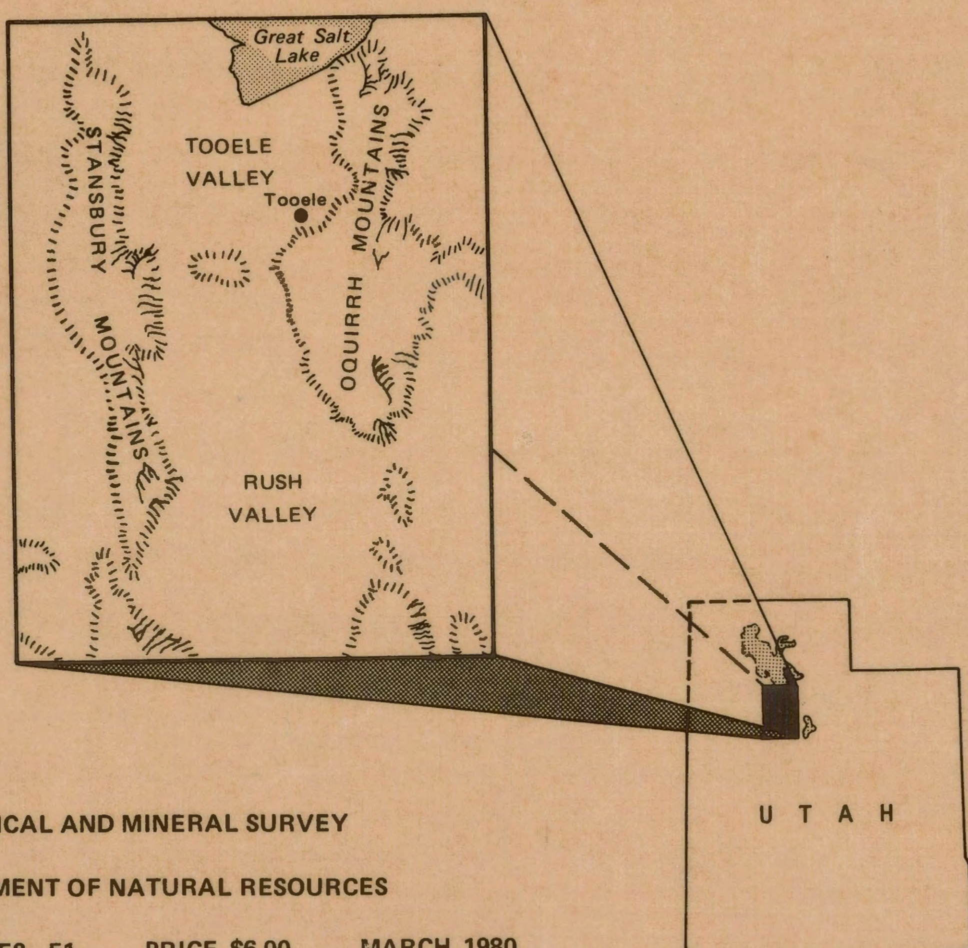
Geology for Assessment of Seismic Risk in the Tooele and Rush Valleys

Special Studies 51

GEOLOGY FOR ASSESSMENT OF SEISMIC RISK IN THE TOOELE AND RUSH VALLEYS TOOELE COUNTY, UTAH

by Benjamin L. Everitt and Bruce N. Kaliser



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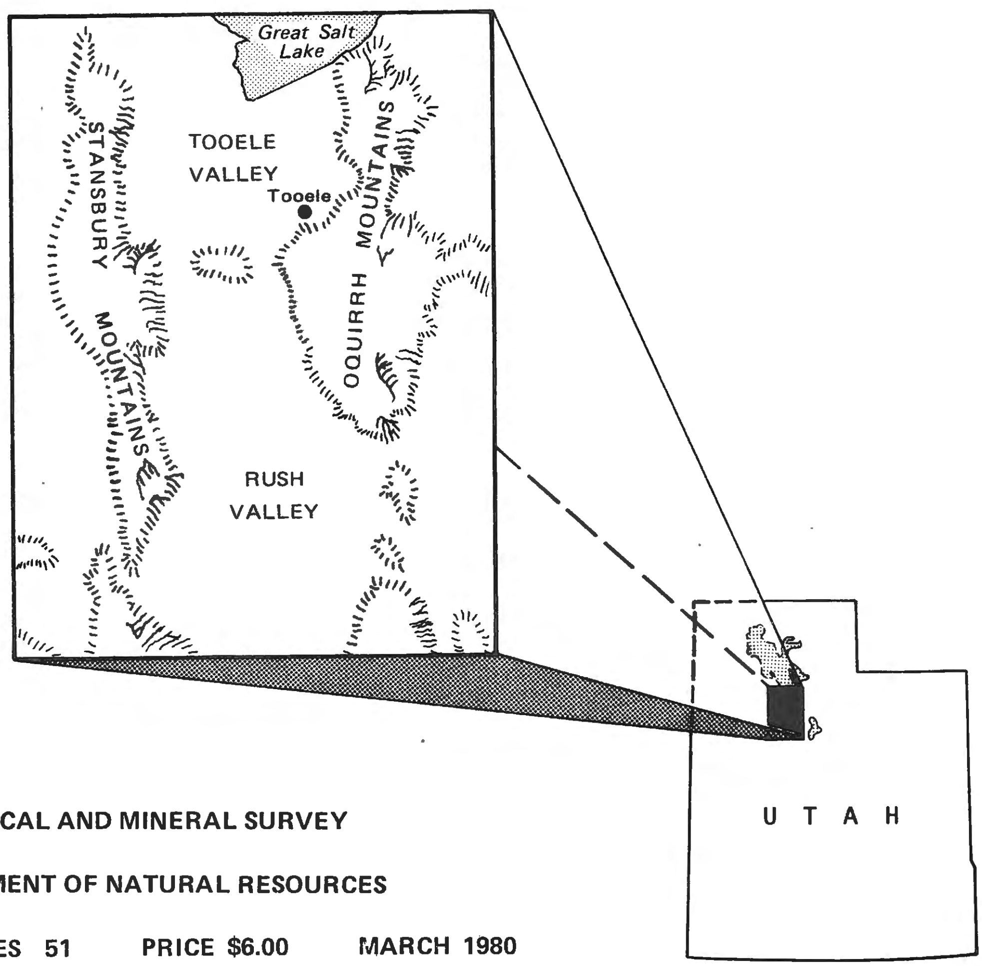

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GEOLOGY AND SEISMIC EVALUATION OF TOOELE AND RUSH VALLEYS, TOOELE COUNTY, UTAH

by
Benjamin L. Everitt[1]

INTRODUCTION

Acknowledgements

The assistance of the U. S. Geological Survey, the Utah Division of Oil Gas & Mining, the Utah Division of Water Rights, and the U. S. Army in furnishing data is acknowledged.

Dr. Don Mabey of the U. S. Geological Survey assisted with the interpretation of geophysical data. The U. S. Army permitted access to the Tooele Army Depot and provided a backhoe to assist in geologic investigations.

Purpose and Procedure

The Utah State Legislature had the foresight to direct in 1977 that the Utah Geological and Mineral Survey "assist local and state government agencies in their planning, zoning and building regulation functions by publishing maps delineating appropriately wide special earthquake risk areas." This work has been done in compliance with that mandate, and is the first of a series to provide the tectonic and geologic framework for seismic risk microzonation in the Tooele and Rush valleys, Tooele County, Utah.

The subject area borders on Utah's growing megalopolis, the Wasatch Front, which is expanding westward towards the Tooele County line from the Salt Lake City International Airport. With its groundwater and available private land resources, it is likely that Tooele County will be drawn into the industrialization of the Wasatch Front with significance far beyond the present dormitory community stage. In addition, a strategic military installation occupies a portion of the area at two important sites.

A review of pertinent previously published data for Tooele and Rush Valleys is provided, including information on geology, groundwater, and regional gravity, reflection seismic, and epicentral determinations. The surficial geology has been newly mapped at a scale of 1:50,000 to provide a basis for estimating ground acceleration, to identify potentially active faults, and to summarize the geomorphic history for the purpose of estimating the age of latest fault displacement. The mapping is based on aerial photography at a scale of 1:63,000, supplemented by 1:20,000 scale photography along the OBT fault zone. Trenching and shallow boring were conducted at a few sites on fault scarps to permit geomorphic interpretation of fault history.

Location

The Tooele and Rush valleys lie between the Oquirrh Mountains on the east and the Stansbury and Onaqui Mountains on the west, in Tooele County in the northwestern quadrant of Utah (figure 1). The Oquirrh and Stansbury Mountains (Plate I) have been known as a typical example of Basin and Range structure since Gilbert's (1890) study of Lake Bonneville. The West Mercur Fault, on the west side of the Oquirrh Mountains, was studied in detail by Gilluly (1928), who related surface fault scarps to exposures of fault planes in subsurface mine workings.

Topographic Setting

Tooele Valley, to the north, and Rush Valley, to the south, are the topographic expression of a northward plunging structural basin, oriented north-south. On either side of the valleys, mountain ranges also trend roughly north-south (Plate I). On the west, Deseret Peak in the Stansbury Mountains rises more than 11,000 feet above sea level, while 20 miles to the east Lowe Peak in the Oquirrh Mountains rises above 10,000 feet. The two valleys are separated by South Mountain.

Both valleys are relatively flat and floored with Lake Bonneville sediments. Rush Valley, the southern portion of the basin, slopes gently down to the north to a depression at an elevation of 5,000 feet (Rush Lake). Drainage probably continued northward to Tooele Valley at one time (Gilluly, 1929), but is now blocked by a bay-mouth bar built between South Mountain and the Oquirrh Mountains by Pleistocene Lake Bonneville. Tooele Valley slopes down to the north to 4,200 feet at the shore of Great Salt Lake.

Both valleys are ringed with coalescing alluvial fans (bajadas). The bajadas of Tooele Valley have been greatly modified by shoreline erosion of Pleistocene Lake Bonneville and possible earlier lakes, but relatively little modification has taken place in Rush Valley.

