U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

AERIAL PHOTOGRAPHIC INTERPRETATION OF LINEAMENTS AND FAULTS IN LATE CENOZOIC DEPOSITS IN THE CACTUS FLAT AND PAHUTE MESA 1:100,000 QUADRANGLES AND THE WESTERN PARTS OF THE TIMPAHUTE RANGE, PAHRANAGAT RANGE, INDIAN SPRINGS, AND LAS VEGAS 1:100,000 QUADRANGLES, NEVADA

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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ABSTRACT

Lineaments and faults in Quaternary and late Tertiary deposits in the southern part of the Walker Lane are potentially active and form patterns that are anomalous with respect to the typical fault patterns in most of the Great Basin. Little work has been done to identify and characterize these faults, with the exception of those in the Death Valley-Furnace Creek fault zone (DVFCFZ) and those in and near the Nevada Test Site. This report includes two quadrangle maps and portions of four others at a scale of 1:100,000; these maps complete a project (previous maps include U.S.G.S. Open-File Reports 90-41 and 90-500) to summarize the existing knowledge about these lineaments and faults within 100 km of the potential high-level nuclear waste repository at Yucca Mountain, based on extensive aerial-photo interpretation, limited field investigations, and published geologic maps.

The map area can be divided into two areas. The principal area, covering all of the map area except the southeast corner in the Las Vegas quadrangle, contains mainly north-trending lineaments and faults with a lesser number of east- to northeast-trending faults and a few inactive northwest-trending faults. The north-trending features include range-bounding faults and scarps, faults within volcanic plateaus (Pahute Mesa), and some clusters of faults and scarps on valley floors. The orientations and sense of slip within this domain indicate that the least principal stress direction is northwest-southeast. In the southeastern area, faults and lineaments associated with the Pahrump fault zone trend northwest and north; in this domain, the least principal stress direction is about east-west.

Most of the area, and particularly the eastern part of the principal area, has previously been considered to be tectonically inactive, at least since the late Miocene. The abundance of steep straight range-front segments and scarps in Quaternary deposits, however, indicates that faulting and extension in this area are still active.

INTRODUCTION

The site being evaluated as a potential high-level nuclear waste repository at Yucca Mountain, Nevada (fig. 1), lies in a tectonic province in the western Great Basin called the Walker Lane belt (Stewart, 1988). This belt, which includes the Walker Lane as originally defined (Locke and others, 1940), has long been recognized as an area of active faulting containing patterns of faults that are anomalous with respect to the typical fault patterns in the central and eastern parts of the Great Basin (Gianella and Callaghan, 1934; Albers, 1967; Stewart, 1988). However, little work has been done to identify and characterize Quaternary faults in the southern part of the Walker Lane, with the exception of faults in the Death Valley-Furnace Creek (DVFC) fault system and faults in and near the Nevada

