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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF FAULTS EXPOSED IN TRENCHES IN CRATER FLAT, NYE COUNTY, NEVADA

by

W C Swadley and D. L. Hoover

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ABSTRACT

Study of three trenches excavated across two faults along the eastern edge of Crater Flat indicates that the main fault movement offset unit QTa in trench 1 at least 2.4 m down to the west, and occurred about 1.1 m.y. ago, as indicated by included basalt ash. Later fault movement, detected in trench 3, and probably related to the faulting at trench 1, displaced unit Q2c a combined distance of 0.8 m down to the west along three faults. Fault movement at trench 3 occurred sometime after 260,000 years ago and before about 40,000 years, but the evidence favors an age that is closer to the older date.

INTRODUCTION

This report gives information gained from trenching across two Quaternary faults in the area of Crater Flat (fig. 1), near the western edge of the Nevada Test Site (NTS). This study is part of a geologic investigation by the U.S. Geological Survey to evaluate a potential nuclear waste storage site at Yucca Mountain. In 1978, geologic investigations for the U.S. Department of Energy were begun to determine if the major geologic formations are suitable for locating a permanent underground repository for isolation of high-level radioactive waste. Recently, work has concentrated around a specific site in the north-central part of Yucca Mountain (fig. 1).

A significant factor in determining the suitability of the proposed repository is the tectonic stability of the site. A principal element in this stability determination is the extent of Quaternary faulting in the area of the repository. To determine the extent of Quaternary faulting, detailed mapping of the surficial deposits in a 2,300-km^2 area centered on the proposed site was begun in 1978. This mapping is now nearing completion. Two faults, shown by mapping to cut Quaternary deposits, were selected for trenching and more detailed examination. These faults lie along the east side of Crater Flat, 5 to 10 km southwest of the Yucca Mountain site. Three trenches were excavated in the spring of 1981 to expose the faults in a vertical face normal to the trace of the fault.

Figure 2 shows the surficial geology of the study area and locations of the three trenches. The walls of the trenches were mapped and sampled to determine the amount and direction of movement on the fault and, if possible, the age of the last movement.

