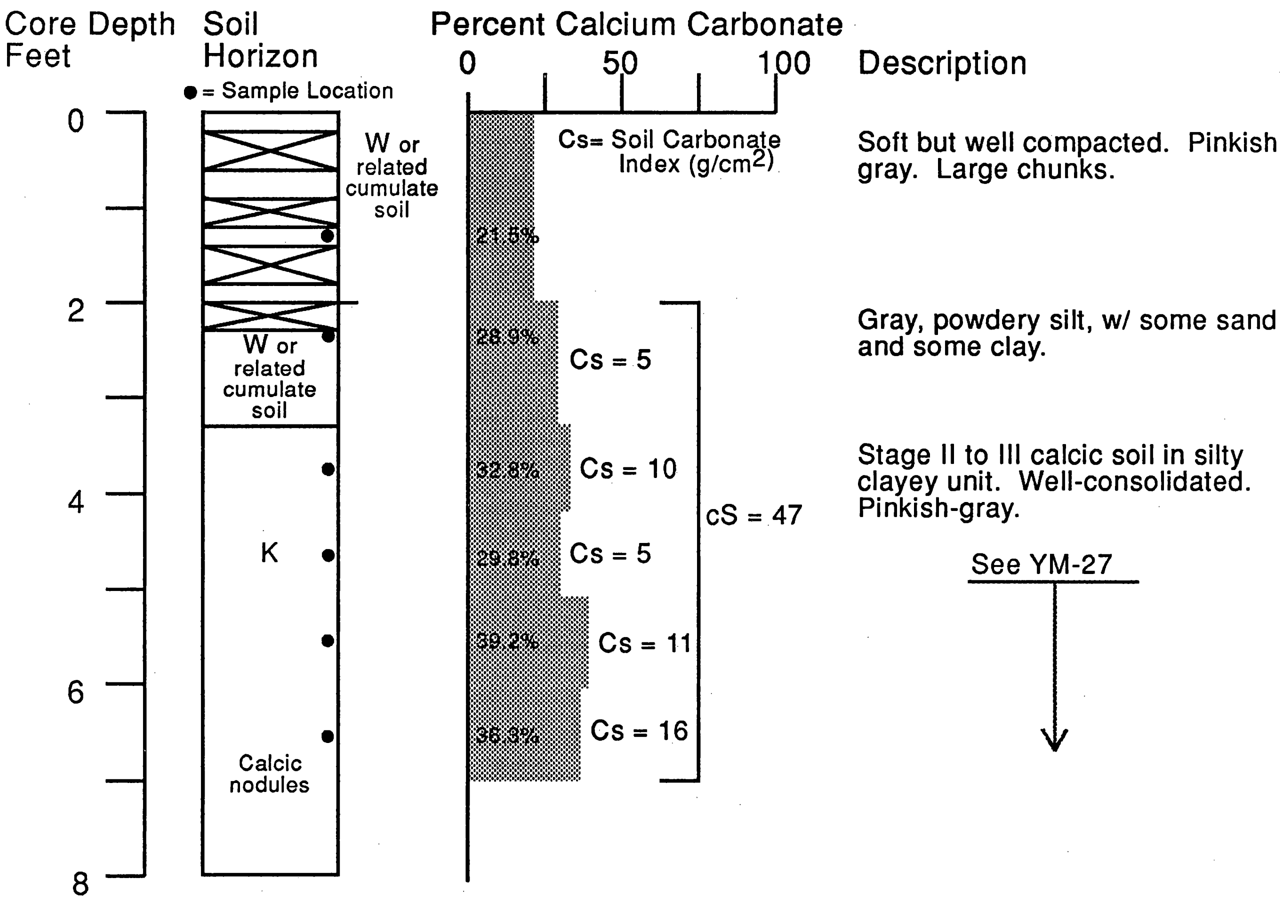


Boring YM-21 Log
Core Depth Feet
Soil Horizon
● = Sample Location
Percent Calcium Carbonate
0
50
100
Description
0
2
4
6
8
10
12
14
16
18
Qe1 or Qe2
K
BK-K
Cs= Soil Carbonate Index (g/cm2)
7.0%
29.3%
Cs = 30
cS = 43.5
22.9%
Cs = 13.5
5.3%
5.4%
4.4%
28.6%
38.3%
4.0%
40.9%
Well-sorted, very fine- to fine-grained sand with few pebbles and calcic nodules.
Stage III petrocalcic horizon. Many incipient calcic nodules.
Blebs of sand in a petrocalcic matrix. Sand is fine- to medium-grained, similar to below.
A few isolated granules. Redder.