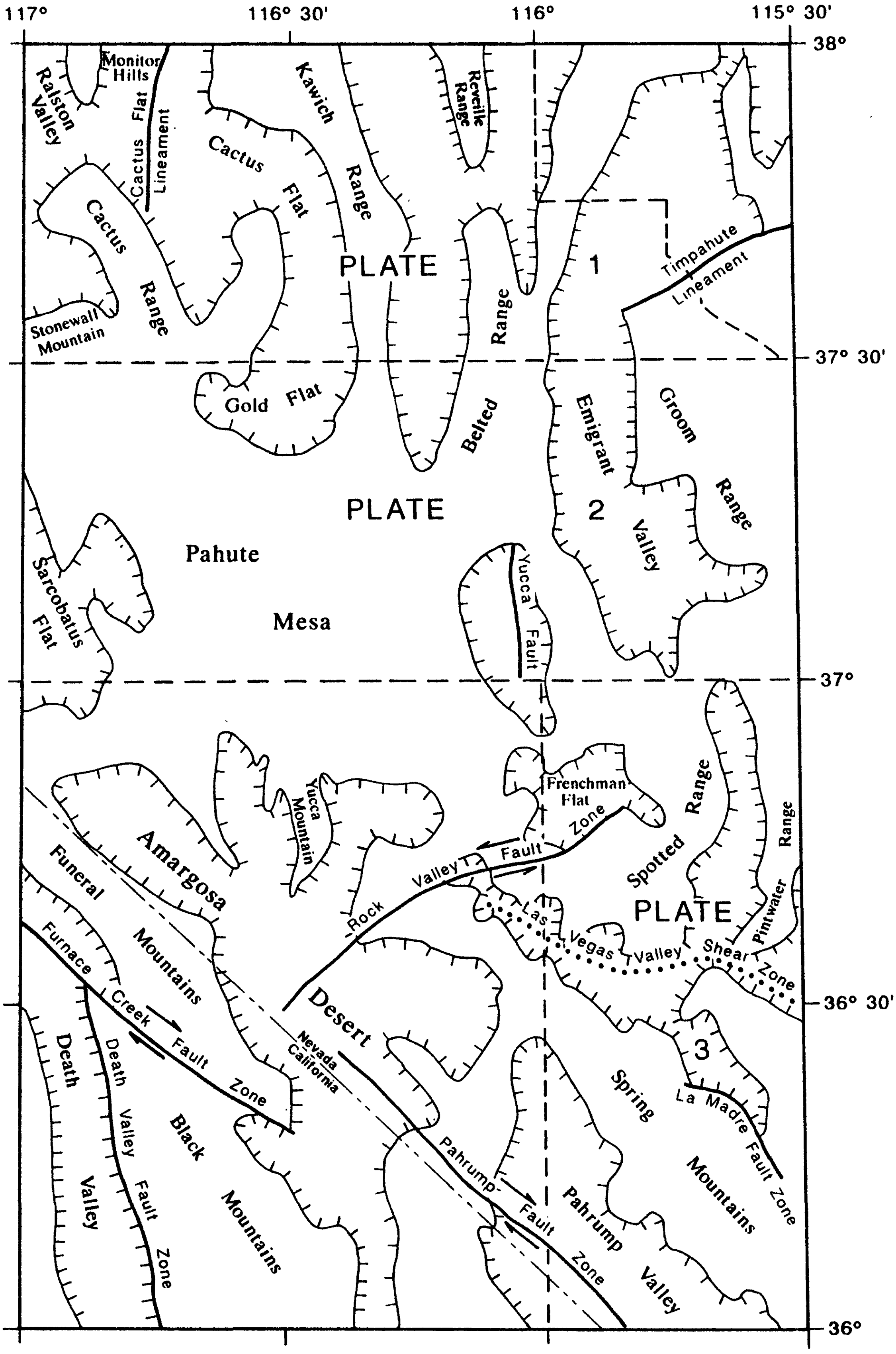

Figure 1.--Sketch map showing physiography, geographic features, principal fault zones, and boundaries of plates.

Test Site. This map is part of a study to locate and characterize Quaternary faults within a 100-km radius of Yucca Mountain (fig. 1) including the southern part of the Walker Lane. The study is supported in part by the Department of Energy under Interagency Agreement DE-AI08-78ET44802.

Lineaments and scarps in Quaternary and late Tertiary deposits were identified on stereopairs of black-and-white aerial photographs at scales of 1:62,500 to 1:80,000. The lineaments were transferred to 1:24,000- or 1:62,500-scale topographic maps by hand and by using the Kern PG-2 stereoscopic plotter. The maps were then photographically reduced and compiled on 1:100,000-scale base maps.

Many surface faults have been produced by nuclear explosions in the areas of Yucca Flat and Frenchman Flat (fig. 1) in the southeast part of the Pahute Mesa and the northwest part of the Indian Springs quadrangles, respectively (Frizzell and Shulters, 1990). Because this report is concerned with the geologic potential for faulting, these artificially induced faults were excluded from this study, insofar as possible, by using aerial photographs taken in 1952 before most of the nuclear testing occurred.