[1] UGMS Staff Geologist, Urban and Engineering Geology Section

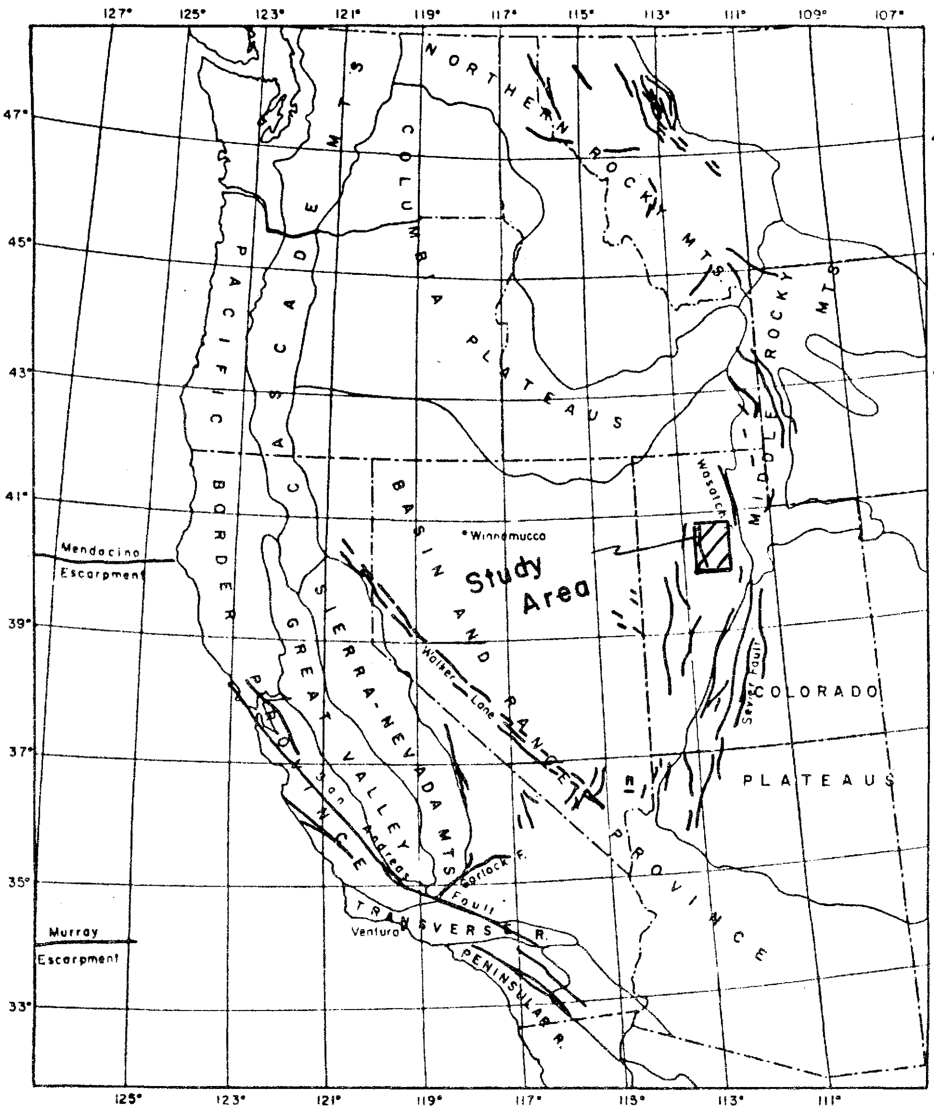


Figure 1. Location of the study area in relation to physiographic provinces and tectonic features of the western United States, *from* D. B. Slemmons, 1967, figure 1, Journal of Geosciences, Osaka City University.

Earthquake History

Although there are many relatively fresh fault scarps in the area suggesting late Quaternary displacement, historic seismic activity has been light since settlement in 1864 and there has been no reported surface movement associated with historic earthquakes. However, continuously recorded micro-earthquakes are evidence that this is still a tectonically active area. The published earthquake epicenters which plot within the area bounded by the parallels of 40°00′ and 40°45′ north latitude and the meridians of 112°00′ and 112°45′ west longitude are shown in Plate I, along with Quaternary fault scarps. There is no very obvious correlation between epicentral locations and potentially active faults. There are two clusters of epicenters of "micro-earthquakes" in Tooele Valley. These are all non-felt instrument-recorded events of less than magnitude 3. One cluster surrounds the limestone quarries at Flux, northwest of Grantsville, and may reflect quarry blasting, and the other, south of Grantsville, apparently reflects the position of the Tooele Army Depot munitions disposal area. The only other significantly active area seems to be in the vicinity of Magna, east of the subject area in Salt Lake Valley, and the site of the 1962 tremor of Richter magnitude 5.2.

There have been two historic earthquakes of Modified Mercalli Intensity V or greater immediately adjacent to the subject area: the Magna earthquake of September 5, 1962, and a shock of August 11, 1915 in the Stansbury Mountains whose epicentral intensity has been variously estimated from V to VIII (Plate I). Cook and Smith (1967, p. 712) list four earthquakes near the town of St. John, in northern Rush Valley (not plotted on Plate I) on December 1 and 2, 1958, two of which had an epicentral intensity of V, and one of which was damaging. In the 1979 revision of the data, however, Richins (1979, p. 142) locates these epicenters 50 miles southeast in the vicinity of Nephi.

Table 1 lists all earthquakes which might have affected the Tooele or Rush valleys. These events were checked for comment in the various newspapers of Tooele, the only publications within the area at the dates involved. Most events were not mentioned, indicating they were not felt at a level greater than about intensity II. The 1962 Magna earthquake (epicentral intensity VI) was reported as felt, but doing no damage. Damage was reported for only one earthquake, the intensity IX shock of 1934, which was centered near Kosmo, on the north shore of Great Salt Lake opposite to and 80 miles north of Tooele Valley. Although newspaper accounts report no damage in Tooele and only slight damage in Grantsville, Neumann's (1936, p. 14) isoseismal map shows an intensity of V-VI for the Tooele Valley, and he states that groceries were thrown from shelves and one window was broken in Tooele (op. cit., p. 16). Neumann shows an intensity of IV-V in Rush Valley, but there are no records of damage.

GEOLOGY

Tectonic Setting

The study area lies near the eastern edge of the Basin and Range structural province, just west of the Wasatch Range (figure 1). The region is characterized by fault-block mountain ranges and intervening sedimentary basins. In eastern Tooele County the crest lines of the mountain ranges trend north-south, roughly parallel to the front of the Wasatch Range which forms the eastern margin of the province. The coarser geologic fabric trends north-northwest, however, as indicated by regional gravity data (Cook and Berg, 1961; Johnson and Cook, 1957; Cook and others, 1975), parallel to most of the Quaternary range bounding normal faults, and parallel to the folds of the Oquirrh Range (Plate II, geology of Tooele and Rush valleys).

Origin of Basin and Range Structure

Two theories to explain the Basin and Range structure are currently in vogue (Rowley and others, 1978): "Simple Extension" and "Megashear".

Simple extension, dating from early studies by Gilbert (1890, 1928) views the normal faulting as a breakup of the earth's crust into tilted blocks due to east-west extension as the Sierra Nevada Range migrates westward away from the Wasatch Range. A regional rate of extension of 1 foot per century has been proposed (Berg and others, 1960, p. 532). The study area probably lies in the eastward extension of Basin and Range deformation field no. 1 of Wright (1977, p. 493) characterized by maximum principal stress oriented vertically, and minimum principal stress oriented east-west, explaining what appears to be the dominant mode of block faulting by pairs of normal faults oriented north-south (figure 2).

This dominant stress pattern is also suggested by fault plane solutions for microearthquakes along nearby portions of the Wasatch Front (Arabasz and others, 1979, p. 279), although no data are yet available for the study area.

Slemmons (1967, figure 8), favors the "megashear" hypothesis in western Utah and suggests that the Basin and Range structures are caused by pairs of strike-slip faults in northwestern Utah, active in Pliocene and Pleistocene time, indicating the possible influence of north-south compressional stress.

Age of Deformation

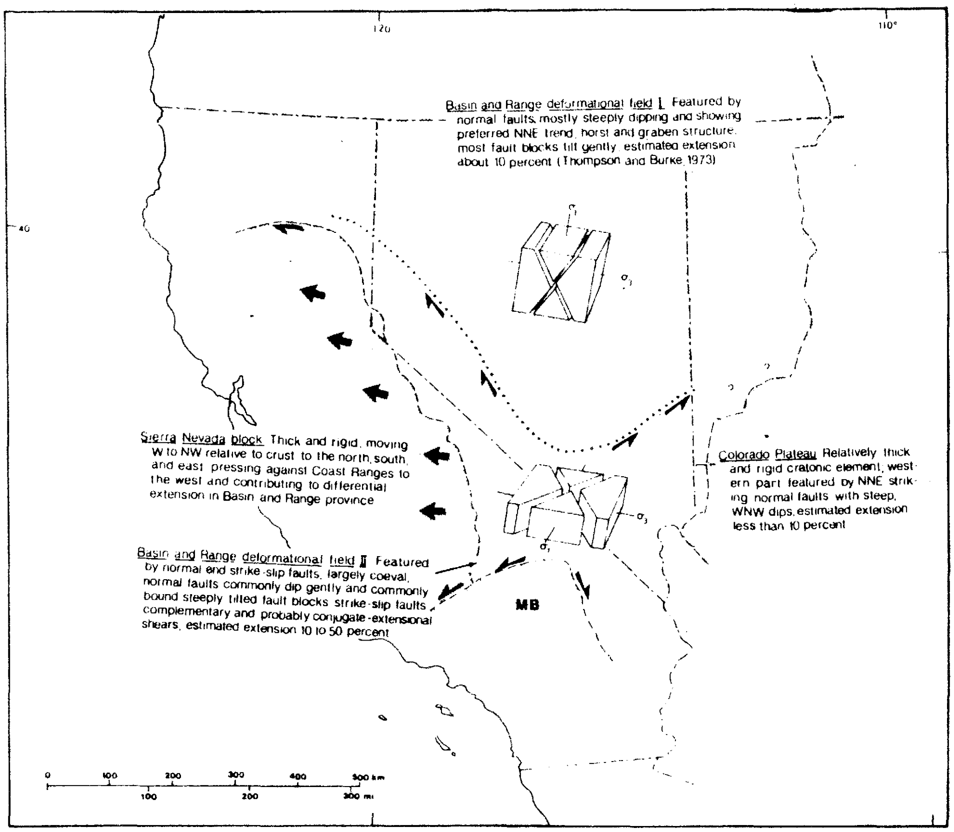
The Basin and Range structural deformation is believed to have started in Oliogocene time (Rowley and others, 1978; Wright, 1977), although the main phase of the Basin and Range normal faulting began in the Miocene (Rowley and others, 1978; Gilluly, 1967). Some evidence exists for normal faulting as early as Cretaceous (Loring, 1976). Rigby (1958) believes Basin and Range normal faulting began in the Stansbury Mountains in the Paleocene. Rigby's history of the development of the Stansbury Mountains is reproduced in figure 3, and gives a good example of this style of deformation.

Many normal faults within the Oquirrh Mountains are mineralized, indicating they are pre-mineral and therefore of pre-Eocene age (Gilluly, 1932, p. 82). They may not have originated as normal faults, but assumed

TABLE 1. CHECK LIST OF EARTHQUAKES
Which May Have Affected the Tooele & Rush Valleys

Date	Local Time	Epicentral Location	Epicentral Intensity(MM)	Felt Area, Sq.Mi.	Description
8-01-00	00-45	Eureka	VII	<1,000	Slight damage in epicentral area (Deseret News)
10-05-09	19-50	Hansel Valley	VII	30,000	Buildings out of plumb at Saltair; waves washed over Lucin Cutoff (Deseret News) no mention (Tooele Transcript-Bulletin)
5-22-10	07-28	Salt Lake City	VII	<1,000	"Salt Lake rocked by earthquake" -- no mention of local effect (Tooele Transcript Bulletin).
8-11-15	03-20	Stansbury Range	V	<1,000	No mention (Tooele Transcript-Bulletin).
10-02-15	23-56	Pleasant Valley, Nev.	X	30,000	"Earthquake in Nevada" - - no mention of local effect (Tooele Transcript-Bulletin).
3-12-34	08-06	Kosmo	IX	170,000	No mention of Tooele, slight damage in Grantsville (Tooele Transcript-Bulletin,3/16/34); intensity V with slight damage in Tooele(Neumann, 1936)
11-18-37	09-50	Lucin	VI	<1,000	Not mentioned in Tooele Transcript-Bulletin
6-30-38	06-37	Magna	V	<1,000	No mention, Tooele Transcript-Bulletin
12-01-58	13-51 &20-23	Clover ? (Probably Nephi)	V	<1,000	No mention, Tooele Transcript or Bulletin
9-05-62	09-04	Magna	VI	<1,000	"Another quake shakes ---" felt locally but no damage (Toole Transcript); no mention (Tooele Bulletin).
9-23-67		Magna	V	<1,000	No mention, Tooele Transcript
3-27-75	08-31	Pocatello Valley	VII		No mention (Tooele Transcript or Bulletin)

SOURCES: Rogers and others, 1976; Richins, 1979; Williams and Tapper, 1953; Neumann, 1936; Deseret News; Tooele Transcript and Tooele Bulletin and their successors.



