UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY DESCRIPTION OF QUATERNARY AND LATE PLIOCENE SURFICIAL DEPOSITS AT YUCCA MOUNTAIN AND VICINITY, NYE COUNTY, NEVADA

By

D.L. Hoover

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ABSTRACT

The Yucca Mountain area, in the south-central part of the Great Basin, is in the drainage basin of the Amargosa River. The mountain consists of several fault blocks of volcanic rocks that are typical of the Basin and Range province. Yucca Mountain is dissected by steep-sided valleys of consequent drainage systems that are tributary on the east side to Fortymile Wash and on the west side to an unnamed wash that drains Crater Flat. Most of the major washes near Yucca Mountain are not integrated with the Amargosa River, but have distributary channels on the piedmont above the river.

Landforms in the Yucca Mountain area include rock pediments, ballenas, alluvial pediments, alluvial fans, stream terraces, and playas. Early Holocene and older alluvial fan deposits have been smoothed by pedimentation. The semiconical shape of alluvial fans is apparent at the junction of tributaries with major washes and where washes cross fault and terrace scarps. Playas are present in the eastern and southern ends of the Amargosa Desert.

The stratigraphic units described in this report range from Pliocene marsh sediments to modern alluvium. The oldest unit, the waterlaid sediments of Amargosa marsh, were deposited mostly in shallow water in an area that covers approximately 1,250 km^2 of the Amargosa Desert. The lower unit of the waterlaid sediments consists of clay, limestone, and minor amounts of sandstone, which were deposited in lacustrine, playa, and paludal environments, and sheet limestones. Two ash beds in the lower unit have radiometric ages of approximately 3.1 and 2.1 Ma. The upper unit of the waterlaid sediments was deposited in channels eroded in the lower unit. The upper unit consists of, in ascending order, sandstones and gravels, chemical and clastic deposits of clay interbedded with limestone, and a tufa caprock. Vertebrate and invertebrate fossils indicate that the upper unit may be as young as early Pleistocene. River gravels of ancestral Rock Valley Wash were deposited in a channel that parallels modern Rock Valley Wash for at least 10 km. These gravels may be equivalent to the upper unit of the waterlaid sediments.

Unit QTa was deposited throughout the Yucca Mountain area, probably soon after deposition of the upper unit of the waterlaid sediments of Amargosa marsh. Unit QTa consists mostly of debris flow deposits and small amounts of alluvial gravel. After deposition, pedimentation removed as much as 50 m of the unit. A soil on the pediment contains a thick calcic horizon. Residual boulders as much as 10 m in diameter protrude above the pediment. After soil development, the unit was dissected by subparallel drainage systems. Ridges between drainages form ballenas that are typical of unit QTa. A regional

unconformity between units QTa and Q2 is defined by the dissected surface of unit QTa, pediment remnants, and the soil on the pediment remnants.

Fossils in a sag pond deposit within unit QTa in Yucca Flat suggest that much of the unit is Quaternary. Terrace deposits, intermediate in age between units QTa and Q2, in the Kyle Canyon area of the Spring Mountains have not been found in the Yucca Mountain area. The sequence of events following deposition of unit QTa and prior to deposition of unit Q2 suggest that unit QTa was deposited significantly before the Bishop ash, 738 ka, was deposited near the base of unit Q2.

Unit Q2 is present throughout the Yucca Mountain area and consists of five subunits: subunit Q2c, alluvial sand and gravel and lesser amounts of debris flow deposits; subunit Q2e, eolian sand; subunit Q2s, alluvial sand; subunit Q2b, alluvial gravel and debris flow deposits; and subunit Q2a, debris flow deposits. Subunits Q2e and Q2s are lithofacies of subunit Q2c. Slopewash deposits in the Yucca Mountain area have a stratigraphic position like that of subunit Q2a, but differ from Q2a in several characteristics and are designated subunit Q2a(?) in this report.

The presence of the Bishop ash at or near the base of subunits Q2e and Q2c at several locations in the Yucca Mountain area indicates that deposition of unit Q2 began before 738 ka. Radiometric ages indicate that a soil within subunit Q2c began development about 425 ka. Surface soils began development on subunit Q2c about 270 ka; on subunit Q2b, about 175 ka; and on subunit Q2a(?), about 40 ka.

Unit Q1 was deposited mostly in washes throughout the Yucca Mountain area. The unit consists of subunit Q1c, alluvial gravel; subunit Q1s, alluvial sand that is a lithofacies of subunit Q1c; subunit Q1e, eolian sands; subunit Q1b, debris flow deposits and minor amounts of alluvial gravels; and subunit Q1a, alluvial sand and gravel. Charcoal within subunit Q1c has been dated at 8.3 ka. Charcoal, fossil seeds, and archaeological material have established three periods of deposition for subunit Q1e: 5,300 to 3,000; 2,000 to 1,000 or less; and 200 yr B.P. to the present. Deposition of subunit Q1a probably began about 1840.

Basalts in Crater Flat have ages of 3.75 Ma, 1.1 Ma, and less than 345 ka. Most of the spring deposits in the Amargosa Desert range in age from pre-QTa to pre-Q2 in age. Spring deposits that are Q2 and Q1 in age are probably restricted to the vicinity of modern springs.

INTRODUCTION

The U.S. Geological Survey began geological, geophysical, and hydrological investigations of Yucca Mountain, Nevada, in 1978. The purpose of these investigations is to provide data for the evaluation of Yucca Mountain as a potential nuclear-waste repository site. This report describes Late Pliocene and Quaternary deposits in the vicinity of Yucca Mountain. Age determinations for these deposits are summarized. The report provides a basis from which the approximate age of faults that displace surficial deposits in the Yucca Mountain area can be determined.

Physiography

Yucca Mountain (fig. 1) is in the south-central part of the Great Basin subprovince of the Basin and Range physiographic province. In the Yucca Mountain area, elevations range from approximately 610 m on the Amargosa River at the southern end of the Amargosa Desert to approximately 2,345 m on Pahute Mesa. Within 100 km of Yucca Mountain (fig. 2), elevations range from -80 m in Death Valley to 3,368 m on Telescope Peak in the Panamint Range on the west (just southwest of fig. 2) and 3,633 m on Charleston Peak in the Spring Mountains (just southeast of fig. 2). The elevation of the piedmont angle (at the junction of the piedmont slope with the bedrock hills) at Yucca Mountain ranges from 865 m at the southernmost ridge to approximately 1,550 m at the head of Yucca Wash. Maximum elevation of Yucca Mountain is 1,783 m at the northern end.

A geologic map of the potential repository site at Yucca Mountain (Scott and Bonk, 1984), a report on the Quaternary faults at and near Yucca Mountain (Swadley and others, 1984), and a report on the structural features and tectonic history of part of the southern Great Basin (Carr, 1984) describe the structural features of Yucca Mountain and the surrounding area. The reader is referred to these reports for descriptions of the structural features mentioned in this report. Landform terminology in this report is in accordance with Peterson's (1981) classification for the Basin and Range province.

The Yucca Mountain area is in the drainage basin of the Amargosa River, which has its headwaters in the western part of Pahute Mesa and drains through the Amargosa Desert and Tecopa Basin into Death Valley (fig. 1). Yucca Mountain consists of one main and several subsidiary, tilted fault blocks of Tertiary volcanic rocks that are typical of the Basin and Range province. West-facing fault scarps on the main fault block have maximum slopes of 60 percent in Solitario Canyon (Scott and Bonk, 1984). A dendritic drainage system was deeply eroded before Quaternary time into the east-facing dip slopes and along faults in the main fault block. Slopes on the main fault block are 10-15 percent near the crests and 20-50 percent on the sides. Small valleys vary from V-shaped with remnants of surficial deposits along the lower valley sides and as thin, narrow deposits in the valley bottoms to flat-bottomed valleys underlain by surficial deposits. The largest valleys, Dune, Drill Hole, and Sever Washes (fig. 3), have sand ramps and alluvial deposits on the valley sides that have slopes of 10 percent and are bordered by terraces underlain by surficial deposits. These terraces are 50 to 300 m wide and have downstream slopes of 3-8 percent.

The sides of ridges that are formed by subsidiary fault blocks have lower slope angles than the sides of ridges formed by the main fault block on both fault scarps and dip slopes. The drainage systems of the subsidiary fault blocks are short, first- and second-order washes that are V-shaped and shallower than washes on the main fault block. The lower slope angles and the lesser development of tributaries in these drainage systems, when compared to those of the main fault block, are the result of lower relief and shorter dip slopes on the subsidiary fault blocks. South of the Dune Wash drainage basin, a few deep V-shaped drainages are present along north-south trending faults, and do not have tributaries.

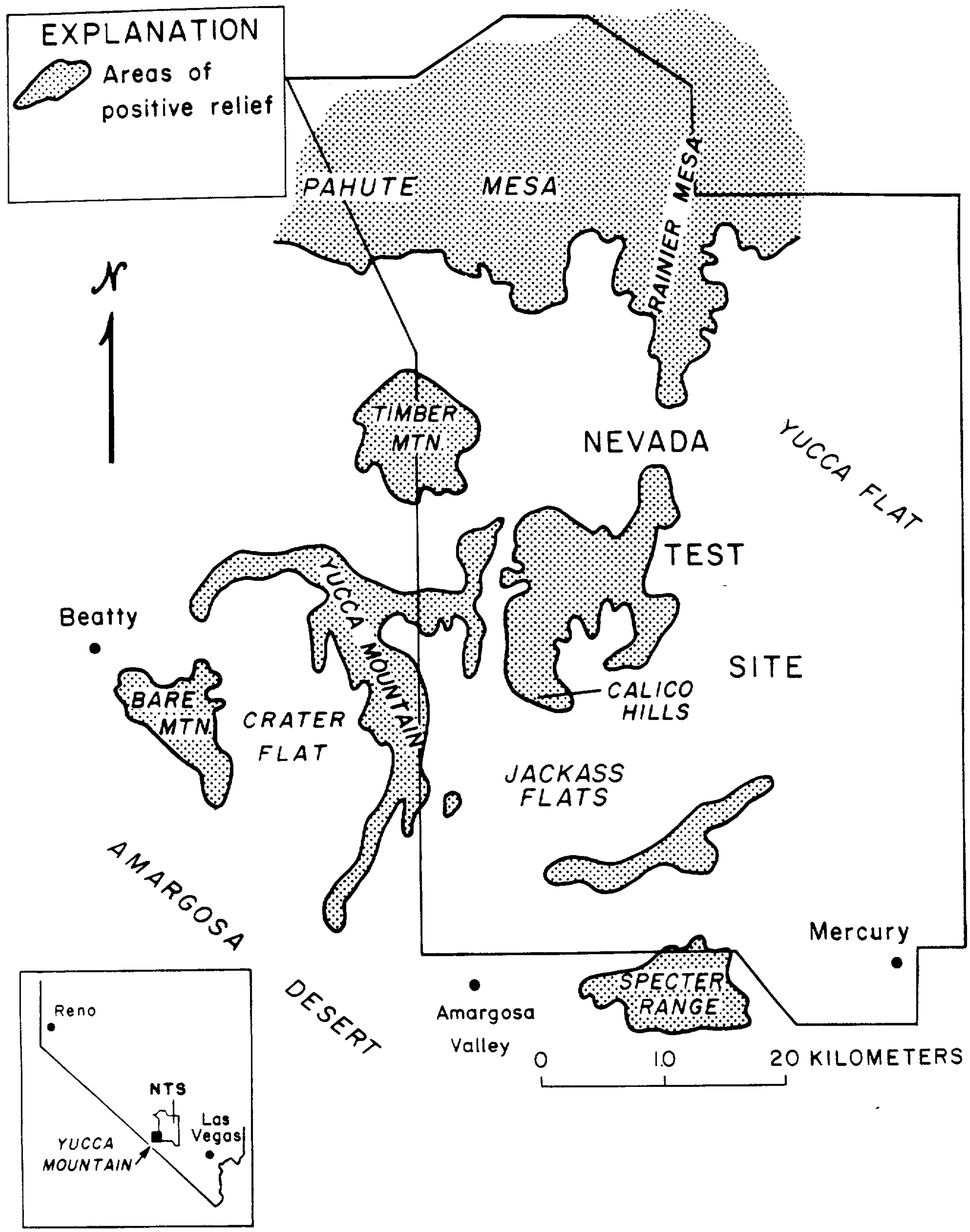

Figure 1.--Index map showing location of Nevada Test Site and Yucca Mountain.

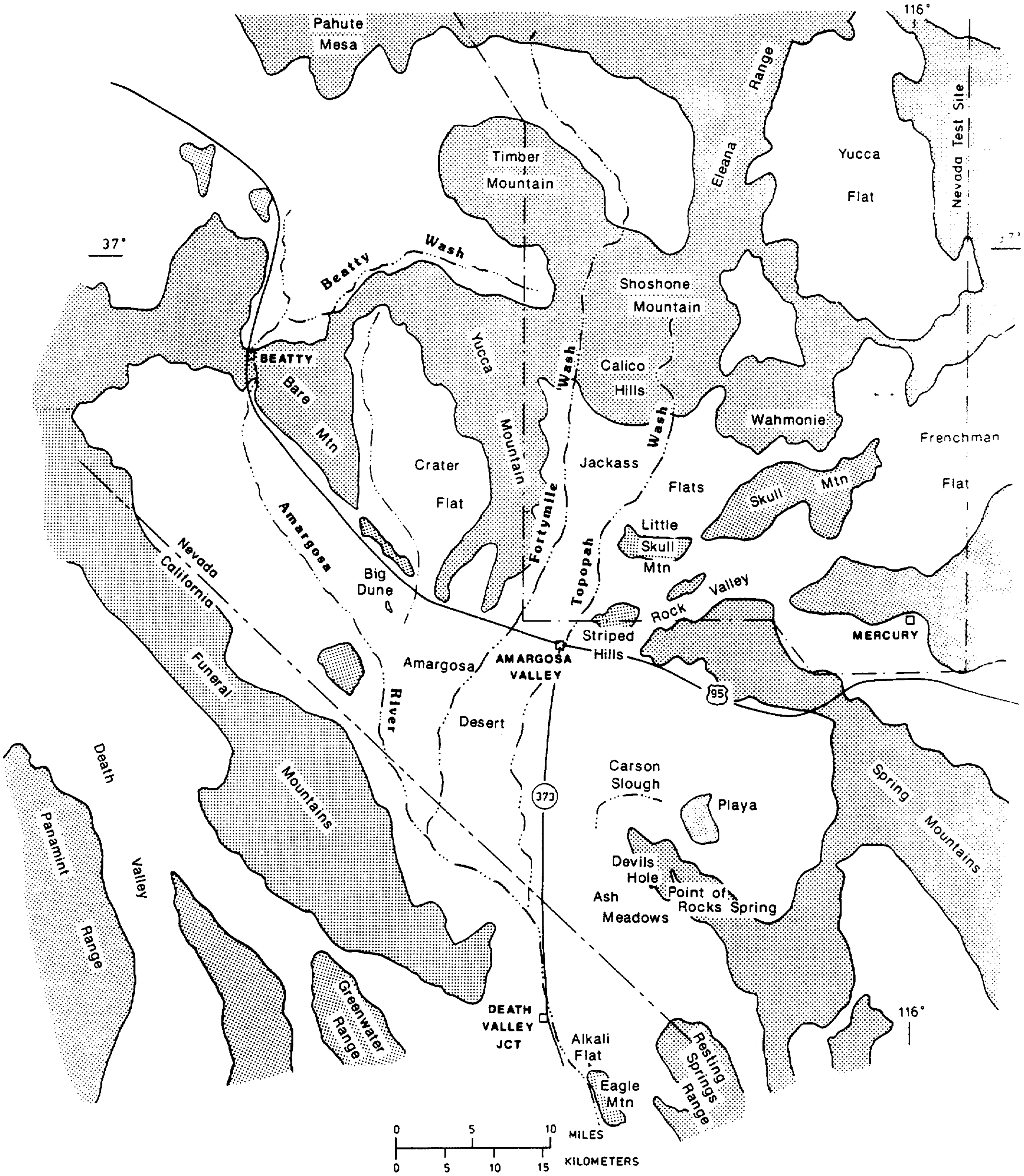

Figure 2.--Bedrock geologic map of Yucca Mountain region.