A numerical scale was devised in order to assign subjective degrees of prominence to the lineaments (see map explanation). Prominent topographic lineaments, such as straight segments of range fronts, were assigned the number 0. Such lineaments typically separate late Cenozoic deposits from bedrock; in this setting, they suggest Quaternary faulting. Topographic lineaments within bedrock were mapped only where they were associated with known deposits or fault systems of Tertiary age. Lineaments in Quaternary deposits were described on a scale of 1 to 4; increased prominence of the lineament is denoted by a higher number. Observations indicate that high-numbered lineaments tend to correspond with faults that have experienced either recurrent movement or relatively recent movement. Low-numbered lineaments are less likely to indicate actual faults unless they occur in the vicinity of high-numbered lineaments. Lineaments in Tertiary deposits were described in a similar manner on a scale of 6 to 9. Finally, the lineaments were compared to those on published and unpublished maps. Lineaments in Quaternary and Tertiary deposits that coincided with mapped faults were assigned the numbers 5 and 10, respectively. In general, mapped faults correspond in prominence to lineaments rated 3 or 4. The few mapped Quaternary faults, excluding those produced by nuclear explosions, that had not been identified during aerial-photo interpretation were added to the map and assigned the number 5.

DISCUSSION OF LINEAMENTS AND FAULTS

The maps in this report cover the northeastern and eastern parts of the area within 100 km of Yucca Mountain (fig. 1). They lie principally within the Basin and Range Province east of the Walker Lane belt, but the western and southern parts of the map area overlap with parts of the belt. Specifically, the western edges of the Cactus Flat and Pahute Mesa quadrangles are within the Goldfield section of the Walker Lane belt, the southwestern part of the Indian Springs quadrangle is within the Spotted Range-Mine Mountain section, and the western part of the Las Vegas quadrangle is within the Spring Mountains section, as defined by Stewart (1988). These different parts of the map area are characterized by groups of faults and lineaments with different orientations and characters, and will be discussed separately.

Basin and Range area

This part of the map area is dominated by north-northwest- to north-northeast-trending faults and lineaments, and includes most of the Cactus Flat and Pahute Mesa quadrangles, all of the mapped parts of the Timpahute Range and Pahranagat Range quadrangles, and the northeast half of the mapped part of the Indian Springs quadrangle (fig. 1). Many of the mapped features, including some in both Tertiary and Quaternary deposits, have characteristics that indicate right-lateral strike-slip motion. The only major exception to the northerly structural trend is in the northeastern part of Plate 3. East-northeast- to northeast-trending faults and scarps in Quaternary deposits in this area may mark the western end of the east-trending Timpahute lineament (fig. 1; R.B. Scott, oral communication, 1991).

Most of the faults and lineaments in Quaternary deposits occur as range-front faults on the west sides of ranges; exceptions are faults and scarps bounding the east sides of the northern Pintwater Range (Plate 3), the northern Kawich Range, and the Reveille Range (Plate 1). Several of these range fronts, including the east side of the Reveille Range and the west sides of the southern Kawich Range, the Belted Range (Plate 1), the Spotted Range, and the Pintwater Range (Plate 3), have not been previously thought to have Quaternary faulting. The southern ends of the Spotted Range and the Pintwater Range, part of the "oroflex" of Albers (1967), bend to the southwest as they approach the Las Vegas Valley shear zone (fig. 1), and their range-front faults correspondingly bend and appear to merge with left-lateral faults of the Spotted Range-Mine Mountain section of the Walker Lane belt as defined by Stewart (1988; discussed below).

Scattered faults and lineaments occur throughout the basins in the map area, but there are several large clusters in Quaternary deposits on valley floors. From northwest to southeast, these clusters include the area of Cactus Flat, Emigrant Valley (Plate 1), and the Yucca fault in Yucca Flat (Plate 2).

There are several groups of lineaments and scarps on the floor of Cactus Flat, but the most striking and extensive of these bounds the west side of Cactus Flat (Cactus Flat lineament, fig. 1, Plate 1). The Cactus Flat lineament consists mostly of west-facing scarps that separate Cactus Flat from the basin of Mud Lake to the west (Mud Lake is in the adjacent Goldfield quadrangle). These scarps, although west-facing, pond most of the drainage from the Kawich Range in an unnamed playa north of Antelope Lake. The Cactus Flat lineament continues north into north-northeast-trending folds in poorly consolidated sediments between the Monitor Hills and the Kawich Range. These sediments are shown as Quaternary alluvium by Cornwall (1972), but their outcrop character on aerial photographs suggests they could be Pliocene or early Pleistocene in age. In either case, the folds indicate Quaternary compression associated with the north-trending scarps in Cactus Flat.

