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TERTIARY HISTORY OF LITTLE FISH LAKE VALLEY, NYE COUNTY, NEVADA, AND IMPLICATIONS AS TO THE ORIGIN OF THE GREAT BASIN

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Abstract.—Little Fish Lake Valley is a north-trending nearly symmetrical graben in the central Great Basin. It lies along a regional axis of anticlinal symmetry; to the east most ranges in the Great Basin dip eastward, and to the west most dip westward. Little Fish Lake Valley and Monitor Valley to its west are the two highest major valleys in the Great Basin and lie within a zone where the crust is thicker than normal for the Great Basin. North-trending Little Fish Lake Valley is superimposed on several east-trending aeromagnetic discontinuities: one of these, referred to herein as the Tulle Creek-Pritchards Station lineament, can be traced eastward for 64 km (40 mi) from Tulle Creek in the Monitor Range through the Pritchards Station quadrangle. The exact nature of the lineament is in doubt, but in central Nevada it serves as a volcanic province boundary between an area to the north that is underlain by thick intermediate lavas and an area to the south where these lavas are virtually absent. During part of its history the lineament has been a left-lateral strike-slip fault, and in the Hot Creek Range, between Little Fish Lake Valley and Pritchards Station, the strike-slip fault is interpreted as passing into a low-angle thrust. The strike-slip faulting and associated thrusting and the development of the Little Fish Lake Valley graben all postdate the youngest tuff in the region, the Bates Mountain Tuff, dated at 23 m.y., but predate tuffaceous sediments that yield vertebrate fossils of late Miocene or early Pliocene age.

In late 1966, the U.S. Geological Survey began geological and geophysical investigations in central Nevada in an attempt to find an underground nuclear testing area for the U.S. Atomic Energy Commission supplemental to the Nevada Test Site. Geographic remoteness and at least 1,800 m (6,000 ft) of alluvium and (or) volcanic rocks were required. Testing at the Nevada Test Site had shown previously that these lithologies provide ideal media for underground nuclear testing. Little Fish Lake Valley (fig. 1) met the geographic requirement admirably, but could not satisfy the geologic requirement.

This report presents the three-dimensional data derived principally from the 1966–67 investigations and discusses the structural setting and age of Little Fish Lake Valley, the nature of east-trending magnetic lineaments that transect the valley and adjacent ranges, and the bearing the structure and history of the valley have on the origin of the Great Basin.

STRATIGRAPHY

The oldest rocks exposed in the Little Fish Lake Valley area are Paleozoic (fig. 2). These were mapped principally by Kleinhampl and Ziony (1967) as part of the northern Nye County mapping and by H. W. Dodge, Jr. (unpub. data), as part of the Morey Peak quadrangle mapping; these maps have been generalized and modified for this report. The Paleozoic rocks of northern Nye County were described briefly by Kleinhampl and Ziony (1967), and the assemblages in central

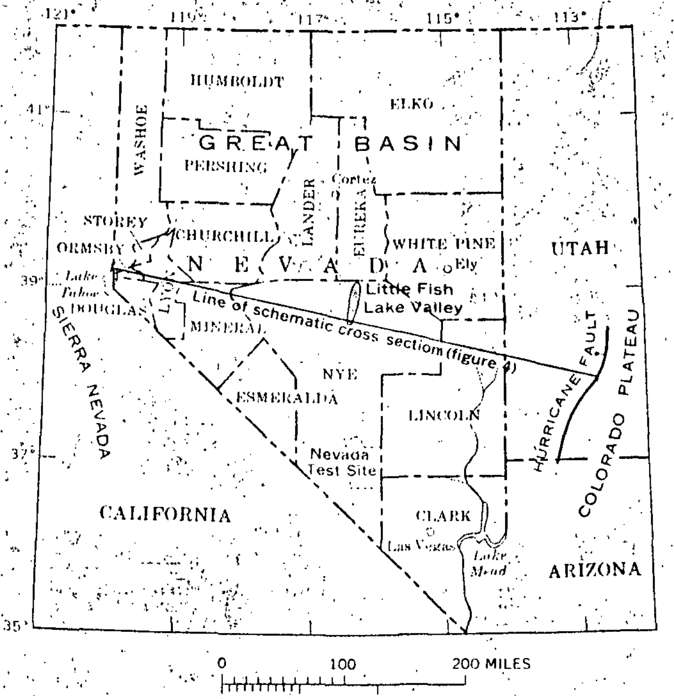


Figure 1.—Index map of Nevada, showing location of Little Fish Lake Valley and line of schematic cross section.

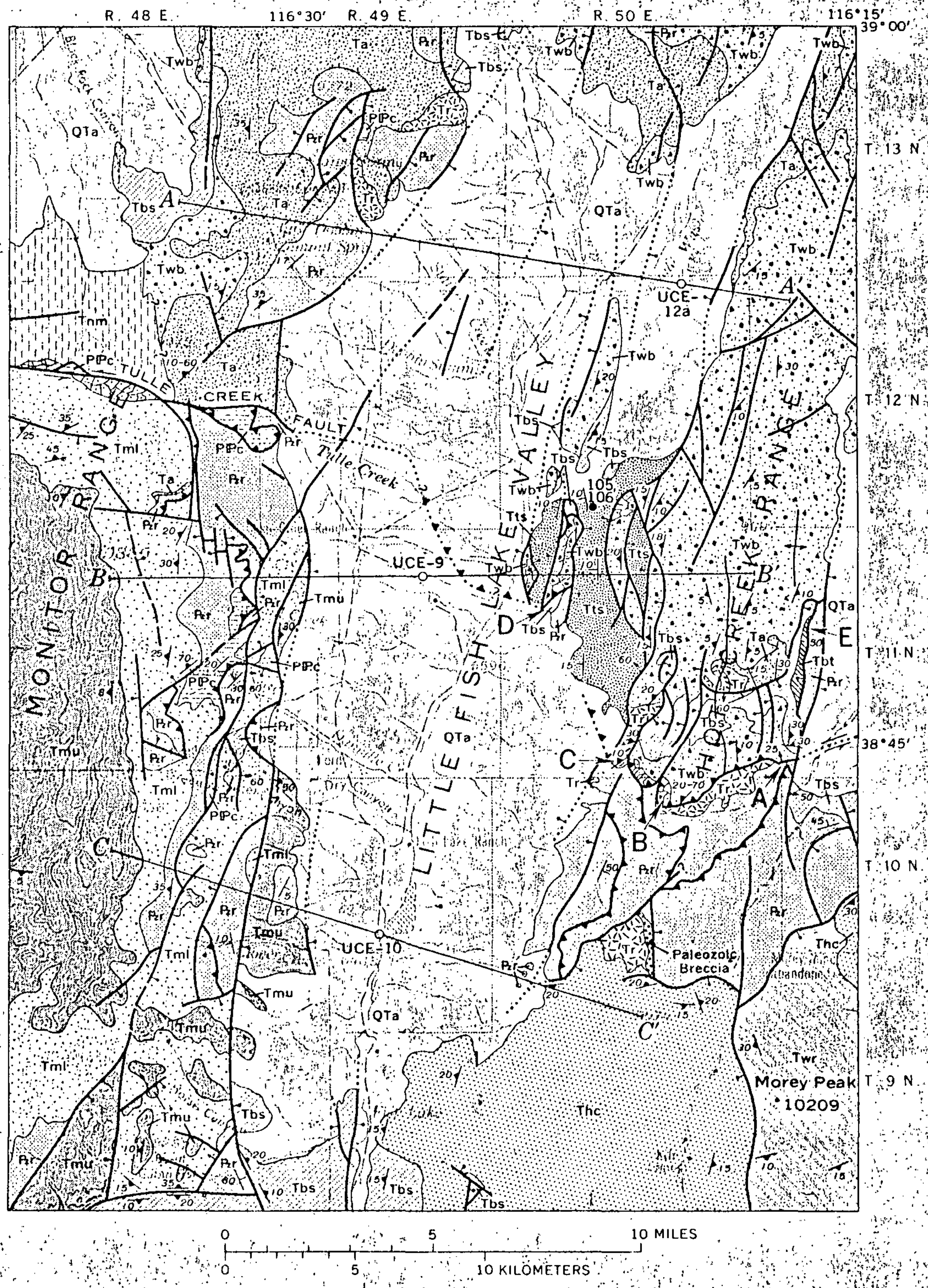
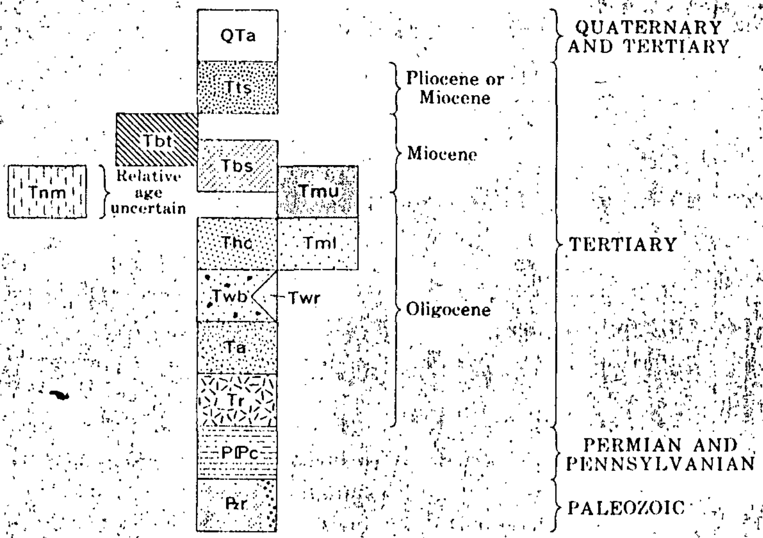