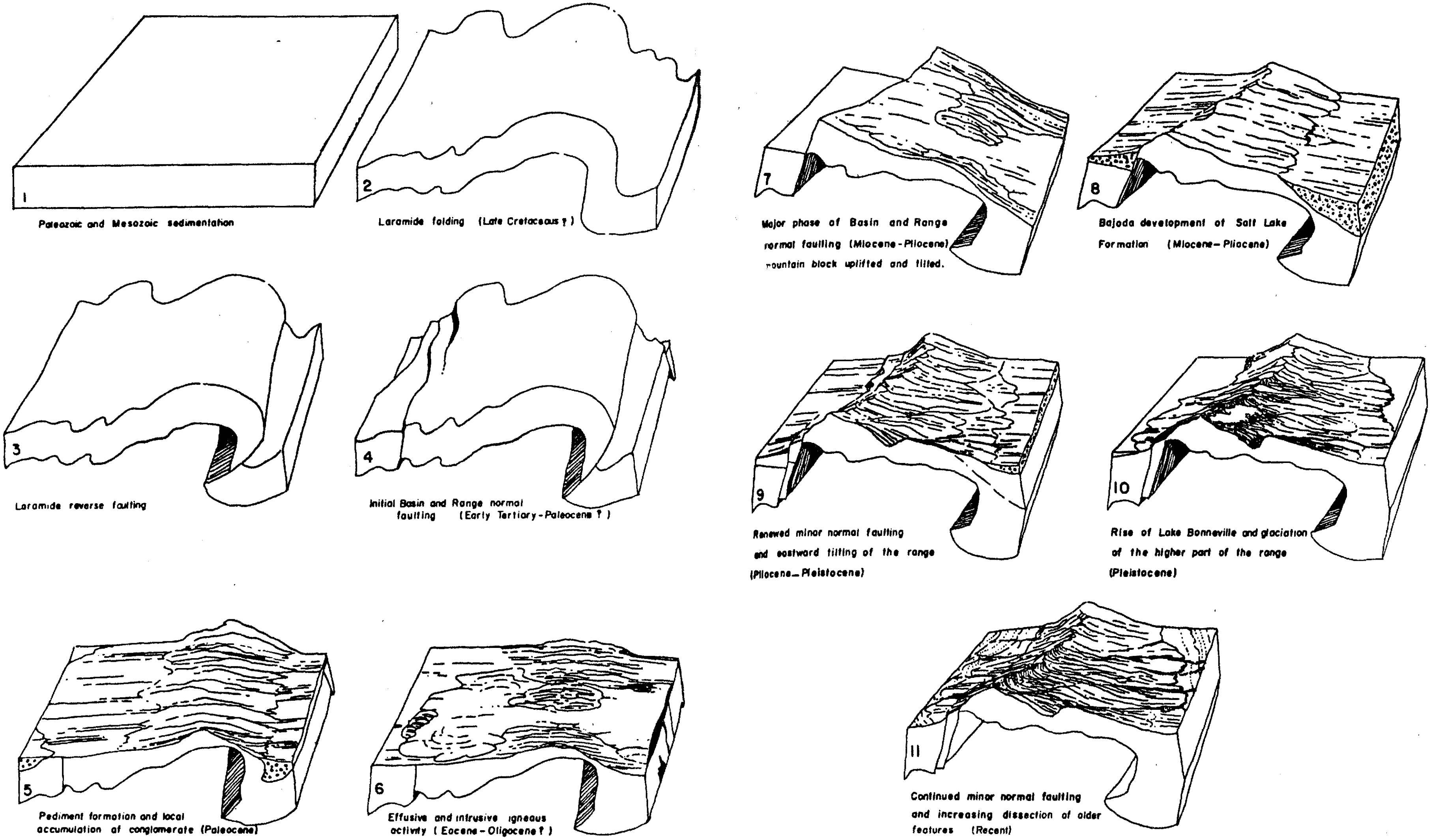
Idealized block diagrams in each field show suggested principal stress orientations; σ_1, maximum principal stress; σ_3, minimum principal stress; MB, Mojave block.

Figure 2. Tectonic model of the Great Basin, *from* Wright, 1977, figure 2, *Geology*, v. 4, p. 491.

that role later. Dip-slip motion continued well past the time of mineralization (Gilluly, op. cit.).

Progressive eastward tilting of the Oquirrh and Stansbury mountain ranges has been inferred from several kinds of evidence: (1) The most active normal faults have been found on the west margins of the Stansbury, Oquirrh, and Wasatch Ranges, each with downthrow on the west (Gilbert, 1928; and Gilluly, 1928, p. 1127). (2) Remnants of old erosion surfaces appear to slope eastward in the Wasatch Mountains (Eardley, 1933) and in the Oquirrh Mountains (Gilluly, 1928). (3) Progressively older terraces and bajada remnants along South Willow Creek in the Stansbury Range show a greater eastward tilt (Rigby, 1958, p. 100).

Available data indicates continued uplift of mountain blocks and subsidence of the basins during the Quaternary epoch. As will be shown in the section on potentially active faults, range front scarps indicate offsets of as much as 200 feet in Quaternary alluvium. In addition, geomorphic evidence suggests a possible regional northward tilting of the study area during the Quaternary. The rocks of the Tertiary Salt Lake Group crop out in many places in the southern part of Rush Valley, and in a few places in the northern part, but are encountered only in the subsurface in Tooele Valley. In southern Rush Valley gravel capped pediments on the Salt Lake Group slope northward at gradients greater than those of the present drainages, and are cut by drainages up to fifty feet deep, indicating that uplift and erosion have dominated in southern Rush Valley during the Quaternary, at the same time that sedimentation has dominated in northern Rush and Tooele Valleys.



Mesozoic and Early Cenozoic structural history

Late Cenozoic structural and geomorphic history

Figure 3. Structural and geomorphic history of the Stansbury Mountains, *from* Rigby, 1958, figures 15 & 16.

Isostatic Rebound

Superimposed upon the Cenozoic Great Basin tectonic deformation is the more recent gentle warping due to the isostatic response of the Bonneville Lake Basin after the disappearance of the lake (Gilbert, 1890). The center of the basin is believed to have risen more than 200 feet since the last high-stand of Lake Bonneville (Crittenden, 1963, p. 8). Uplift in the study area is estimated to have been from 200 feet at the northern end of the Stansbury Mountains to 100 feet in the southern end of Rush Valley (Crittenden, op. cit., p. 9). This has created a southeastward tilting on the order of 3 feet per mile.

Cenozoic Geology

Basin Fill

The two intermontaine basins of the study area are partly filled with moderately consolidated to unconsolidated layers of sand, gravel, silt, and clay of Neogene age, derived from the adjacent mountains. These were deposited by a combination of alluvial processes, which dominated around the basin margins, and lacustrine processes, which dominated toward the centers of the basins (Plate III). Sediment is coarse near the mountain fronts and finer basinward. Beds of alluvial gravel thinning basinward and pinching out between beds of silt and clay are common and contain the artesian groundwater in the basins (Gates, 1965).

The basin fill is traditionally separated into two ages. The older sequence of moderately consolidated sands, gravels, silts and clays is named the Salt Lake Group and assigned an age of upper Tertiary. It outcrops extensively in the southern part of Rush Valley and is encountered at depth in Tooele Valley. It is characterized by considerable deformation, with dips locally to 60°, and an abundance of volcanic ash. In the center of Rush Valley it crops out as interbedded calcareous tuff, tuffaceous limestone, siltstone, sandstone, and conglomerate. A measured section from Heylmun (1965, figure 4) is reproduced here as figure 4. Around the basin margins along Boulter Creek in southern Rush Valley, or in Fivemile Pass, for example, are outcrops of coarse conglomerate in a matrix of brown or red clay, in many places interbedded with tuffaceous deposits.

At the mouth of Bates Canyon, in eastern Tooele Valley, an outcrop of faulted and tilted lime-cemented conglomerate is probably also of upper Tertiary age.

Unconformably overlying the Salt Lake Group are relatively undeformed deposits of mostly unconsolidated sand, gravel, silt, and clay, assigned to the Quaternary system.

Fossiliferous beds are rare in the Cenozoic deposits, and dating therefore has been difficult. The volcanic ashes of the Tertiary deposits are susceptible of chemical correlation (Smith & Nash, 1976), and some progress is being made in defining the upper Tertiary in northwestern Utah by using this technique. For most purposes, however, the boundary between the Tertiary and Quaternary is defined on the basis of the abundance of volcanic debris, degree of induration, and degree of deformation of the sediments, characteristics which seldom appear in driller's logs of water wells. In the basin centers, where most water wells are drilled, the boundary appears to be gradational. It is difficult to determine precisely from either cutting samples or geophysical logs.

Tooele Valley

Sufficient data now exist to permit an assessment of the thickness of the basin fill in the valleys, and to reveal the irregular shape of the basins (figure 5, pocket). Gravity anomalies (Johnson, 1958) indicate that the basin is probably not a single downfaulted graben between the bordering Oquirrh and Stansbury Mountain ranges, but is probably a complex collection of troughs and ridges. This assessment is confirmed by the patterns of strata encountered in deep wells, of which there are a number in various parts of the valley (Plate IIIa, and Plate IV). Across the northern end of the valley (Plate IV), the Paleozoic rock which outcrops in the Oquirrh Mountains is overlain by 1200 feet of basin fill a mile west of the mountain front at USGS borehole No. 5. One and a half miles farther west, drill hole (C-2-4) 3ccc-1 encountered bedrock at 290 feet, and hole (C-2-4) cda-1, another mile southwest, encountered rock at 668 feet. Three miles farther west, the abandoned oil test Hickey No. 1 Cassity encountered the Paleozoic at 4830 feet, and less than a mile farther west, Walker-Wilson No. 1 penetrated 7100 feet of basin fill without reaching bedrock (Heylmun, 1965, p. 29). The steep dropoff in the basin floor between these two wells correlates roughly with an inflection point in Johnson's (1958, figure 2) gravity profile, and was used by him to infer the position of a normal fault. The existence of a fault at this location is reinforced by the presence of shallow grabens and other surface features of probable tectonic origin (Plate III-a, site 216).