Two lines of evidence suggest late Pleistocene motion on the Cactus Flat lineament: (1) The northern playa is ponded abruptly against the backslope of the main scarp, and several other small basins nearby are also ponded behind this scarp. Small drainages south of this playa flow along or are diverted by left-stepping scarps of the lineament formed in Quaternary deposits. (2) The basins of the northern playa and Antelope Lake apparently contained no pluvial lake in the late Pleistocene, despite their relatively large drainage areas including the high-elevation Kawich Range, whereas late Pleistocene pluvial-lake shorelines of Mud Lake are well preserved (south side of Ralston Valley in the northeast corner of Plate 1). The lack of shorelines and the local topography suggest that the basin containing the northern playa and Antelope Lake was once contiguous (in pre-late Pleistocene time?) with the Mud Lake basin but was later separated from it by motion on the Cactus Flat lineament.

There are two clusters of faults in Emigrant Valley (eastern part of Plate 2). One cluster extends north from Quaternary faults and scarps that bound the western front of the Fallout Hills. The other cluster, including many previously mapped Quaternary faults, is a much larger group of north-northeast-trending scarps between the east side of the Belted Range and Groom Lake. This cluster includes many scarps formed on late Quaternary fan deposits and possibly on pluvial lake deposits of Groom Lake. These faults may transfer slip on the Yucca fault, southwest of the cluster, to the Quaternary fault bounding the west side of the Groom Range, northeast of the cluster.

The Yucca fault is a long, east-dipping, north-trending fault that bisects Yucca Flat (fig. 1, Plate 2). This fault is part of a group of parallel right-oblique faults that have controlled basin deposition since the late Miocene (Carr, 1984). The relative amounts of dip-slip and strike-slip offset on the Yucca fault are unknown, but the persistence of the fault in a valley-floor position suggests that the amount of lateral offset must be at least as much as the amount of vertical offset, if not more. Shroba and others (1988) suggested that pre-historic fracture fills on the parallel Carpetbag fault (not shown on this map because surface offset is due to nuclear explosions) may reflect seismic shaking caused by major surface-rupturing events on the Yucca fault.

Along most of its length the Yucca fault is a single strand broken by a few minor left steps, but on the north end of the valley, approaching the bedrock hills around Oak Springs Butte, it breaks into several splays in Quaternary fan deposits. Many north-trending faults in Tertiary volcanic rocks extend north and east from the Yucca fault, connecting it with the cluster near Groom Lake discussed above. Although these faults are largely confined to bedrock, their occurrence between two prominent sets of Quaternary faults suggests that the bedrock faults have also experienced Quaternary movement.

Faults on Pahute Mesa (fig. 1, Plate 2) occur mostly in Tertiary volcanic rocks and are not associated with large scarps (on the scale of range fronts). These faults are nearly all north-trending and relatively widely spaced; some have offset features that indicate right-lateral displacement. This orientation and sense of offset are similar to that of faults to the south in the Beatty quadrangle (Reheis and Noller, 1991), and agree with the sense of offset indicated by earthquakes triggered by underground nuclear explosions on Pahute Mesa (Hamilton and others, 1972). The apparent lack of major vertical scarps associated with faults on Pahute Mesa suggests that strike-slip motion is greater than vertical motion on these faults.

Goldfield section

The western edges of the Cactus Flat and Pahute Mesa quadrangles (fig. 1) are characterized by a few widely spaced northwest- and northeast-trending faults and lineaments that bound the west sides of the Cactus Range (Plate 1) and Pahute Mesa (Plate 2) and the north side of Stonewall Mountain (Plate 1). This pattern is similar to that of faults and lineaments to the west in the adjacent Goldfield quadrangle (Reheis and Noller, 1991) and is apparently characteristic of the Goldfield section of the Walker Lane belt as defined by Stewart (1988).