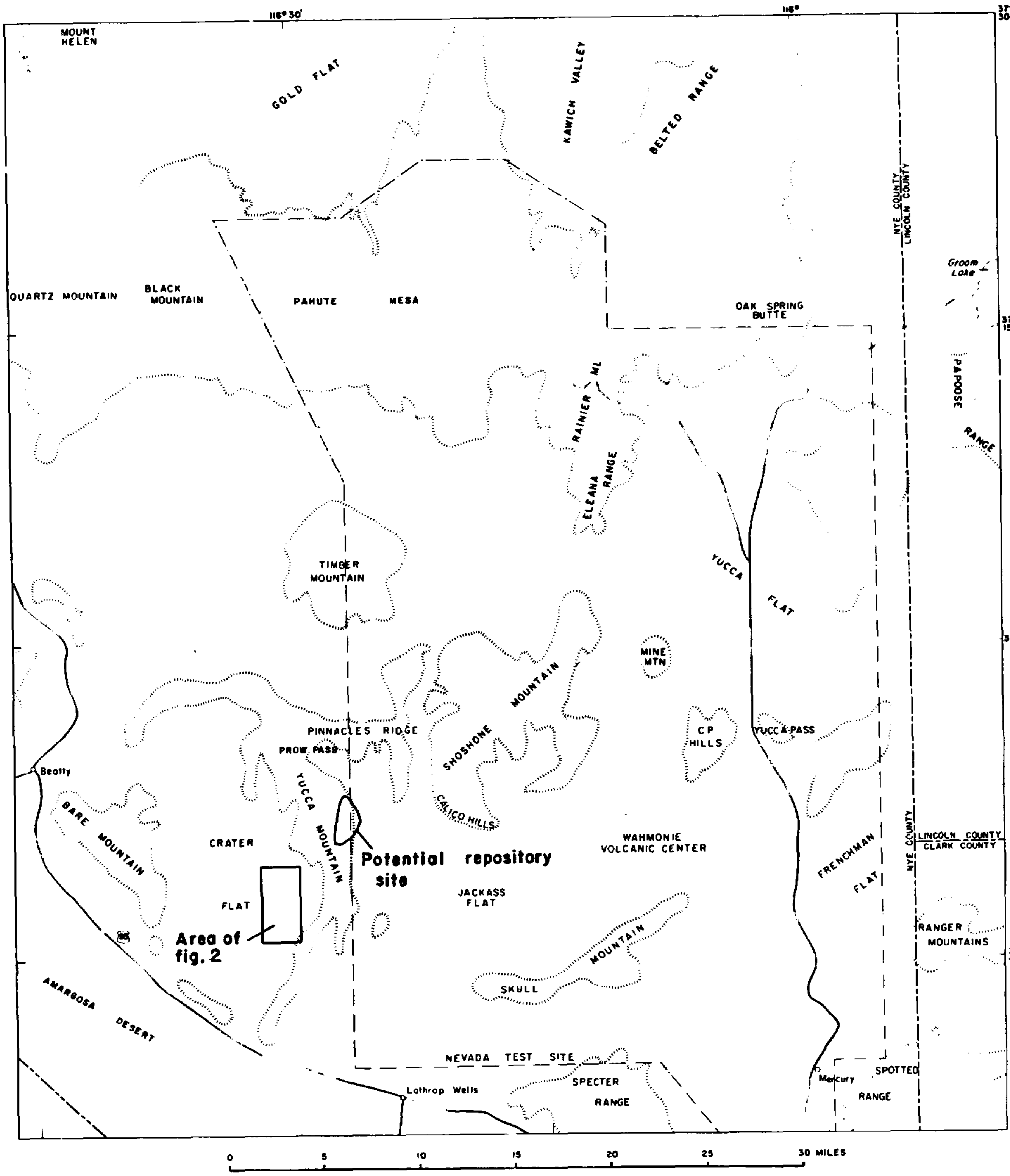


Figure 1.--Index map of the Nevada Test Site and vicinity showing location of study area and potential waste repository site.

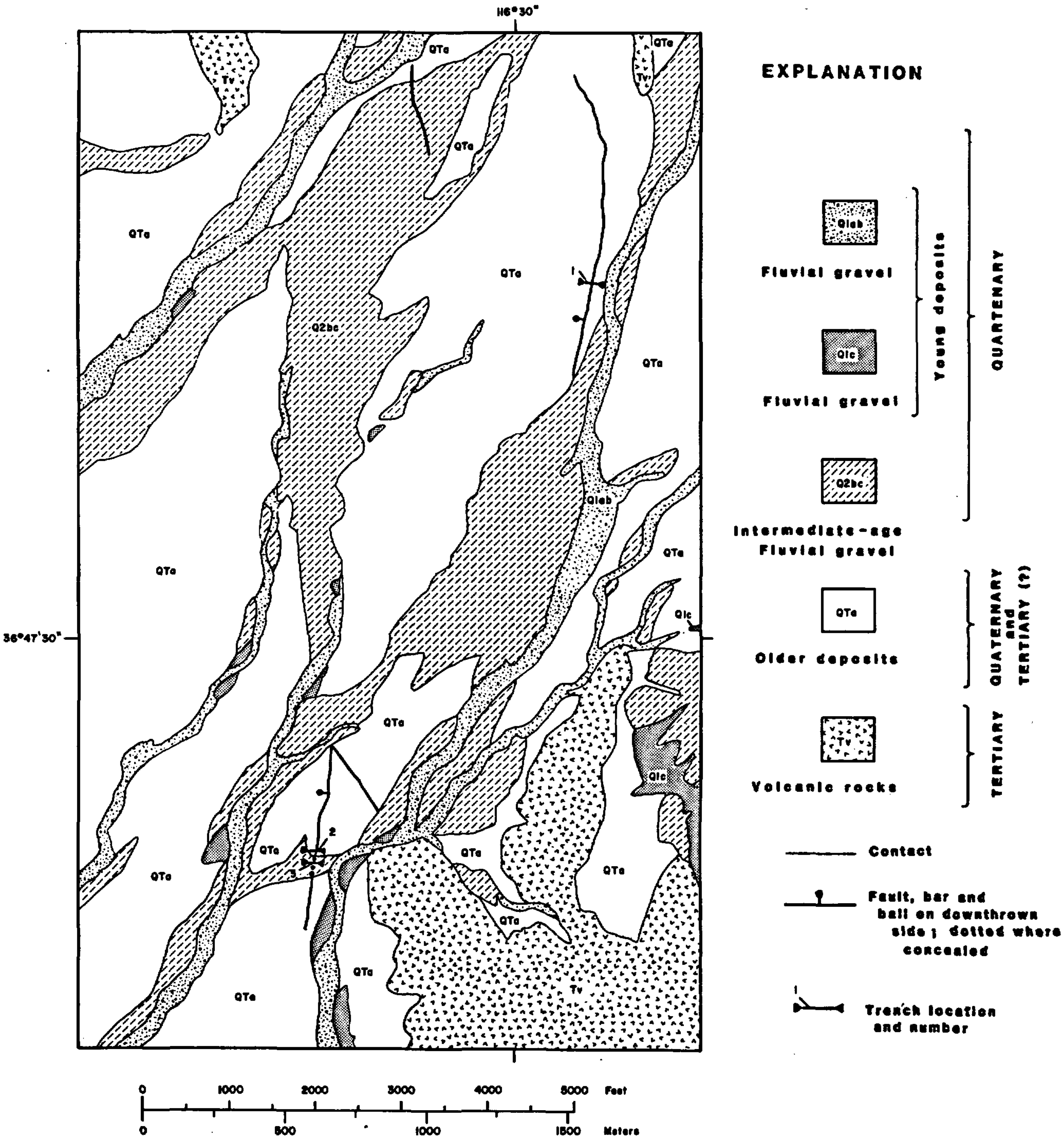


Figure 2.--Map of study area showing surficial geology and locations of trenches.