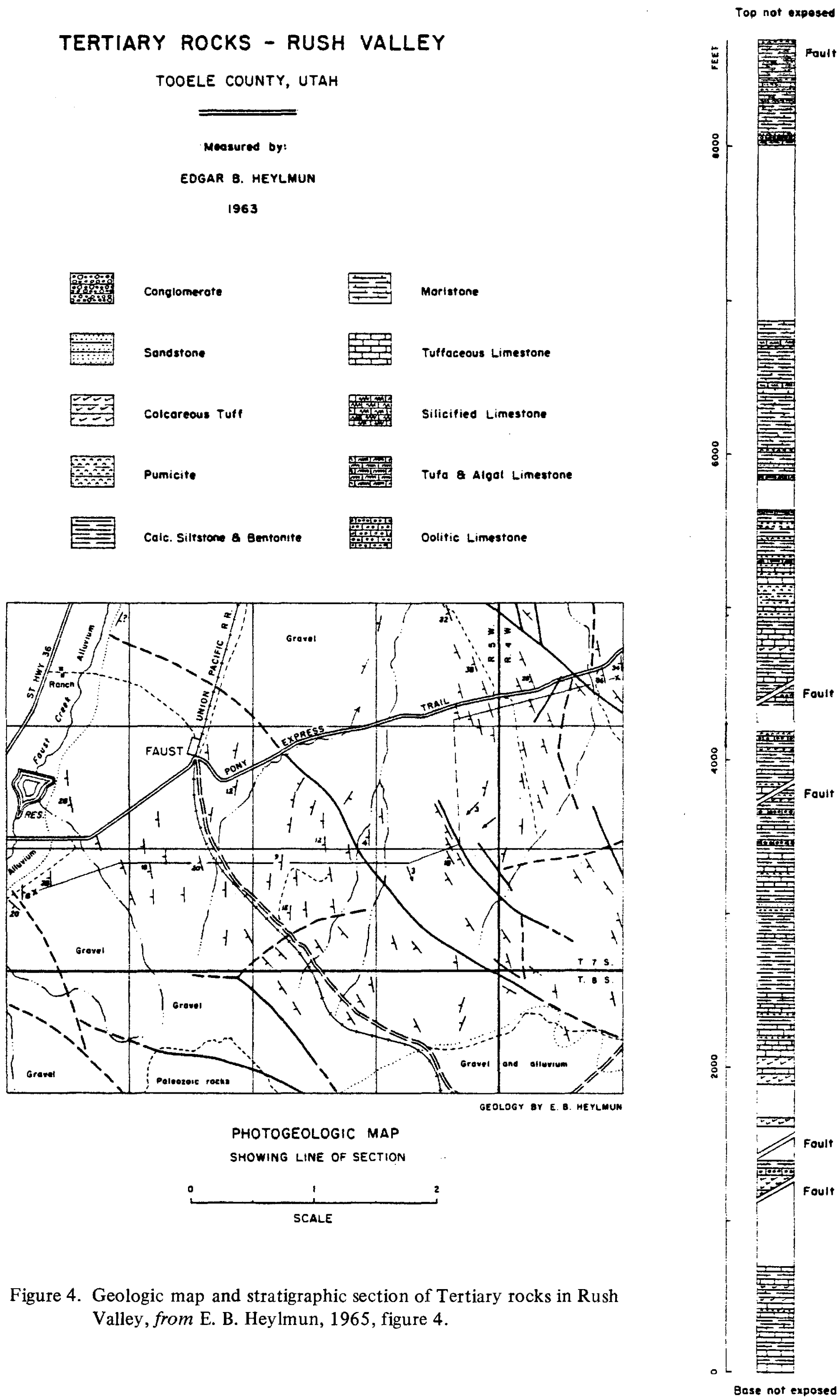


Figure 4. Geologic map and stratigraphic section of Tertiary rocks in Rush Valley, *from* E. B. Heylmun, 1965, figure 4.

Three miles south of the Hickey-Cassity hole, USGS No. 1 penetrated 1500 feet of unconsolidated basin fill, and in Grantsville, 4½ miles west of USGS No. 1, USGS No. 6 also penetrated 1500 feet of basin fill, but encountered thin beds of moderately consolidated tuff of the Tertiary Salt Lake Group at a depth of 728 feet. An analysis of pollen content gives an age of lower Pliocene (Earl Peterson, Amoco, personal communication, 9-25-79). Two miles NNW of Grantsville a 1948 oil test struck Paleozoic rock at 1655 feet (Cohenour, 1963).

Two miles south of Grantsville, USGS hole No. 7 penetrated 1500 feet through basin fill, and 1 and 3 miles farther south, wells on the Tooele Army depot went to 500 and 780 feet, respectively, without finding bedrock. Four to five miles west of this north-south line of holes Paleozoic rock crops out at the base of the Stansbury Mountains.

Rush Valley

Rush Valley is similar to Tooele Valley in being composed of a number of smaller horsts and grabens. Potentially active faults both down-to-the-west and down-to-the-east are found throughout the basin (Plates III-b, III-c). The depth of basin fill is less well known, due to the smaller number of deep wells. Only recently has mineral exploration begun to provide data at depth, and most of this is not yet publicly available.

The basin fill in Rush Valley is mostly of Tertiary age. Quaternary deposits in the center of the southern part of the valley form thin gravel caps on pediments eroded on Salt Lake Group rocks, and only around the basin margins are Quaternary alluvial fans greater than 50 feet in thickness (Plate V; figure 6). In northern Rush Valley only two exposures of Salt Lake Group rocks were observed: Site 425, 2½ miles NNW of the Morgan Ranch Warm Spring (see Plate III-b for site locations), where white tuffaceous sediments appear in an abandoned and eroded road cut; and, at site 515 on the south unit of the Tooele Army Depot, where a trench excavated across a fault scarp encountered moderately consolidated white tuff within 5 feet of the surface on the upthrown side (see discussion of Mid-Valley Horst below). Many driller's logs for water wells throughout the valley mention "white clay" which suggests that the Salt Lake Group sediments are close to the surface in most of the basin. This lends support to Gilluly's (1929, p. 678) suggestion that Rush Valley has drained northward into Tooele Valley during a substantial part of the Quaternary, carrying most finer-grained Quaternary sediment out of the basin.

Surficial Geology

Introduction

The surficial geology of the study area is presented in Plate III, in three parts, a, b, and c, at a scale of 1:50,000. The map is designed to present an information base for general land use planning and for site evaluation in terms of seismic hazard. The mapping units are based on three criteria:

1) to show surficial geology to a depth of 20 or 30 feet and to provide generalized soil characteristics important to foundation and site studies;
2) to show the geomorphic features of the area for interpretation of seismic pre-history; and
3) to devise a classification of geologic and geomorphic units easily mappable on the available inch-to-the-mile aerial photography without undue recourse to subsurface investigations and laboratory testing of samples.

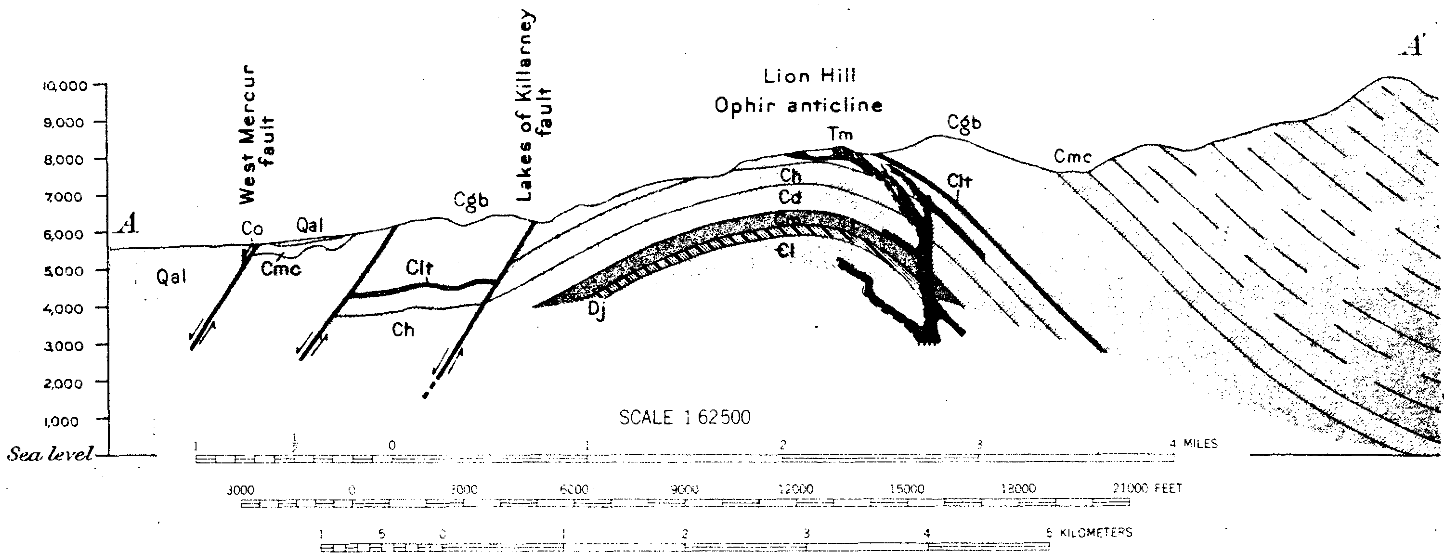
All faults with known Quaternary offset have been shown. All faults shown in Quaternary sediments and surfaces may be taken as potentially active faults, since, of those investigated in detail, none have been proven not to have been active in post-Bonneville time. For supplimentary information, the location of wells which provide important subsurface information, and the contours of the piezometric surface as mapped by several groundwater reports of the Utah Division of Water Rights, are shown in figure 5 (pocket). The piezometric surface may be used with due caution to approximate the elevation of the water table in the study area.

The surficial geology map (Plate III) treats only the basins, and does not extend into the areas of bedrock outcrop. It contains no information about the relative activity of faults or fault zones within the mountain blocks. Generalized geology of the areas of bedrock outcrop is provided in Plate II at a scale of 1:250,000.

Tooele Valley

Tooele Valley is characterized by gravelly bajadas sloping toward and grading to a sandy and silty valley bottom. The steeper slopes on coarse-grained alluvium have a relatively deep water table. The valley floor, however, is characterized by deep unconsolidated

A–A': Cross section from the mouth of Ophir Canyon to Lewiston Peak
from Gilluly, 1932, Plate 12



B–B': Geologic cross section of Ophir Creek alluvial fan
from the bottom of Rush Valley to the mouth of Ophir Canyon

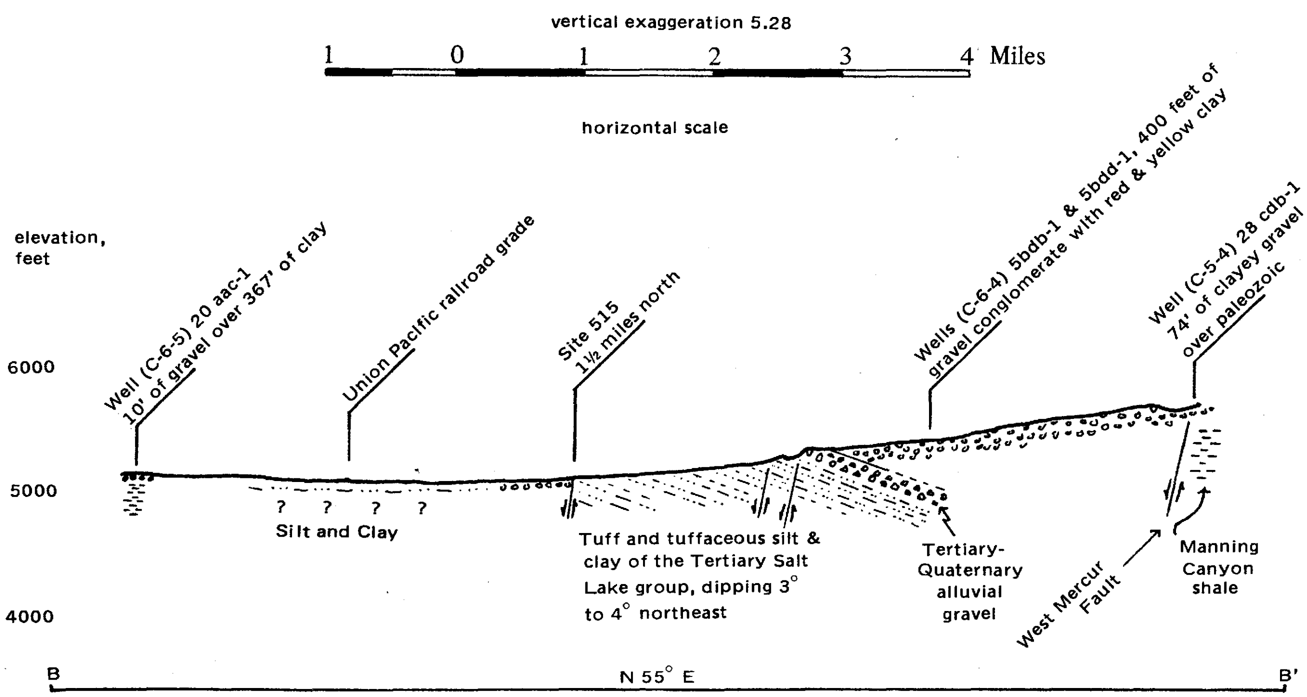


Figure 6. Geologic cross sections of northern Rush Valley, (see Plate III-b for location).

deposits of fine-grained sediments, with a high water table and high artesian pore pressure in confined aquifers (figure 5).