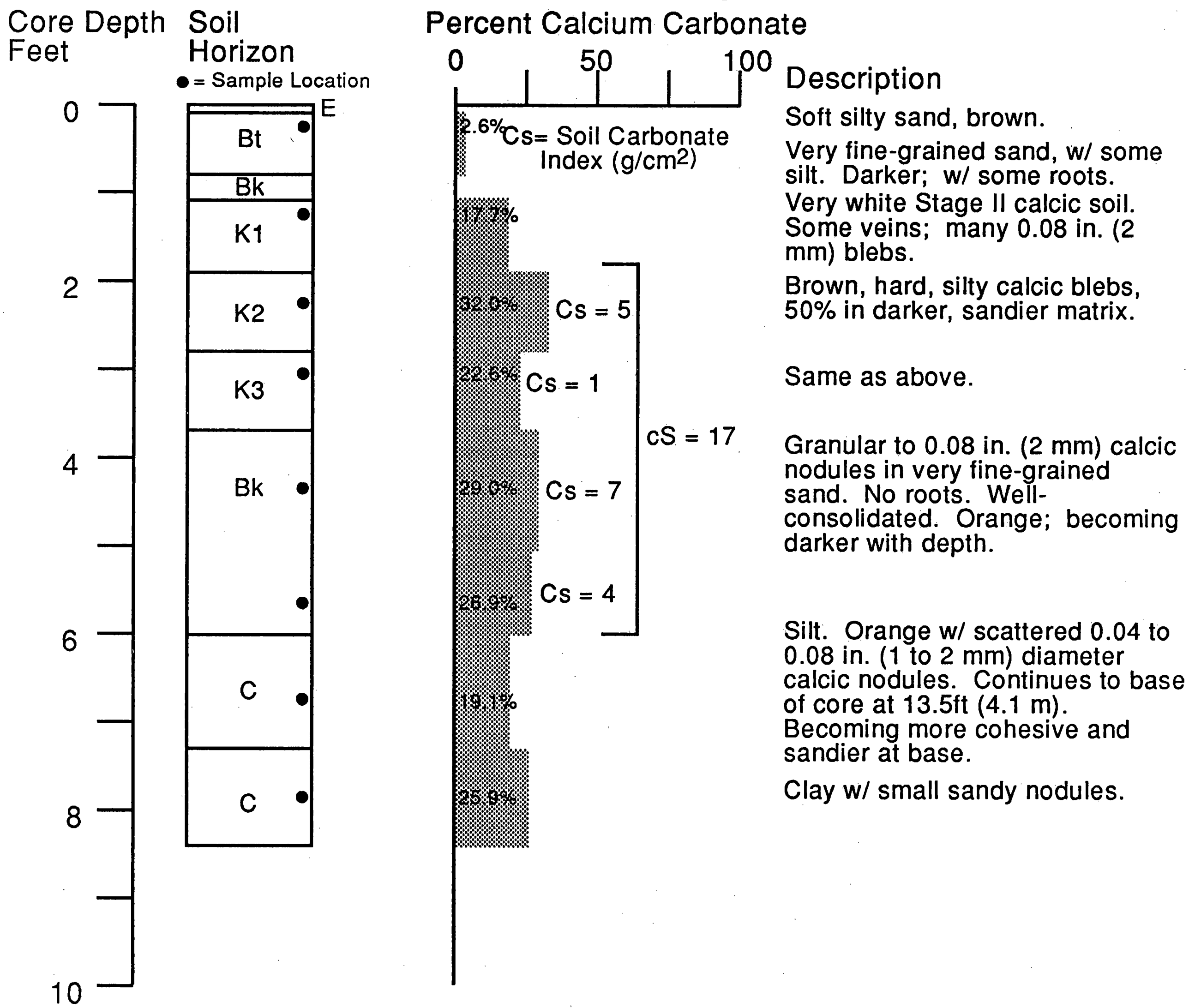
Boring YM-27 Log



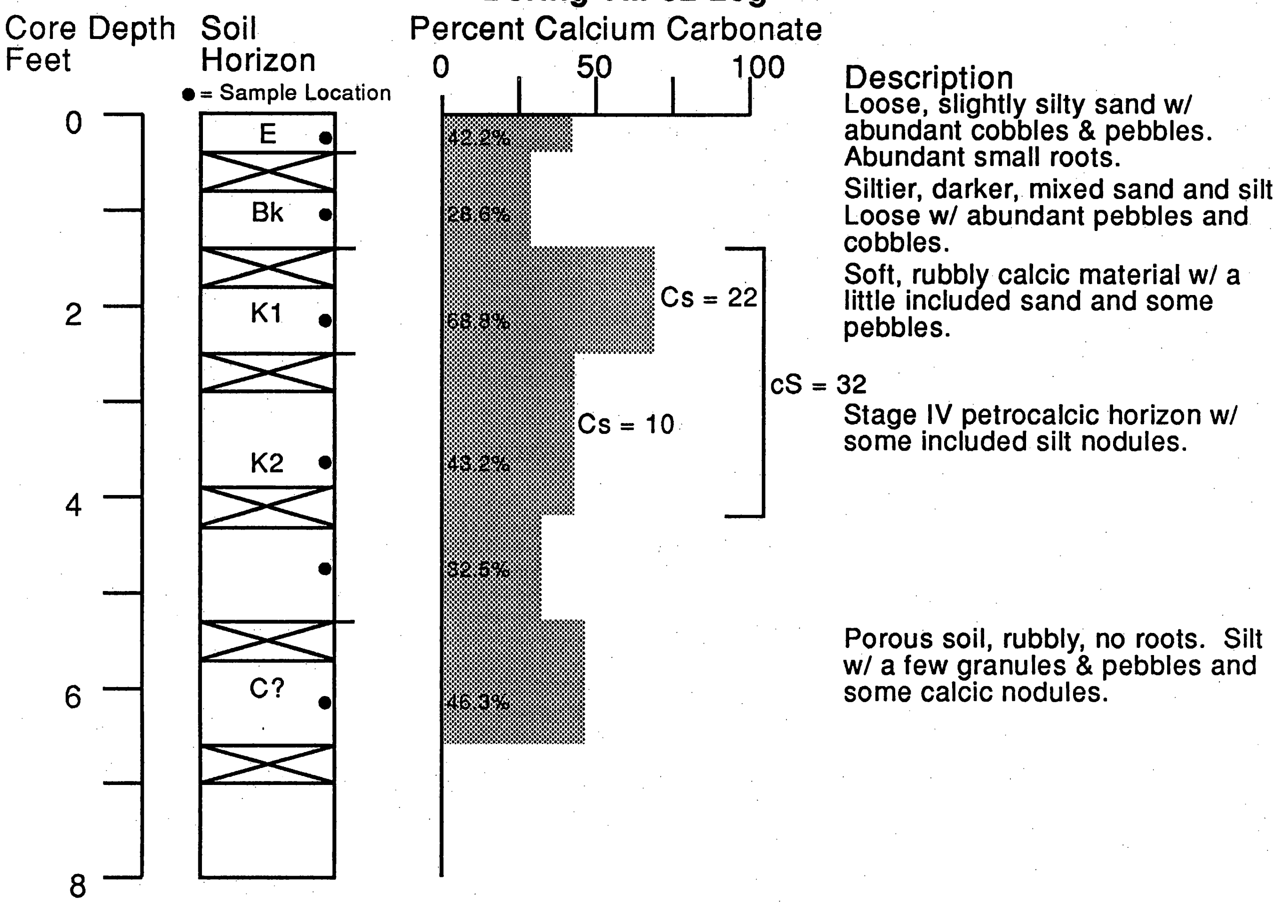
Boring YM-28 Log



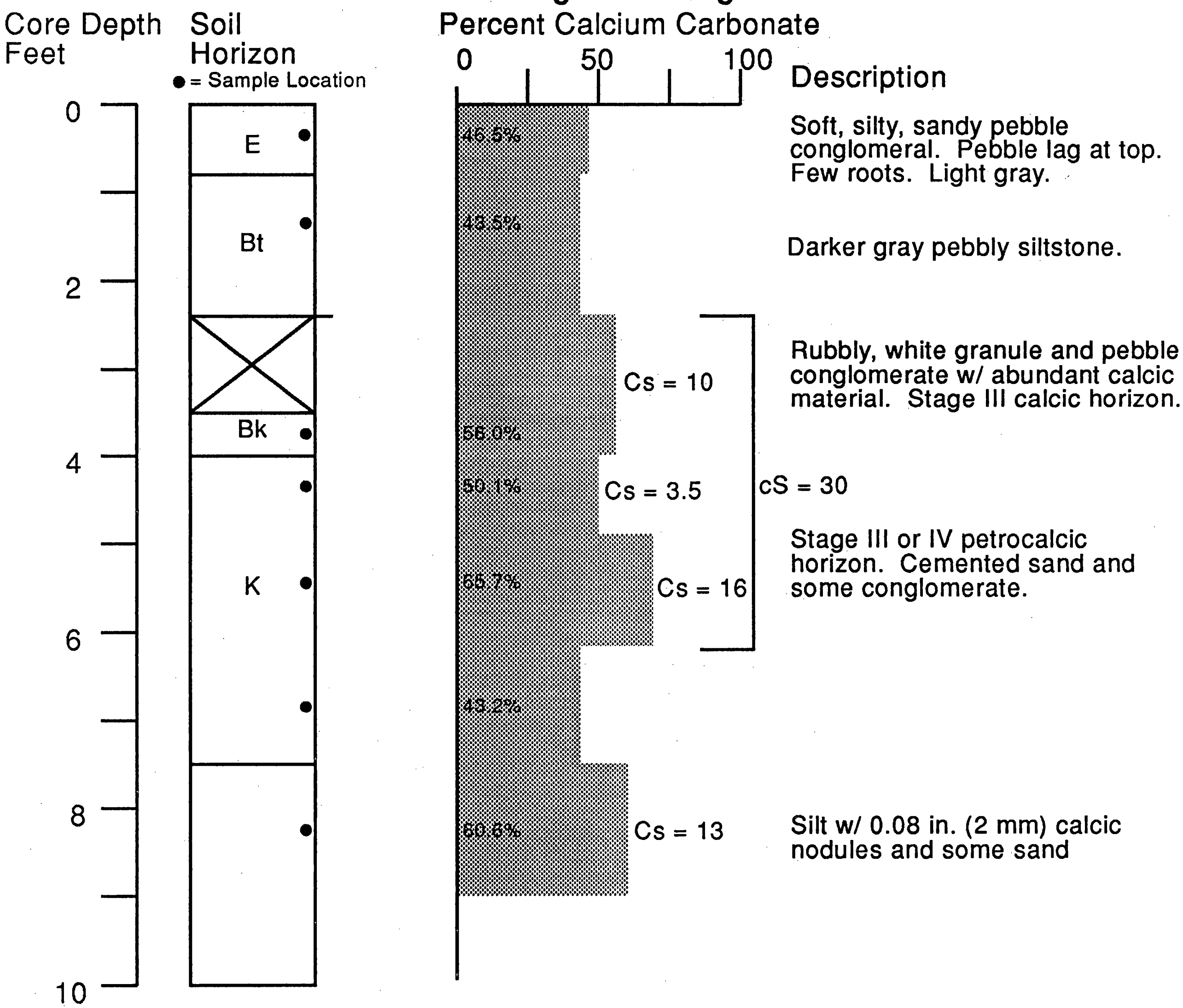
Boring YM-29 Log



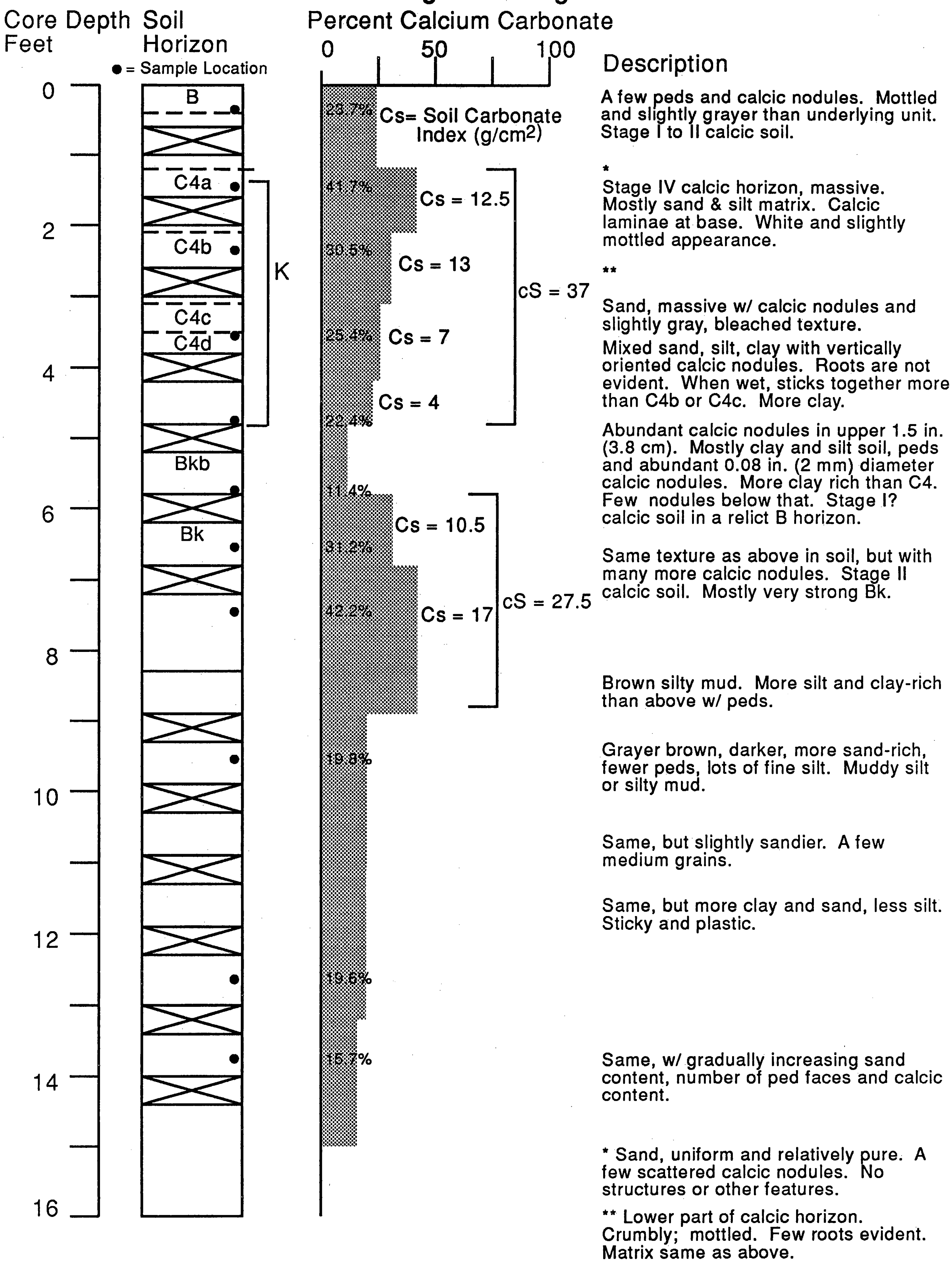
Boring YM-32 Log



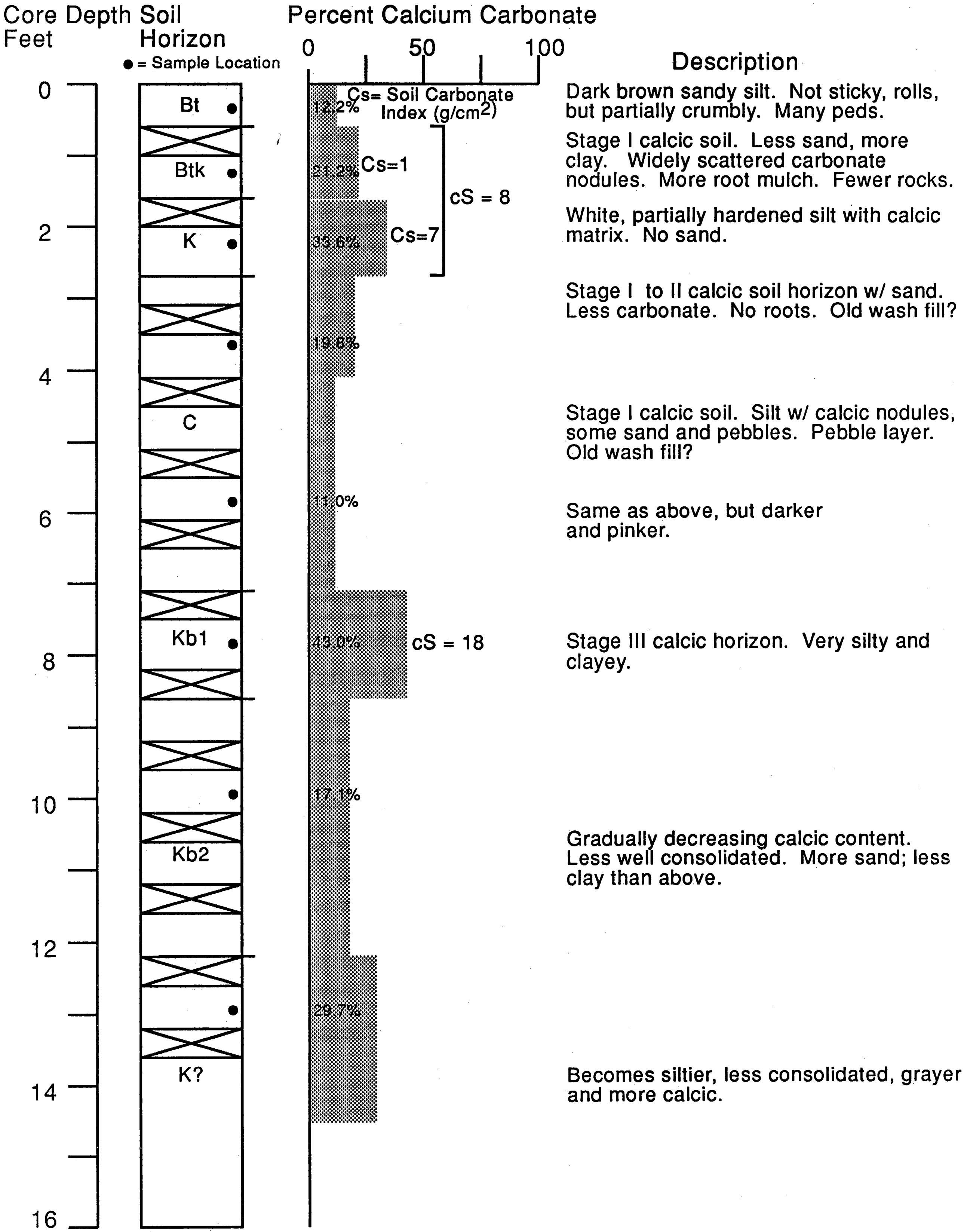
Boring YM-33 Log



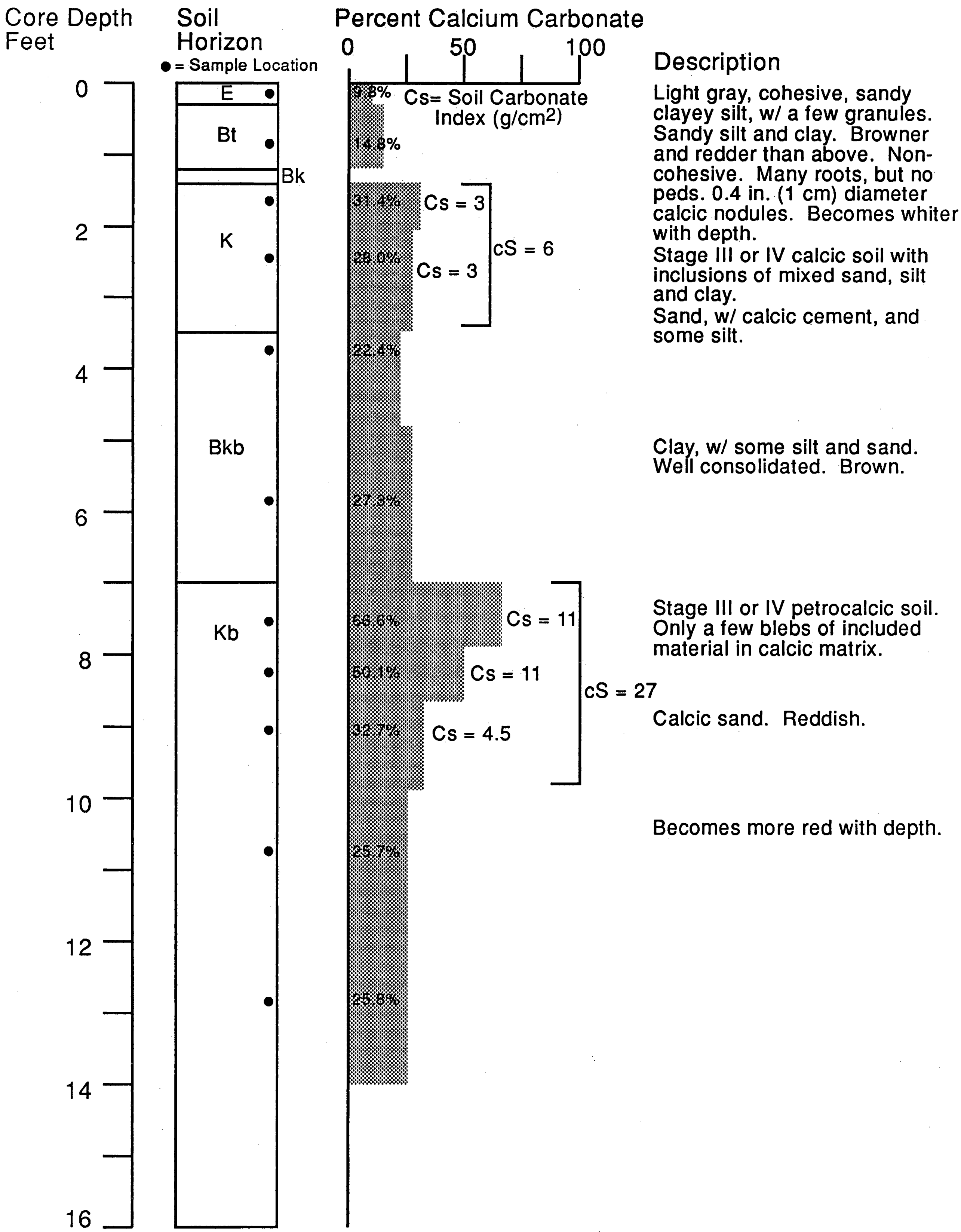
Boring YM-35 Log



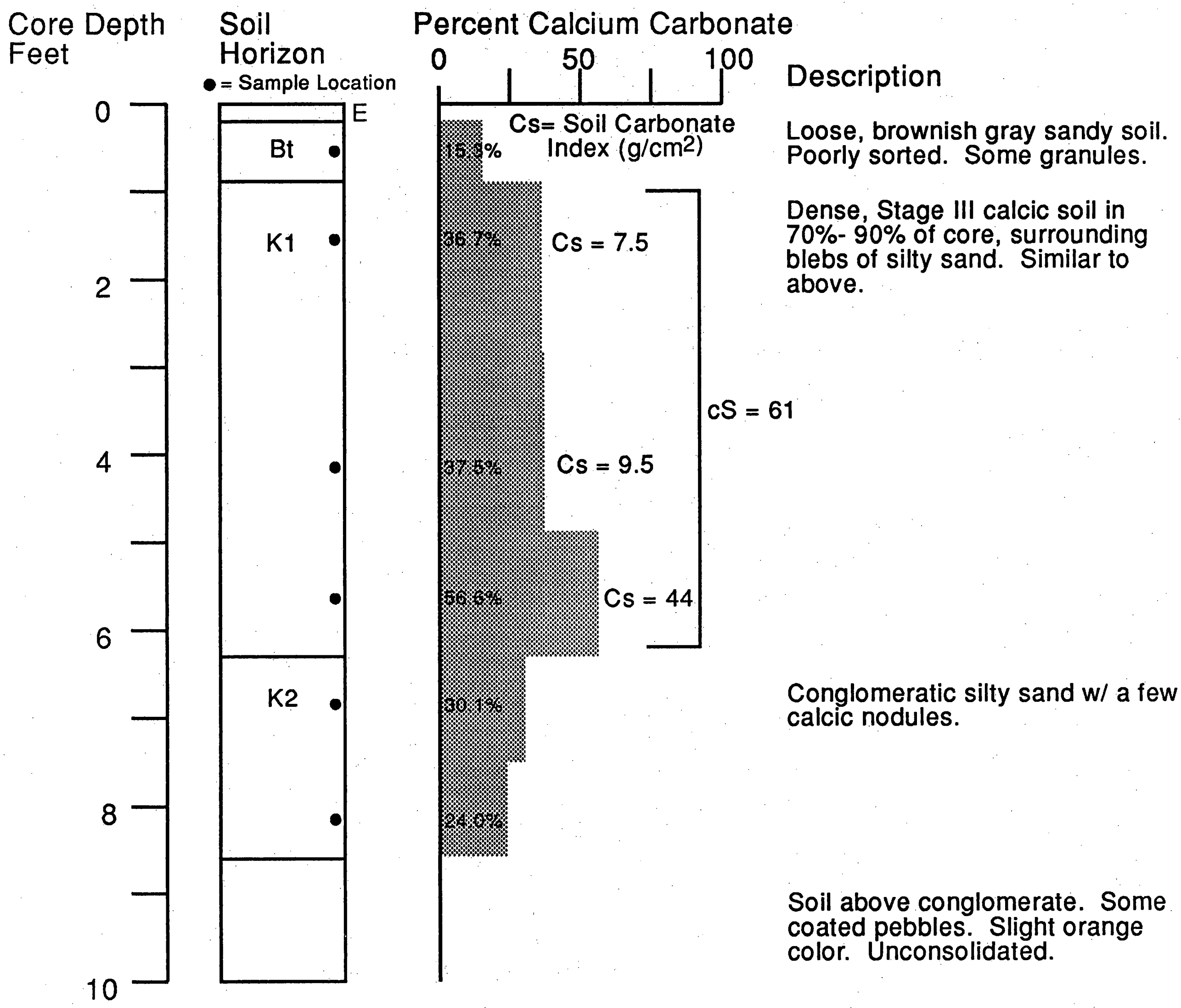
Boring YM-36 Log

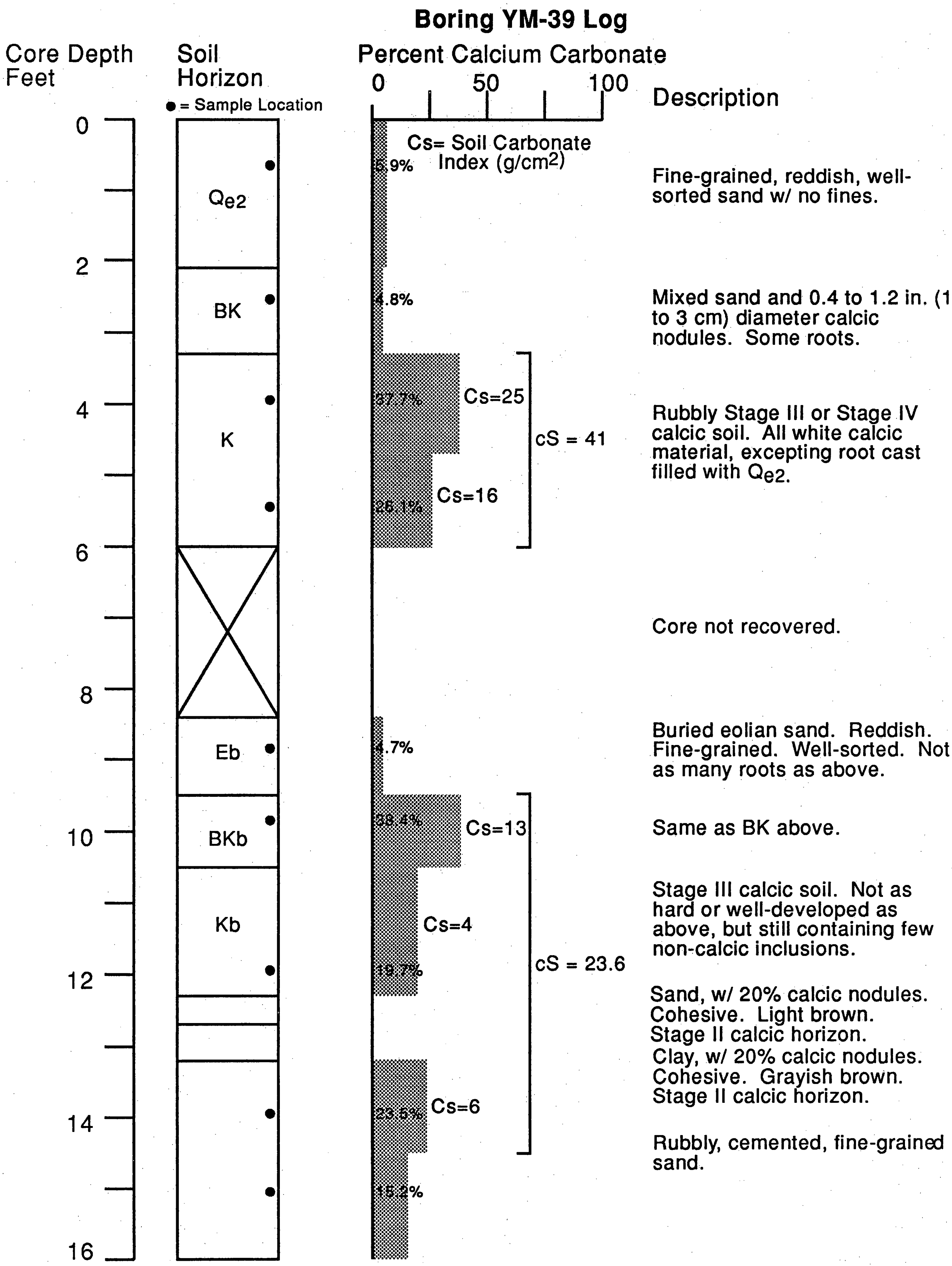