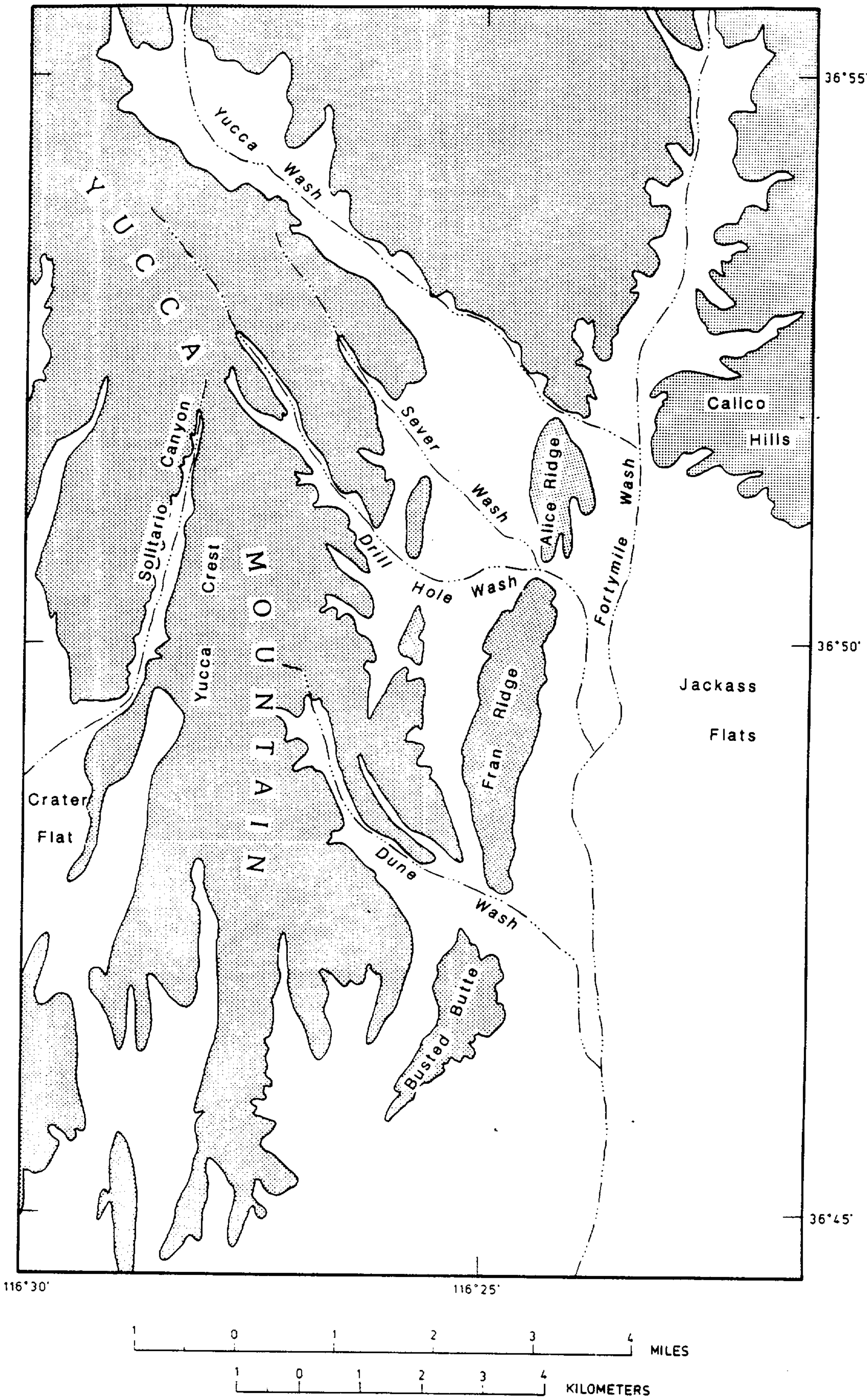

Figure 3.--Physiographic features of Yucca Mountain and vicinity.

Most of the washes that drain east-southeast to east on Yucca Mountain and adjacent fault blocks are consequent washes developed on dip slopes. Valleys that drain to the north or south and valleys at the north end of Yucca Mountain that drain southeast were developed along faults (Scott and Bonk, 1984; Carr, 1984). Although faults are not exposed in Yucca Wash, a geomagnetic anomaly suggests that a probable Miocene structural boundary may have influenced the distribution of older rocks, and thus the location of Yucca Wash (Carr, 1984).

The drainage basin of the Amargosa River above Beatty (fig. 2) is deeply incised in volcanic rocks. Fortymile Wash, Topopah Wash, Rock Valley Wash, Carson Slough, and the unnamed wash that drains Crater Flat are the major tributaries of the Amargosa River between Beatty and the southern end of the Amargosa Desert. East of Rock Valley Wash and Carson Slough, drainage is into the playa at the eastern end of the Amargosa Desert. South and west of the Amargosa River and north of Eagle Mountain, tributaries originating in the Funeral Mountains are much smaller than tributaries north of the river. Although Crater Flat, Fortymile Wash, Topopah Wash, and the unnamed wash that drains Crater Flat are deeply incised on middle to upper piedmont slopes, these washes are not integrated with the Amargosa River. On the lower piedmont slopes south of U.S. Highway 95, these washes are distributary and their runoff reaches the Amargosa River only during times of flooding. Rock Valley Wash and the drainage basin of Carson Slough are integrated with the Amargosa River.

Major landforms in the Yucca Mountain area include rock pediments, ballenas, fan and alluvial pediment remnants,[1] alluvial fans, stream terraces, and playas. The only rock pediment near Yucca Mountain is on argillite of the Eleana Formation in the center of the Calico Hills. Rounded, subparallel ridges, called ballenas, are common on the oldest surficial deposits near bedrock hills. On piedmont slopes between bedrock hills and on the basin floor of the Amargosa Desert, deposits of coalescing alluvial fans of different ages form nearly flat remnants between washes. Most of these fan deposits have been modified by creep and slopewash into smooth alluvial pediments. Because of fan coalescence and alluvial pedimentation, the semiconical topographic expression of alluvial fan cones is absent on most piedmont slopes. Small, semiconical fans are present at the junction of tributaries and larger washes in valleys in the Yucca Mountain area. Just west of Fran Ridge, Drill Hole Wash has a large, low semiconical fan just above the junction with Sever Wash. Steep semiconical fans are present below fault scarps along the east front of Bare Mountain and along terrace scarps east of Beatty. Major washes have stream terraces that extend from near the head of the wash down to where the washes become distributary on the lower part of the piedmont slope. A playa defines the end of a closed drainage system at the eastern end of the Amargosa Desert. Alkali Flat, at the south

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[1]Peterson (1981) uses the term pediment for a surface eroded on unconsolidated material on the piedmont slope. In this report, the adjective, alluvial, is added to avoid confusion with rock pediments by readers unfamiliar with Peterson's terminology.

end of the Amargosa Desert, is a late Pleistocene playa that has been breached by the Amargosa River (fig. 2).

Although calderas north of Yucca Mountain and northwest-trending faults alter the north-south pattern of ranges and valleys that are typical of the Great Basin, the general physiography and types of landforms in the Yucca Mountain area are similar to other areas of the Great Basin. The dimensions and topographic relationships of the landforms in Quaternary deposits in the Yucca Mountain area and in the Amargosa Desert do not differ greatly from those of similar landforms in the closed basins of Frenchman and Yucca Flats and appear to be relatively unaffected by the presence of the Amargosa River.

Previous Work

The bedrock geology of the NTS area has been published in a series of geologic maps at a scale of 1:24,000 (fig. 4). In the Yucca Mountain area, these maps include Topopah Spring NW (Christiansen and Lipman, 1965), Topopah Spring SW (Lipman and McKay, 1965), Topopah Spring (Orkild and O'Connor, 1970), Jackass Flats (McKay and Williams, 1964) and Lathrop Wells (McKay and Sargent, 1970). The geology of the Bare Mountain 15-minute quadrangle was mapped by Cornwall and Kleinhampl (1961). The Quaternary deposits as shown on these quadrangles were simplified and based mostly on clast size and geomorphic position.

Fernald and others (1968) mapped the surficial deposits of Yucca Flat for engineering purposes on the basis of depositional processes and fragment size. Units QTa, Q2, and Q1 were first described in the Syncline Ridge area of western Yucca Flat (Hoover and Morrison, 1980), which has Quaternary deposits similar to those in the Yucca Mountain area. Correlation characteristics and the stratigraphy of Quaternary surficial deposits in the NTS area were described by Hoover and others (1981). Swadley (1983) mapped the Quaternary deposits in the Lathrop Wells quadrangle and Swadley and Carr (1987) mapped Quaternary deposits in the Big Dune quadrangle. Field mapping of the Quaternary deposits in most of the Topopah Spring 15-minute quadrangle by the author was included in a map of the Quaternary geology of the Yucca Mountain area compiled by Swadley and others (1984).

Waterlaid sediments in the Amargosa Desert were first mapped in a reconnaissance investigation of the hydrology of the Amargosa Desert (Walker and Eakin, 1963). Denny and Drewes (1965) mapped these sediments as playa and spring deposits in the Ash Meadows quadrangle. Swadley (1983) mapped the recrystallized chalk caprocks and claybeds separately in the Lathrop Wells quadrangle. The waterlaid sediments have also been mapped in the Big Dune quadrangle (Swadley and Carr, 1987). Mapping of the NE1/4 of the Ash Meadows 15-minute quadrangle by Pexton (1985) established the stratigraphy of the waterlaid sediments and the relationship of these deposits to younger surficial deposits. Studies of the basalts in Crater Flat (Crowe and Carr, 1980) provided the stratigraphic relationships of these basalts to Quaternary and older surficial deposits.

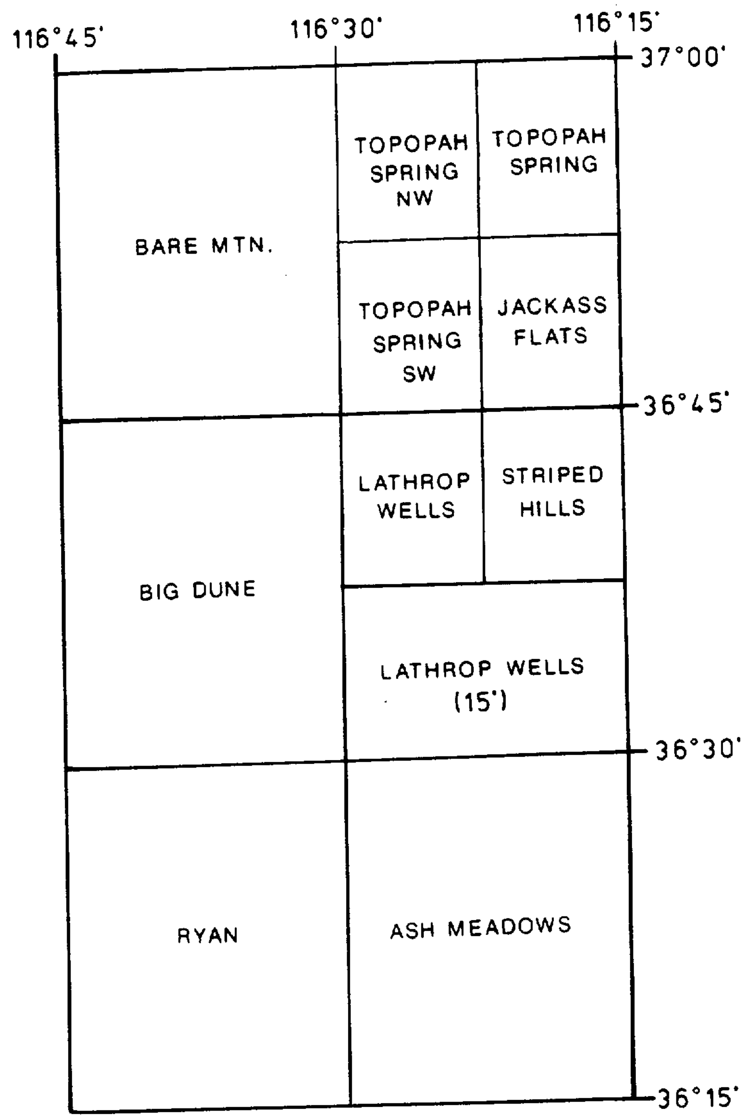

Figure 4.--Index map of the Yucca Mountain area showing outlines of quadrangle maps.

IDENTIFICATION OF QUATERNARY SURFICIAL DEPOSITS

Multiple criteria, called correlation characteristics (Hoover and others, 1981) are used for identification and correlation of surficial deposits in the NTS area. Correlation characteristics are used because Pliocene and Quaternary sediments in nearby areas could not be identified in the NTS area. The detailed Pliocene and Quaternary section of the Searles Lake area in California (Smith, 1979; Smith and others, 1983) was not comparable, because it was deposited in a different environment than the NTS deposits. The Quaternary deposits of the Tule Springs area near Las Vegas (Haynes, 1967) were deposited in a different environment, and over a much shorter time span. The correlation characteristics (see Hoover and others, 1981 for definitions) are:

- I. Topography
  - A. Macrotopography
  - B. Microrelief
- II. Drainage
  - A. Pattern and development direction
  - B. Cross-sectional shape
  - C. Depth
- III. Soils
  - A. A and B horizons
    1. Color
    2. Secondary clay, carbonate, and silica content
    3. Thickness
  - B. Calcic horizon
    1. Stage (Gile and others, 1966)
    2. Thickness
- IV. Topographic relationships to other depositional units
- V. Desert pavement
  - A. Packing and sorting
  - B. Maximum fragment size
  - C. Rock varnish color and luster
- VI. Lithology
  - A. Sand and clay content
  - B. Color
  - C. Maximum fragment size and frequency
  - D. Ratio of clast lithologies

The order of these characteristics reflects their decreasing importance in the identification of a stratigraphic unit. Except for the order of listing, these characteristics are the same as described by Hoover and others (1981).

The use of soil properties to identify stratigraphic units was limited to macroscopic differences in the A, B, and calcic horizons that are easily identifiable by geologists unfamiliar with the descriptions and techniques of soil science. These differences include the presence of vesicular A and cambic B horizons, and the presence and the degree of development of argillic

B and calcic horizons. The soil-horizon designations used in this report differ somewhat from those defined by the Soil Conservation Service (Soil Survey Staff, 1975), and are defined in the following paragraphs.

Vesicular A (Av) horizons are surface horizons that contain numerous vesicles that are 1-10 mm in diameter. Av horizons are formed in a layer of silty sand that underlies a desert pavement. Most Av horizons overlie an unconformity at the top of the underlying B or calcic horizon. This unconformity is indicated by: (1) the presence of similar Av horizons on either B or calcic horizons of a single stratigraphic unit, and (2) an abrupt decrease in secondary carbonate in some soils between the Av and the underlying B horizon.