Rush Valley

Like Tooele Valley, Rush Valley is ringed by coarse-grained alluvial deposits with a deep water table. In the southern part, the valley bottom is characterized by erosional surfaces or pediments on the semi-consolidated late Tertiary deposits and in the northern part has only thin patches of fine-grained unconsolidated sediment over the Tertiary. High water table is present only along the narrow flood plains and in the central playa (figure 5).

Deformation of Lake Bonneville Shorelines in Rush Valley

In the southern Oquirrh Mountains in northern Rush Valley, scarps in old alluvial fans associated with mineralized faults in bedrock extend southward from just north of the mouth of Ophir Creek Canyon to the mouth of Mercur Canyon (Plate I and III–b). Short, discontinuous west-facing scarps in Quaternary alluvium are also found to the south adjacent to the southern Oquirrh Mountains, the Thorpe Hills, Topliff Hill, and the northern end of Boulter Mountain. Scarps cross strandlines of Pleistocene Lake Bonneville in two places, site 531, T. 9 S., R. 4 W., Sec. 1, and site 1106, T. 8 S., R. 3 W., Sec. 8 (Plates III-b and III-c).

In Rush Valley the highest, or "5200 foot", shoreline of Lake Bonneville drops in elevation southward from 5220 feet north of St. John Station (Plate III-b) to about 5175 feet near Tenmile Pass (Plate III-c). This drop has been interpreted as due to isostatic rebound of the lake basin, following lake recession, but the southward slope of the shoreline is not uniform, and the changes in elevation may occur in steps where the shoreline trace crosses faults. This suggests that these faults have been active in post-Bonneville time, and that the deformation of the shoreline is due to more than simple doming of the basin due to isostatic rebound. However, the multiplicity of shorelines and the inaccuracies inherent in uncontrolled photogeologic mapping make precise determination of the amount of deformation impossible without detailed field study with vertical control surveys.

Just south of St. John Station, on the eastern side of Rush Valley, there are shorelines at 5220, 5210, 5150, 5130, 5110, and 5050 feet. The 5220 foot shoreline also appears on the western side of the valley (Plate III-b). These shorelines occur in a highly faulted area, and some may represent displaced sections of a single shoreline. Farther south, on and south of the south unit of the Tooele Army depot, in the broad flat which flanks the Oquirrh Range, the highest and only visible shoreline is at 5190 feet, and may represent a downfaulted segment of either the 5220 or 5210 foot shoreline. The highest of these shorelines may be traced southward for about ten miles, varying in elevation from 5175 to 5200 feet. It terminates abruptly at a fault scarp at site 1106 (Plate III c, T. 8 3., R. 3 W., Sec. 8). South of this scarp are remnants of spits and bars at an elevation of 5160 to 5165 feet, which may or may not be equivalent in age.

POTENTIALLY ACTIVE FAULTS

Introduction

Ten fault zones identified within or adjacent to the study area show evidence of Quaternary surface faulting (table 2 and Plate I). These are: (in the order described below):

1) Northern Oquirrh-Boulter-Tintic (OBT) fault zone (West Mercur Fault)
2) Southern Oquirrh-Boulter-Tintic (OBT) fault zone
3) Mid-Valley Horst
4) South Mountain marginal fault
5) Vernon Hills marginal faults
6) Sheeprock marginal fault
7) Onaqui east marginal fault
8) Oquirrh marginal fault
9) Sixmile Creek fault
10) Stansbury west marginal fault.

Evidence of post Lake Bonneville displacement has been confirmed for three of these: the OBT fault zones, the Oquirrh marginal fault, and the Sixmile Creek fault. All are apparently Basin and Range normal faults, and most of the individual faults strike NNE to NNW and dip to the west or east at a high angle.

Northern OBT Fault Zone

The largest identified zone of faulting bounds the western front of the East Tintic, Boulter, and southern Oquirrh Mountains, and has been called the Oquirrh-Boulter-Tintic (OBT) fault zone by Cook & Berg (1961), who identified it by a continuous 60 miles-long gravity

TABLE 2 COMPILATION OF QUATERNARY FAULTS

Fault Zone	Location	Strike of Scarp	Max. Width (feet)	Length (miles)	Max. Scarp Lngth (feet)	Repres. Scarp Height (h) in ft.	Repres. Scarp Angles (a)	Notes	Relative Slope Retreat Age: (logh)/a[3]	Estimated age of Latest Offset[1]	Sum of Scarp Lengths (miles)
Tooele Valley, Plate 3a											
Oquirrh Mtn Marginal Middle Canyon to Pine Canyon		N-S to N80°E	3000	4	2460	200-300	25-30°	gravel(est)	0.08-0.09	(Holocene)	3.5
Pine Canyon to Lake Point		N50°W to N80°E	4000	6	5250	15	20°	gravel(est)	0.06	Post-Provo	3.5
Six Mile Creek	T2S,R5W, Secs 13, 14, 23 & 24	N30°E	3000	3½	1640	4	5°	site 216, sand	0.12	Holocene	2.0 = 9.0
Northern Rush Valley, Plate 3b											
South Mtn Marginal	T4S,R6W, Secs 13 & 24	N20°W	1000	2	1310	100	15°	50' gravel on qtzt pediment	0.13	(Pleistocene)	0.8
Mid-Valley Horst, Western Margin	St. John Station to Tooele Ord. Depot	N20°W	5000	4	9350	2	2°	site 705, sand	0.15	Post-Bonneville[2]	5.3
Eastern Margin	Tooele Ord. Depot T5S,R5W,Sec 25 to T6S,R4W, Sec 18	N10°W	1000	5	1800	---	---	--------------	-------	Post-Bonneville[2]	1.3
Northern OBT	Ophir Canyon to Pony Express Rd.	N20°W to N-S	5000-10,000	9	4590	40 40 5½ 2	25° 20° 7½° 4½°	gravel rock site 531, gravel site 531, gravel	0.06 0.08 0.10 0.07	(Post-Bonneville) (Post-Bonneville) Post-Bonneville[2] Post-Bonneville[2]	5.4
Onaqui East Marginal Fault	Near & South of Clover	N30°W	5000	3	2300	20	10°	gravel	0.13	(Pleistocene)	1.9 = 14.7
Southern Rush Valley, Plate 3c											
Onaqui East Marginal Fault	T7S,R5W,Secs 7-31	N-S	12,000	4½	2460	10	5°	gravel	0.20	(Pleistocene)	3.4
Southern OBT	Pony Express Road to 40th Parallel	N30°W to N40°E	15,000	20	3610	4½ 22	5° 14°	site 1106, below the beach site 1106, above the beach	0.13 0.10	Post-Bonneville[2]	6.5
Vernon Hills Marginal Faults	T8S,R5W,Secs 4, 9, 10, 12-36	N20°W to N25°W	3000	4	1310	---	---	--------------	-------	(Pleistocene)	3.5
Sheeprock Range Marginal Fault	Government Creek to Bennion Creek	N55°W to N30°E	2000	8½	2950	50 30	20° 15°	gravel gravel	0.08 0.10	(Holocene)	5.4 = 18.8
Skull Valley Stansbury Range West Marginal Fault	Timpie to Deadman Canyon	N30°W to N30°E	5000	25	----	25-80	20-25°	gravel	0.07-0.08	(Holocene)	----
										TOTAL	42.5

[1]Brackets indicate age estimated from scarp morphology only; measurements of the beach cliff of the 5200' shoreline yielded slope-retreat ages of 0.06-0.11

[2]Because Rush Valley is a small, shallow depression, isolated from the main part of the Lake Bonneville basin by the bay-mouth bar at Stocton, there is yet no proof that the 5200' shoreline in Rush Valley represents the same event, or is the same age, as the Bonneville shoreline in Tooele Valley. A Bonneville age is probable, however, and is assumed for the purposes of this report.

[3]After Bucknam and Anderson, 1979

gradient of 10 milligals per mile (Plate I).

Early Studies

In his early study of the mines in Mercur and Ophir Canyons, Spurr (1896) describes open fractures along what are probably potentially active normal faults of the Basin and Range system extending east to the crest of the Oquirrh Range. In his discussion of the Silver Cloud Shaft (1 mile northwest of Mercur, Plate III b), he writes (op., cit., p. 387):

> "The drift at the bottom of the shaft follows a strongly fractured zone, which has a trend of N. 50° E. and a general dip of 70° NW. The actual strike of the rocks is about

N. 60° E. and the dip is about 27° SE. The fractures are open, without vein filling. They often show slickensided walls, indicating slight faulting."

In his discussion of the Uncle Sam Tunnel of the Mercur Mine (Plate III-b, Mercur), he observes, (op. cit., p. 409-410):

"Besides these open fissures there is a distinct set of fractures which are filled with crystalline calcite, and which evidently belong to an earlier period of formation. Wherever these two sets of fractures occur together, not only in this mine but anywhere else in the district, the same relation in point of age is noticed between them. The older are entirely filled with coarsely crystalline calcite, and appear in general to be non-persistent. The smaller are simply gash veins, and may be seen to thin out and disappear at both ends on the walls of the drifts. The larger are often 2 or 3 inches wide, and in places along their course bulge out into irregular shapes, as if waters which coursed along the fissures had here fashioned spaces by their corrosive power alone. These irregular spaces may be a foot or more in diameter. The veins vary in trend from about N. 10° W to N. 60° E, but average N. 20° E. in trend, and hade* about 80° W.

"The empty cracks and fissures mark a period of sheeting of the rock which was evidently posterior to the formation of the calcite veins just described. In trend and hade* these later fissures are approximately similar to the calcite veins; but they are much more persistent in their nature, since they usually run from the top to the bottom of the drift, with no evidence of diminishing in either direction. Some of the smaller cracks have quite bare walls, but there is usually a thin coating of calcite, with small crystals projecting inward from either wall."

*Note: "Dip" rather than "hade", may be meant since his illustrations show nearly vertical fractures.

West Mercur Fault

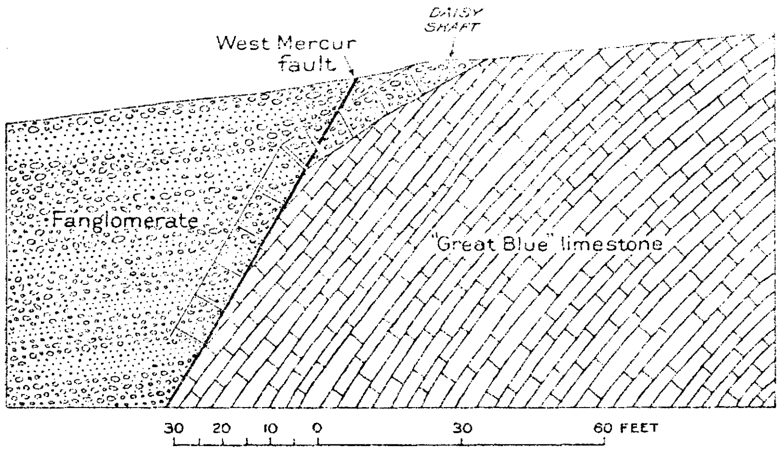
Most faults described during the early studies of the Ophir and Mercur districts were identified by displacement of bedrock east of the range front, but the westernmost, which Gilluly (1928, 1932) called the West Mercur Fault, forms the boundary between bedrock and alluvial basin fill for several miles between the mouths of Ophir and Mercur Canyons, and may be identified in several places both by scarps in alluvium and by fault planes exposed at depth in mine workings (Plate III-b).