REGIONAL SETTING

The NTS is in the southern part of the Basin and Range province, an area characterized by linear mountain ranges and valleys with a general northerly trend. Crater Flat, near the southwest edge of NTS (fig. 1), is an alluvial basin bordered on the north, east, and south by ridges of Tertiary volcanics rocks, and on the west by the Paleozoic and late Precambrian sedimentary rocks of Bare Mountain (Cornwall and Kleinhampl, 1961). Late Tertiary basalt flows dated at about 3.75 m.y. and Quaternary basalt flows and cinder cones dated at 1.1 to 1.5 m.y. are present within the basin (Carr, 1982). Yucca Mountain consists of several subparallel ridges and valleys broken by north-northeast-trending faults that are generally downthrown to the west (Lipman and McKay, 1965; and Christiansen and Lipman, 1965). The trenched faults are considered to be part of this fault pattern.

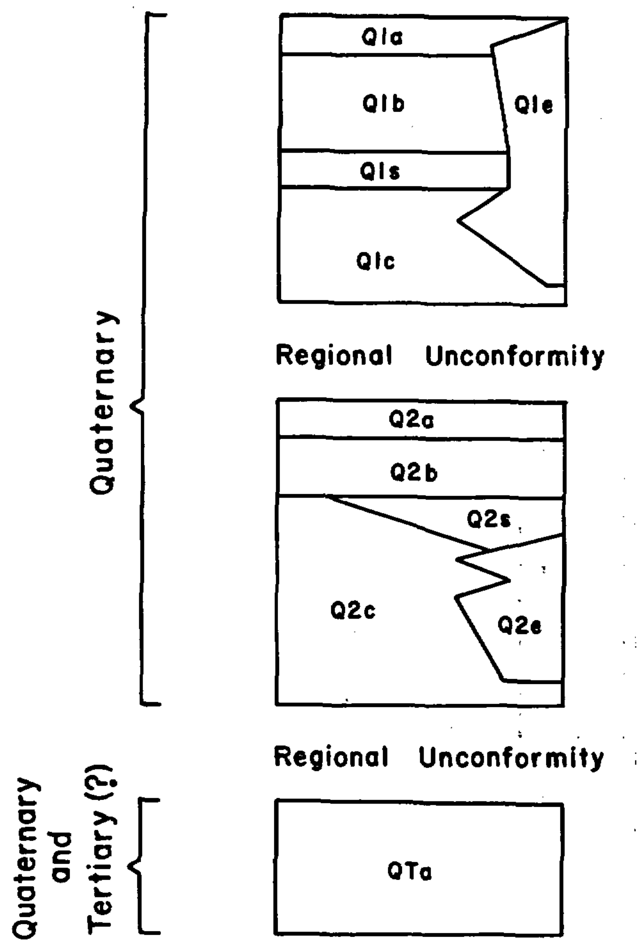
STRATIGRAPHY

Any study of Quaternary faulting requires a detailed knowledge of the stratigaphy of the Quaternary deposits of the area. Hoover and others (1981) described the surficial deposits of the NTS area and established characteristics by which these deposits can be mapped and correlated throughout the region. A brief description of the units exposed in the study area follows.

The surficial deposits of the NTS area consist largely of debris-flow material, fan alluvium, fluvial deposits, and windblown sands. These deposits comprise three major depositional units separated by regional unconformities (fig. 3). Two units, young deposits (Q1) and intermediate deposits (Q2), are entirely Quaternary in age; the third unit, older deposits (QTa), is Quaternary and Tertiary(?). These ages have been established by radiometric dating, by correlation of intercalated ash beds, and by relative degree of soil development (Hoover and others, 1981, p. 24).