Cambic and argillic B horizons are present on most Pleistocene and older surficial deposits. Cambic B horizons are distinguished on the basis of better developed structure and (or) stronger colors than the underlying horizon. Cambic B horizons lack significant clay accumulation, but a few, thin clay coatings on sand grains and larger fragments are present in some cambic B horizons. Most cambic B horizons are yellowish brown. Argillic B horizons have significant clay accumulations as indicated by abundant clay films. Most argillic B horizons are reddish brown, and contain more clay than the underlying horizon. Some argillic B horizons are indurated by abundant secondary calcium carbonate and locally by secondary silica. Most cambic and argillic B horizons are less than 50 cm thick.

Calcic horizons are characterized by the deposition of abundant calcium carbonate and locally by some secondary silica. The calcic horizons referred to in this report include the Cca, calcic, and petrocalcic horizons of the Soil Survey Staff (1975) and the K horizon of Gile and others (1966). Thicknesses of calcic horizons in this report include the entire thickness of visible secondary carbonate which ranges from less than 0.1 to greater than 1.5 m. The morphological characteristics of secondary carbonate in calcic horizons were used to assign stages as defined by Gile and others (1966). Calcic horizons range from stage I films and coatings on the bottoms of clasts in early Holocene and late Pleistocene deposits to thick, plugged, stage IV horizons in early Pleistocene deposits. The carbonate stages that are reported are the maximum stage developed in the entire calcic horizon (Gile and others, 1966). Carbonate-rich laminae, characteristic of strongly developed stage IV horizons, are common in early Pleistocene and older deposits, but they occur only locally in some middle Pleistocene deposits. Pisolites and brecciated and recemented laminae occur in a few locations in early Pleistocene and older deposits.

STRATIGRAPHY

Stratigraphic units in the Yucca Mountain area range from Precambrian to Holocene. Metamorphic and sedimentary rocks from Precambrian to Mississippian in age and volcanic rocks of Miocene and Pliocene age form the hills and ranges of the Yucca Mountain area. Sedimentary rocks of Miocene and early Pliocene age are present in the Funeral Mountains, at the southern and eastern ends of the Amargosa Desert, and in Crater Flat. All of these rocks are highly deformed and densely faulted. In contrast, the waterlaid sediments in the Amargosa Desert and younger surficial deposits are relatively undeformed and are faulted in only a few places. Late Pliocene and Quaternary deposits in the Yucca Mountain area include the waterlaid sediments of Amargosa marsh, unit QTa, unit Q2, which has five subunits, and unit Q1, which also has five subunits (fig. 5).

Pliocene and Quaternary(?) Deposits

Waterlaid Sediments of Amargosa Marsh

That waterlaid sediments of Amargosa marsh consist of clays, limestones, and tufas that crop out in much of the Amargosa Desert south of lat 36°30' and west of long 116°10'. Scattered outcrops are present along the Amargosa River northwest to lat 36°40', between U.S. Highway 95 and the hills that form the southern edge of Crater Flat, and at the southern end of Crater Flat along the unnamed wash that drains Crater Flat. Driller's logs (Walker and Eakin, 1963) indicate that the waterlaid sediments underlie most of the Quaternary surficial deposits between the Skeleton Hills and the Amargosa River south of U.S. Highway 95. The sediments were deposited in an area called Amargosa marsh in this report (fig. 6). These sediments are referred to as the waterlaid sediments of Amargosa marsh. Amargosa marsh had an area of approximately 1,250 km^2.

Pexton (1985) divided the waterlaid sediments of Amargosa marsh into a lower and an upper unit separated by a disconformity. The lower unit was further divided and mapped as four lithofacies: three units that are mostly argillaceous and a fourth unit of sheet limestones that overlies and interfingers with two of the argillaceous lithofacies; the "lake" deposits and the paludal deposits. The lower unit, as described by Pexton (1985), consists of:

Undifferentiated Pliocene "lake" deposits (unit Tld):

> Mostly brown to green, illitic and montmorillonitic claystones with soft to hard limestone beds, pods, and nodules that contain minor dolomite. Thin sandstone beds are sparse. Clay beds pinch and swell noticeably over short distances and grade into limestone with inclusions of irregular clay masses. Claystones contain only small amounts of magnesium silicate clays. Evaporites were not observed, but masses of selenite and thenardite blooms are found at the surface. Abundant rootmarkings. Contains two ash-fall tuffs. Deposited in floodplains, swamps, ponds, and playas.

Pliocene playa deposits (unit Tpl):

> Mostly buff to brown, hard, blocky claystones that are predominantly magnesium silicate clays with some authigenic potassium feldspar. Some claystones have pelletal textures. Minor, hard, white dolomite sheets grade into soft, white limestone. Calcium carbonate breccia masses (caliche-breccia) found near Carson Slough contain interstitial magnesium silicate clays. Contains one ash-fall tuff. Probably deposited in a seasonally flooded playa.

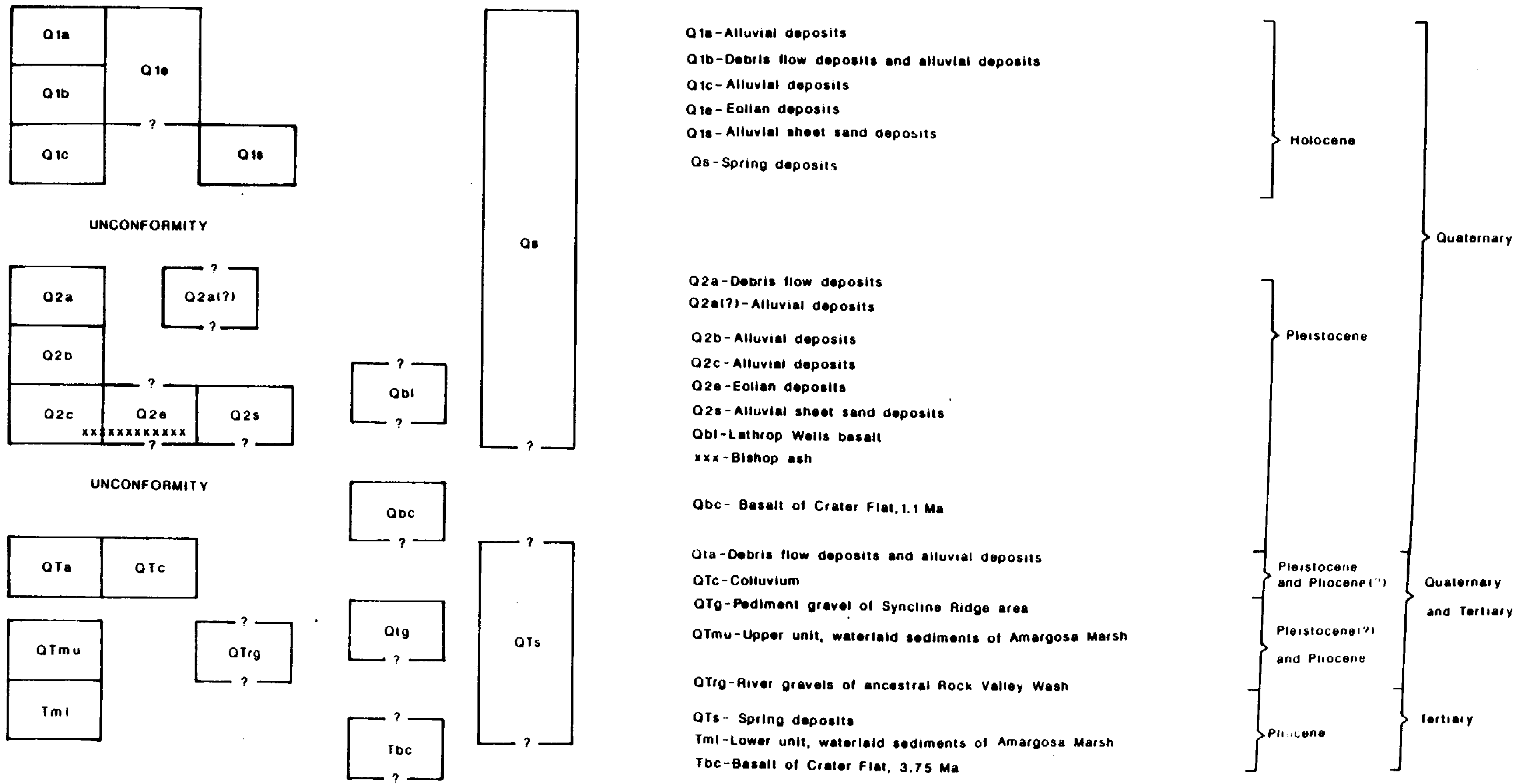

Figure 5.--Correlation chart of late Pliocene and Quaternary stratigraphic units in the Yucca Mountain area. Query indicates that stratigraphic position of base and (or) top is

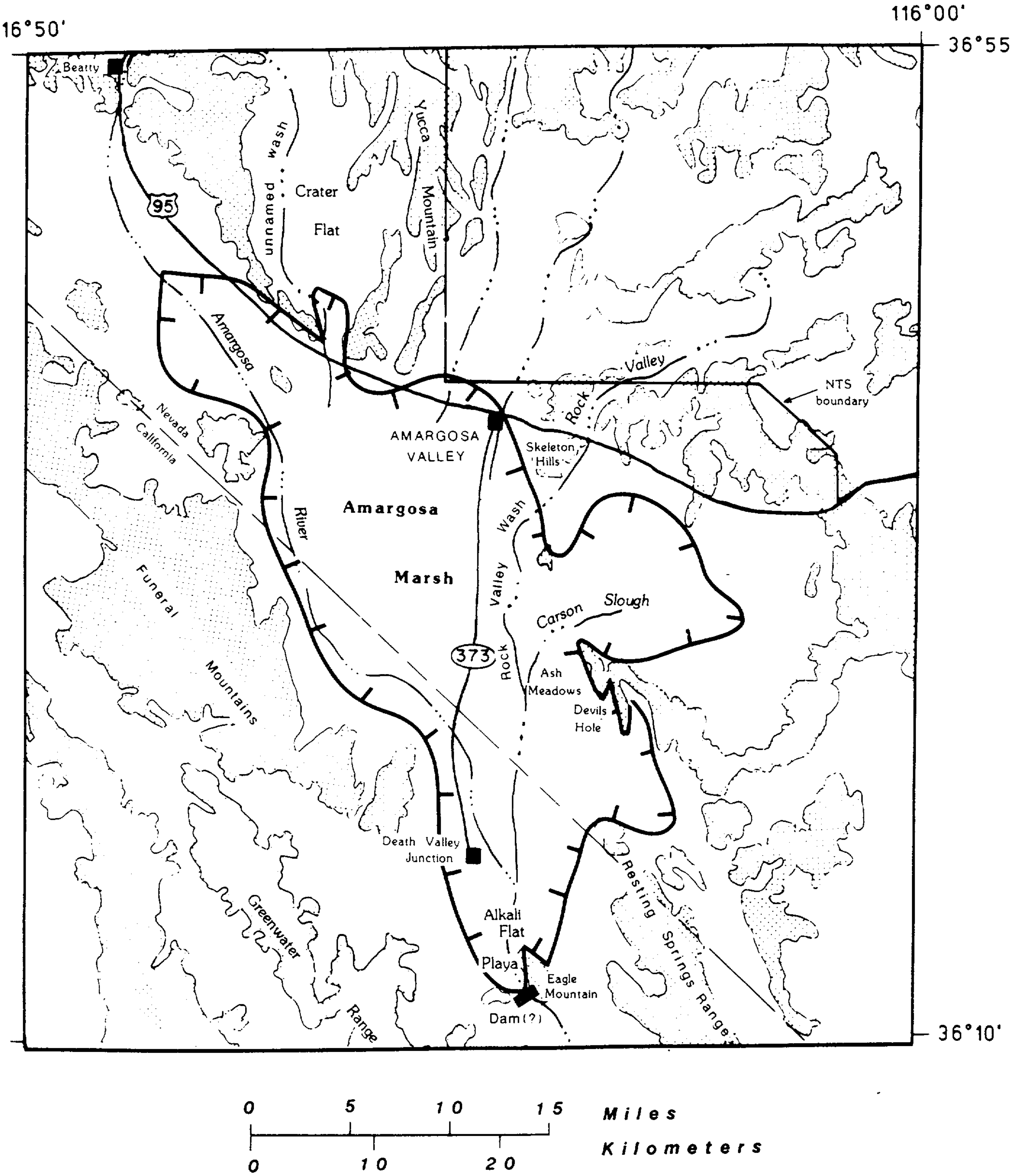

Figure 6.--Approximate area of Amargosa marsh. Boundary based on data from the Lathrop Wells quadrangle (Swadley, 1983), the Big Dune quadrangle (Swadley and Carr, 1987), drill-hole data (Walker and Eakin, 1963), and reconnaissance mapping by the author.

Pliocene paludal deposits (unit Tpa):

Mostly white, chalky limestones with minor amounts of sandstone and claystones. Claystone occurs as irregular masses of illitic to montmorillonitic clay within chalky limestones. Limestone contains gastropods, bivalves, and ostracodes. Probably deposited in spring-fed marshes and ponds.

Pliocene sheet limestones (unit Tll):

White to light gray, dense, recrystallized, fenestral limestone sheets. Contains rootmarks and occasional plant casts that resemble plants growing in runoff from springs. Probably deposited in isolated ponds.

The disconformity that separates the lower and upper units has been recognized in the Carson Slough and Rock Valley Wash drainage basins and in the area southwest of Devils Hole. The disconformity is marked by channels that are 3 to 10 m deep and a few meters to a few tens of meters wide. Between Carson Slough and Rock Valley Wash, the channels have a low gradient to the south. South of Carson Slough along the west side of the ridge of Paleozoic rocks that contains Devils Hole, the channels have a slightly steeper gradient to the west. At the south end of this ridge, the channels have a gentle gradient to the southwest.

The upper unit fills the channels cut into the lower unit. The base of the upper unit is marked by coarse sands or gravels. In the Carson Slough and Rock Valley Wash drainage basins, basal sands contain sparse pebbles as much as 2 cm in diameter. Along the west side of the ridge south of Carson Slough, similar sands and local gravels are present in lenses at the base of the upper unit. West of Devils Hole and south of the Paleozoic ridge, the base of the upper unit contains beds of limestone gravel as much as a meter thick. Clasts of the gravels are mostly less than 20 cm in diameter.

Above the basal clastic deposits, the upper unit is mostly white, soft limestone that contains minor amounts of siltstone and claystone. Clay minerals are mostly illite and montmorillonite, but magnesium silicate minerals are also present (Pexton, 1985). Beds are mostly less than 1 m thick.

The deposits of the upper unit are capped by tufa. The tufa is brown to orangish brown in outcrop and medium gray to pale yellowish gray on a fresh surface. The tufa consists of limestone and sandy limestone that preserves casts and moulds of plants and algal structures. Where the plant casts and moulds are well preserved, they contain a triangular reed and two broad-leafed plants that closely resemble plants that grow in the runoff from modern springs. The tufa is usually 1-2 m thick near the head of the channels and thins downslope. In sec. 26, T. 17 S., R. 50 E., the tufa covers an area about 1 km^2 and is 2-4 m thick. Although Pexton (1985) mapped the tufas separately from the underlying sediments of the upper unit, the association of the tufas with the sediments and the channels of the disconformity indicate that the tufas are a lithofacies of the upper unit.

The upper unit is not continuous. The association of the channels of the disconformity and the upper unit, similar lithologies throughout the upper unit, and a similar elevation of the disconformity noted by Pexton (1985) from Carson Slough and Rock Valley Wash to the area southwest of Devils Hole indicates that these deposits were probably deposited at the same time by the same processes.