Gilluly (1932, Plate 12) mapped a series of 5 faults en echelon and sub-parallel to the range front, stepped down to the west, with a cumulative throw of 3000 to 5000 feet (Plate III-b). Individual faults are "non-persistent" (Gilluly, 1932) and are not quite parallel with the range front but intersect it at angles, some faults passing from bedrock into alluvium. Measured displacement varies greatly along the length of individual faults. The displacement measured on the Lakes of Killarney Fault (Plate III b) changes from "slight" near West Dip Gulch to 3000 feet just north of Ophir Canyon, a distance of 3 miles (Gilluly, 1932, p. 83).

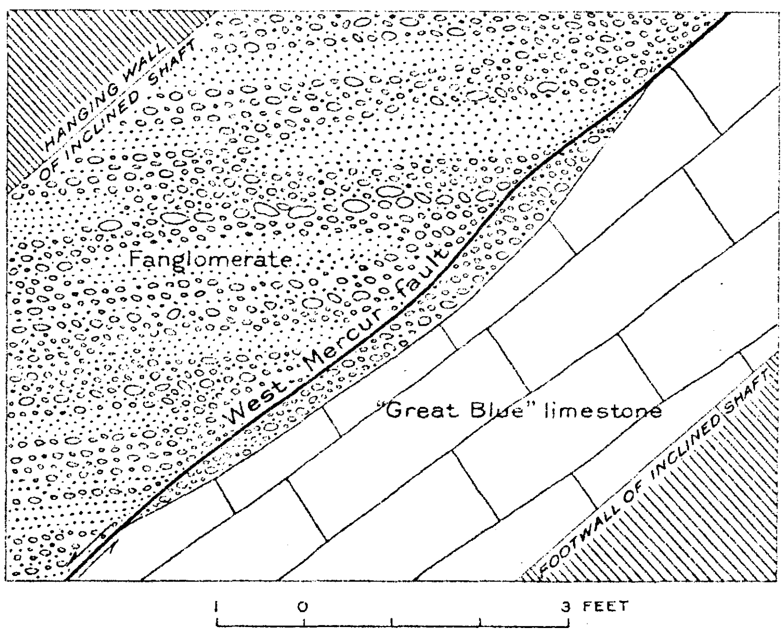
Gilluly's (1932) figures 9, 10, and 11 are reproduced herein (figure 7) to show typical exposures of the West Mercur fault plane. As Gilluly notes (1932, p. 82), alluvium in the footwall in the "*La Cigalle*" mine and the back-wasted and buried fault scarp exposed in the "Daisy" both indicate recurrent movement along the fault. Figure 8 illustrates this second relationship in what remains today of the "Daisy" (site 711, Plate III-b), at a depth of about 20 feet. The fault plane, dipping westward at about 60°, rises from lower left, where the footwall and hanging wall are composed of alluvium. Neither the alluvium of the footwall nor the hanging wall is mineralized, although both contain fragments of reddish mineralized limestone. In the footwall, the pedimented surface of the mineralized bedrock dips westward at about 30°, its weathered (?) surface overlain by 20 feet of alluvial gravel. Fault movement continued after deposition of the alluvium, and both are post-mineralization in age.

Exposure at Site 703

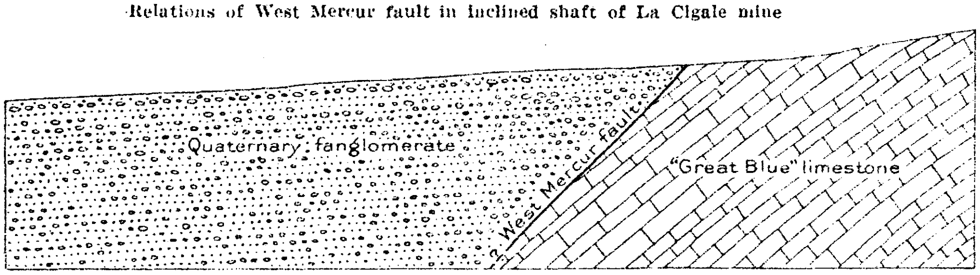
The best exposure of the West Mercur Fault discovered during this study is in an abandoned mine at the mouth of a small gulch just south of Silverado Canyon (site 703, Plate III-b, T. 6 S., R. 4 W., Sec. 3), where an inclined shaft following the fault remains open to a depth of 120 feet (Plate VI). The entrance to the shaft is in alluvium overlying bedrock at the toe of a fault scarp. The surface of the alluvial deposit is part of a recently active alluvial fan. The incline descends westward at roughly 55°, and encounters reddish fault gouge



Relations of West Mercur fault in inclined shaft of Daisy (West Dip No. 1) mine



Relations of West Mercur fault in inclined shaft of La Cigale mine



Relations of West Mercur fault to the topography, alluvium, and bedrock near West Mercur

Figure 7. Exposures of the West Mercur Fault in abandoned mine shafts, western Oquirrh Mountains, *from* James Gilluly, 1932.

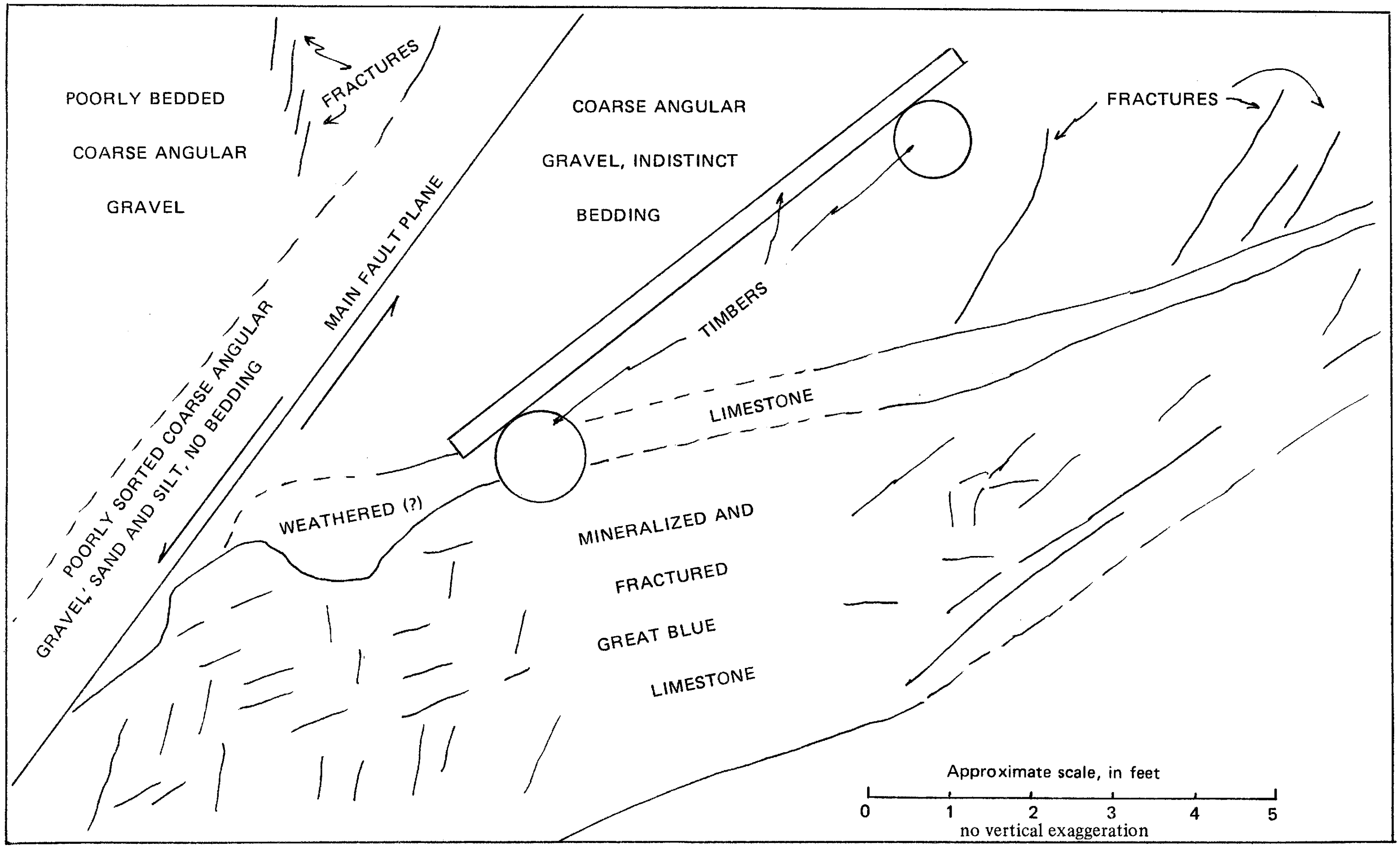


Figure 8. Detail of the West Mercur Fault in the north wall of the "Daisy" Mine, Site 711, T. 6 S., R. 4 W., Sec. 10, Sketch from photographs.

in the floor at a depth of 20 feet. The main fault, which dips westward at 45°, appears higher on the walls at greater depth, until at a depth of 80 feet the slickensided surface of the hanging wall forms the roof. At the bottom of the shaft, at a depth of 120 feet, the hanging wall is composed of poorly cemented coarse angular gravel, in places porous with unfilled voids between the stones, and with partial caliche rinds on many of the stones. The hanging wall is plastered with a sheet of red micaceous clay, from ¼ to 2 inches thick, which presents a smooth planar surface except for many shallow slickensides. The fault plane strikes N. 10° W., and dips 46½° west southwest. The slickensides plunge 45° due west. At 120 feet, a drift remains open for 100 feet northward along the fault plane, providing additional exposures which show the hanging wall to undulate somewhat in the horizontal plane.

Where the limestone footwall is exposed, mineralized fractures may be seen ranging from N. 10° W. to northeasterly in strike, as were observed by Spurr in the mines of the Mercur District (1896, p. 410). However, only the north to northwesterly striking fractures appear to have been active in the Quaternary, and only these are expressed in the surface topography of the West Mercur Fault.

The contact between bedrock and alluvium is not well exposed at the mine entrance, but the relationship appears similar to that which Gilluly found at the "Daisy" (figure 8). The main fault, with a thick zone of gouge, is visible to within 20 feet of the surface, where it disappears. Above this point erosion has backwasted the bedrock slope from the original angle of the fault, destroying the fault gouge, and the toe of the slope has subsequently been buried by alluviation (Plate VI).

At site 703, the exposed and backwasted part of the bedrock scarp is 80 feet high (figure 9). The upthrown side is a bedrock pediment of gentle westward slope with no cover of alluvium; the bevelled edges of limestone beds are clearly visible on 1:20,000 scale aerial photographs. This pediment extends back from the brow of the scarp for about 1000 feet, and suggests a substantial period of quiescence prior to the most recent episode of uplift. The 80 feet of exposed scarp plus the 120 feet of Quaternary alluvium in the hanging wall indicates at least 200 feet of offset during this most recent episode, which may safely be assigned to the Quaternary.

Near the mine entrance, where the alluvium of the hanging wall is exposed in cross section, it is broken by several high angle fractures which curve upward from the main fault, and approach verticality near the surface (Plate VI). Marker beds in the alluvium have been offset by as much as 1 foot on some of these, and fractures may be followed to within 7½ feet of the surface, obscured only by poor exposure. One fracture remains as an open void, suggesting relatively recent formation. Distortion of the sedimentary structure increases with depth (Plate VI) indicating repeated disturbances during the deposition of the alluvium.

Exposure at Site 531

While the exposures of the West Mercur Fault in the mines of the West Mercur mining district provide evidence of recurrent movement on the fault over a long period of time, they do not provide solid evidence for the date of latest movement. However, six miles to the south (site 531, Plate III-b, T. 7 S., R. 10 W., Sec. 1), along the alignment of the West Mercur Fault, a scarp in alluvium crosses the 5200′ strandline of Lake Bonneville, and offsets a post-lake alluvial fan (Plate VII). A trench was dug across the fault scarp just south of and below its intersection with the beach to study the stratigraphy and look for evidence of deformation.