The oldest major unit, QTa, consists of fan material deposited almost entirely as debris flows with only minor fluvial material. Unit QTa is coarse, poorly sorted, angular to subrounded gravel with little or no bedding and only minor amounts of sand and finer material. It typically occurs as dissected fans and fan remnants adjacent to bedrock ridges. Outcrops are commonly well cemented with caliche. Soils formed in QTa deposits were developed well after deposition of QTa and following a lengthy period of erosion. The soil consists of a K horizon that has Stage IV carbonate morphology (Gile and others, 1966), and is as much as 3 m thick. The K horizon is overlain by a well developed argillic B horizon that is only locally preserved. In areas where QTa has not been buried by younger deposits, and thus isolated from soil forming processes, the surface soil is of QTa and Q2 age. The A horizon, where present, is the same composition and is assumed to be the same age as the A horizon described below for Q2 units.

Intermediate age deposits of the region consist of fan alluvium and eolian and fluvial sands. These deposits have been subdivided into five subunits: three fluvial fan units (in order of decreasing age), Q2c, Q2b, and Q2a; eolian sand sheets and dunes, Q2e; and fluvial sand sheets, Q2s. Units Q2a, Q2e, and Q2s are not present in the study area and are not described here.



Young Deposits

Qla — Coarse fluvial deposits

Qlb — Coarse fluvial deposits and debris flows

Qle — Eolian sand in dunes and sheets

Qls — Fluvial sand sheets

Qlc — Coarse fluvial deposits, minor debris flows

Intermediate Deposits

Q2a — Local debris-flow deposits

Q2b — Fluvial deposits and strath terraces

Q2s — Fluvial sand sheets

Q2e — Eolian sand in dunes and sheets

Q2c — Coarse fluvial deposits, fluvial sand sheets, and minor debris flows

Older Deposits

QTa — Debris flows, minor fluvial deposits

Figure 3.--Correlation chart of major surficial units in the NTS region (after Hoover and others, 1981).

Unit Q2c forms fans and terrace deposits that generally overlie or are inset into unit QTa. Q2c consists of fluvial deposits with some debris-flow material and is typically made up of poorly to well-sorted, nonbedded to well-bedded gravel with sand and silt in the matrix and as distinct beds and lenses. Soils of three ages have developed in Q2c. Typically, the oldest soil has a well-developed K horizon, 1 to 2 m thick (Stage III to IV of Gile and others, 1966). The K horizon is overlain by a reddish-brown argillic B horizon, and a vesicular pale-brown silty and clayey A horizon formed in material primarily of eolian origin. The intermediate age soil has a Stage III to IV K horizon, about 1 m thick, overlain by a lighter reddish-brown argillic B horizon and an A horizon as described above. The youngest soil has a Stage II Cca horizon or a Stage III K horizon, 0.5 to 1 m thick, a light-brown cambic B horizon, and an A horizon that is similar to that of the other soils.

Unit Q2b is very similar to Q2c in lithology and depositional environment. Q2b differs only in topographic position and can be distinguished from Q2c only by the degree of soil development or in areas where it forms inset or strath terraces in Q2c. Soils developed in Q2b consist of a Stage I Cca horizon overlain by a light-brown cambic B horizon and a vesicular A horizon similar to that of soils of Q2c. While the soil of Q2b differs significantly from those of Q2c, mapping based on this distinction requires extensive examination of soils and was not practical at the scale of this study. Therefore, Q2c and Q2b are commonly combined in a single map unit, Q2bc, in areas where they cannot be separated on the basis of topographic position.

Fluvial gravels, fluvial sand, and eolian sand make up the youngest depositional unit. It is subdivided into five units: three fluvial gravel units (in order of decreasing age), Q1c, Q1b, and Q1a; fluvial sand sheets, Q1s; and eolian sand sheets and dunes, Q1e. Units Q1s and Q1e are not present in the study area and are not described here.

Unit Q1c consists of fluvial deposits with only minor amounts of debris-flow sediments. It occurs as terrace remnants 1 to 5 m above the floor of the modern stream channel along larger drainages and as thin sheets overlying older fans and bedrock. Q1c is typically poorly to well-bedded, moderately well-sorted gravel with a sandy matrix. Soil development on Q1c is limited to a Cca horizon with Stage I carbonate morphology.

Unit Q1b consists of fluvial deposits and debris-flow deposits that form low terraces 1 to 2 m above the floors of most washes and thin sheets downslope from the incised segments of steeper washes. Generally, the unit is poorly sorted, poorly bedded gravel with a sandy matrix and scattered beds and lenses of sand. Unit Q1b is unmodified by soil development.

The youngest of the Q1 units, Q1a, is made up of sand and gravel deposits along the floors of modern washes. Except in the largest washes, Q1a deposits are narrow and so closely interlaced with Q1b that the two units cannot be mapped separately and are, therefore, combined as Q1ab.