Figure 2.–Reconnaissance geologic map and stratigraphic sections of Little Fish Lake Valley area, Nye County, Nevada. Base from U.S. Geological Survey, Tonopah 1:250,000 quadrangle, 1956–62.

Nevada have been described elsewhere in a multitude of reports: Merriam (1963), Lowell (1965), Nolan, Merriam, and Williams (1956), Winterer and Murphy (1960), and Quinlivan and Rogers (1974). The rocks in the area are chiefly miogeosynclinal carbonates of early and middle Paleozoic age, but include dark cherts and carbonaceous shale of late

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

QTa	Alluvium (Quaternary and Tertiary)
Tts	Tuffaceous sedimentary rocks (Pliocene or Miocene)
Tbt	Stratified breccia and reworked tuff (Miocene)
Tbs	Principally Bates Mountain Tuff and Shingle Pass Tuff (Miocene) — Also includes tuffs of Lunar Cuesta, Kiln Canyon, Orange Lichen Creek, Pott Hole Valley, and Crested Wheat Ridge
Tnm	Tuff of the northern Monitor Range (Tertiary — Age relative to other Tertiary rocks uncertain)
	Tuff of the Monitor Range (Miocene and Oligocene)
Tmu	Upper unit
Tml	Lower unit
Thc	Tuff of Hot Creek Canyon (Oligocene)
Twb	Windous Butte Formation (Oligocene)
Twr	Tuff of Williams Ridge and Morey Peak (Oligocene)
Ta	Intermediate lavas (Oligocene)
Tr	Rhyolite lavas (Oligocene)
PIPc	Dark-gray to black chert and shale (Permian and Pennsylvanian)
Pz	Paleozoic rocks — Stippled where brecciated

35	Contact — showing dip
60	Fault — Showing dip. Dashed where approximately located or inferred; dotted where concealed. Bar and ball on downthrown side; arrows show direction of inferred relative movement
	Low-angle fault of compressional or gravity-slide origin — Approximately located; dotted where concealed. Sawteeth on upper plate
	Cracked and broken rock — Showing random dips
	Trace of axial plane of anticline — Approximately located
22	Strike and dip of beds
25	Strike and dip of eutaxitic structure in welded tuff
105 ●106	Fossil locality
○UCE-12a	Exploratory drill hole

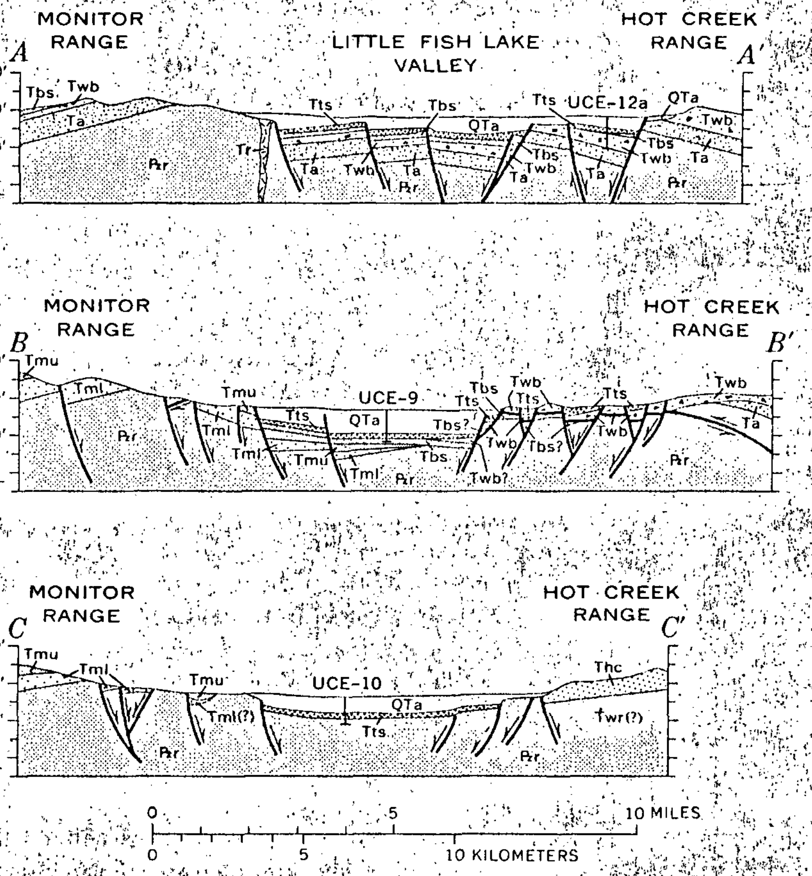


Figure 2.—Continued.

Paleozoic age in the Monitor Range south of Tulle Creek which are mapped as allochthonous.