Plate VIIa shows the geomorphic relationships of the fault scarp. Although the scarp is not clearly visible at or above the 5200′ shoreline, a 5-foot scarp is very evident angling southward just below it. Since the lake sediments here are very thin, it is probable that most of this offset pre-dates the existance of the lake, and that the lake failed to erase the scarp except for a very few feet at the highest shoreline. To the south (Plate VIIa) the fault crosses the post-lake terrace of a small drainage with a 2-foot scarp, suggesting a minimum of 2 feet of post-Bonneville offset. South of this drainage, a scarp of variable height continues across surfaces of various ages, and disappears under active alluvial surfaces toward the middle of Rush Valley.

The primary excavation at site 531 (trench 1, Plate VIIa), showed a layer of silty sand underlain by a sequence of alluvial sand and gravel partly and variably cemented by calcium carbonate (caliche) of presumed pedogenic origin (Plate VIIc). These older deposits show offsets of as much as 5 feet along vertical fractures, some of which were found remaining as open voids 2 inches wide, only partly filled with plant roots. The pattern of deformation exposed in the trench indicates a fault zone striking approximately north-south, consisting of a main westward-facing normal fault, paralleled on the west by

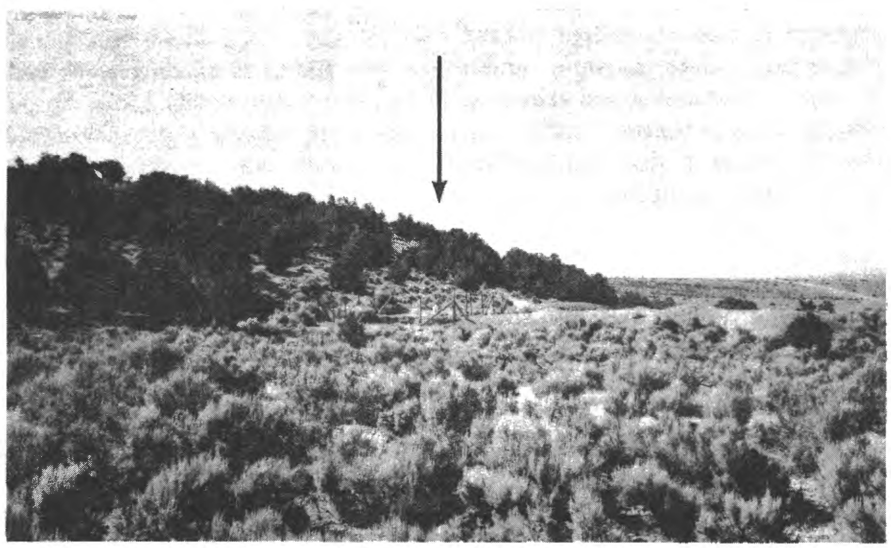


Figure 9. View southward along the scarp of the West Mercur Fault at Site 703. The mine shaft entrance is at center, enclosed by the fence (arrow), while the waste dump extends to the right. See Plate VI for geology.

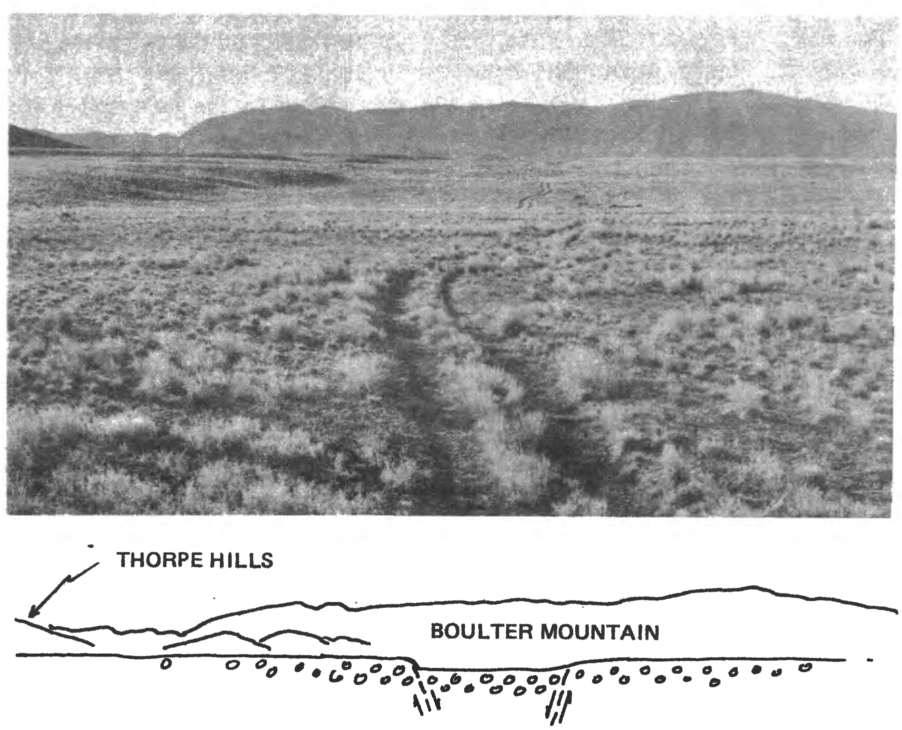


Figure 10. View southward at Site 1107 west of the Thorpe Hills, to show faulted alluvial fans typical of the southern OBT fault zone.

a series of smaller eastward-facing antithetic faults, the whole forming a graben about 40 feet across.

Uncomformably overlying the older alluvial sequence, 1 to 3 feet of tan gravelly or sandy silt with a basal gravel at the eastern end are interpreted as Lake Bonneville sediments and/or younger alluvium derived therefrom. The silt unit is structureless and shows no evidence of deformation, although the basal contact and basal gravel appear to be warped in three places (Plate VIIc) reflecting the underlying displacements. Twenty-one feet west of Plane Table Station B the gravel is warped down to the east, and 44 feet west of Plane Table Station B a wedge of silt extends downward into a fracture. Four feet from Plane Table Station B, possible evidence for deformation of the lake sediments is indicated by the involvement of the basal gravel in the main fault plane. The gravel thickens at the fault and pebbles in the hanging wall are oriented parallel to the fault plane from top to bottom of the deposit. Although no deformation is visible in the overlying silt, the roots of a sagebrush growing above the fault trace follow what would be the extension of the fault plane to the surface, indicating a possible zone of weakness which developed in the silt some time after deposition.

Site 531 provides evidence of both repeated surface faulting during the late Pleistocene, and some 2 feet of offset which post-dates Lake Bonneville.

Southern OBT Zone

Farther south along the OBT fault zone much the same structural relationships occur indicating that the OBT zone is a continuous structure. Short discontinuous scarps trending from slightly east of north to slightly west of north break Quaternary surfaces along the western foot of the Thorpe Hills and northern Boulter Mountain (Plates I and IIIc and figure 10). Scarps appear highest and most numerous adjacent to the outcrop areas of highest relief, and lowest or nonexistant adjacent to passes, such as Fivemile Pass. However, south of Edwards Canyon, in Boulter Mountain, even though the relief of the range continues to increase, the parallel scarps on the bajada slopes disappear, and no evidence of faulting is apparent except for the abrupt rise of the linear, faceted range-front from the active alluvial apron.

In the bedrock terrain to the east of this zone there are exposures of mineralized faults of various dips and ranging in strike from ESE to NNW. As with the west Mercur Fault, only the N to NNW directions are expressed by the most recent activity. An exception is an anomalous series of scarps in the vicinity of Twelvemile Pass, each sharply curved at the southern end so that its strike progresses through 60 degrees, from NE to NNW (Plate III-c).

Scarps cross surfaces of various ages, and scarp heights are generally higher on older surfaces than on younger, indicating repeated surface faulting throughout at least the late Pleistocene. At site 1106, west of Topliff Hill, (NW corner, Section 8, T. 8 S., R. 3 W.) a fault scarp crosses the 5200-foot shoreline (figure 11). Although no offset of the shore platform has been proven (no survey was made), the fault scarp cuts an apparent post-lake Bonneville alluvial fan. A scarp height of 5 to 10 feet below the beach, and of some 25 feet above the beach, suggests repetitive faulting continuing into post-Bonneville time. Higher scarp heights suggest that this fault may be somewhat more active than the one trenched at Site 531.

Mid-Valley Horst

From 3 to 6 miles west of the West Mercur Fault and parallel to it, near the center of Rush Valley and opposite the mouth of Ophir Canyon, are two nearly parallel series of scarps in both alluvium and gravel capped pediments. Discontinuous scarps extend northward for several miles from the south unit of the Tooele Army Depot and die out in the center of the valley near St. Johns Station (Plate III-b). Scarps on the west show downthrow to the west and scarps on the east show downthrow to the east, indicating the existence of a central horst, flanked on either side by grabens. The horst and grabens correspond closely to gravity ridges and troughs mapped by Cook & Berg, 1961 (see Plate II, this report) and indicate that small scale block faulting has probably affected the entire valley, as Gilluly surmised in 1932, (p. 82).

Several of the Mid-Valley Horst fault scarps intersect Lake Bonneville shorelines at small angles, and some extend into the bottom of Rush Valley, but there is no unequivocal evidence of post-lake faulting. At site 203 (Plate III-b) is a small north-northwest trending graben one-fourth mile wide which is crossed at right angles by a drainage presumed to be antecendent to the faulting. Spits formed by the most recent invasion of this valley by Lake Bonneville are not visibly interrupted where they cross the fault scarps, indicating no Holocene displacement.