Although absolute ages for the surficial units of the area are not known, Hoover and others (1981, p. 16) have summarized the available age data and derived the following age limits for surficial deposits in or near NTS. QTa is younger than an ash bed of an underlying unit dated at 2.1 ± 0.4 m.y. (R. L. Hay, Univ. of California, Berkeley, written commun., 1983) and older than

730,000 years (Hoover and others, 1981, p. 16). Most Q2c is less than about 730,000 years old and the soils developed in it are more than 80,000 years old. The A horizons of Q2 soils are formed primarily in eolian sediments. These eolian sediments do not occur on Holocene surfaces so they are assumed to be older than about 12,000 years. They commonly overlie a soil horizon and slope wash deposits that have been dated by the uranium-trend method at 40,000 ± 8,000 years (J. N. Rosholt, U.S. Geological Survey, written commun., 1983). The eolian sediments are believed to have been largely deposited during a very dry climatic period and have been tentatively correlated by Hoover and others (1981) with a dry period at Searles Lake, California that occurred 27,000 to 35,000 years ago (Smith, 1979). Unit Q1c is inferred to be less than 12,000 and more than 7,000 years old, and Q1b is inferred to be between about 5,000 and 140 years old.

FAULTS

The two faults that were trenched are part of a group of north-trending faults along the east side of Crater Flat. The northern fault (fig. 2) trends N. 10° E. at the trench site. North of the trench site, the strike changes to N. 20° W. The fault is marked by a low, west-facing scarp that is locally as much as 3 m high, but more commonly 1 to 2 m high. The scarp can be traced for about 1.1 km entirely within unit QTa.

The southern fault, also indicated by an inconspicuous west-facing scarp as much as 2 m high, extends for about 0.6 km and trends N. 10° E. The scarp is developed in QTa but is not present where the fault crosses an area of Q2bc (fig. 4).

TRENCHING AND MAPPING

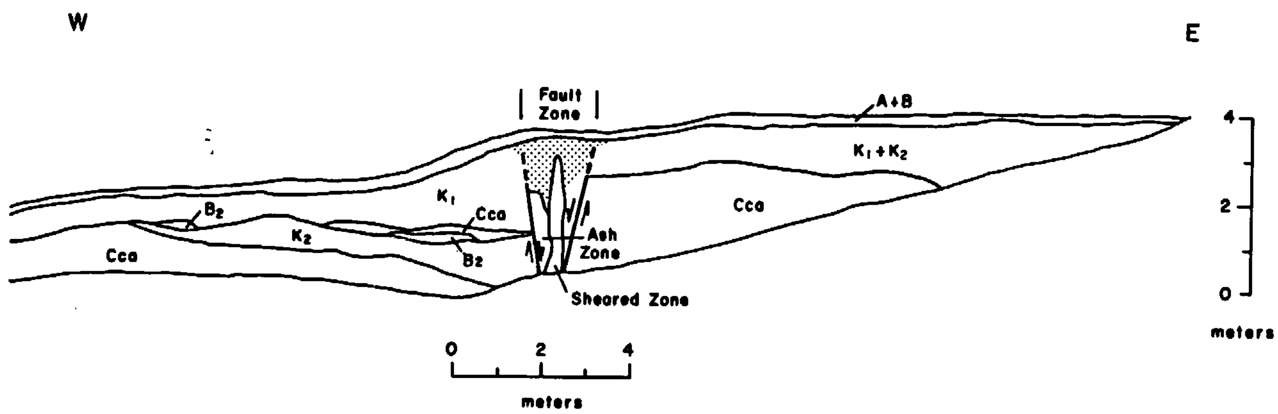
Three trenches were excavated by bulldozer normal to the strike of the faults (fig. 2). Trench 1 was excavated across the northern fault in an area where the fault scarp is prominent. Trenches 2 and 3 were excavated on the southern fault segment, trench 2 located in an area of QTa where the fault scarp is present, and trench 3 in an area of Q2bc where no scarp is evident. All three trenches were cut to a depth of 3-4 m and a length of 30-40 m.

One face of each trench was mapped by establishing a horizontal reference line, then laying out a 2-m grid from which fault planes, fractures, sedimentary features, and soil horizons could be located and plotted.