The oldest Tertiary rocks are rhyolite lavas that constitute discontinuous piles in the Hot Creek Range and in the Monitor Range north of Tulle Creek. Most of the rhyolite is crystal poor, nearly aphyric, but some flows at the top of the pile in the Hot Creek Range are crystal rich and grade in composition toward quartz latite. East of the Hot Creek Range, in the Moores Station quadrangle (Ekren and others, 1973), the rhyolite lavas were dated by R. F. Marvin (written commun., 1970) at 37.2±1.0 m.y.

The rhyolites are overlain locally by intermediate lavas that range in composition from andesite to quartz latite. The intermediate lavas underlie the north half of the valley and are widespread to the north and east, nearly blanketing the Pritchards Station quadrangle and the next 15-minute quadrangle to the east. Near Ninemile Peak, about 16 km (10 mi) north of Little Fish Lake Valley, the intermediate lavas have been dated at 35.2±1.1 m.y. (F. J. Kleinhampl and R. F. Marvin, written commun., 1971). Phenocryst compositions of the principal volcanic rocks discussed are shown by histograms in figure 3.

Along the northeast and northwest flanks of the valley, the intermediate lavas are overlain by the Windous Butte Formation (Cook, 1965). The Windous Butte consists of a hundred meters or more of rhyolitic welded tuff that grades upward to a thick quartz latitic caprock (fig. 3). The unit is as much as 480 m (1,600 ft) thick in the Hot Creek Range, 390 m (1,300 ft) thick in drill hole UCE-12a in northeastern Little Fish Lake Valley, and about 60 m (200 ft) thick in the Monitor Range north of Tulle Creek. It is not present in the Monitor Range south of Tulle Creek. The age, paleomagnetic properties, and areal distribution of the Windous Butte are discussed by Grommé, McKee, and Blake (1972), who concluded that the unit is 30.7 m.y. old and that it has a reversed magnetic polarity.

At Morey Peak in the southeastern part of the mapped area a thick prism of welded tuff, the tuff of Williams Ridge and Morey Peak, occurs which is at least 910 m (3,000 ft) thick. W. J. Carr (written commun., 1972) concluded that this tuff lies within a resurged part of a large caldera. The tuff is lithologically similar to the upper quartz latitic part of the Windous Butte Formation, and potassium-argon analyses indicate that the two units are virtually the same age. The Windous Butte is inferred to have been extruded from either the Morey Peak area or another part of the central Nevada caldera complex that lies east of Morey Peak (U.S. Geological Survey, 1970, p. A39–A40).

Welded tuffs younger than the tuff of Williams Ridge and Morey Peak crop out on the west flank of Morey Peak; the principal one of these tuffs is the tuff of Hot Creek Canyon, which consists of several ash-flow tuff cooling units (H. W. Dodge, Jr., unpub. data). These cooling units are compositionally zoned from rhyolitic bases to quartz latitic tops (no "representative" histograms are shown in fig. 3). Potassium-argon analyses indicate that they are between 28 and 30 m.y. old. The tuff of Hot Creek Canyon is overlain by the Shingle Pass Tuff (fig. 2) and also by local units in the vicinity of Morey Peak (H. W. Dodge, Jr., unpub. data).

In the Monitor Range, south of Tulle Creek, the ash-flow

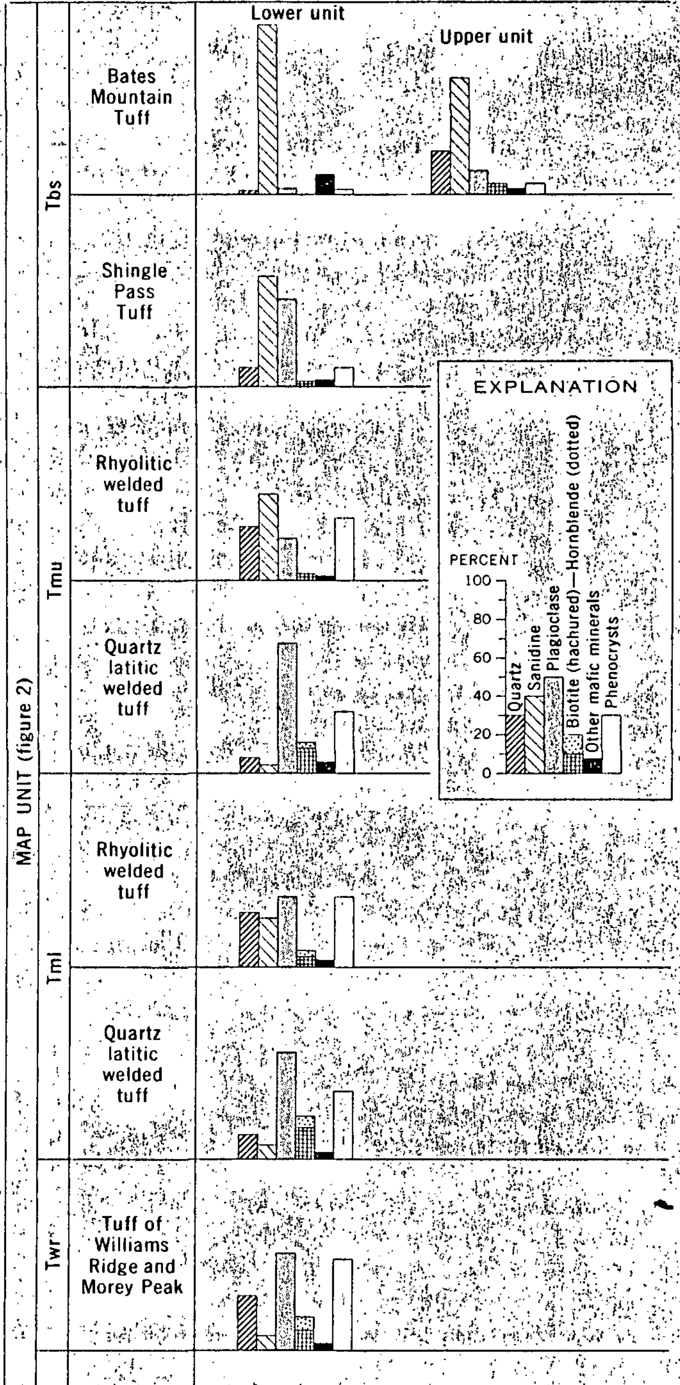


Figure 3.—Histograms showing volume of phenocrysts and abundance of six crystal components of principal volcanic rocks of Little Fish Lake Valley area.

tuffs are divided into two units. The lower unit of the Monitor Range (fig. 2) is rhyolite and quartz latite tuffs, highly altered in most exposures and superficially resembling the tuff of Hot Creek Canyon. The upper unit of the Monitor Range includes three ash-flow tuff cooling units. The lowest two are quartz latitic mafic-rich tuffs which have been dated at 26.5±0.7 m.y. (R. F. Marvin, written commun., 1972). The upper most cooling unit is rhyolitic and relatively poor in mafic minerals.

North of Tulle Creek, within the mapped area, the tuffs of the Monitor Range, which are thick and widespread south of the creek, are absent and several local tuffs of the northern Monitor Range are present. In the vicinity of a fault wedge of Pennsylvanian-Permian black chert and shale the exposed tuff is nonwelded to partially welded, highly altered, and unlike either the lower unit or the upper unit of the Monitor Range exposed south of the creek. This altered tuff is overlain by a distinctive quartz-rich mafic-poor tuff that has not been recognized south of Tulle Creek. Both the altered partially welded tuff and the quartz-rich tuff are inferred to be younger than the Windous Butte which rests depositionally on the intermediate lavas.