West of the area mapped by Pexton (1985), a large outcrop of sediments similar to the upper unit may also be the upper unit. The outcrop covers an area about 6 by 3.5 km in the Ash Meadows quadrangle in T. 17 and 18 S., R. 49 E. in Nevada and T. 26 and 27 N., R. 5 E. in California between Nevada State Highway 373 and the Amargosa River. Diatomite and white, soft limestone and claystone are capped by tufa. Sand less than 20 cm thick occurs at the base of the deposit. The sand contains very sparse pebbles that are less than 10 cm in diameter. At the southern end, a lobate shape of the deposit suggests filled channels like the channels filled by the upper unit about 10 km to the east.

Outcrops in the Big Dune quadrangle resemble both the lower and upper units. Along the Amargosa River, claystones and limestones resemble sediments of the lower unit. In the Big Dune quadrangle in secs. 22 and 23 (estimated), T. 14 S., R. 48 E., pebbly tuffaceous sands underlie claystone and diatomite that resemble similar sediments in the upper unit. These sediments are capped by tufa in which mammalian fossils occur. Tufas on the south and west sides of this outcrop appear to occur in channels that slope to the south. In sec. 19, T. 14 S., R. 49 E., claystone and remnants of tufa are exposed south of the hills that bound Crater Flat on a terrace or pediment along the unnamed wash that drains Crater Flat.

In southern Crater Flat in the Big Dune quadrangle in secs. 12 and 13, T. 14 S., R. 48 E. and secs. 7 and 18, T. 14 S., R. 49 E., tufas are interbedded with sand and gravel. Tufas and limestone also form erosional mounds. Along the unnamed wash, where it drains east-southeast, gravel beds dip 5°-15° south to southeast, and are interbedded with tufas. In a trench exposure, the gravel on the north edge of the wash grade vertically from poorly sorted at the base of a bed to well-sorted at the top and laterally from poorly sorted on the north to well sorted to the south. The gravels in the trench are interbedded with pebbly sands. A yellowish to orangish, iron-oxide stained band from 5 to 15 cm thick, which slopes slightly to the south, cuts across bedding of the sands and gravels that have a slightly greater dip to the south. South of the wash, tufa and white, soft limestone form eroded mounds that appear to have been deposited along a north-south line of springs.

In the southern part of the Lathrop Wells quadrangle, Swadley (1983) mapped calcareous clays and silts and dense limestones that are continuous with outcrops mapped by Pexton (1985) as the lower unit of the sediments of Amargosa marsh. Swadley's (1983) unit QTld is equivalent to Pexton's (1985) units Tld, Tpl, and Tpa; Swadley's unit QTll is equivalent to Pexton's sheet limestones, unit Tll. The upper unit was not recognized by Swadley (1983), but areas of calcified vegetal mats in sec. 19 and 30, T. 16 S., R. 50 E. may be the upper unit.

The deposits needed to interpret the early history of Amargosa marsh are concealed by the waterlaid sediments and by younger deposits, but some evidence suggests that at least part of Amargosa marsh may have been occupied by a lake early in its history. The evidence consists of a possible dam at Eagle Mountain and possible beach terraces near the dam, near Devils Hole, and at the north end of the limestone ridge that contains Devils Hole.

The possible dam at Eagle Mountain was formed by older, deformed gravels, alluvial fans, and basalt that may have provided barriers on either side of Eagle Mountain to runoff from Amargosa marsh. Between Eagle Mountain and the Resting Springs Range to the east, older, deformed gravels and alluvial fans provided a barrier that still exists. West of Eagle Mountain, alluvial fans and faulted younger basalts formed a similar barrier. The basalts are probably the same basalts as in the Greenwater Range, less than 5 km from these basalts. The barrier west of Eagle Mountain has been breached by the Amargosa River. When this breaching occurred is uncertain, but the breaching was probably early in the history of Amargosa marsh.

Faint traces of possible beach terraces are present on the basalt at the possible dam, on Paleozoic carbonate rocks near Devils Hole, and at the north end of the limestone ridge that contains Devils Hole. In the Ryan quadrangle, in sec. 30, T. 24 N., R. 6 E., a bench that is 3-5 m wide is cut in basalt almost completely around a knob that is about 5 m higher than the bench. The bench does not coincide with any apparent lithologic changes and is overlain by 0.3-0.6 m of fine-grained material. The fine-grained material could be eolian in origin, but it is not present on other nearby outcrops of basalt. The bench is about 45 m above the waterlaid sediments at an altitude of approximately 652 m.

In the Ash Meadows quadrangle, in sec. 36, T. 17 S., R. 50 E., about 1/2 km west of Devils Hole, a bench is cut across the bedding of Cambrian limestone at an altitude of approximately 737 m. This bench may be an old terrace at the junction of washes in adjacent drainage basins, but similar benches are not present adjacent to other nearby, similar junctions of washes in the limestone. In sec. 23, T. 17 S., R. 50 E. and sec. 19, T. 17 S., R. 51 E., benches about 15 m wide are cut in the limestone at elevations of 725-745 m, and are partly covered by waterlaid sediments of Amargosa marsh. The benches cut across bedding and appear to be unrelated to lithologic differences or faults. The topographic setting and location of the benches make differential weathering or stream erosion unlikely. A few limestone clasts on these benches are highly rounded, but are too deeply pitted by weathering to determine their origin.

River Gravels of Ancestral Rock Valley Wash

The river gravels of ancestral Rocky Valley Wash consist of coarsely crossbedded pebbly sands and sandy gravels that underlie a north-south ridge just west of Rock Valley Wash in the Ash Meadows and Lathrop Wells quadrangles. The outcrops can be traced from sec. 30, T. 17 S., R. 50 E. north for approximately 10 km to the SE 1/4 sec. 19, T. 16 S., R. 50 E. The best exposures are in the SW 1/4 NE 1/4 sec. 19, T. 17 S., R. 50 E., where crossbedding and the relationship to the lower unit of the sediments of Amargosa marsh are well exposed.

Crossbeds are 5-20 cm thick in beds that are 0.3-0.6 m thick. Clasts of volcanic rock as large as 10 cm are scattered in a sandy matrix that is cemented by calcite. A few beds are sandy gravel. Clasts are mostly silicic volcanic rocks, but minor amounts of basalt are present.

The crossbedded sand and gravel fill a channel 1.5 km wide and as much as 5 m deep. Remnants of sheet limestones of the lower unit of the sediments of Amargosa marsh form part of the east bank of the channel. The parallelism of the channel with Rock Valley Wash for at least 10 km indicates that the channel is probably an ancestral Rock Valley Wash.

Slopes and ridgetops above the crossbedded sands are covered by deposits that contain boulders of basalt and other volcanic rocks as much as 0.5 m in diameter. These boulders are probably from the next younger unit, unit QTa.

Pliocene(?) and Quaternary Deposits

Unit QTg

Unit QTg consists of thin-bedded gravels that fill shallow valleys of a dissected pediment between the Eleana Range and Syncline Ridge in western Yucca Flat (fig. 2). The gravels are composed of quartzite, conglomerite, and siliceous argillite derived from the Eleana Range. Clasts are angular, platy, and prismatic, have a maximum dimension 0.7 m, and have thicknesses that are 20 to 50 percent of the maximum dimension. In contrast, the overlying unit QTa contains numerous boulders of Tertiary welded tuff that have diameters of 1 to 10 m, are subangular to subrounded, and are roughly equidimensional. The gravels of unit QTg are as much as 5 m thick near the Eleana Range and 22 m thick near Syncline Ridge beneath units QTa and Q2 (Hoover and Morrison, 198[illegible])

The pediment beneath the gravels is defined by a nearly planar surface that covers approximately 17 km^2 between the Eleana Range and Syncline Ridge. The pediment is cut on gently to steeply dipping quartzite and clayey argillite of the Eleana Formation (Mississippian and Devonian) and on Tippipah Limestone (Permian(?) and Pennsylvanian). Where unit QTg is present on ridges near the Eleana Range, it is overlain in most places by unit QTa. These ridges are 10 to 20 m wide and have rounded to flat tops. The contact between the Eleana Formation and the gravels dips into the ridges. The upper part of the gravels is thoroughly cemented by dense calcium carbonate. At the base of the gravels on one ridge, a trench exposes soft, pulverent to nodular calcium carbonate. The soft carbonate forms 50 percent or more of the matrix in both the gravels and the weathered rock of the underlying Eleana Formation in a zone approximately 0.7 m thick.

Plates of calcium carbonate occur as residual deposits at the edge of the gravel and on the Eleana Formation along the ridges upslope from the edge of the gravel. The carbonate plates can be traced to a thrust fault in the Eleana at the east foot of the Eleana Range. The plates are siliceous near the thrust fault. The carbonate and silica plates and the carbonate in the gravel appear to have been deposited by ground water seeping out of the thrust fault and into the gravel.

Unit QTa

Unit QTa consists of predominantly debris flow deposits and small amounts of alluvium. Unit QTa is present at the periphery of all basins in the NTS area, around isolated bedrock hills in the Amargosa Desert, and as erosional remnants in valleys in the hills and ranges. Unit QTa lies unconformably on Precambrian to Paleozoic sedimentary rocks, on Tertiary volcanic and sedimentary rocks, and on the waterlaid sediments of Amargosa marsh. In the Calico Hills and between Syncline Ridge and the Eleana Range in Yucca Flat, unit QTa was deposited on unit QTg and pediments that were cut on argillite of unit J of the Eleana Formation. In most areas, exposures of unit QTa are less than 2 km from the hills and ranges. In a few places, such as Rock Valley Wash near the Skeleton Hills and in Crater Flat, exposures are 10 km or more from the ranges. The maximum observed thickness of unit QTa is approximately 55 m.

Natural exposures of unit QTa are sparse. The best developed soils and landforms that are typical of unit QTa occur between Yucca Mountain and Alice Ridge, just south of Yucca Wash (fig. 3). Debris flow deposits and poorly sorted alluvial gravel that may have been reworked from debris flows are exposed in Crater Flat trenches 1 (lat 36°48'14", long 116°29'50") and 2 (lat 36°46'59", long 116°30'38") and in some of the deeper washes near these trenches.

Unit QTa crops out as elongate, well-rounded ridges called ballenas. The ballenas are separated by washes that form parallel to subparallel drainage systems. The washes, where not filled by unit Q2 or dissected by Holocene erosion, have rounded cross sections. Relief on the ridges ranges from 1 to 25 m; the macrotopography is rounded. Microrelief is flat except where erosion during the pedimentation of unit QTa has left residual cobbles and boulders protruding above the desert pavement. Within 1-2 km of bedrock hills, residual boulders are as much as 10 m in diameter. At distances of 5 km, residual boulders are less than 1 m in diameter. Along Rock Valley Wash south of U.S. Highway 95, basalt boulders from Skull Mountain, more than 30 km away, are commonly 0.5 to 1 m in diameter. Residual boulders are rarely present on deposits younger than unit QTa.

Soils on unit QTa typically consist of an Av horizon and a calcic horizon. The Av horizon on unit QTa overlies the calcic horizon or, where present, an argillic B horizon. The Av horizon is formed in material that is probably much younger than the underlying deposits. Thickness of the Av horizon ranges from 10 to 40 cm. The B horizon has been eroded from most QTa soils. Only one area, just south of Yucca Wash and west of Alice Ridge, has been found with an argillic B horizon intact in a QTa soil. At this location, the argillic B horizon is dark reddish brown, contains abundant clay, and is approximately 50 cm thick. Secondary silica increases downward in the B horizon. Where the argillic B horizon is preserved, the calcic horizon has engulfed the lower part of the B horizon and consists of laminar layers that enclose lenses of pale-brown opaline silica that are as much as 5 cm thick. The laminar layers that enclose these silica lenses are dense, hard, and probably contain secondary silica. Calcic horizons of unit QTa are stage II to III at elevations of about 700 m in the Ash Meadows area and stage IV above 900 m in the Yucca Mountain area. Stage IV calcic horizons are 2 to 3 m thick. Laminar layers are present in most stage IV calcic horizons.

Pisolites and brecciated and recemented laminar layers occur in a few locations.

On the uppermost part of piedmont slopes, interfluves of unit QTa between washes that head in the bedrock hills, are topographically above units Q2 and Q1. Deposits of QTa are also present at drainage junctions within bedrock hills, as erosional remnants on pediments, and as the highest erosional terrace along major washes within bedrock hills. On Yucca Mountain, remnants of unit QTa are present on steep slopes 20-50 m above the bottoms of some washes. Terraces and dissected hills of unit QTa are present on lower piedmont slopes along Rock Valley Wash from U.S. Highway 95 south to about lat 36°30'. At distances of 5 km or more from bedrock hills, unit QTa is buried by younger surficial deposits on most piedmont slopes.

Desert pavement on unit QTa is very densely packed and poorly to moderately sorted. Maximum fragment size in the pavement is about 20 cm, but residual boulders, which range from 0.5 to as much as 10 m in diameter, commonly protrude above the pavement. Varnish on pavements and residual boulders is shiny brownish black to black, 0.5 to 2 mm thick, and continuous in areas undisturbed by soil creep.

Trenches and a few natural exposures reveal unsorted, nonbedded layers that are 1 to 2 m thick. Each layer contains coarse fragments ranging from pebbles to boulders that are supported by a matrix of clay- to sand-size material. Clay and silica coat larger fragments below the calcic horizon. Natural exposures of unit QTa are light brown with a pinkish to reddish cast. Boulders of welded tuff, limestone, or quartzite are commonly 1 to 4 m in diameter on the uppermost piedmont slopes and in QTa deposits in bedrock hills. Boulders at the base of unit QTa, deposited on a pediment cut on the Eleana Formation in the Calico Hills and in Yucca Flat, are as much as 10 m in diameter.

At the foot of the Eleana Range in the west-central part of Yucca Flat, lenses of calcium carbonate that contain ostracodes, gastropods, and small mammal remains are interbedded with debris flow deposits of unit QTa. Two lenses, exposed in trenches cut at right angles, are as much as 2 m thick, extend at least 50 m downslope, and are at least 30 m wide along the slope contour. The upper part of both lenses contains greenish-gray clay and clasts as much as 20 cm in diameter. The location of the calcium carbonate lenses, adjacent to faults that displace the uphill side of the faults down against quartzite of the Eleana Formation, indicate that the fossiliferous carbonate lenses are sag pond deposits.

Alluvial pediments were cut on unit QTa throughout the NTS area. The pediments are defined by the concordant tops of the ridges that characterize unit QTa. Concordancy of the ridges extends across small washes that originate in bedrock hills and across some major washes. The concordant ridges extend into bedrock in a few locations in the Calico Hills, east of Jackass Flats, and on the southwest side of Bare Mountain. Benches cut on bedrock and "lines" of calcium carbonate that stain steep bedrock slopes may record the original surface of unit QTa. These features occur as scattered remnants in the ranges east of Yucca and Jackass Flats, in the Calico Hills, and on the southwest side of Bare Mountain. The benches and carbonate lines suggest that 25 to 50 m of unit QTa may have been eroded where the ranges have the greatest relief and highest slopes. Near hills that are low in relief, erosion may have been much less than 25 m.

On hillslopes that have 10-25 m of relief, QTa deposits lack any evidence of bedding. The few exposures along washes and in trenches are predominantly layers of unsorted cobbles and boulders. In Crater Flat trenches 1 and 2 and in some exposures in washes, coarse, poorly to moderately sorted alluvial gravel is present in the upper 1-3 m of unit QTa. In a few wash exposures, alluvial gravel occurs as thin beds between unsorted layers of cobbles and boulders. Numerous large boulders are present in almost all exposures of unit QTa, regardless of relief or lithology of the bedrock above the outcrops.