The north-northwest- to northwest-trending faults and lineaments that bound the western edges of the Cactus Range and Pahute Mesa (Plates 1 and 2) are subdued and apparently have had little or no offset in the Quaternary. This pattern is similar to that of the few northwest-trending faults and lineaments in the Goldfield section of the Walker Lane belt, with the exception of faults that bound the Goldfield section on the west that are part of the Death Valley-Furnace Creek fault system (Reheis and Noller, 1991).

In contrast, the east-northeast- to northeast-trending faults and scarps that bound the northern front of Stonewall Mountain (southwest corner of Plate 1) are abrupt, and some scarps occur in late Quaternary deposits. This pattern is consistent with the steep scarps and Quaternary offset on northeast-trending faults in the Goldfield section (Reheis and Noller, 1991). The faults on the north side of Stonewall Mountain are well exposed in the Goldfield quadrangle. The observed fault planes mainly dip northeast at 70-90 degrees and have slickenlines that indicate dip-slip motion, although one outcrop displayed slickenlines that indicate a minor component of left-lateral slip (Reheis and Noller, 1989).

Spotted Range-Mine Mountain section

East- to northeast-trending faults and lineaments in the southwestern part of the Indian Springs quadrangle (fig. 1, Plate 3) are part of the Spotted Range-Mine Mountain section of the Walker Lane belt (Carr, 1984; Stewart, 1988). Several of these features are mapped faults with Tertiary and Quaternary left-lateral displacement (Poole, 1965; Barnes and others, 1982); some of the mapped Tertiary faults have previously unrecognized scarps in Quaternary deposits associated with them. As noted above, the southern ends of Quaternary scarps that bound the generally north-trending Spotted Range and Pintwater Range bend to the southwest and appear to merge with the northeast-trending left-lateral faults.

The Quaternary faults south of Frenchman Lake (Plate 3) clearly form the eastern end of the Rock Valley fault zone (fig. 1), although they are not shown on the sketch map of this fault zone by Yount and others (1987). Trenches on one strand of this fault zone in the Beatty quadrangle to the west revealed multiple fault movements with vertical separation of 1.4-2.9 m and an unknown amount of strike-slip offset in the past 180,000 yr; the most recent of these events occurred not more than 38,000 yr ago (Yount and others, 1987). Many earthquakes of magnitude 5.5 or less occurred between 1931 and 1974 in the area of the faults south of Frenchman Lake (Gawthrop and Carr, 1988).

The southern edge of the Indian Springs quadrangle and the northern edge of the Las Vegas quadrangle (fig. 1, Plate 3) straddle the west-northwest-trending Las Vegas Valley shear zone (Longwell, 1960). This shear zone, active until the late Miocene (Albers, 1967) but apparently not in the Quaternary, separates the Spotted Range-Mine Mountain section of the Walker Lane belt from the Spring Mountains section and has a right-lateral offset of 40-67 km (Stewart, 1988). With the possible exception of a few scarps near the town of Indian Springs, mapping for this report indicates no Quaternary activity on this part of the Las Vegas Valley shear zone.

Spring Mountains section

The Spring Mountains section of the Walker Lane belt, represented in this report by the western part of the Las Vegas quadrangle (fig. 1, Plate 3), is bounded on the north by the Las Vegas Valley shear zone and on the west by the Pahrump fault zone. The Spring Mountains contain a few possible Quaternary faults and lineaments, generally north-trending, but they appear to be relatively inactive. The northeast side of the Spring Mountains is bounded by the northwest-trending La Madre fault zone, mapped as a

Tertiary fault by Burchfiel and others (1974). Aerial-photo interpretation for this report suggests that this fault may have been active in the late Tertiary or early Quaternary based on subdued scarps in indurated fan gravel.

The west side of the Spring Mountains is bounded by a complex of north-northwest- to north-trending Quaternary faults and scarps (Plate 3). Although these faults have not been field-checked, their outcrop pattern suggests that they are predominantly dip slip with little or no strike-slip offset.