The Shingle Pass Tuff is present at the south end of Little Fish Lake Valley, on dip slopes of the Hot Creek Range, and in drill holes UCE-9 and -12a. Except for a landslide mass north of Tulle Creek it is not present in the Monitor Range north of the south boundary of the map (fig. 2). The Bates Mountain Tuff (Stewart and McKee, 1968; Sargent and McKee, 1969) is present in both ranges and in drill hole UCE-9. It has been dated at 23.1±0.6 m.y. (Grommé and others, 1972), and the Shingle Pass has been dated at 25.1±1.0 m.y. (Sargent and McKee, 1969).

Those tuffs in the mapped area exclusive of the Shingle Pass and Bates Mountain are typically calc-alkaline, and certain nearly identical lithologies occur in many different cooling units. In contrast, the Bates Mountain and Shingle Pass Tuffs are phenocryst poor, rich in alkali feldspar, and provide very distinctive marker horizons.

Overlying the Shingle Pass and Bates Mountain Tuffs along the east flank of Little Fish Lake Valley are tuffaceous sedimentary rocks that include weakly lithified conglomeratic mudstone, reworked bedded tuff, zones of thin-bedded Paleozoic debris, and very thin bedded yellow-weathering argillaceous limestone. One fossil locality in this sedimentary unit found by E. N. Hinrichs (105, fig. 2) yielded 64 vertebrate fragments. These were examined by G. E. Lewis (written commun., 1967), who reported that six fragments are referable to a small equid characteristic of the upper part of the Miocene. Another locality (106) yielded 42 fragments, 4 of them referable to a camelid, genus and species indeterminate, of medium size comparable to that of the genus *Procamelus* (whose age range is late Miocene to early Pliocene). These trata are very similar to, and probably the same age as, uffaceous sediments that overlie the Shingle Pass Tuff in the orthwestern part of the Moores Station quadrangle (Ekren and others, 1973). Rocks of similar lithology were found at the base of the valley fill in the three drill holes in Little Fish Lake Valley. We infer, therefore, that these rocks constitute the oldest graben-filling sediments and that locally they have been relatively uplifted, tilted, and exposed to erosion. The dissection and exposure of the older alluvium in Little Fish Lake Valley is due in part to the effective lowering of the base level in the valley following the breaching of the valley at its south end by the headwaters of Hot Creek.

Along the east flank of the Hot Creek Range (loc. E, fig. 2), adjacent to a north-trending fault, is a sequence of stratified breccia derived principally from the Windous Butte tuff. The breccia is interbedded with ash-fall tuff. The stratified breccia is as much as 60 m (200 ft) thick and reflects rapid accumulation of debris and landslipped blocks presumably shed from the adjacent footwall block lying to the east that has been completely denuded of volcanic strata. The possibility that this deposit accumulated during a period of strike-slip movement in the area is discussed in the following section on structure.

The valley-filling alluvium, as indicated by cuttings and a few cores from the three drill holes, consists mostly of gravel and sand and interbeds of silt and mud. The coarsest material was in drill hole UCE-12a (the hole nearest to bedrock source terrane), and the finest in UCE-10 where the strata are mainly of lacustrine origin. The abundance of lacustrine strata in drill hole UCE-10, which is adjacent to a present-day temporal lake, suggests that lakes have existed in the south-central part of the valley from the beginning of graben development.

STRUCTURE

Little Fish Lake Valley (fig. 1) is a nearly symmetrical graben (Stewart, 1971) that lies in the central Great Basin, equidistant between Lake Tahoe in the Sierra Nevada and the Hurricane fault at the edge of the Colorado Plateau. Along the latitude of Little Fish Lake Valley, the ranges of the Great Basin display a well-defined symmetry (fig. 4). East of Little Fish Lake Valley nearly all the ranges, as defined by Tertiary strata, dip to the east; west of the valley most dip to the west. This anticlinal symmetry does not persist throughout the Great Basin (Stewart, 1971), although, in general, most of the ranges in the east half of the Great Basin dip to the east and most in the west half dip to the west.

Little Fish Lake Valley and Monitor Valley to its west are the two highest valleys in the Great Basin and lie within a regional gravity low (fig. 5). If isostatic balance is assumed (Pakiser, 1963; Mabey, 1960), the crust in the area of Little Fish Lake and Monitor Valleys is thicker than is normal for the Great Basin. Seismic data support the inference that the crust is thicker in this central zone (Eaton, 1963; Hill and Pakiser, 1966; Warren, 1968; and Prodehl, 1970). The central area of high average altitude in the central Great Basin and its general relation to gravity is shown by Gilluly (1970, fig. 1,

Figure 4.–Schematic cross section between Lake Tahoe, Nevada-California, and the Hurricane fault, Utah, showing medial location of Little Fish Lake Valley and its relationship with east-dipping and west-dipping fault blocks. Vertical exaggeration approximately ×20. Dips not exaggerated, but generalized. Attitudes of blocks west of Monitor Valley from Kleinhampl and Ziony (1967), Calkins and Thayer (1945), Reid (1911), and Smith (1904). Attitudes in Utah from Mackin (1960). All others are based on our own observations.

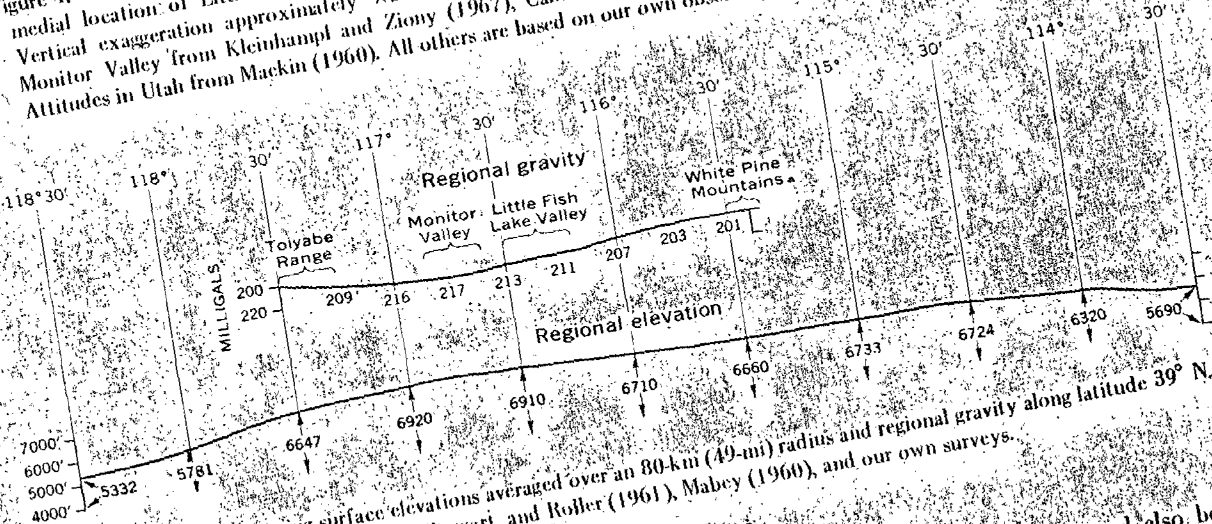


Figure 5.–Profiles comparing surface elevations averaged over an 80-km (49-mi) radius and regional gravity along latitude 39° N. Data from Diment, Stewart, and Roller (1961), Mabey (1960), and our own surveys.

p. 48). The north-trending valley is superimposed on several east-trending aeromagnetic discontinuties: one of these can be traced for a distance of 64 km (40 mi) eastward from Tulle Creek in the Monitor Range (figs. 2, 6) through the Pritchards Station quadrangle. On the following pages this discontinuity will be referred to as the Tulle Creek-Pritchards Station lineament. The exact nature of the lineament is in doubt, but during part of its history, it has been a strike-slip fault.