Subunit QTc.--Colluvium that consists of unsorted fine to coarse angular rubble was mapped separately as a subunit of unit QTa on steep slopes of Little Skull Mountain in the Lathrop Wells quadrangle (Swadley, 1983) and in the northeast corner of the Big Dune quadrangle (Swadley and Carr, 1987). Colluvium of subunit QTc is included in map unit QTa at other locations. The colluvium includes rock falls and debris flow deposits that grade downslope into unit QTa. Slightly dissected smooth slopes of subunit QTc are underlain by stage III to IV calcic horizons that are several meters thick. A and B horizons are not present.

Regional Unconformity

Where subunit Q2c overlies unit QTa in the Yucca Mountain area, a regional unconformity is present. This unconformity is defined by the soil developed on unit QTa and the dissected pediments of unit QTa, and represents a long period of erosion and nondeposition. The pediments were dissected by subparallel drainage systems throughout the Yucca Mountain area after pedimentation of unit QTa and development of a soil on the pediments. This dissection of unit QTa formed long, narrow, rounded ballenas, usually less than 20 m wide. At the upslope end of ballenas, the ridge crests merge into the pediments and ridges wider than 20 m usually have flat tops that are remnants of the pediments on unit QTa. Slopes of the valleys between ballenas are convexo-concave in contrast to steep, straight slopes of washes in younger deposits. Where not obscured by younger deposits, valleys between ballenas are rounded.

No deposits are present between unit QTa and unit Q2c near Yucca Mountain, but near the head of the Kyle Canyon (just southeast of fig. 2) alluvial fan, alluvial gravels form terraces that are intermediate in elevation between the ballenas of unit QTa and the terraces of unit Q2. The lithology, pedimentation, soils, landforms, and dissection of unit QTa are similar at both Kyle Canyon and in the Yucca Mountain area. Except for thicker soil horizons, the same aspects of unit Q2 are also similar in both areas. These similarities and the proximity of Kyle Canyon to Yucca Mountain indicate that deposits of intermediate age should also be present in the Yucca Mountain area. Deposits of intermediate age may be buried in Yucca and Frenchman Flats or removed by erosion in Mercury Valley, Crater Flat, Rock Valley, Jackass Flats, and the Amargosa Desert.

Pedimentation, soil development, and dissection of unit QTa represent a long period of erosion and nondeposition. The absence at the surface of the Yucca Mountain area of the intermediate-age deposits that are present at Kyle

Canyon suggests that intermediate-age deposits are not present in the Yucca Mountain area. The probable absence of the intermediate-age deposits in the Yucca Mountain area extends the period of erosion and nondeposition after deposition of unit QTc, and requires a regional unconformity between unit QTa and subunit Q2c.

Quaternary Surficial Deposits

Quaternary surficial deposits of the Yucca Mountain area include units Q1 and Q2, both of which have five subunits. Both units consist of alluvial sand and gravel, debris flow deposits, and eolian sand. The major differences between the two units are that the older unit, unit Q2, has moderately to well developed soils and desert pavements, whereas unit Q1 has incipiently developed soils and desert pavements are absent. Except for topographic position, all other characteristics of the two units and their subunits are similar.

Unit Q2

Unit Q2 consists of alluvial deposits, debris flow deposits, and eolian sand. Unit Q2 contains five subunits: Q2c, Q2b, and Q2a and Q2a(?), alluvial and debris flow deposits; Q2e, eolian sand ramps and sand sheets; and Q2s, alluvial sand sheets. These subunits range in age from middle to late Pleistocene. Soils in unit Q2, except for the youngest deposits, are moderately to well developed. Desert pavements are well developed except on the youngest deposits. The youngest deposits and eolian sand have a limited extent, but alluvial deposits of oldest and intermediate ages are present throughout the Yucca Mountain area. The topography, drainage, and desert pavements of all subunits are similar, but soils, lithology, and topographic position differ.

Alluvial deposits of subunits Q2c and Q2b are found in all the valleys of the NTS area and in washes in the hills and ranges. The debris flow deposits of unit Q2a have been identified only in the Calico Hills and in the Syncline Ridge area of Yucca Flat. Thin slopewash deposits with similar radiometric ages at several locations in the Yucca Mountain area are called Q2a(?) in this report, and may be equivalent in age to subunit Q2a, which has not been dated radiometrically. Subunits Q2e and Q2s have been identified only in the northern part of the Amargosa Desert, Jackass Flats, and Crater Flat.

Subunit Q2c.--Subunit Q2c consists of alluvial deposits and equal to lesser amounts of debris flow deposits. The alluvial deposits vary from pebbly sands to coarse gravels. Debris flow deposits that are exposed in trenches and in washes vary from small lenses to layers longer than 100 m.

Subunit Q2c is present throughout the NTS area. The subunit occurs as terrace deposits in larger washes within the bedrock and unit QTa, as fan deposits in a few intramontane valleys, as slopewash and talus deposits on the sides of most of the valleys on Yucca Mountain, and as fan deposits on upper to lower piedmont slopes in all valleys. Subunit Q2c forms the highest terrace along major washes on the piedmont slope and along most of the washes in the Amargosa Desert. Drill-hole data in Jackass Flats indicate a maximum thickness of 65 m, but beneath some valley floors the thickness may be greater.

Terraces that are typical of subunit Q2c are present between Sever Wash and Fortymile Wash and at and below the mouth of Topopah Wash west of Fortymile Wash. The best exposure of the youngest Q2c soil is in a trench (lat 36°51'58", long 116°13'19").

Subunit Q2c has a flat macrotopography even on steeply sloping deposits. Along much of Fortymile, Topopah, and Rock Valley Washes, overbank flood deposits and debris flow deposits form low levees. Microrelief is less than 0.2 m, except where residual boulders of unit QTa protrude through Q2c deposits. Drainage patterns on Q2c are parallel, have few or no tributaries on middle to upper piedmont slopes, and are distributary on middle to lower piedmont slopes. Most washes cut into subunit Q2c have very steep to vertical banks that have been steepened by Holocene erosion. Where banks below the terraces are undisturbed by Holocene erosion, these banks are also steep.

The Av horizon of Q2c soils is younger than the underlying soil horizons. The Av horizon is 10 to 50 cm thick, consists of clay-size to very coarse sand-size material, and is pale yellowish brown. The Av horizon has a sharp contact with the B horizon, or where the B horizon has been stripped, with the calcic horizon.

Soils of two different ages are present on subunit Q2c and can be differentiated only by uranium-trend age dating or by detailed soil investigations. Above 1,000 m elevation, both soils have a moderate- to dark-reddish-brown, argillic B horizon, that is partly silicified, and stage III to IV calcic horizons. The calcic horizons rarely have a laminated layer. Some calcic horizons locally may engulf the lower part of the argillic B horizon. At elevations below 800 m in the Amargosa Desert, both soils in Q2c have cambic B horizons and stage I to II calcic horizons.

The older soil is present at a depth of a few meters within subunit Q2c or at the surface in some locations. The older, buried soil has been identified by uranium-trend dating of samples from some trenches in the Yucca Mountain area. The older soil is probably the buried soil exposed in the west wall of Fortymile Wash just south of the road to Yucca Mountain. At the surface locally in the Yucca Mountain area, the older soil also has been identified by uranium-trend dating locally in the Yucca Mountain area. The maximum depth of burial of the older soil is approximately 7 m in Fortymile Wash. The younger soil has been identified at the surface or beneath less than 1 m of younger subunits in northeastern Jackass Flats, on Yucca Mountain, and in Crater Flat.

Subunit Q2c is present beneath terraces along washes that are incised in bedrock and unit QTa, and is also present on much of the upper piedmont slopes. Q2c is the highest surficial deposit on middle piedmont slopes, on some lower piedmont slopes and valley floors, and along most major washes incised in lower piedmont slopes and valley floors.

Desert pavements on subunit Q2c are densely packed, moderately to well sorted, and have a maximum clast size that is commonly less than 0.2 m in most places. Near bedrock hills or where unit QTa underlies Q2c at depths of less than 2 m, larger clasts may be present at the surface of subunit Q2c. Varnish ranges from very dark brown to blackish brown and from dull to shiny; it forms a thin film that usually covers most or all of the upper surfaces of desert pavement clasts.

Sand content of Q2c deposits ranges from less than 20 percent in coarse gravels to more than 90 percent in the Jackass Flats and Yucca Mountain areas, where the subunit contains sand that is reworked from subunit Q2e. Clay content is probably very low. Except in debris flow deposits, clay coatings on clasts below the soils are rare. The color in outcrop ranges from a light yellowish brown to grayish brown. Clasts in alluvial deposits are rarely more than 0.2 m in diameter. In most debris flow deposits, clasts are as much as 0.5 m in diameter, but on the two highest terraces of Fortymile Wash, debris flow deposits contain numerous clasts as much as 1 m in diameter.

Subunit Q2c consists of mostly alluvial deposits that range from pebbly sands, common east of Yucca Mountain and south of Jackass Flats, to sandy, coarse gravels. The volume of debris flow deposits may equal the volume of alluvial deposits on upper piedmont slopes and in intramontane valleys, but is usually less than the volume of alluvial deposits on and below middle piedmont slopes. Much of the alluvial material was deposited along shallow distributary washes. Along major washes, the alluvial deposits appear to be the result of channel aggradation. On steeper slopes, particularly within the ranges, slopewash deposits are abundant and may grade into debris flow deposits.

Along Fortymile Wash, debris flow deposits of subunit Q2c cap most of the three uppermost terraces (fig. 7). On the highest terrace, discontinuous patches of cobbles and boulders from debris flows overlie mostly pebbly sands and a few sandy pebble and cobble beds that are typical of subunit Q2c. The cobbles and boulders of the debris flow range from 0.1 to 1 m in diameter. At some locations on the east bank of the wash, the debris flow deposits form a levee that is 20 to 50 m wide and less than 1 m high. Remnants of the debris flows are sparse on the west bank, but are almost continuous for 10 km below the Calico Hills along the east bank. About 7 m below the highest terrace, a soil that is probably the older soil of subunit Q2c is exposed along the west bank. The soil has a stage IV carbonate horizon about 1 m thick and remnants of a red argillic B horizon. The soil on the highest terrace is the younger soil of subunit Q2c and has a stage III carbonate horizon less than a meter thick beneath the debris flow deposits.

Fortymile Wash is the only wash in the NTS area that is known to contain three terraces of Q2 age. In other washes, where only two terraces are present, Q2b is the lowermost terrace. Therefore, the lowest Q2 terrace in Fortymile Wash is considered to be Q2b and the middle terrace to be the youngest Q2c deposits (fig. 7). The middle terrace consists of cobbles and boulders that range from 0.1 to 1 m in diameter in a sandy matrix. The deposit on the middle terrace is 2-4 m thick and overlies sandy deposits similar to those that underlie the upper terrace. The upper meter of the debris flows of the middle terrace are cemented by a stage III calcic horizon.

<u>Subunit Q2e</u>.--Subunit Q2e is a lithofacies of subunit Q2c (fig. 8), and consists of eolian sand and reworked eolian sand that was deposited as sand ramps and sand sheets on the hillslopes that border the Amargosa Desert from the south end of Bare Mountain to Little Skull Mountain and from Ash Meadows to Yucca Wash and the center of the Calico Hills (fig. 9). The sand ramps

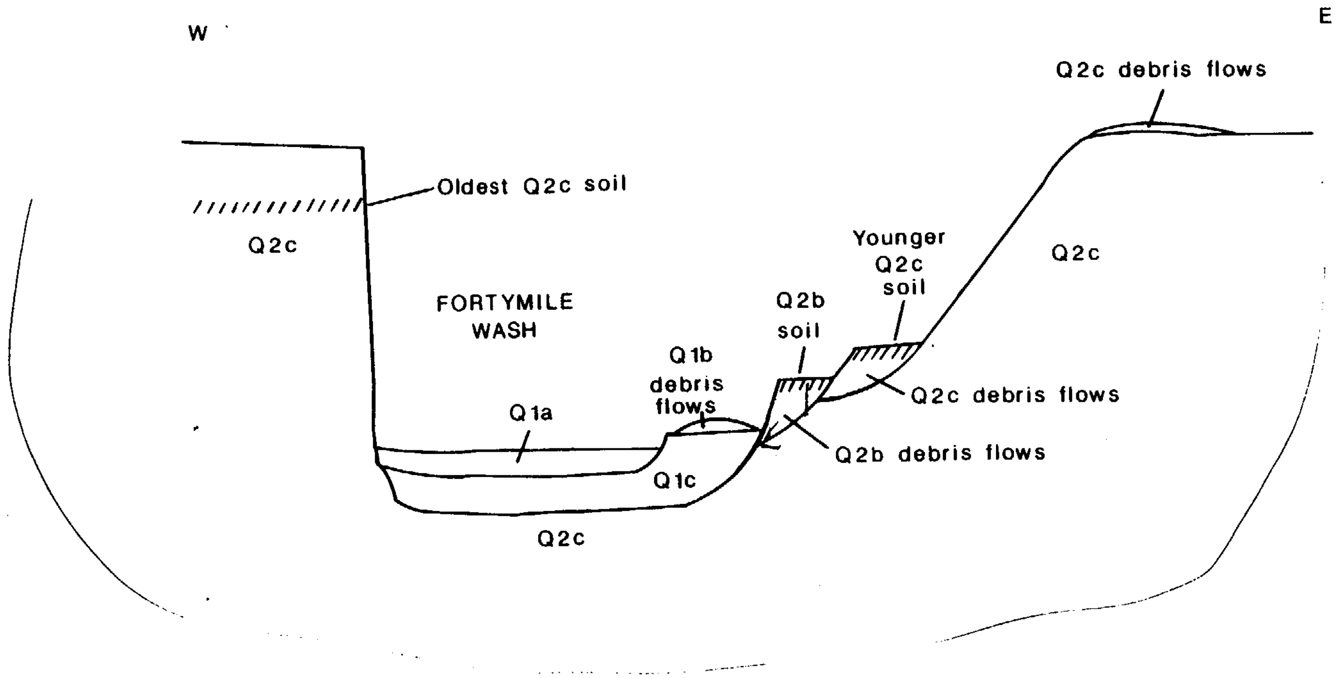

Figure 7.--Schematic cross section showing relationship of stratigraphic units and terraces in Fortymile Wash. Not to scale.