TRENCH DESCRIPTIONS

Trench 1, excavated across the northern fault, exposed three faults within unit QTa that extend to the floor of the trench at a depth of about 4 m (fig. 5). The eastern fault strikes N. 10° E. and dips 75° W. The base of a well developed K horizon (unit K_2) is downthrown to the west approximately 2.4 m. A post-faulting K horizon (unit K_1) that developed in QTa and fault scarp colluvium in the downthrown block, occurs above K_2 near the fault and rests on the truncated top of K_2 farther to the west. In the upthrown block, K_1 developed above K_2 by engulfment of the overlying soil horizons. It merges with K_2 and could not be mapped separately. Both K horizons thicken toward the fault zone in the downthrown block, probably due to deposition of non-pedogenic car-

Figure 4.--Aerial view of southern fault at trenches 2 and 3. Fault scarp in unit QTa is marked by dotted line where it crosses trench 2 (background). No scarp is developed where fault crosses unit Q2bc near trench 3. Photo taken looking north. (Photo by W. J. Carr)



STRATIGRAPHIC UNITS AND TECTONIC FEATURES

Unit	Age	Description
A & B	Q2	A and B horizons undivided A horizon--silty clay, light-gray, vesicular; 6 to 8 cm thick; overlain by a moderately developed desert pavement B horizon--cambic, slightly clayey sand and gravel, light-brown; 8 cm thick
B2	QTa	B horizon--argillic, reddish-brown, sand and gravel; 0 to 20 cm thick; unit is a remnant of the pre-fault soil
K_1	QTa and Q2(?)	K horizon--gravel, moderately to well cemented with Stage III to IV caliche; laminated Stage IV caliche at top; unit is 3+ m thick. On the downthrown block, unit K_1 represents only post-fault soil development; on the upthrown block, the K_1 horizon merges with the underlying pre-fault K horizon (K_2). Upper part of K_1 horizon is probably Q2 in age
K_2	QTa	K horizon--poorly sorted gravel, moderately to well cemented with Stage III to IV caliche; locally has laminated Stage IV caliche at top. Unit represents pre-fault K horizon preserved in downthrown block; in the upthrown block, it can not be distinguished from the overlying K_1 horizon
Cca	QTa	Cca horizon--poorly sorted gravel; Stage I caliche development
Fault zone		Disturbed zone composed of gravel cemented with secondary calcite. Soil horizons not recognized in stippled area
Ash zone		Gravel and sand containing basalt ash

Figure 5.--Profile of north wall of trench 1. Trench trends east-west. Mapped in February 1982 by W C Swadley and H. Huckins.

bonate in the more permeable material adjacent to the fault. The argillic B horizon (unit B2) is preserved as a few remnants below the Cca and K1 horizons on the downthrown side of the fault, but has been eroded from the upthrown side. A vesicular A horizon and a thin cambic B horizon, both of Q2 age, extend across the fault zone with no apparent displacement. The fault zone consists of a jumble of QTa fragments, probably in part, eroded from the upthrown side of the fault scarp, that is well cemented with carbonate. A minor antithetic fault on the west side of the fault zone strikes N. 10^{o} E. and dips 80^{o} E. Displacement on this fault seems to be down to the east but the amount of throw could not be determined. The third fault is marked by a sheared zone in the center of the fault zone. Most of the offset within the fault zone may have occurred along this fault, but no offset could be measured because of the lack of bedding or soil horizons within the fault zone.

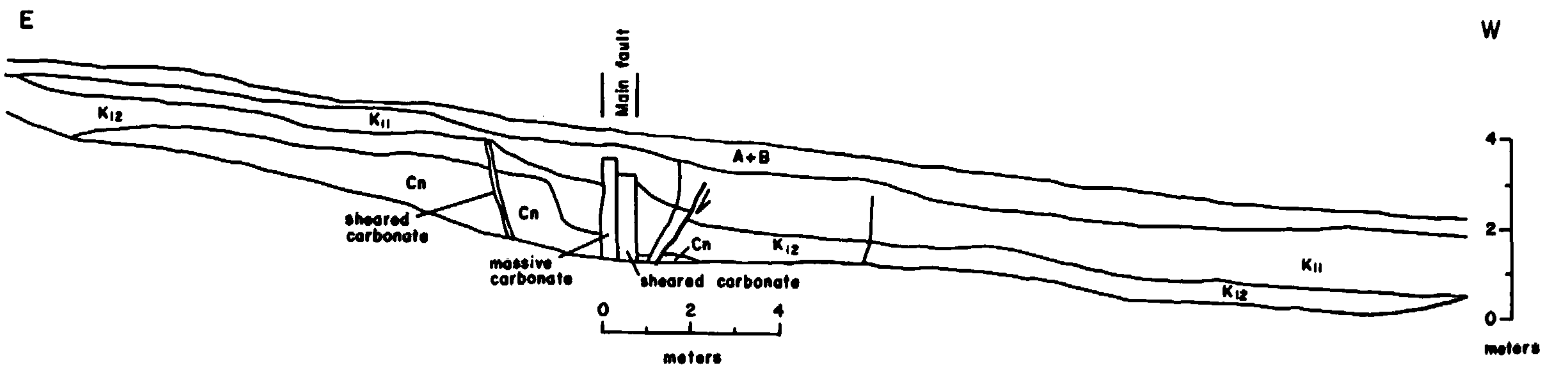
Along the western edge of the fault zone, there is a 0.2 to 0.4 m wide body of sand and gravel that contains basalt ash (fig. 6). The ash has been correlated by petrographic analysis with a line of Quaternary basalt cinder cones and flows 6.4 km to the west (B. M. Crowe, Los Alamos National Laboratory, oral commun, 1981). The basalt has been dated by K-Ar whole-rock method at 1.1 m.y. (W. J. Carr, U.S. Geological Survey, written commun., 1982). This ash was probably washed into an open fracture formed at the time of faulting. Since open fractures are usually short lived, especially in poorly consolidated sediments, it seems very likely that the faulting, the eruption of the basalt, and the redeposition in the open fracture occurred in a very brief period of time.