The Pahrump fault zone is represented by northwest- and north-trending faults and scarps on the floor of Pahrump Valley (Plate 3). The north-trending scarps splay from northwest-trending faults and may connect the Pahrump fault zone with the north-trending range-front fault of the Spring Mountains. Although little is known about relative motion on the individual faults of the Pahrump fault zone, the sense of movement is thought to be right-lateral (Burchfiel and others, 1974). The weak topographic expression of many of these valley-floor faults suggests that strike-slip motion is predominant (Reheis and Noller, 1991). Fox and Carr (1989) and Reheis and Noller (1991) have suggested that the Pahrump fault zone is a right-lateral strike-slip system that is offset relative to the right-lateral Furnace Creek fault zone to the northwest by the left-lateral Rock Valley fault zone (fig. 1).

IMPLICATIONS FOR REGIONAL TECTONICS

The distribution of late Tertiary and Quaternary faults and lineaments in the map area indicates that faulting and extensional activity are ongoing and widespread. Some areas, such as the valleys of Gold Flat and Sarcobatus Flat and the Cactus Range and Las Vegas Valley and the Spring Mountains (fig. 1), appear relatively quiescent. Other areas previously thought to have little or no Quaternary faulting, in particular the eastern part of the mapped area of the Indian Springs quadrangle, apparently have been quite active in the Quaternary. This interpretation is in direct conflict with previous work indicating that extension in the Las Vegas area was complete by 5 Ma (summarized in Wernicke and others, 1988). Although the onset of major crustal extension has apparently moved westward from the area of Las Vegas to Death Valley with time (Hamilton, 1988), mapping within the 100-km radius of Yucca Mountain (fig. 1; this study and Reheis and Noller, 1989, 1991) indicates that widespread Quaternary faulting continues in the area east of Death Valley.

The orientations and slip directions of faults and lineaments of late Cenozoic age in the map area can be used to infer stress directions. The entire map area, with the exception of the southeastern corner (south and west of the Spring Mountains, fig. 1), is characterized by north-trending faults and lineaments; the west side of this area also has a few northwest- and northeast-trending faults, and the south side has a zone of east- to northeast-trending faults. Based on the common occurrence of indicators of right-lateral movement on north-trending faults, left-lateral movement on east-trending faults, and dip-slip movement on northeast-trending faults, the least principal stress direction for most of the map area is northwest-southeast. This conclusion is consistent with previous work (for example, Carr, 1984; Zoback, 1989). In such a stress regime, northwest-trending faults should be under compression and thus relatively inactive, and this appears to be the case; northwest-trending faults that bound the Cactus Range, the west side of the northern Kawich Range, and the northeast side of the Spring Mountains, as well as faults in the Las Vegas Valley shear zone (fig. 1), show little or no evidence of Quaternary offset. These faults may have been active in the early and middle Miocene, when the least principal stress direction in the Basin and Range was oriented east-northeast-west-southwest (Zoback and others, 1981).

The area around the Pahrump fault zone in the southeastern part of the mapped region (fig. 1) has northwest-trending right-lateral strike-slip faults and north-trending dip-slip faults. Hence, this area is probably characterized by an east-west direction of least principal stress, like the Death Valley-Furnace Creek fault system (Reheis and Noller, 1991) and the boundary zone between the Basin and Range and the Sierra Nevada (Zoback, 1989) to the northwest.

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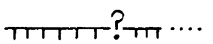
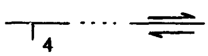
MAP SYMBOLS

Quaternary landslide deposit



Shoreline of pluvial lake--Queried where uncertain, dotted where concealed

Approximate trend of fold axis--Interpreted from aerial photographs



Lineament--Dotted line extends from or connects linear features interpreted to be related. Bar indicates facing direction of scarp. Arrows show inferred direction of strike-slip motion. Number indicates:

0 — Topographic lineament, shown either bounding a linear range front or, rarely, within bedrock

1-4 — Lineament or scarp in Quaternary deposits; number increases with prominence of lineament

6-9 — Lineament or scarp in Tertiary deposits; number increases with prominence of lineament

Fault--dashed where inferred, dotted where concealed. Bar indicates downthrown side. Arrows show direction of strike-slip motion. Number indicates:

5 — Fault in Quaternary deposits identified from previous mapping; generally equivalent in prominence to lineaments number 3 or 4

10 — Fault in Tertiary deposits identified from previous mapping; generally equivalent in prominence to lineaments numbered 8 or 9