Tulle Creek-Pritchards Station lineament and other east-trending magnetic features

The Tulle Creek-Pritchards Station lineament on the aeromagnetic map (fig. 6) separates a northern area underlain by thick normally polarized intermediate lavas, which are associated with strong magnetic highs, from a southern area underlain by reversely polarized welded tuffs and local rhyolite-quartz latite lavas that give rise to magnetic lows. This magnetic discontinuity can be traced across Little Fish Lake Valley, beneath the valley-fill alluvium and also beneath the Windous Butte Formation in the Hot Creek Range. There is no surface expression of the lineament in either the valley or the Hot Creek Range. At Tulle Creek in the Monitor Range, however, the lineament coincides with a major east-west fault, and in the Pritchards Station quadrangle it coincides with an east-trending zone interpreted by Dixon, Hedlund, and Ekren (1973) as a left-lateral transcurrent fault.

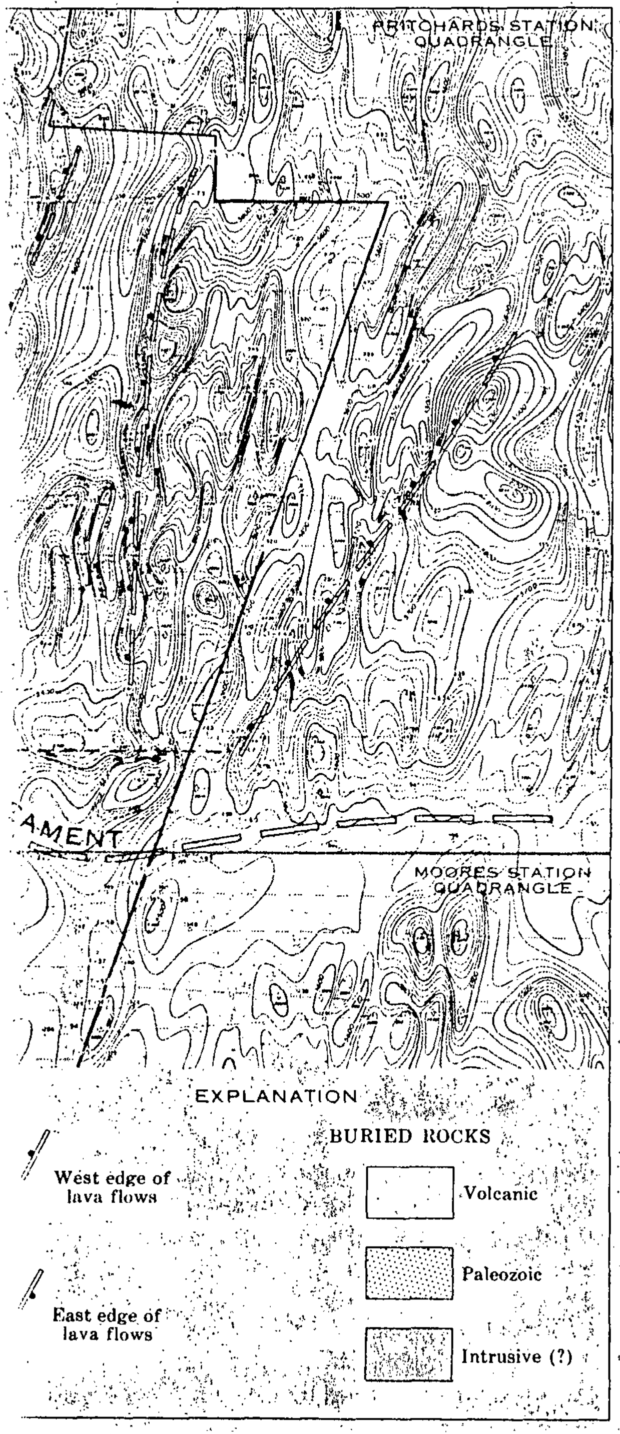
The major fault at Tulle Creek juxtaposes different Oligocene volcanic strata and places a block of Paleozoic strata on the south, which contains a thick sequence of Pennsylvanian-Permian black chert and shale, against a block to the north that contains little chert and shale. F. J. Kleinhampl and J. I. Ziony (written commun., 1972) consider the black chert and shale sequence to be part of an upper plate that presumably was thrust from west to east. Although the authors are well aware of the fact that numerous explanations can account for the virtual absence of the chert sequence north of the Tulle Creek fault, that absence is consistent with an interpretatio of left-lateral strike-slip faulting—movement of the northern block westward with respect to the southern block. A wedge of black chert caught between two branches of the Tulle Creek fault (fig. 2) seemingly is best accounted for as having been dragged to this position by left-lateral movement along the fault. The stratigraphic relationships of the Tertiary volcanic rocks likewise support a left-lateral strike-slip fault interpretation. For example, north of the Tulle Creek fault the Paleozoic rocks are overlain directly by at least 450 m (1,500 ft) of intermediate lavas (principally andesite and quartz latite). The lavas are absent south of Tulle Creek except for a small slide mass that is intercalated in the lower unit of the tuff of Monitor Range and a thin andesitic flow(?) less than 15 m (50 ft) thick that rests on Paleozoic strata in a fault block north of Danville Canyon (not shown on fig. 2). The andesite at Danville Canyon, however, is nearly aphyric and does not have a counterpart north of Tulle Creek; it could be a thin sill or dike. The virtual absence of the andesite lavas south of the Tulle Creek fault and the juxtaposition along the fault of Windous Butte Formation and thick piles of ash-flow tuff (lower tuffs of the Monitor Range, fig. 2), which are unknown in exposures to the east, are most easily explained by left-lateral strike-slip movements along the Tulle Creek fault.

East of the mapped area in the Pritchards Station quadrangle (Dixon and others, 1973), the relations are very similar to those at Tulle Creek in the Monitor Range. The aeromagnetic lineament (fig. 6) coincides with an east-trending fault zone that separates contrasting Tertiary volcanic sequences. North of the fault zone the Windous Butte Formation is as much as 485 m (1,600 ft) thick, and the underlying intermediate lavas, together with an older welded tuff, the Stone Cabin Formation (Cook, 1965), are 300–600 m (1,000–2,000 ft) thick. South of the fault zone between lat 38°45′ and 38°40′ the Windous Butte is present only as parts of large completely brecciated allochthonous masses that include intermediate lavas and the Stone Cabin. Autochthonous intermediate lavas and the underlying Stone Cabin are present for about 1.6 km (1 mi) south of the fault zone. Apparent offsets of the contact between Stone Cabin Formation and intermediate lavas suggest from 3 to 10 km (2–6 mi) of left-lateral offset across the fault zone. The allochthonous masses south of the fault zone are not easily accounted for as simple gravity-slide blocks, because they occur at virtually the same elevations as their in situ counterparts north of the fault zone. The masses appear to be best explained as remnants of a thrust plate associated with strike-slip movement along the east-trending fault zone.