Boring YM-37 Log

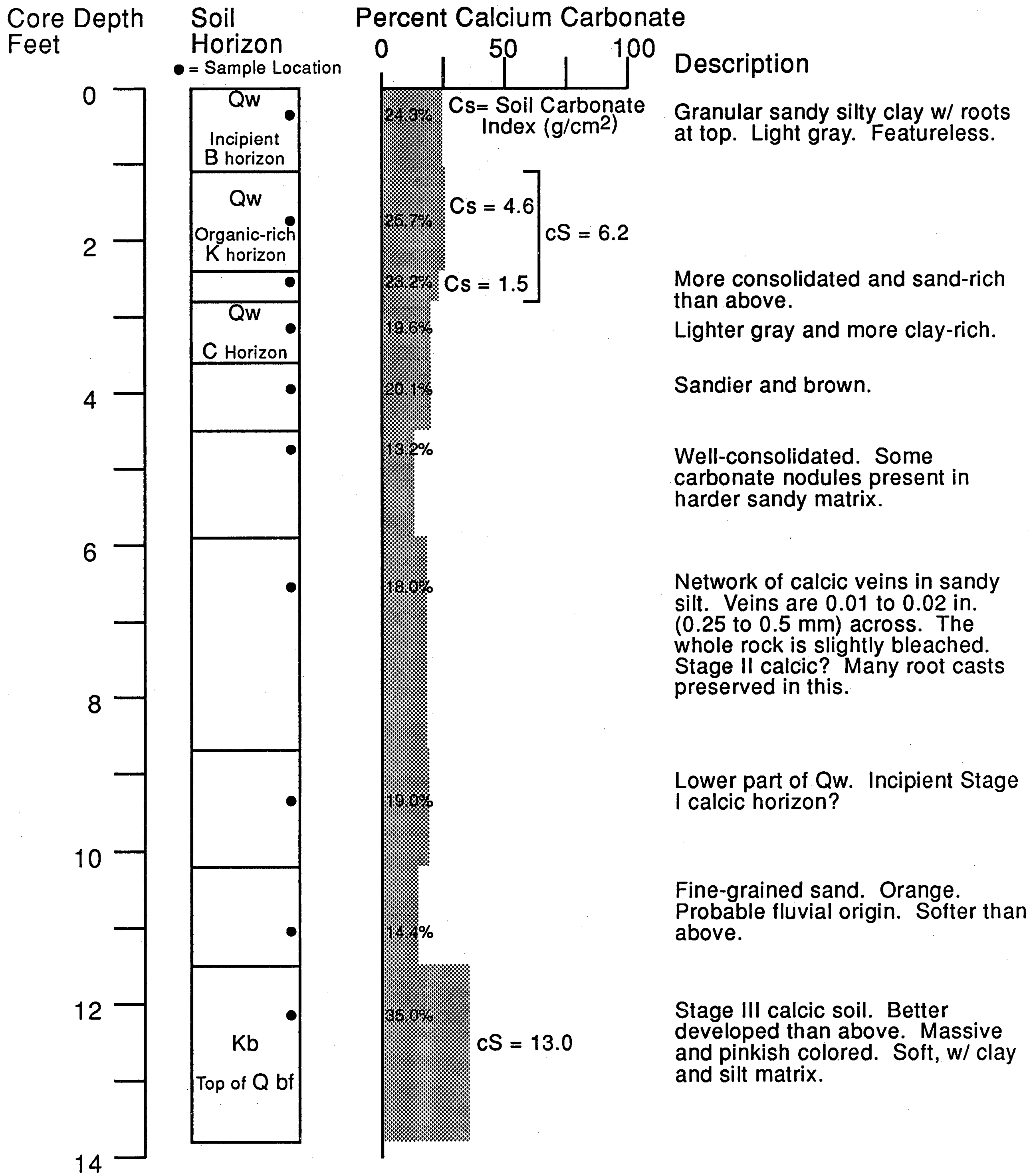


Boring YM-38 Log




Boring YM-39 Log
Core Depth Feet
Soil Horizon
● = Sample Location
Percent Calcium Carbonate
0
50
100
Description
0
2
4
6
8
10
12
14
16
Qe2
BK
K
Eb
BKb
Kb
Cs= Soil Carbonate Index (g/cm2)
5.9%
4.8%
37.7%
Cs=25
25.1%
Cs=16
cS = 41
4.7%
38.4%
Cs=13
Cs=4
19.7%
cS = 23.6
23.5%
Cs=6
15.2%
Fine-grained, reddish, well-sorted sand w/ no fines.