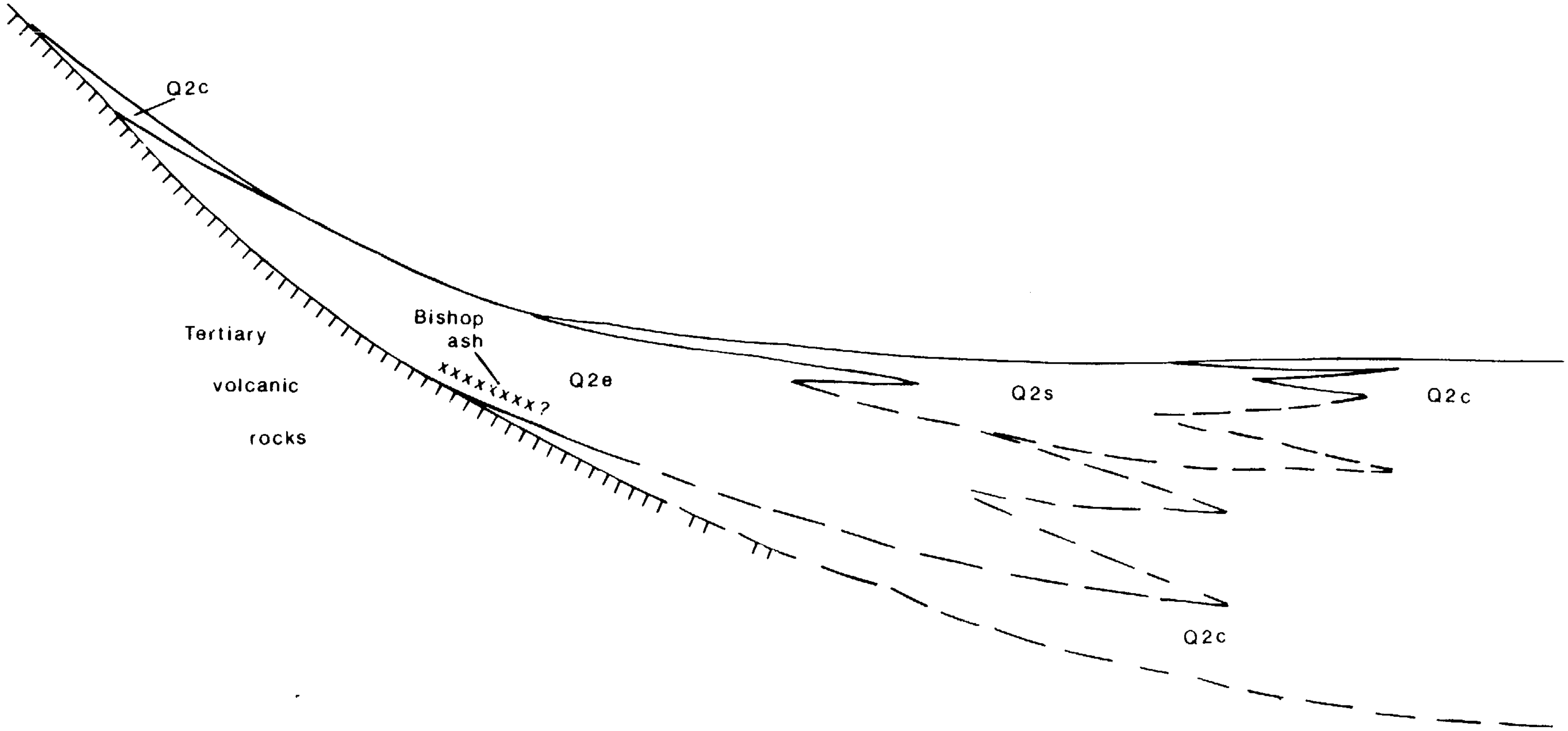

Figure 8.--Schematic diagram showing relationship of subunits Q2c, Q2e, and Q2s in Yucca Mountain area. Dashed lines are inferred.

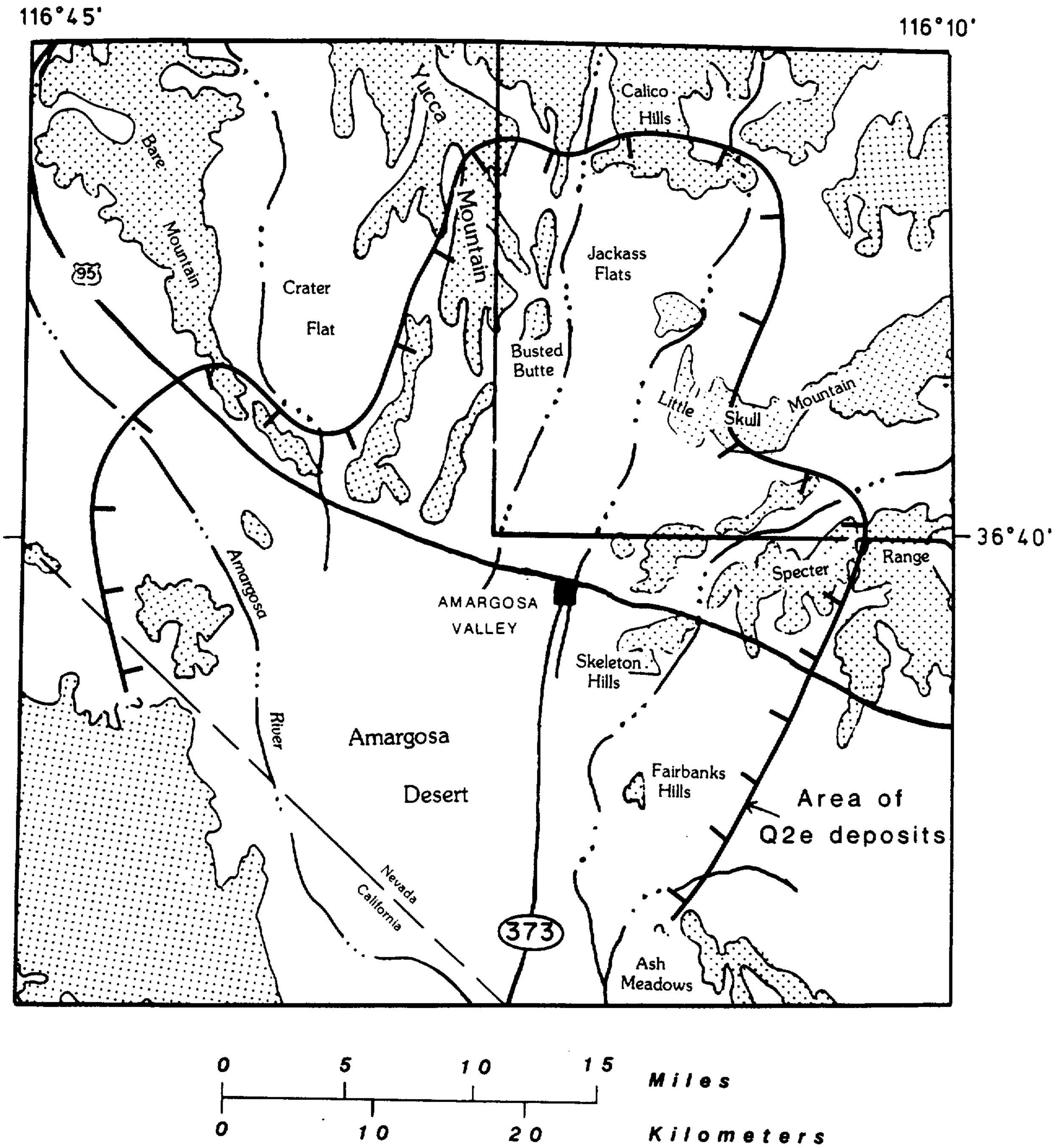

Figure 9.--Distribution of Q2e deposits. Based on the Lathrop Wells quadrangle (Swadley, 1983), the Big Dune quadrangle (Swadley and Carr, 1987), the Bare Mountain quadrangle (Swadley and Parrish, in press), author's mapping in the Topopah Spring quadrangle, and reconnaissance mapping elsewhere.

were deposited by prevailing winds from the south to southwest on any or all sides of topographic obstructions. At the southern end of Yucca Mountain, dissected ramps are present on both sides of north-south ridges. Busted Butte is surrounded by Q2e ramps. On Yucca Mountain, ramps appear to be thicker on the west faces than on the east faces of north-south ridges except for Yucca Crest. On the west side of Yucca Crest and the ridges to the west, Q2e is absent or present only as small patches and thin sheets. In the Calico Hills, Q2e was deposited as sand sheets on unit QTa and on bedrock on south-facing slopes. In the center of the Calico Hills, sheets of Q2e less than 1 m thick were deposited on pediments cut on the Eleana Formation and unit QTa. East of Topopah Wash, most sand ramps are on south- or west-facing slopes. Small, low hills of Paleozoic rocks in the central and western part of the northern Amargosa Desert are completely surrounded by ramps or may have isolated ramps on all faces. The maximum stratigraphic thickness of subunit Q2e is about 50 m. In the Striped Hills, ramps were built as much as 80 m above the piedmont slope. The best exposures of subunit Q2e are on the lower slopes of Busted Butte where washes have dissected these deposits.

Subunit Q2e is a lithofacies of subunit Q2c (fig. 8). Where subunit Q2e is underlain by subunit Q2c, the contact is less than 5 m above bedrock. Subunit Q2c also overlies subunit Q2e and occurs as tongues within Q2e. The Bishop ash (738 ka) occurs at or near the base of subunit Q2e at several locations in Jackass Flats and around the northern edge of the Amargosa Desert (Swadley, 1983; Swadley and Carr, 1987). The Bishop ash also occurs within 3 m of the base of subunit Q2c in the Calico Hills.

Macrotopography on subunit Q2e is flat between washes. Microrelief is less than 0.2 m. Drainage on subunit Q2e is poorly developed. Washes that dissect Q2e originate almost wholly from preexisting washes in bedrock. Small washes are V-shaped with steep banks in their upper parts. The lower parts of small washes and most of the larger washes have flat bottoms with steep banks. A few tributary washes south of Dune Wash and some washes on Little Skull Mountain have Q2c, Q2b, and (or) Q1c terraces inset into subunit Q2e.

Soils on subunit Q2e are typically eroded down to the calcic horizon. The A horizons vary from typical Av horizons to eolian silt and clay mixed with the underlying sand. Most Q2e soils consist of an Av horizon less than 20 cm thick that overlies a stage II to IV calcic horizon that is 0.5 to 1.0 m thick. Cambic B horizons, less than 0.5 m thick, occur locally. The variations in the development of calcic horizons suggest that some of the soils are of different ages. Dissection of the sand ramps around Busted Butte has exposed several calcic horizons within subunit Q2e. Alternating periods of eolian deposition, reworking by sheetwash, and nondeposition and soil development may account for the multiple calcic horizons in Q2e.

Calcium carbonate has also been deposited in and below the calcic horizon as root casts and as fracture fillings. Root casts vary from single roots that penetrate as deep as 2 m below the surface to dense mats less than 15 cm thick that are less than 2 m below the surface. Fracture fillings are commonly 5-10 cm thick and extend to depths of more than 4 m even though the sand next to the fracture fillings is very friable.

The topographic relationship of subunit Q2e to other deposits differs from place to place. At some locations, Q2e overlies subunit Q2c, but most of the sand ramps of Q2e at the southern end of Yucca Mountain and sand sheets of Q2e south of the Calico Hills are covered by subunit Q2c. On some ramps, subunit Q2c is inset into Q2e as terrace deposits, occurs as slopewash deposits at the foot of Q2e sand ramps, or is deposited along washes that transect the lower end of a sand ramp. Thus, subunit Q2c is both older and younger than subunit Q2e, and subunit Q2e is a lithofacies of subunit Q2c.

Desert pavement on Q2e varies from scattered and poorly packed to continuous and densely packed. Packing appears to increase with decreasing slope. The paucity of pebble- to cobble-sized clasts within most Q2e deposits indicates that pavements on Q2e are formed by coarser clasts that migrated down ramp surfaces. These clasts were derived from slope wash from bedrock or surficial deposits above the ramps. On one sand ramp south of Dune Wash, pavement clasts have migrated downslope 0.6 km from volcanic cliffs above the ramp. Clasts have maximum dimensions less than 0.2 m. Varnish is a dull, patchy film that ranges from very dark brown to brown.

The areal distribution of subunit Q2e (fig. 9) indicates that winds from the south and southwest deposited sand where air flow was perturbed by topographic obstructions. Much of the sand probably came from the Amargosa Desert, but dunes near the Funeral Range (W C Swadley, U.S. Geological Survey, oral commun., 1983) indicate that some of the sand may have come from Death Valley. Beds range from 0.1 to 1 m in thickness, and usually lack crossbedding. In some sand ramps, a single tongue of coarse slopewash material is present near the middle of the sand deposit. The tongues of coarse debris have a maximum thickness of 1 m and thin within a few hundred meters downslope to less than 0.5 m. Sand in the upper 0.5 to 1 m of Q2e contains scattered pebbles, cobbles, and boulders below some bedrock cliffs in the Yucca Mountain area. The coarse clasts are probably gravity-transported debris.

Subunit Q2s.--Subunit Q2s consists of alluvial sands and pebbly sands and is a lithofacies of subunits Q2c and Q2e (fig. 8). It is topographically lower than subunit Q2e on middle to lower piedmont slopes from the Calico Hills to the floor of the Amargosa Desert and from Yucca Mountain to the eastern edge of Jackass Flats. Subunit Q2s was derived mostly from deposits of subunit Q2e that blocked washes in the Yucca Mountain area. The maximum thickness seen in subunit Q2s is about 5 m.

The best exposures of subunit Q2s are on the upper piedmont slopes south of the Calico Hills. On the southwest side of the Calico Hills, washes that drain into Fortymile Wash expose 3-5 m of Q2s intertongued with subunit Q2c.

Most of the topographic characteristics of Q2s are like those of subunit Q2c. Where washes have dissected Q2s and the underlying deposits, the banks of these washes have shallow, rounded "rills" in Q2s that are a few meters apart.

Soils in subunit Q2s have an Av horizon like that of Q2c. B horizons are argillic, brownish red, have thin clay films on the sand grains, and are usually 50 to 80 cm thick. The argillic B horizon grades downward into a stage II to IV calcic horizon.

Subunit Q2s occurs on the lower slopes and on piedmonts downslope from Q2e, the main source for Q2s. On middle and upper piedmont slopes, Q2s is at the surface, but on the south and southwest piedmont slopes of the Calico Hills, subunit Q2s is overlain by a few meters of Q2c. On lower piedmont slopes of Jackass Flats and on the floor of the Amargosa Desert, either subunit Q2c or Q2b may overlie subunit Q2s.

Desert pavement ranges from loosely to densely packed and from well sorted to poorly sorted. Densely packed and poorly to moderately sorted pavements are present on middle to upper piedmont slopes. Loosely to moderately packed and moderately to well sorted pavements are present on middle piedmont slopes down to the floor of the Amargosa Desert. In some areas of the Amargosa Desert, the pavement is denser in surface lows that are less than a meter deep and less than 20 m across. The lows and the pavement appear to be the result of deflation. Maximum fragment sizes range from about 20 cm on upper piedmont slopes to less than 10 cm on the floor of the Amargosa Desert. Varnish is usually a very dark brown to blackish brown, dull to shiny film that covers part to all of the upper surface of pavement fragments.

Subunit Q2s is predominantly fine to medium sand. Clasts of volcanic and sedimentary rocks are usually less than 10 mm and are rarely as much as 50 mm in diameter. The larger clasts comprise less than 1 to about 5 percent of less than half the beds. Clay- or silt-size material is rarely present in sandy beds, but beds of clay or silt a few centimeters thick are locally present. Graded beds are locally present and indicate an alluvial origin for subunit Q2s. Color in fresh exposures is very light gray to very pale brownish gray. In outcrop, subunit Q2s is pale brownish gray.

Subunit Q2b.--Subunit Q2b consists of terrace deposits and thin sheets of alluvial fan deposits. The terrace deposits are present on strath terraces in most washes that are incised to depths greater than 3-5 m in the Yucca Mountain area. Alluvial fan deposits of subunit Q2b are present as irregular, thin sheets on piedmont slopes downslope from the mouths of incised washes and on the lower piedmont slopes of the Amargosa Desert. These sheets cannot be distinguished from Q2c except by comparison of soils. Subunit Q2b was included with subunit Q2c as subunit Q2bc on most lower piedmont slopes and the floor of the Amargosa Desert (Swadley, 1983). In major washes such as Fortymile and Topopah Washes, subunit Q2b forms the lowest terrace that has a desert pavement and an Av horizon. Terrace deposits are less than 4 m thick. Alluvial fan deposits on lower slopes probably have a similar thickness. Although much of surface is covered, the best exposures of subunit Q2b are along Fortymile Wash south of the road to Yucca Mountain. Typical terrace surfaces on Q2b deposits can be seen on the west side of Fortymile Wash just north of the road to Yucca Mountain.

Macrotopography is flat; microrelief is less than 0.2 m on lower piedmont slopes and basin floors. Terrace deposits of subunit Q2b in and near bedrock have a low slope toward the washes; on middle to lower piedmont slopes, they are nearly horizontal across the terraces. Drainage patterns on thin sheets on lower piedmont slopes are like those on subunit Q2c.