In the Hot Creek Range (figs. 2, 6), we infer that the Tulle Creek-Pritchards Station strike-slip fault passes into a low-angle thrust which shoulders or shoals along the belt of Paleozoic rocks exposed north of Morey Peak. The low-angle fault dips northward, and the upper plate is inferred to progressively thicken northward. At some location beneath the range the fault probably approaches a vertical attitude. This location does not necessarily coincide precisely with the aeromagnetic lineament (fig. 6). The thrusting is somewhat analogous to that described by Sharp (1967, p. 710, 711, fig. 3, pl. 1) along the right-lateral strike-slip San Jacinto and Coyote Creek faults in the Peninsular Ranges of southern California. Our interpretation of thrusting in the Hot Creek Range is based on (1) the direct observation of a low-angle fault that dips 20°–30° N. at locality A (fig. 2), (2) intense local brecciation where the Windous Butte Formation abuts older volcanic rocks or Paleozoic rocks along the south edge of the plate (fig. 2), (3) the occurrence of an anticlinal fold that affects only upper-plate rocks south of the Tulle Creek-Pritchards Station lineament, and (4) the occurrence of several normal faults that affect only the upper-plate rocks. At locality A (fig. 2), the upper plate consists of the uppermost part of the Windous Butte Formation. The tuff is brecciated, and attitudes are chaotic. Between localities A and B the upper plate rests on or abuts the old rhyolite, and very little brecciation occurs there. In this area abundant north-trending normal faults (only two of which are shown in fig. 2) consistently drop the strata down to the west. These faults appear to be entirely confined to the upper plate and have displacements ranging from 3.0 m (10 ft) or less to as much as 46 m (150 ft). Their cumulative effect is to greatly thin and extend the upper plate. At locality B, the rhyolite lava is cut out and the upper plate is again badly broken where it rests directly on Paleozoic strata. Between localities B and C, two normal faults in the upper plate cannot be traced into the underlying Paleozoic rocks. They appear to merge with the sole of the thrust. At locality C the rhyolite is not brecciated where the fault is inferred to pass between the rhyolite and Paleozoic rocks, but the Paleozoic rocks are badly fractured and, adjacent to the rhyolite, strike parallel to the fault contact. At locality D the upper plate, consisting of the Windous Butte (and including the Bates Mountain Tuff at the north end of the ridge) is locally crackled throughout. It rests directly on Paleozoic rocks along the southeast flank of the ridge and on the Bates Mountain Tuff at the southwest end of the ridge. The Bates Mountain Tuff in this locality includes the tuff of Pott Hole Valley, which is about 25 m.y. old, based on K-Ar dates of underlying and overlying strata. The tuff of Pott Hole Valley appears to be in depositional contact with the Paleozoic rocks. The structural inversion of the Windous Butte over a much younger tuff and the fact that the Bates Mountain Tuff is involved in the thrusting place a definite lower limit of 23 m.y. on the age of thrusting and associated strike-slip faulting. In this area tuffaceous sediments containing equid and camelid fossils of late Miocene and (or) early Pliocene age are faulted down against the plate (fig. 2). This places an upper limit on the age of sliding and probably also dates the onset of valley formation. (See discussion on valley configuration.)

At locality E, a north-trending fault drops the upper plate down to the west exposing the lower plate, which consists of brecciated strata ranging in age from Ordovician to Permian.

Figure 6.—Aeromagnetic map of Little Fish Lake Valley area, showing location of Tulle Creek-Pritchards Station lineament and alined edg
Contour interval 20 gammas. Magnetic contours from



flows, and showing inferred distribution of buried rocks.
ological Survey (1968).

The beds in the upper plate include the Windous Butte Formation, the tuffs of Crested Wheat Ridge, and the Shingle Pass and Bates Mountain Tuffs. These are overlain by 61+ m (200+ ft) of stratified breccia (fig. 2) that dips 50° E. The breccia is composed of fragments of upper-plate rocks that range in size from less than 3 cm (1 in.) to large blocks 10 m or more long. Interbeds of nonwelded ash-fall tuff indicate that this breccia accumulated during a period when tuff vents were still active, probably in areas west of Little Fish Lake Valley. The north-trending fault plane is concealed by breccia debris, but judged from the positioning of breccia against the Paleozoic rocks the plane probably dips no steeper than about 40° W. The breccia must have been derived from broken upper-plate rocks that lay to the east, and it probably accumulated simultaneously with active thrusting. Upcanyon from locality E, thin latite lavas which are interbedded with tuffaceous conglomerate containing subrounded cobbles of intermediate lavas crop out. These strata dip 30° E. in the easternmost exposures but flatten to about 15° where they overlie Paleozoic rocks and rhyolite lava. The Windous Butte rests depositionally on these strata with a 10°–20° angular unconformity. The unconformity indicates that some tilting and erosion occurred after the extrusion of intermediate lavas and before the deposition of the Windous Butte. The base of the upper plate is believed to be below the canyon level in this area. On the south side of the canyon, a fault plane is exposed that dips 60° S. and displays slickensides ranging from vertical to horizontal. The fault drops the Windous Butte, Bates Mountain, and Shingle Pass Tuffs (fig. 2) against Paleozoic rocks near the upper end of the canyon, and near the lower end it swings northward to drop the younger tuffs against bedded conglomerate and the Windous Butte. The rocks in the downthrown block of this fault are badly fractured and in places completely brecciated. The degree of fracturing suggests that this fault is not a simple normal fault. Despite its curvature, it probably has an appreciable component of lateral displacement, and it separates an area to the south characterized by abundant normal faults (described above) from an area to the north that has few normal faults.

The Paleozoic rocks exposed south of the volcanic rocks (locs. A–C, fig. 2) are highly fractured in all exposures, and locally they are intensely brecciated. According to H. W. Dodge, Jr. (oral commun., 1972), the brecciation is compatible with shallow-depth deformation and the possibility exists, therefore, that the low-angle faults in the Palezoic rocks are Tertiary in age. If this is true, there is no evidence to indicate whether, or in what manner, such faults might be related to the deformation that affected the volcanic strata.

The aeromagnetic map (fig. 6) shows a pronounced discontinuity where the volcanic rocks abut Paleozoic strata to the south of the Tulle Creek-Pritchards Station lineament. This discontinuity coincides closely with the south edge of the upper plate. In this area, however, unaltered rhyolite lavas in the lower plate probably contribute to the magnetic anomalies. The strong magnetic low at the edge of the valley is possibly caused by a thick pile of buried strongly reverse-magnetized quartz latitic lava that in surface exposures rests on the old rhyolite and was mapped with the rhyolite (fig. 2).

Between the southernmost discontinuity (fig. 6) and the Tulle Creek–Pritchards Station lineament is an east-trending anomalous zone characterized by a series of small highs and lows. These are almost entirely confined to a single flight line (T-62, fig. 6) and probably are due principally to a datum shift along that flight line. Along the east flank of the Monitor Range in the vicinity of Danville Canyon (fig. 6), however, and extending out into the valley, magnetic rocks are indicated by aeromagnetic data even where surface outcrops are either Paleozoic rocks or intensely altered tuffs that are almost nonmagnetic. In this vicinity and in the Green Monster Canyon area (fig. 6) the rocks are locally impregnated with copper sulfides and are intruded by a few thin dikes. The magnetic anomalies therefore could reflect a buried east-trending intrusive mass.