Mixed sand and 0.4 to 1.2 in. (1 to 3 cm) diameter calcic nodules. Some roots.
Rubbly Stage III or Stage IV calcic soil. All white calcic material, excepting root cast filled with Qe2.
Core not recovered.
Buried eolian sand. Reddish. Fine-grained. Well-sorted. Not as many roots as above.
Same as BK above.
Stage III calcic soil. Not as hard or well-developed as above, but still containing few non-calcic inclusions.
Sand, w/ 20% calcic nodules. Cohesive. Light brown. Stage II calcic horizon.
Clay, w/ 20% calcic nodules. Cohesive. Grayish brown. Stage II calcic horizon.
Rubbly, cemented, fine-grained sand.

Boring YM-40 Log



APPENDIX C.
RESULTS OF GRAIN SIZE ANALYSES PERFORMED ON SAMPLES OF SURFICIAL DEPOSITS

This appendix provides the results of textural analyses on samples of surficial deposits. The samples were collected from auger holes and shallow pits from the northern Faskin Ranch area (approximately the area of figures 3 and 12). The first set of results notes the surficial deposit from which each sample was collected and provides detailed textural information. This is followed by a summary listing of the sand, silt, and clay fractions in the samples. Sample locations are in the Bureau of Economic Geology QA files.

	Sample	92RL1A	92RL1B	92RL1C	92RL2A	92RL2B	92RL3A	92RL3B	92RL4	92RL5	92RL6	92RL7
	Surf. Dep. Type	Qbf	Qbfc	Qbfc	Qe2	Qe2	Qe2	Qe2	Qe1	Qe1	Qe2	Qe2
Grain	-2	0	0	1	0	0	0	1	0	6	0	0
Size	-1	0	0	0	0	0	0	0	0	0	0	0
(Phi)	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	1	2	3	2	2	2	4	4	3
	2	7	1	6	33	32	32	27	27	21	34	29
	3	30	5	23	38	32	35	30	30	24	32	31
	4	17	7	17	9	10	16	12	9	12	11	15
	5	13	8	14	4	5	6	7	9	9	5	7
	6	4	4	4	1	1	1	3	2	3	1	2
	7	2	8	3	1	2	0	2	1	3	1	1
	8	1	4	3	1	1	0	2	1	1	1	1
	9	1	2	3	1	1	0	3	1	1	2	2
	10 to 14	25	61	25	10	13	8	11	18	16	9	9