The soil on subunit Q2b has an Av horizon like that on older deposits. The B horizon is cambic and yellowish to grayish brown below elevations of about 1,200 m and argillic and light brown to pale reddish brown at higher elevations. Calcic horizons range from stage I to II at elevations below about 1,200 m to II and III at higher elevations. Desert pavement is similar to that of subunit Q2c, but is commonly less densely packed and has a duller, less complete varnish than pavements on adjacent Q2c.

Terrace deposits of subunit Q2b are topographically lower than all other Q2 subunits. Thin, alluvial fan deposits of Q2b on lower piedmont slopes and basin floors are at the same level as or overlie older deposits.

Subunit Q2b is mostly coarse alluvial gravel deposited on strath terraces or as thin sheets of alluvium in the distributary part of washes that originate in bedrock hills. Clast sizes and clay content of Q2b are like those of Q2c. In some washes just downslope from bedrock on the south side of the Calico Hills, subunit Q2b consists of scattered clasts from 10 to 50 cm in diameter that lie on strath terraces.

Terraces of Q2b are eroded only along the edges, but on piedmont slopes, Q2b may be eroded by anastamosing channels for a short distance downslope from the end of the wash responsible for deposition of the material. On lower piedmont slopes and on valley floors, Q2b is eroded only by washes that originate in bedrock or unit QTa.

Subunit Q2a.--Subunit Q2a, as originally defined (Hoover and Morrison, 1981), consists of debris flow deposits that have been identified only in the Calico Hills and between Syncline Ridge and the Eleana Range in western Yucca Flat. At these locations, subunit Q2a occurs along the washes as terrace deposits in bedrock and as sheets that overlie subunit Q2c on the uppermost piedmont slopes. Deposits at both locations are similar: (1) below drainage basins of less than 5 km^2 that originate in argillite of unit J of the Eleana Formation, (2) along washes that lack subunit Q2b, and (3) overlying subunit Q2c. The maximum thickness of subunit Q2a is 2 m.

Macrotopography is flat, but microrelief that ranges from less than 0.5 m to 1 m gives the subunit a hummocky appearance. Except for incision along pre-Q2a washes, no drainage has been developed in the subunit. The soil consists of an Av horizon, a weakly developed cambic B horizon, and a stage I calcic horizon. Desert pavement is poorly developed and very loosely packed. Varnish on pavement fragments is a patchy, dull, brown to dark-brown film.

In addition to microrelief, lithology is the major difference between Q2a and older Q2 subunits. Clasts of volcanic rock or quartzite from 0.5 to 1 m in diameter are scattered through a matrix of pebbles, sand, and silt. In the Calico Hills, most of the matrix grains are argillite; in Yucca Flat, the matrix grains are volcanic rock and argillite. Lack of bedding and the large clasts supported by a silt- to pebble-size matrix indicate a debris flow origin of subunit Q2a.

Subunit Q2a(?) occurs as slopewash deposits and local debris flows at the foot of steep slopes on Yucca Mountain and below fault scarps in Rock Valley and Crater Flat. Subunit Q2a(?) overlies subunits Q2b and Q2c at these locations. The subunit has also been recognized where it overlies older Q2 terrace deposits along Yucca and Drill Hole Washes. In mapping, subunit

Q2a(?) has been included with underlying units, because of its patchy distribution and thinness.

Deposits of Q2a(?) are similar to Q2a deposits in macrotopography, microrelief, lack of drainage development, and desert pavement. At most locations, the sand-sized matrix has a reddish-brown color that may be inherited partly from B horizons of older deposits from which it was derived. An Av horizon is present on all Q2a(?) deposits. A cambic B horizon may be present, but is not readily apparent. Calcic horizons are stage I. Deposits of subunit Q2a(?) that overlie older terrace deposits contain fewer clasts than the slopewash deposits and have a crude bedding or layering.

Subunit Q2a(?) differs from subunit Q2a in that:

1. Deposits of Q2a(?) are reddish brown, whereas those of Q2a are shades of gray to brown.

2. Deposits of Q2a(?) appear to have originated on steep slopes rather than in a single drainage basin as did deposits of Q2a.

3. Crude bedding is apparent in deposits of Q2a(?) that overlie older Q2 terrace deposits, whereas, the few exposures of Q2a seem to be a single, unbedded layer.

4. Deposits Of Q2a(?) were derived mostly from volcanic rocks, whereas, Q2a was derived mostly from argillite of the Eleana Formation.

5. The volume of clasts larger than 10 mm is greater in Q2a(?) than in Q2a, but maximum sizes are greater in Q2a.

Although Q2a(?) and Q2a differ, the similarity of their stratigraphic position and topographic location, just downslope from bedrock, suggests that they are probably equivalent in age. Deposits of Q2a(?) have been dated radiometrically, but Q2a has not been dated.

Unit Q1

Unit Q1 consists of alluvial deposits, debris flow deposits, and eolian sand that are mapped in five subunits: Q1c and Q1a, predominantly alluvial gravels and sands; Q1b, debris flows and alluvial gravels; Q1s, alluvial sand sheets; and Q1e, eolian dunes and sand sheets. In comparison to units QTa and Q2, unit Q1 has been only slightly modified since it was deposited. Soils are weakly developed, desert pavements are not present, and only the oldest surfaces have been smoothed by creep and sheetwash.

Subunit Q1c.--Subunit Q1c occurs as terrace deposits, as alluvial fans and sheetwash deposits on middle to lower piedmont slopes, and as alluvial fans at the junction of tributaries with larger washes and across a few fault and terrace scarps. Terrace deposits of subunit Q1c occur in all washes that originate in bedrock or unit QTa. Alluvial fans and sheetwash deposits overlie units Q2 and QTa on middle to lower piedmont slopes. Alluvial fans of Q1c occur at the junction of tributaries with major washes and across some terrace scarps and Quaternary fault scarps. Thickness of subunit Q1c is usually less than 5 m. The best exposures of subunit Q1c are along the banks of terrace deposits in major washes, such as Fortymile Wash and Topopah Wash.

Subunit Q1c has a flat to slightly convex macrotopography. Microrelief is usually less than 0.2 m, but dissection of terraces of Q1c in larger washes can result in a greater relief. Drainage development in Q1c occurs along pre-existing washes and as short distributory channels below these washes.

In gravelly deposits, the only noticeable soil horizon is a stage I calcic horizon that consists of calcium carbonate coatings on clasts. In sandy deposits, an A horizon can be detected by a slight darkening of the sand and, locally, a slight increase in calcium carbonate at a depth of 2-5 cm. Desert pavement is lacking on subunit Q1c.

Subunit Q1c varies from pebbly sands to gravels that contain boulders as much as 0.5 m in diameter. Individual beds are commonly well sorted, but clasts may vary from sand to cobbles in adjacent beds. Debris flow deposits make up less than 25 percent of the volume of subunit Q1c, but in alluvial fans at the junction of tributaries to larger washes, debris flow deposits may comprise about half of subunit Q1c. In fresh exposures, subunit Q1c is light gray; the surface is light brownish gray.

Subunit Q1s.--Subunit Q1s occurs as alluvial sands on middle to lower piedmont slopes and on the floor of the Amargosa Desert. The subunit is a lithofacies of subunit Q1c that was produced primarily by erosion of subunits Q2e and Q2s. The subunit overlies all Q2 subunits except Q2a and Q2a(?) and is overlain by subunit Q1b. Subunit Q1s is limited to middle and lower piedmont slopes below Q2e and Q2s and to the floor of the Amargosa Desert. Maximum thickness of subunit Q1s is 5 m. The best exposures of Q1s are on the piedmont slopes between Little Skull Mountain and Fortymile Wash.

Topography, drainage, soils, topographic relationships, and depositional process in Q1s duplicate these characteristics in subunit Q1c. In subunit Q1s, the deposits range from 90 to 100 percent sand. Clasts larger than sand are commonly less than 10 cm in diameter and a have a maximum diameter of about 20 cm. A deflation pavement is usually present on subunit Q1s; pebbles and larger clasts cover 20-50 percent of the surface.

Subunit Q1b.--Subunit Q1b occurs as debris flow deposits and small amounts of alluvial gravels in all washes. The best exposures of Q1b are along Fortymile Wash, north of the road to Yucca Mountain. In small washes that contain remnants of Q1c terraces, Q1b is preserved as long, convex tongues that are 5 to 10 m wide or as long, flat-topped tongues with convex sides that are 10 to 20 m wide. Maximum thickness of subunit Q1b is 3 m, but most deposits are less than 1.5 m thick. In major washes, such as Dune, Sever, Yucca, Fortymile, and Topopah Washes, subunit Q1b occurs as scattered, elongate patches of cobbles and boulders between individual channels of braided sections of these washes. The patches of cobbles and boulders usually range from 1x2 to 10x50 m, but they may be longer at the edge of a braided channel pattern. Small patches are convex across both the long and short dimensions; larger patches are convex to flat topped across the short dimension. Relief on these patches ranges from 0.3 to 1 m.

Soil development in Q1b deposits is usually weak because of the youthfulness of these deposits and because most of the upper 0.5 m is comprised of pebble- to boulder-sized clasts. Spaces between the larger clasts are empty at the surface and are partly to completely filled by sand- to clay-sized material below the surface. In some exposures, a stage I calcic horizon is present. Subunit Q1b overlies Q1c in small washes, in the upper to middle reaches of major washes, and on middle to lower piedmont slopes. In major washes and the Amargosa River, subunit Q1b locally occurs as terrace remnants less than 0.5 m below Q1c terraces.

The debris flow origin of Q1b is indicated by the lack of bedding, the predominance of cobble- to boulder-sized clasts, and by its occurrence as undissected tongues on Q1c terraces. Small tongues have noses and short levees trailing back from the noses that consist of only boulders from 0.3 to 1 m in diameter. Longer and wider tongues of Q1b have levees that trail back from the noses for most of the length of the tongues. Elongated patches 1 to 5 m wide and 5 to 50 m long of boulders occur on the surface within the larger tongues.

Subunit Q1e.--Subunit Q1e occurs as eolian sand that forms dunes and sandsheets in the Big Dune quadrangle and on the basalt cone and flows northwest of Amargosa Valley. Q1e also forms sand sheets in the southern Yucca Mountain area and near bedrock outcrops on the east side of Jackass Flats. Big Dune is the largest outcrop of subunit Q1e; it is about 5 km long, as much as 2 km wide, and approximately 100 m high. Deposits older than Q1e are not exposed on Big Dune, but to the northwest and southeast of Big Dune, outcrops of Paleozoic rocks are partly covered by Q2e and Q1e dunes. Sand sheets around Big Dune are less than 3 m thick. Sand dunes on lava flows of the Lathrop Wells basalt cone are 2 to 5 m high and lie on a sand sheet 2 to 3 m thick. Sand on the south side of the basalt cone has a maximum thickness of about 2 m. In the Ash Meadows quadrangle, layers of peat are interbedded in sand dunes (Mehringer and Warren, 1976) that are probably equivalent to subunit Q1e.

Soil horizons are not apparent in most outcrops of subunit Q1e. In the Ash Meadows area, weakly developed soils of middle Holocene age are present within dunes of subunit Q1e (Mehringer and Warren, 1976). Radiometric ages, archaeological material in Holocene dunes, and soil morphology (Mehringer and Warren, 1976; Haynes, 1967) indicate that subunit Q1e includes three separate periods of Holocene eolian deposition. The volume and areal distribution of Q1e deposits are much smaller than for subunit Q2e. Except for a small dune on the north side of the Skeleton Hills and the sand on the Lathrop Wells basalt cone, most of subunit Q1e was deposited on the basin floor of the Amargosa Desert or in areas of little topographic relief. Along Fortymile and Topopah Washes and at the mouth of the unnamed wash that drains Crater Flat, subunit Q1e is deposited on Q1b and older units as small patches of rippled sand that are less than 0.5 m thick. Near sources of silt- and clay-sized materials, these particles form laminations between sand beds or are mixed into sand beds.

Subunit Q1a.--Subunit Q1a occurs as alluvial deposits in the bottom of active channels. In braided channels, the subunit was deposited as small elongated patches that are a few centimeters thick. In major washes, subunit Q1a was deposited as channel fill, a few centimeters to 1.5 m below Q1c or Q1b terraces. About 1 km south of the road to Yucca Mountain in Fortymile Wash, subunit Q1a is less than 1 m thick, and fills a channel approximately 30 m wide. Along single channels, subunit Q1a usually has a relatively smooth surface for 100 to 200 m along the wash with ripples 2 to 5 cm high. Across single channels, 10 to 30 m wide, subunit Q1a may have 0.5 to 1 m of relief. Subunit Q1a lacks soil development. Within the hills and on upper piedmont slopes, Q1a consists of well-sorted gravels that are mostly pebbles with small amounts of sand. On middle to lower piedmont slopes and on the basin floors, Q1a consists mostly of sand that contains minor amounts of pebbles.

Pliocene and Quaternary Basalts

Remnants of basalt flows form part of the possible dam west of Eagle Mountain. The basalt flows overlie debris flow deposits and alluvial gravels that were derived partly from Eagle Mountain and partly from the Greenwater Range. The basalts are less than 4 km from basalts in the Greenwater Range that are 4.03-7.16 m.y. old (Luedke and Smith, 1981).

Basalts that are 3.75 and 1.1 m.y. old crop out in Crater Flat (Carr, 1982). The older group of basalts in southeastern Crater Flat is highly dissected. Unit QTa overlies the older basalts that in turn overlie older alluvium (Carr, 1982). The younger group of basalts consists of flows and cones from four eruptive centers that form a gently curved line extending north-northeast across central Crater Flat. The cones and lava flows of the younger group of basalts are dissected, but dissection is limited to ejecta layers on the cones, the brecciated tops of flows, and flow edges.

Basalt flows and a cinder cone occur about 10 km northwest of Amargosa Valley. The flows and the cone are undissected. Basalt ash is interbedded with subunit Q2c less than 1 km north of the cone. Stalactitic calcite on welded tuff cobbles that immediately underlie the basalt flow has been dated at 345 ka (Szabo and others, 1981).

Pliocene and Quaternary Spring Deposits

Spring deposits that consist of tufas and calcite veins and spring vents occur in deposits that range in age from pre-QTa to the present. The spring deposits occur in the Amargosa Desert and near outcrops of Paleozoic carbonate rocks east of Nevada State Highway 373.

Spring deposits occurred between deposition of the waterlaid sediments and deposition of unit QTa, during deposition of unit QTa, and between deposition of unit QTa and post-QTa pedimentation. Some outcrops of tufa that overlie the waterlaid sediments of Amargosa marsh in the headwaters of Carson Slough differ from tufas in the upper unit of the sediments. The tufas occur as single outcrops or a few scattered outcrops that are a few meters to 50 m in their maximum dimension and are not related to channels. Calcite veins and vents cut across the tufas. At one location, tufa that lies on the waterlaid sediments is overlain by unit QTa. At several locations, from Devils Hole to the north side of the Amargosa Desert (Winograd and Doty, 1980), calcite veins and vents in unit QTa are truncated by the pediment cut on unit QTa. At Devils Hole (Cave) No. 2, a sinkhole approximately 300 m north of Devils Hole, a small spring mound that contains tufa is enclosed within unit QTa.

Spring deposits have not been found in units Q2 and Q1, but probably occur locally in these units near modern springs. At Point of Rock Springs in the Ash Meadows area, tufas form a spring mound that covers an area of at least 10,000 m^2. Rounded ridges that are characteristic of unit QTa extend from the tufa upslope into unit QTa. The relationship of the spring deposits to Q1 and Q2 deposits in the wash below the springs is not clear.