The fact that the Tulle Creek-Pritchards Station lineament virtually forms the south boundary of the intermediate lavas for a distance of at least 64 km (40 mi) (despite the fact that where the lineament surfaces no enormous lateral displacements are required to explain all the stratigraphic relationships) suggests that the lineament is a deep-seated structure which first served as a volcanic province boundary and then became an active strike-slip fault zone.

Valley configuration

Gravity data (fig. 7) define a symmetrical low which is centered on drill hole UCE-9 in the west half of Little Fish Lake Valley, and a smaller low centered on UCE-12a at the northeast end of the valley. The southern terminus of the low at UCE-12a is defined by the -225 mGal contour line that coincides fairly closely with the buried Tulle Creek-Pritchards Station lineament. The lineament serves not only as a terminus to the low at UCE-12a but also as a structural boundary that divides the valley into two parts that have decidedly different tectonic styles. North of the Tulle Creek-Pritchards Station aeromagnetic lineament, the valley is anticlinal, the Monitor Range dipping westward and the Hot Creek Range dipping eastward. South of the lineament, both ranges dip westward and the valley is synclinal; the strata exposed in fault blocks on the flanks of both ranges dip toward the valley.

Drill hole UCE-12a cut 450 m (1,500 ft) of alluvium, 15 m (50 ft) of Bates Mountain Tuff, 85 m (280 ft) of tuffs of Crested Wheat Ridge (Dixon and others, 1973), 400 m (1,300 ft) of Windous Butte Formation, and bottomed in andesite lava at a depth of 975 m (3,200 ft). A downdropped block exposed southwest of the drill hole (fig. 2) dips 15°–20° E. into a boundary fault or faults having about 1,520 m (5,000 ft) of stratigraphic displacement. This east-dipping block has the same attitude as the Hot Creek Range to the east. Similarly, on the western flank of the valley along section *A–A′* (fig. 2), the buried blocks are inferred to dip west into western bounding faults. This interpretation is based on the character of the magnetic profiles over buried faulted blocks where "edges" develop as a result of faulting. Magnetic highs are positioned over the tilted normally magnetized lava on the upthrown blocks, and magnetic lows are positioned over the downthrown blocks. The profile resulting from a west-dipping fault block is a mirror image of the profile over an east-dipping block.

In the southern part of the valley in the vicinity of drill hole UCE-9, (section *B–B′*, fig. 2), where the deepest gravity low occurs in Little Fish Lake Valley and, by inference, the thickest combined alluvial-volcanic fill is present, displacement at the west margin of the graben is distributed across several faults that are down to the east and have a combined throw of at least 1,820 m (6,000 ft). These faults include northeast-trending normal faults and a major younger north-trending fault that parallels the margin of the graben as defined by gravity data. One northeast-trending fault, however, projects out into the valley, as evidenced by a recent fault scarp in the alluvium. The upper unit of the Monitor Range on the downthrown block adjacent to the valley (section *B–B′*) dips about 30° toward the valley. The attitude of these blocks contrasts with the previously noted attitudes of the downthrown blocks along the flanks of the valley to the north (section *A–A′*). Along section *B–B′*, drill hole UCE-9 cut 850 m (2,800 ft) of alluvial fill and tuffaceous sediments underlain in turn by the Bates Mountain and Shingle Pass Tuffs. The latter two units together are only 75 m (250 ft) thick, a thickness comparable to that where they are preserved in the flanking ranges. The hole bottomed at a depth of 1,000 m (3,295 ft) in bedded tuff and tuffaceous sandstone which apparently correlate with bedded strata that crop out beneath the Shingle Pass Tuff adjacent to the mapped area on the south. In the vicinity of section *C–C′* (fig. 2) and southward along the west flank of the valley, the downthrown fault blocks adjacent to the valley dip inward. This dip of volcanic rocks away from the ranges gives the deceptive appearance of younger volcanic rocks lapping up on older fault blocks.

Combined geologic and geophysical data indicate that the southern half of Little Fish Lake Valley is superimposed on a prevalley topographic high that either was never covered by volcanic rocks or was stripped of volcanic rocks by erosion before development of the valley. Gravity calculations based on densities of alluvium and volcanic rock that were obtained from geophysical logs (drill holes UCE-9, UCE-12a, UCE-10) indicate that Paleozoic rocks probably are within 1,460 m (4,800 ft) of the surface at drill hole UCE-9, or about 460 m (1,500 ft) below the hole bottom. The valley fill in a considerable area south of UCE-9 is probably underlain directly by Paleozoic rocks, as suggested by a strikingly featureless aeromagnetic configuration which extends from this area into Paleozoic outcrops in the Hot Creek Range and near locality D (fig. 2), about 5 m (3 mi) southeast of UCE-9.