	Sample	92RL8	92RL9	92RL10A	92RL10B	92RL10C	92RL10D	92RL11A	92RL11B	92RL11C	92RL12A	92RL12B
	Surf. Dep. Type	Qe1	Qe1	Qbfc	Qbfc	Qbfc	Qbfc	Qbfc	Qbfc	Qe2	Qw	Qw
Grain	-2	7	4	0	0	0	0	9	4	0	0	0
Size	-1	0	0	0	0	0	1	0	0	0	0	0
(Phi)	0	0	1	2	0	0	1	1	0	0	0	0
	1	3	3	3	1	2	2	4	4	4	1	2
	2	8	11	11	8	9	14	16	29	30	5	7
	3	22	25	15	7	9	14	13	26	29	16	13
	4	15	14	7	6	4	5	8	8	10	15	13
	5	12	12	18	13	10	9	9	6	6	13	13
	6	4	3	8	10	7	5	2	2	2	4	3
	7	3	3	4	6	8	3	3	1	2	3	3
	8	2	3	2	4	5	2	4	1	1	2	3
	9	2	3	2	2	3	2	3	1	1	1	2
	10 to 14	22	18	28	44	42	42	28	18	15	40	41

	Sample	92RL13A	92RL13B	92RL13C	92RL13E	92RL14	92RL15	92RL16	92RL17	92RL18	92RL19	92RL20
	Surf. Dep. Type	Qw	Qw	Qw	Qe1	Qw	Qbf	Qbf	Qw	Qbfc	Qbfc	Qw
Grain	-2	0	9	0	0	0	0	0	1	0	0	0
Size	-1	0	0	0	0	0	0	0	0	0	0	0
(Phi)	0	1	2	0	0	0	0	0	0	0	0	0
	1	1	8	0	1	0	1	0	1	0	0	0
	2	4	26	2	3	2	8	3	5	8	2	6
	3	11	30	12	12	8	25	8	16	28	10	19
	4	7	11	15	10	13	18	7	13	21	13	13
	5	11	3	21	11	14	14	13	11	16	14	7
	6	4	1	8	5	7	4	7	4	4	5	4
	7	3	1	5	5	4	2	6	4	2	3	3
	8	3	1	3	3	3	1	4	3	2	3	3
	9	3	1	2	3	3	1	4	3	2	3	2
	10 to 14	52	7	32	47	46	26	48	39	17	47	43

	Sample	92RL21	92RL22	92RL23	92RL24B	92RL24C	92RL26	92RL27	92RL28	92RL29	92RL30	92RL31
	Surf. Dep. Type	Qe1	Qe2	Qw	Qbfc	Qbf	Qrs	Qrs	Qbf	Qbf	Qbf	Qbfc
Grain	-2	0	0	0	2	5	0	27	3	0	0	12
Size	-1	0	0	0	0	0	0	0	0	0	1	0
(Phi)	0	0	0	0	1	0	0	1	0	0	3	2
	1	2	2	0	1	0	1	2	0	0	2	3
	2	14	18	2	3	3	2	4	3	1	9	7
	3	25	40	13	8	10	7	11	12	11	21	14
	4	13	19	15	10	8	7	14	11	7	10	11
	5	12	9	21	17	10	5	16	9	11	11	18
	6	6	3	6	10	6	4	7	4	5	3	6
	7	3	2	4	5	5	6	3	4	6	4	3
	8	2	1	3	4	7	7	2	5	7	3	2
	9	1	1	3	3	9	7	2	5	7	2	2
	10 to 14	22	5	33	36	37	54	11	44	45	31	20

	Sample	92RL32	92RL33	92RL34A	92RL34B	92RL35A	92RL35B	92RL35C	92RL35D
	Surf. Dep. Type	Qof	Qof	Qyf	Qyf	Qyf2	Qyf2	Qyf2	Qyf2
Grain	-2	10	26	36	0	0	1	4	66
Size	-1	0	0	0	0	0	0	0	0
(Phi)	0	1	3	3	3	3	3	2	13
	1	4	2	2	4	6	2	2	6
	2	12	4	4	9	5	3	4	4
	3	22	12	14	27	9	7	10	5
	4	8	8	6	15	12	8	10	1
	5	14	10	10	20	21	16	16	1
	6	4	5	4	6	8	9	8	1
	7	4	3	3	3	5	6	6	0
	8	3	2	2	2	3	5	4	0
	9	2	3	1	3	2	4	3	1
	10 to 14	16	22	15	8	26	35	31	2

Core sample textural data. Sand is 2 to 0.0625 mm, silt is 0.0625 to 0.0039 mm, and clay is <0.0039 mm.

Sample Number	Total sand (%)	Total silt (%)	Total clay (%)
92RL1A	54	21	25
92RL1B	13	26	61
92RL1C	48	27	25
92RL2A	82	8	10
92RL2B	77	10	13
92RL3A	85	7	8
92RL3B	72	17	11
92RL4	68	14	18
92RL5	67	17	16
92RL6	81	10	9
92RL7	78	13	9
92RL8	55	23	22
92RL9	58	24	18
92RL10A	38	34	28
92RL10B	22	34	44
92RL10C	24	34	42
92RL10D	37	21	42
92RL11A	51	21	28
92RL11B	71	11	18
92RL11C	73	12	15
92RL12A	37	23	40
92RL12B	35	24	41
92RL13A	24	24	52
92RL13B	86	7	7
92RL13C	29	39	32
92RL13E	26	27	47
92RL14	23	31	46
92RL15	52	22	26
92RL16	18	35	47
92RL17	36	25	39
92RL18	57	26	17
92RL19	25	28	47
92RL20	38	19	43
92RL21	54	24	22
92RL22	79	16	5
92RL23	30	37	33
92RL24B	25	39	36
92RL24C	26	37	37
92RL26	17	29	54
92RL27	59	30	11
92RL28	29	27	44
92RL29	19	36	45
92RL30	46	23	31
92RL31	49	31	20

Sample Number	Total sand (%)	Total silt (%)	Total clay (%)
92RL32	57	27	16
92RL33	55	23	22
92RL34A	65	20	15
92RL34B	58	34	8
92RL35A	35	39	26
92RL35B	25	40	35
92RL35C	32	37	31
92RL35D	95	3	2