Spring deposits are not recognizable in the lower unit of the waterlaid sediments, but the large volume of chalk and magnesium silicates in the lower unit required a large volume of spring discharge during deposition (R.L. Hay, Univ. of Southern Illinois, oral commun., 1980). Evidence of springs was probably not preserved because the waterlaid sediments were not indurated. Induration of the lower unit probably formed an aquitard above the Paleozoic aquifer that underlies most of the Amargosa Desert (Winograd and Thordarson, 1975). This aquitard would restrict the location of most of the upper unit and younger spring deposits to outcrops of Paleozoic carbonate rocks at the edge of the aquitard.

Age of Late Pliocene and Quaternary Deposits

Ages of the waterlaid sediments of Amargosa Marsh and younger surficial deposits have been determined mostly by radiometric dating methods. Most of these methods, such as ^{14}C, $^{40}K/^{40}A$, and fission-track dating, are standard methods, but the uranium-trend method used extensively on middle to late Pleistocene deposits, is relatively new. The uranium-trend method is an empirical method. This method assumes vertical migration of isotopes in a continuously open system, has a variable accuracy that is dependent on the isotopic quantities originally in the sediments, and may require calibration by other dating methods at new locations (Rosholt, 1980, 1985). The consistent determinations of similar ages for deposits and soils considered to be stratigraphically equivalent have clearly demonstrated the usefulness of this method for determining the age of surficial deposits in the Yucca Mountain area.

In this report, the Pliocene-Pleistocene boundary is considered to be 1.7 Ma (Obradovich and others, 1982). The boundary between early and middle Pleistocene is considered to be at the Brunhes-Matuyama magnetic boundary at 788 ka (Johnson, 1982). The boundary between the middle and late Pleistocene is considered to be the boundary between oceanic ^{18}O isotope stages 5 and 6 at 132 ka (Johnson, 1982). The Pleistocene-Holocene boundary is considered to be at the boundary between ^{18}O stages 1 and 2 at 11 ka (Kominz and others, 1979).

Basalt flows at the possible dam near Eagle Mountain have not been dated, but basalts in the Greenwater Range, less than 4 km to the west, have K-Ar ages between 4.03±0.12 and 7.16±0.22 Ma (Luedke and Smith, 1981). Both the basalt at the possible dam and in Greenwater Range are faulted. The proximity of the faulted basalts at the two locations suggests that the basalts are probably the same age, and that impoundment of a lake probably began less than 4-7 Ma ago.

Deposition of the lower unit of the waterlaid sediments of Amargosa marsh began prior to deposition of an included ash bed dated at 3.22±0.12 Ma by the K-Ar method (R.F. Marvin and others, U.S. Geological Survey, written commun.,

1983) and 2.95±0.42 Ma by the fission-track method (C.W. Naeser, U.S. Geological Survey, written commun., 1980). An ash bed in the lower unit, where it is unconformably overlain by the river gravels of ancestral Rock Valley Wash in SE1/4 NE1/4 sec. 19, T. 16 S., R. 50 E., has been dated at 2.1±0.4 Ma by the fission-track method (C.W. Naeser, U.S. Geological Survey, written commun., 1982). The ash bed underlies recrystallized chalk at the edge of the river gravels and is probably just below the top of the lower unit.

Fossils in the upper unit of the waterlaid sediments indicate that Amargosa marsh may have persisted into the Quaternary period. In secs. 22 and 23, T. 14 S, R. 49 E., just north of U.S. Highway 95, a small outcrop of the upper unit consists of tuffaceous sands and clays overlain by diatomaceous marl, which in turn is overlain by tufa. Richard M. Forester (U.S. Geological Survey, written commun., 1979) identified several species of ostracodes from the diatomaceous marl. Cypridopsis vidua (Muller), also identified by Forester from a sag-pond deposit in unit QTa in Yucca Flat, is known from the Pliocene and Quaternary, but is much more common in the Quaternary. Charles A. Repenning (U.S. Geological Survey, written commun., 1982) identified vertebrate fragments from the tufa and the underlying diatomaceous marls as being less than 2 m.y. old. Tooth fragments of Mammuthus sp. cf. M. columbi (Falconer), Equus sp., and a large camelid were identified. Poorly preserved fragments of a tusk and limb bones occur in the diatomaceous marl. Repenning states that Mammuthus is not known to be older than 2 Ma in North America. He states that the thickness of the enamel plates from the Mammuthus teeth suggest an age considerably less than 2 Ma. Thus, deposition of the waterlaid sediments of Amargosa marsh probably ended in early Pleistocene time.

The fossils in the upper unit verify the stratigraphic position of the 2.1 Ma-old ash bed in the lower unit. Although the recrystallized chalk above the ash bed is known only in the lower unit, the topographic position of the chalk, when compared to that of the tufas of the upper unit, which are exposed 2 km to the east, suggest that the chalk might be in the upper unit. If the ash is in the upper unit, then either a long hiatus occurred shortly after deposition of the ash and before deposition of the fossils in the upper unit, or the chronologic range of Mammuthus is incorrect. Because neither alternative seems reasonable, the 2.1 Ma-old ash is assumed to be in the lower unit of the waterlaid sediments of Amargosa marsh.

Unit QTa overlies the upper unit of the waterlaid sediments of Amargosa marsh on the west side of the Paleozoic ridge that contains Devil Hole. It also overlies the river gravels of ancestral Rock Valley Wash. Unit QTa is, therefore, younger than the 2.1 Ma-old ash in the lower unit of the waterlaid sediments and the Mammuthus remains in the upper unit, and is probably Quaternary in age.

Delicate leaves are preserved on plant casts in the tufa of the upper unit west of Devils Hole. The preservation of the leaves occurs only near the eroded edge of overlying deposits of unit QTa. Further from the edge of QTa deposits, exposed plant casts are partially dissolved and leaves are not discernible. The preservation near the edge of unit QTa and dissolution further away suggests that unit QTa was deposited shortly after the deposition of the tufa and thus preserved the leaves of the plant casts that otherwise would not have been preserved.

Unit QTa is designated as both Pliocene(?) and Pleistocene, but the faunal evidence indicates that it is probably only Pleistocene in age. In addition to the probable Pleistocene age of the upper unit of the waterlaid sediments of Amargosa marsh at the Mammuthus locality, fossils in sag-pond deposits within unit QTa in Yucca Flat also indicate a Quaternary age. Richard M. Forester (U.S. Geological Survey, written commun., 1979) reports that Cypridopsis vidua (Muller) in the sag-pond deposits in western Yucca Flat has not been found in sediments believed to be Miocene or older, but is far more common in the Quaternary than in the Pliocene. Scottia n. sp. (sensu stricto), also found in the sag-pond deposits is known only from Pleistocene sediments in North America, and therefore, the sag-pond deposits and the overlying part of unit QTa are probably Quaternary.

The Bishop ash, 738 ka (Izett, 1982), has been found at several locations in the Yucca Mountain area at or within 5 m of the base of subunit Q2e and less than 3 m above the base of subunit Q2c in the Calico Hills just west of Fortymile Wash. The pedimentation, development of a soil, and dissection of unit QTa prior to deposition of unit Q2 and the presence of an alluvial unit between units QTa and Q2 strongly suggest that deposition of unit QTa took place significantly before 738 ka.

Although the Bishop ash (738 ka) occurs at or near the base of subunits Q2e and Q2c at all locations where the ash has been found, deposition of subunit Q2c could have begun significantly before the ash was deposited. All locations of the ash are topographically high and on or just above bedrock. These locations suggest that older deposits of subunit Q2c may be concealed at lower elevations.

Radiometric ages determined for units Q2 and Q1 are shown in table 1 (Rosholt and others, 1985; Szabo and others, 1981). The uranium-trend method determines when deposition or erosion ended, and thus, when soil formation began. Uranium-trend plots of data are linear for samples of unit Q2 that include both the B and calcic horizons. Disturbance of the vertical, open system, on which the empirical uranium-trend method is based, by biotic or tectonic processes can affect the system and may result in ages younger than the actual age (J.N. Rosholt, U.S. Geological Survey, oral commun., 1981). At the ETS trench in Jackass Flats, the soil that was sampled appears to be undisturbed, but the age of 160 k.y. is much younger than the stratigraphic position of Q2s warrants. About 20 m south of the sample site the beds from which the sample was taken are eroded at a topographic scarp. The sample age, therefore, probably indicates the end of erosion, rather than the end of deposition.

The repetition of ages determined for multiple samples of subunits Q2a(?), Q2b, and Q2c for both buried and surface deposits at different locations demonstrates the precision of the uranium-trend method. Coincidental agreement of ages at two or three locations for a single stratigraphic unit may be possible, but coincidental agreement of five or six ages in widely separated locations that vary in geomorphic position, soil development, and soil parent material seems unlikely. Similarly, the hypothesis that numerous ages of four stratigraphic units could be displaced equally by some unknown mechanism also seems unlikely.

Table 1.--Radiometric ages of Quaternary stratigraphic units in the Yucca Mountain area

Stratigraphic unit	Material	Age (ka)[1]	Method	Sample locality
Subunit Q1c	Charcoal in fluvial sand	8.3±0.075	^{14}C 2	Amargosa River bank 6 m below surface 2 km SE of Beatty
Av horizon	Eolian silt and sand	30±30	U-trend[4]	SW Frenchman Flat trench
Av horizon[3]	Carbonate in eolian silt and sand	25±10	U-series[5]	Basalt cone 11 km WNW of Amargosa Valley
Subunit Q2a(?)	Slopewash gravel	31±10	U-trend[4]	RV-1 trench, Rock Valley
Do-----	B horizon	36±20	U-trend[4]	RV-2 trench, Rock Valley
Do-----	B horizon in slopewash gravel	37±24	U-trend[4]	RV-1 trench, Rock Valley
Do-----	B horizon in slopewash gravel	38±10	U-trend[4]	RV-2 trench, Rock Valley
Do-----	B horizon in slopewash gravel	38±10	U-trend[4]	Trench 14, Yucca Mountain
Do-----	Alluvial gravel	40±10	U-trend[4]	CF-3 trench, east-central Crater Flat
Do-----	Slopewash gravel	41±10	U-trend[4]	Trench 13, Yucca Mountain
Do-----	Alluvial gravel	47±18	U-trend[4]	Trench 2, Yucca Mountain
Do-----	B horizon in slopewash sand	55±20	U-trend[4]	Trench 14, Yucca Mountain

Table 1.--Radiometric ages of Quaternary stratigraphic units in the Yucca Mountain area--Continued

Stratigraphic unit	Material	Age (ka)[1]	Method	Sample locality
Subunit Q2b	Alluvial gravel	145±25	U-trend[4]	Trench 2, Yucca Mountain
Do-----	Alluvial gravel	160±25	U-trend[4]	Charlie Brown gravel pit, Shoshone, California
Do-----	Calcareous B horizon	180±40	U-trend[4]	RV-1 trench, Rock Valley
Do-----	Alluvial gravel	190±50	U-trend[4]	CF-3 trench, east-central Crater Flat
Do-----	Alluvial gravel	190±0	U-trend[4]	SW Frenchman Flat trench
Do-----	Alluvial gravel	200±80	U-trend[4]	SW Frenchman Flat trench
Subunit Q2s	B and calcic horizons	160±90	U-trend[4]	ETS trench, Jackass Flats
Subunit Q2c (younger soil and underlying deposits)	Alluvial gravel	240±50	U-trend[4]	Trench 13, Yucca Mountain
Do-----	K horizon	270±30	U-trend[4]	RV-1 trench, Rock Valley
Do-----	Alluvial gravel	270±30	U-trend[4]	CF-3 trench, east-central Crater Flat
Do-----	Alluvial gravel	270±35	U-trend[4]	Jackass Divide trench
Do-----	K horizon	270±90	U-trend[4]	Trench 14, Yucca Mountain
Do-----	Alluvial gravel	310±40	U-trend[4]	RV-1 trench, Rock Valley

Table 1.--Radiometric ages of Quaternary stratigraphic units in the Yucca Mountain area--Continued

Stratigraphic unit	Material	Age (ka)[1]	Method	Sample locality
Subunit Q2c (older soil and underlying deposits)	Alluvial gravel	390±100	U-trend[4]	RV-1 trench, Rock Valley
Do-----	Alluvial sand	400±50	U-trend[4]	Western SCF trench southern Crater Flat
Do-----	Slopewash sand	420±50	U-trend[4]	Trench 14, Yucca Mountain
Do-----	Alluvial gravel	430±40	U-trend[4]	Jackass Divide trench
Do-----	Alluvial gravel	480±60	U-trend[4]	Western SCF trench southern Crater Flat
Do-----	K horizon in gravel	480±90	U-trend[4]	Trench 14, Yucca Mountain

1 ± one standard deviation.

2 Analyzed by S.W. Robinson, U.S. Geological Survey, Menlo Park, California.

3 Correlated to Av horizon by appearance.

4 Rosholt and others, 1985.

5 Szabo and others, 1981.

The age of subunit Qle in the Yucca Mountain area has not been determined, but numerous ^{14}C dates for charcoal and fossil seeds from sand dunes in two nearby areas indicate the probable times of accumulation. In the Ash Meadows area, three dates for charcoal in dunes and 10 dates for fossil seeds in peat interbedded with sand that is probably equivalent to Qle range from 2,940±100 to 5,320±70 yr B.P. (Mehringer and Warren, 1976). In the Corn Creek Springs area, about 35 km northwest of Las Vegas, seven charcoal samples at and near the base of dunes ranged from 4,030±100 to 5,200±100 yr B.P. (Haynes, 1967). A weakly developed soil occurs above this older material in both areas (Mehringer and Warren, 1976; Haynes, 1967). Three charcoal samples in eolian sand above the soil in the Ash Meadows area were dated between 1,950±100 and 440±280 yr B.P. These intermediate-age deposits are overlain by a very weakly developed soil, which in turn, is locally overlain by Paiute pottery shards. Virgin Branch pottery shards that occur locally below the soil provides a maximum age of about 1,000 yr B.P. for the soil. Charcoal associated with the shards above the soil was dated at 220±100 yr B.P. (Mehringer and Warren, 1976).

On the basis of the stratigraphy in several trenches in the dunes at Ash Meadows, archaeological artifacts, and similar age dates in both the Ash Meadows and Corn Creek Springs areas, Mehringer and Warren (1976) concluded that there were three periods of eolian sand deposition during Holocene time: 5,300 to 3,000, 2,000 to 1,000 or less, and 200 yr B.P. to the present. The periods of sand deposition were separated by intervals of nondeposition and soil development from 3,000 to 2,000 and about 1,000 to 400 yr or less B.P. Similar periods of deposition and soil development in subunit Qle in the Yucca Mountain area are likely, because of the proximity of the Ash Meadows and Corn Creek Springs areas to Yucca Mountain.

At the numerous locations where subunits Qlc or Qls and Qle occur together, Qle always overlies Qlc or Qls. The minimum age of Qlc and Qls is, therefore, probably greater than 5,300 yr B.P. Where subunits Qle and Qlb occur together, sand sheets of Qle less than 0.5 m thick overlie Qlb. The stratigraphic position of Qlb above Qlc and Qls and the thinness of Qle overlying Qlb suggest that Qlb may be younger than the oldest period of Qle deposition, 5,300 to 3,000 yr B.P., and older than the youngest period of Qle deposition, or older than 1,000 yr B.P.

Subunit Qla probably corresponds to a period of arroyo erosion that began about 1840 throughout the southwestern United States (Antevs, 1955). In the Syncline Ridge area, a juniper tree, dated by dendrochronology, began growing in 1858 on a Qlc terrace. Erosion of the terrace by a Qla wash to a depth of 0.7 m exposed and killed a large root of the juniper tree in 1928.

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