Mapping of the trench and analysis of the samples collected indicate the post-QTa fault displacement was approximately 2.4 m down to the west. The inclusion of the basalt ash establishes the time of displacement at 1.1 m.y. The unbroken vesicular A horizon, which formed in sediment that is believed to be 27,000 to 35,000 years old (Hoover and others, 1981, p. 26) indicates no fault movement after that time.

Trench 2, across the southern fault, exposes unit QTa and several faults (fig. 7). At this site, QTa is mostly debris-flow deposits with minor amounts of fluvial gravel. The bodies of fluvial gravel are poorly defined and are distinguishable from the debris flows only by smaller clast size and better sorting. Pedogenic carbonate in unit QTa consists of a K horizon made up of a lower part (unit K11) that has Stage III carbonate morphology and ranges in thickness from 0.5 to about 1.5 m. The lower part of the K horizon is overlain by a massive to laminated zone (K12) that has Stage IV zone carbonate morphology and which ranges in thickness from 0 to 1.5 m. The Stage IV zone pinches out near the east end of the trench, possibly due to erosion at the upper part of the fault scarp. A vesicular A horizon and a cambic B horizon, with a combined thickness ranging from about 0.2 m to about 0.8 m, overlie the K horizon.

Four faults and one fracture are exposed in the trench. The main fault strikes N. 20^{o} E. and is vertical. It is marked by a zone of sheared carbonate 0.5 m wide and a 0.2 m-wide zone of massive carbonate bordering the sheared carbonate on the east. Displacement on the fault is probably down to the west, although displacement of the sediments cannot be determined because of a lack of bedding. The apparent displacement of the carbonate horizons, down to the west, may be due in part to post-fault solution and redeposition of carbonate in more permeable zones. The fault does not offset the top of

Figure 6.--Photograph of south wall of trench 1. Dark areas (circle near end of pick handle) are basalt ash. Sheared area to left is main fault zone. (Photo by W. J. Carr)



STRATIGRAPHIC UNITS AND TECTONIC FEATURES

Unit	Age	Description
A & B	Q2	A and B horizons undivided A horizon--clay and silt, vesicular, light-gray; 5 to 20 cm thick; overlain by moderately developed desert pavement B horizon--Cambic, sandy gravel, pale-yellowish-brown to pale-brown; 5 to 70 cm thick
K_{11}	QTa and Q2(?)	K_{11} horizon--gravel, well cemented with massive to laminated Stage IV caliche; 0 to 1.5 m thick. Upper part of unit is probably Q2 in age, lower part is QTa age
K_{12}	QTa	K_{12} horizon--gravel, moderately cemented with Stage III caliche; 0.5 to 1.5 m thick
Cn	QTa	Cn horizon--coarse, poorly sorted gravel

Figure 7.--Profile of south wall of trench 2. Trench trends N. 88° W.
Mapped in July 1981 by D. L. Hoover.

the K horizon, suggesting the fault is probably the same age (1.1 m.y.) as the main fault in trench 1.

A fault 2 m east of the main fault strikes N. 12° W. and dips 82° W. Sheared and massive carbonate about 0.2 m wide fill the fault zone. The fault does not penetrate the K11 horizon, indicating this fault is somewhat older than the main fault. Displacement on this fault cannot be determined because of a lack of bedding, but it is probably down to the west.