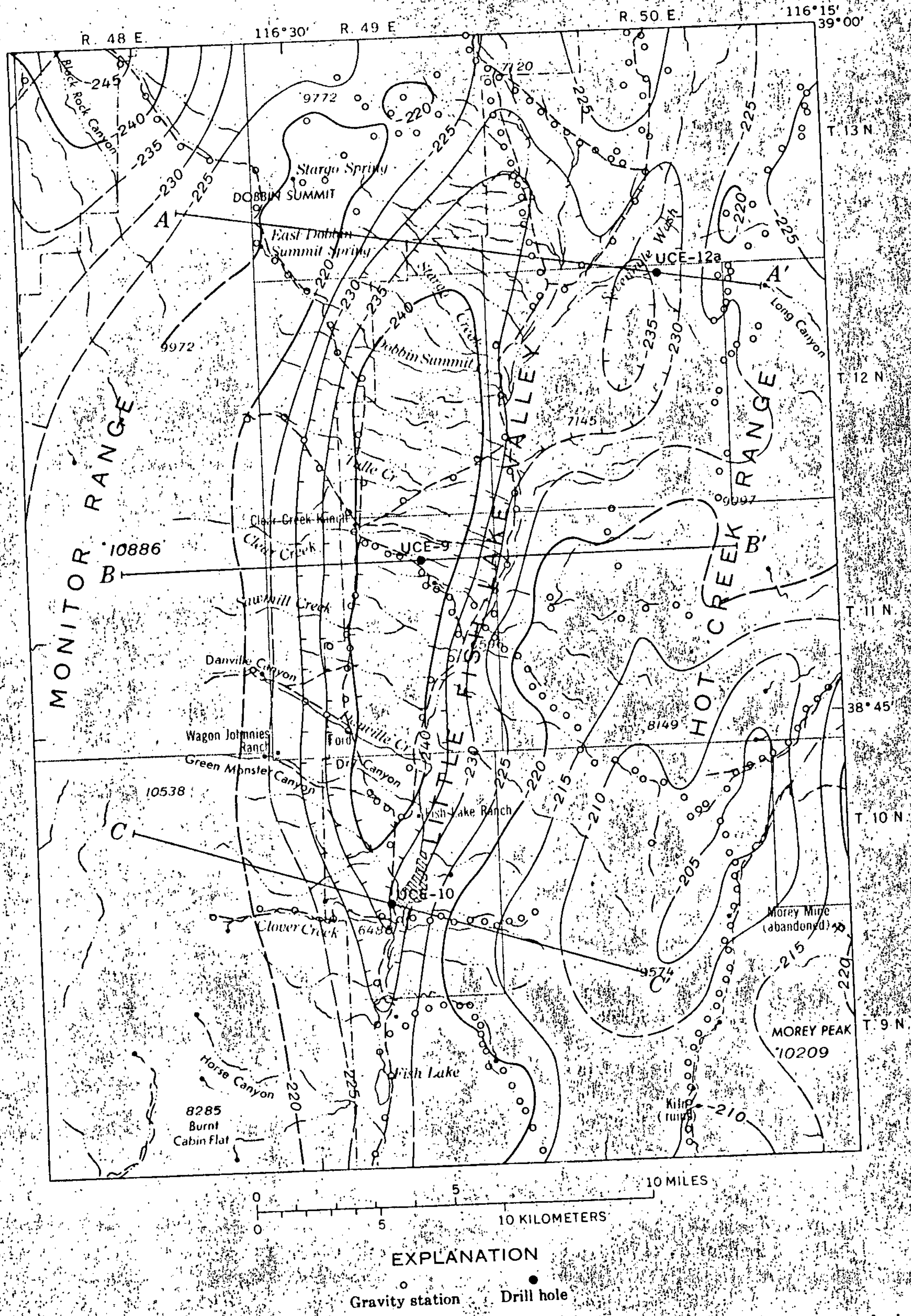


Figure 7.—Complete Bouguer gravity anomaly map of Little Fish Lake Valley area. Contours are dashed where approximately located; hachures indicate closed areas of lower gravity. Interval is 5 mGal. Contours by D. L. Healey. Base from U.S. Geological Survey, Tonopah 1:250,000 quadrangle, 1956–62.

That Paleozoic rocks directly underlie the valley fill in this area is confirmed by data from drill hole UCE-10, which bottomed in massive relatively unfractured dolomite of probable Devonian age at a depth of 903 m (2,963 ft) after cutting 810 m (2,660 ft) of valley-fill alluvium. The occurrence of valley-fill alluvium directly above Paleozoic strata in parts of the valley indicates that the valley is younger than the youngest ash-flow tuff, which was dated at about 23 m.y.

The data indicate that valley formation began in late Miocene or early Pliocene time, and it is inferred to have extended through Pliocene time. Late Miocene or early Pliocene valley formation is suggested by Gilluly and Masursky (1965) for valleys in the Cortez area to the north, by Noble, McKee, Smith, and Korringa (1970) for valleys in northwestern Nevada, by Ekren, Rogers, Anderson, and Orkild (1968) in the Nevada Test Site to the south-southeast, and by Anderson, Longwell, Armstrong, and Marvin (1972) and Anderson (1971a) for valleys in the Lake Mead area in the southern part of the Great Basin. We concur with Stewart (1971), who suggested that most basin-and-range structure in central Nevada is late Cenozoic in age and probably is younger than 17 m.y.

SUMMARY OF CENOZOIC EVENTS

Volcanism started in the Little Fish Lake Valley area in Oligocene time about 37 m.y. ago with the eruption of discontinuous piles of virtually aphyric rhyolite lava. Extensive sheets of intermediate lavas were then erupted north of a line that now corresponds to the Tulle Creek-Pritchards Station lineament, and we infer that this distribution conforms closely to the original distribution. Locally, eruption of the sheets was followed by tilting and erosion. About 33 m.y. ago eruption of ash-flow tuff started and it continued through about 23 m.y. ago. Some of these eruptions were from centers located marginal to Little Fish Lake Valley—the center closest to the valley is at Morey Peak. Left-lateral movement along the Tulle Creek-Pritchards Station lineament commenced after the deposition of the Bates Mountain Tuff (23 m.y. ago) but had ceased before the development of the Little Fish Lake Valley graben and the deposition of the earliest graben-filling sediments in late Miocene and early Pliocene time.

RELATIONSHIP OF LITTLE FISH LAKE VALLEY TO ORIGIN OF THE GREAT BASIN

An interrelationship must exist between the central location of Little Fish Lake Valley, the ancestral and present-day topographic and structural high, and the anticlinal symmetry of the Great Basin as reflected by range attitudes east and west of the valley. These features must be controlled by and must reflect the mechanism that gave rise to the basin-and-range province. The possibility that the central Great Basin was uplifted to form a north-trending anticline prior to block faulting seems remote for two reasons: (1) to establish a dip of even a few degrees on the flanks of the "anticline" would require an unrealistic central uplift of tens of thousands of meters, and such an uplift would have caused the erosion of much, if not all, of the volcanic strata along the axis of the uplift; and (2) the youngest ash flows found by drilling within the graben are also the youngest ash flows cropping out in broad areas on adjacent ranges. One fact seems inescapable, therefore: the block faulting and the east and west tilting of the ranges developed as a single process without an initial central uplift of large magnitude. The fact that Little Fish Lake Valley, however, remained relatively high until the graben actually formed and is topographically and structurally high today suggests that the central part of the Great Basin was constantly buoyed up during rifting of the province, possibly by the addition of new crustal material.

In Little Fish Lake Valley the rifting of the crust that gave rise to the present pattern of basins and ranges began several million years after the last ash-flow tuff was erupted, probably in late Miocene or early Pliocene time or about the same time inferred for basin-and-range development in other parts of the Great Basin. There apparently was no outward migration of basin-and-range faulting from a central area as suggested by Armstrong, Ekren, McKee, and Noble (1969). Certainly, no close time and space relationship exists between calc-alkaline ash-flow tuff volcanism in the central Great Basin and crustal rifting as expressed by the present pattern of basins and ranges. If, as postulated in this report, east-west magnetic lineaments were loci for strike-slip movements that predate the formation of grabens in the central Great Basin, then it is necessary to conclude that in parts of the Great Basin, transcurrent faulting has both preceded and developed concurrently with basin-and-range normal faulting (Shawe, 1965; Hamilton and Myers, 1966; Anderson, 1971a, b).

In the adjacent areas of the Great Basin the development of basins and ranges was accompanied by the eruption of rhyolite and basalt (McKee and Silberman, 1970; McKee, 1971). Christiansen and Lipman (1972) and Lipman, Prostka, and Christiansen (1972) related the inception of biomodal basalt-rhyolite volcanism and crustal extension with changes resulting from collision of the East Pacific Rise with a mid-Tertiary continental margin trench and the resulting direct contact of the American and eastern Pacific plates along a right-lateral transform fault system. McKee (1971) considered the possibility that the change in the type of volcanism noted above and the inception of basin-and-range faulting were caused by the East Pacific Rise reaching a position beneath the Great Basin 16 m.y. ago (see also Menard, 1964). Scholz, Barazangi, and Sbar (1971) postulated that the change was due to the termination of the early to middle Cenozoic west coast subduction zone about 25 m.y. ago, which released the compressive stress field and allowed extension to occur in the Great Basin. Whatever the reason for the development of the east-west zone of extension and the drastic change of volcanism that accompanied this development, any model of plate tectonics must take into account the mounting evidence that the basins and ranges began to form at virtually the same time throughout the Great Basin.

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