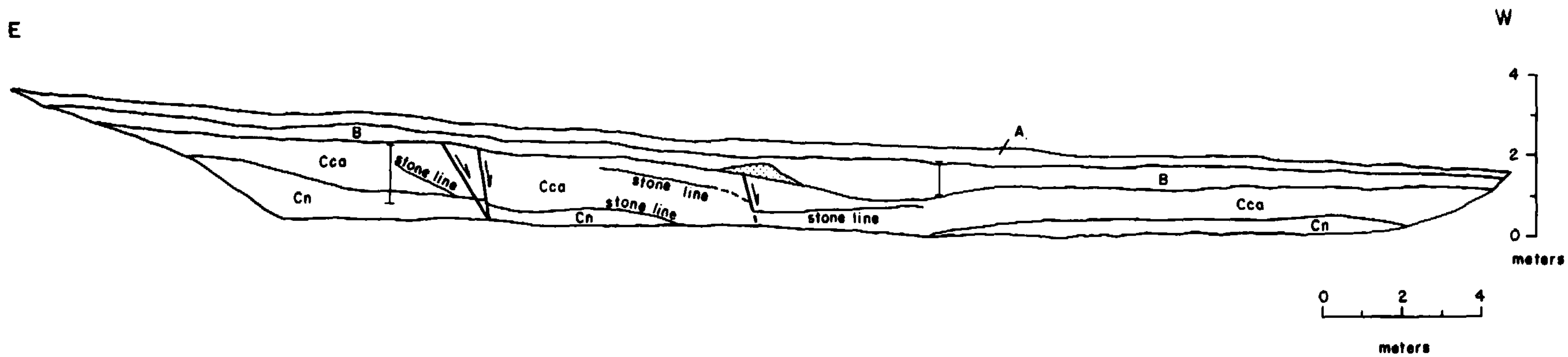
Two minor faults 1.0 m and 1.3 m west of the main fault strike N. 2° W. The eastern fault has an average dip of 79° E., ranging from vertical near the top of the trench to 70° at the bottom. Massive carbonate, a few centimeters thick, occurs along the fault plane. The western fault has an average dip of 77° to the east, ranging from 85° near the top of the trench to about 60° at the bottom. About 5 m west of the main fault is a fracture in the K horizon that strikes N. 9° E. and dips 84° W. The two faults and the fracture do not cut any units above the K horizon, indicating an age similar to that of the main fault.

Trench 3, 300 m south of trench 2, exposes subunit Q2c and three faults (fig. 8). Subunit Q2c consists of fluvial gravel and sandy gravel that contain a few thin cobble layers that may be debris flows. The upper part of Q2c contains a Cca horizon with Stage II pedogenic carbonate that ranges from 0.7 to 1.5 m in thickness. Carbonate coats fragments that occur in scattered lenses and cobbles beds in the underlying Cn horizon. Overlying the Cca horizon is a zone that consists of an upper B horizon, 20 to 45 cm thick, above discontinuous remnants of an older B horizon (not shown in fig. 8), and locally part of an oxidized C horizon that shows no carbonate development. An overlying A horizon differs from the typical A horizon that formed in Q2c in that it is mostly sand and contains few vesicles. It ranges in thickness from 10 to 60 cm but, as mapped, may include some colluvial sand in the thicker portions. Typical A horizons form in a mixture of silt, clay, and sand and are highly vesicular.

The main fault in trench 3 strikes N. 10° E. and dips 85° W. It does not cut any horizons above the Cca horizon. The fault is a single plane that displaces a stone line 0.5 m down to the west. Above the fault the B horizon is locally cemented with carbonate. This fault is probably an extension of the main fault exposed in trench 2.

Two minor faults occur 6.7 m and 7.2 m east of the main fault. The western fault strikes N. 20° E. and dips 82° W.; the other fault strikes N. 20° E. and dips 72° W. These two faults merge at the bottom of the trench. The western fault offsets a stone line 0.1 m down to the west and the eastern fault offsets the same stone line 0.2 m down to the west.

Both the Cca horizon and the cambic B horizon were sampled in trench 3 for dating by the uranium-trend method (fig. 8). The Cca horizon and the older part of the B horizon gave an age of 260,000±30,000 years and the upper part of the B horizon an age of 40,000±10,000 years (J. N. Rosholt, U.S. Geological Survey, oral commun., 1982). These data along with other dates for the NTS area indicate a maximum age of about 260,000 years for the faults in trench 3. Since the faults do not cut the upper part of the B horizon, the minimum age of these faults may be about 40,000 years.



STRATIGRAPHIC UNITS AND TECTONIC FEATURES

Unit	Age	Description
A	Q2	A horizon--sand and silt, slightly vesicular, light-brownish-gray, 10 to 60 cm thick
B	Q2	B horizon--cambic, fluvial sand and gravel, light-brown; 0.3 to 1.2 m thick; locally cemented with carbonate (shown by stipple pattern)
Cca	Q2	Cca horizon--gravel and sandy gravel, fluvial; 0.7 to 1.5 m thick; moderately cemented with Stage II caliche
Cn	Q2	Cn horizon--gravel and sandy gravel, fluvial, Stage I carbonate coatings on scattered cobbles

Figure 8.--Profile of south wall of trench 3. Trench trends N. 83° W. Mapped in July 1981 by D. L. Hoover. Vertical bar indicates sample locality.

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