At site 515 (Plate IIIb) a trench was excavated

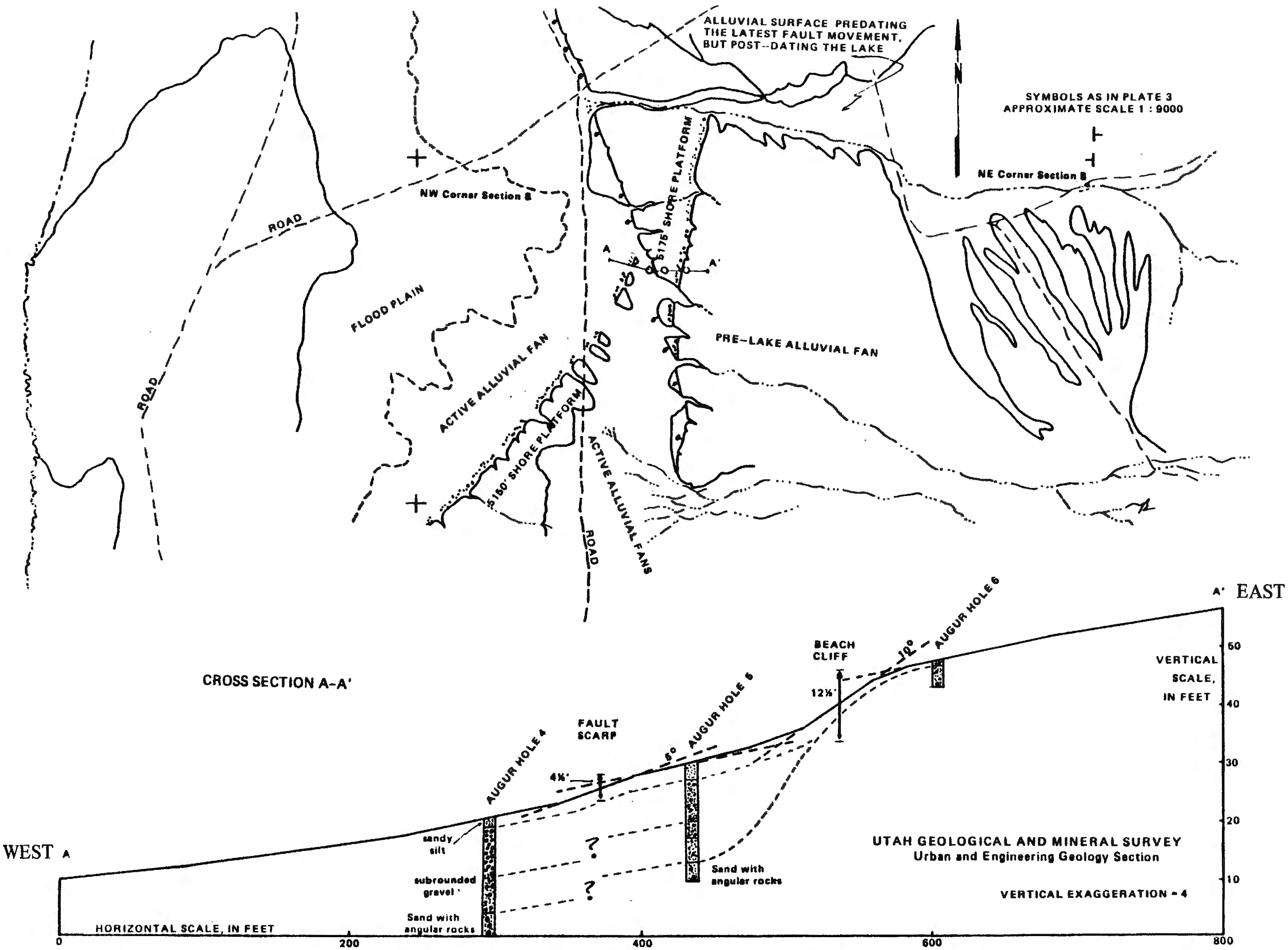


Figure 11. Geomorphology of the intersection of a fault scarp with the Bonneville shoreline, Site 1106; T. 8 S., R. 3 W., Section 8.

across a west-facing fault with no surface scarp, but just in front of a beach cliff (figure 12). Coarse Quaternary alluvium was found downfaulted against tuff of the Tertiary Salt Lake Group. No clue to the age of the most recent faulting was found, but the absence of a scarp suggests a pre-Bonneville age.

In the center of the valley, just south and west of St. John Station, a gentle 2 to 3 foot high scarp can be traced for more than a mile in valley-bottom sandy or clayey silt, suggesting a possible offset of post-Bonneville age (site 705, Plate III-b).

South Mountain Marginal Fault

A series of north-northwest vegetation lineations can be traced from St. John Station toward the western end of South Mountain, where remnants of old scarps are visible (Plates I and III-b).

Vernon Hills Marginal Faults

A central horst in the Rush Valley can be defined farther south where Paleozoic rocks crop out in the Vernon Hills, and Tertiary Salt Lake Group crops out near Faust (Plate III-c). North-northwest trending fault scarps in Quaternary alluvium are visible on both the east and west sides of the Vernon Hills, and a series of high-angle normal faults dipping east, and separating westward-tilted blocks of Tertiary Salt Lake Group sediments, are exposed in roadcuts along the Pony Express Road east of Faust (Plate II). There is no conclusive evidence of Holocene displacement (table 2).

Sheeprock Marginal Fault

A north-east facing scarp in Quaternary alluvium, 30 to 50 feet high and nearly continuous for about 4 miles, runs along the northeast margin of the Sheeprock Mountains from Harker Canyon northwestward to Government Creek. Along most of the mountain front only a single well defined scarp is present, but at the mouth of Government Creek the fault turns abruptly northeastward and is exposed as a series of shorter scarps, many of which have antithetic scarps across a

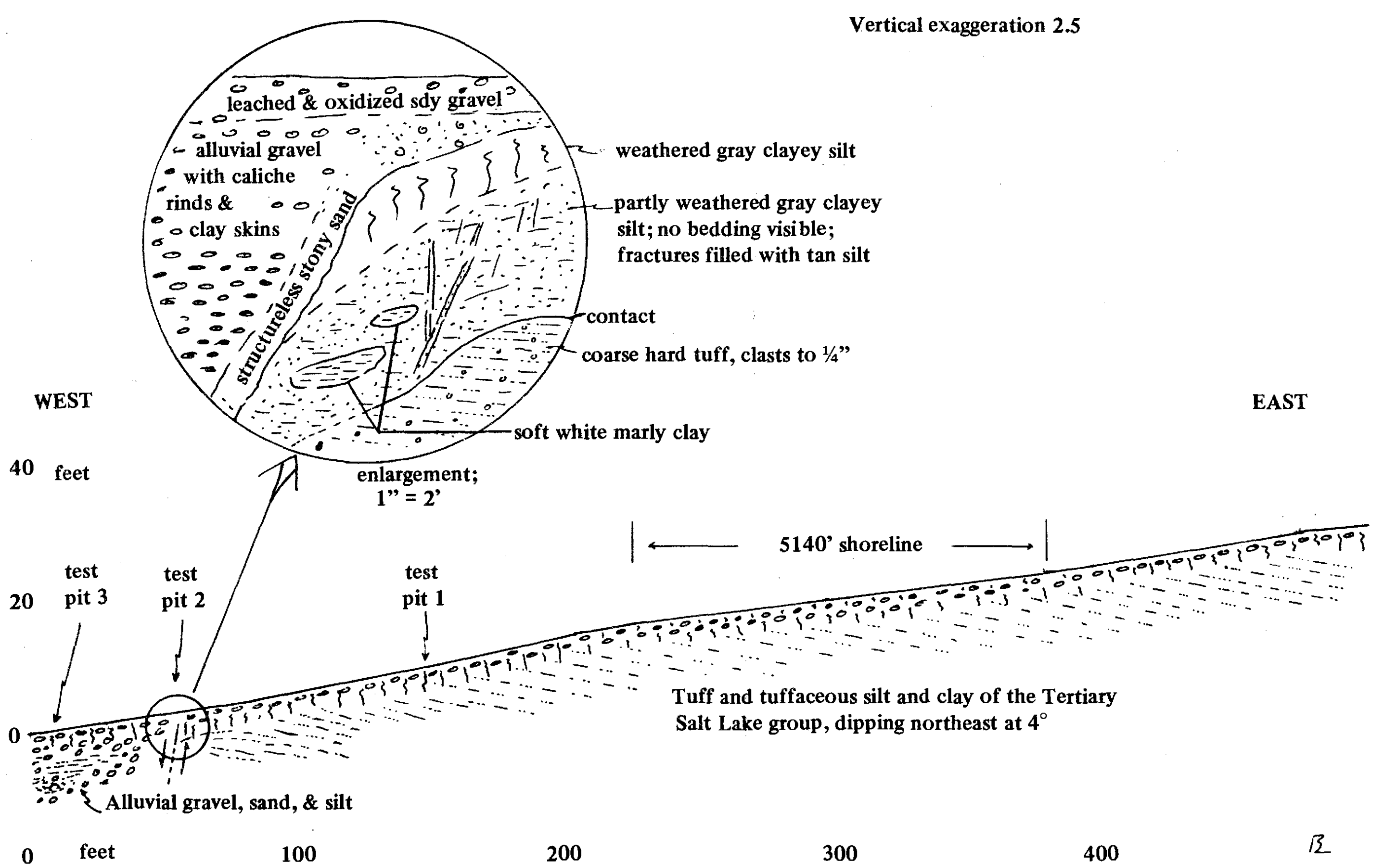


Figure 12. Geologic cross section, Site 515, Tooele Army Depot, South unit.

shallow graben (Plate III-c, T. 9 S., R. 6 W., Sec. 16). Lower terraces or Holocene valley bottoms are unbroken where they are crossed by the fault. While there is no geomorphic evidence to indicate more than one episode of movement, Cohenour (1959, p. 108) believes that activity began in the Pliocene and has continued to the present. He gives no estimate of total throw.

The front of the Sheeprock Mountains differs from that of the Oquirrh Mountain block, in that (1) the Sheeprock Mountains present a higher, steeper, and more continuous rangefront fault scarp than do the Oquirrhs along the West Mercur Fault; (2) the Sheeprock fault lies farther out from the range front, and (3) it does not present the exposures of alluvium against bedrock that appear in the West Mercur Fault. The Sheeprock Range does not present the imposing facade of faceted spurs rising dramatically from the alluvial outwash typical of active mountain fronts. Instead, the range is moderately indented with alluvial valleys, and the intervening spurs may not reach the scarp, nor show traces of having been truncated by faulting. Range-front morphology suggests very intermittent activity with long intervening periods of inactivity. Scarp morphology suggests a possibly Holocene age (table 2) for the latest displacement.

Onaqui East Marginal Fault

A number of short discontinuous east-facing scarps break the alluvial apron on the eastern footslope of the Onaqui Mountains from the Pony Express Road northward to Clover. Toward the south the scarps are very gentle, barely discernable on the ground. Just south of Clover a series of scarps 20 feet in height are associated with springs. No geomorphic or geologic clues were found which indicate Holocene activity (table 2).

Oquirrh Marginal Fault

Middle Canyon to Pine Canyon

A single, well defined break in slope along the west base of the Oquirrh Range just east of Tooele begins south of Middle Canyon and extends northward past Middle Canyon, curving around the base of the range with a jog at Spring Gulch, to the mouth of Pine Canyon. This feature is interpreted as a fault scarp because of the linear contact between bedrock and alluvium and a truncated alluvial fan or pediment some 200 feet high at the mouth of Spring Gulch. Additional sub-parallel scarps trending NNE break the alluvial surface just west of the mouth of Spring Gulch between the mountain front and the Bonneville shoreline, and a series of NNW trending scarps terrace the alluvial fan of Middle Canyon north of its mouth. The latter are most likely alluvial terraces predating Lake Bonneville but could be tectonic in origin. No natural exposures are provided and trenching would be necessary to resolve this question.

That the range front is a fault is indicated by the fact that it parallels very well the gravity contours mapped by Johnson (1958), and that it continues southward as a bedrock fault as mapped by Moore and Sorensen (1978) (Plate III-a). There is no physiographic evidence of post-Bonneville faulting and no exposure of the fault plane.

Pine Canyon to Lake Point

Proceeding northward along the west margin of the Oquirrh Range from Pine Canyon there are a series of short discontinuous scarps in alluvium or lake sediments below the Provo and Bonneville shorelines. Just north of the mouth of Bates Canyon the surface of the Provo delta is broken by several scarps, one of which can be traced northward nearly unbroken for several miles to the range front east of Lake Point. This 30 foot scarp is particularly interesting because it appears to record two episodes of offset: an older upper slope modified by lacustrine erosion, and a later basal slope unaffected by the lake, and presumably post-Provo in age. Figure 13 illustrates the appearance of this feature at Site 420 (Plate III-a). The fault is on line with, and no doubt continuous with, a down-to-west normal fault in Tertiary fanglomerate exposed in Bates Canyon a mile south of site 420.

Sixmile Creek Fault

A series of low scarps and a string of circular depressions with a relief of 2 to 4 feet trends northwest across Sixmile Creek in Sections 13, 14, 23, and 24 of T. 2 S., R. 5 W., near the abandoned oil test Hickey No. 1 Cassity. This is near the location of a fault with the same trend previously inferred from gravity data and study of the stratigraphy of three oil tests, and named the Sixmile Creek Fault by Gates (1965, p. 18). A presumed Holocene gravel spit at elevation 4225′ has been offset vertically by about 5 feet (site 216, Plate III-a).

Stansbury West Marginal Fault

The Stansbury Fault (Rigby, 1958, p. 75) bounds the Stansbury Range on the west. An almost continuous

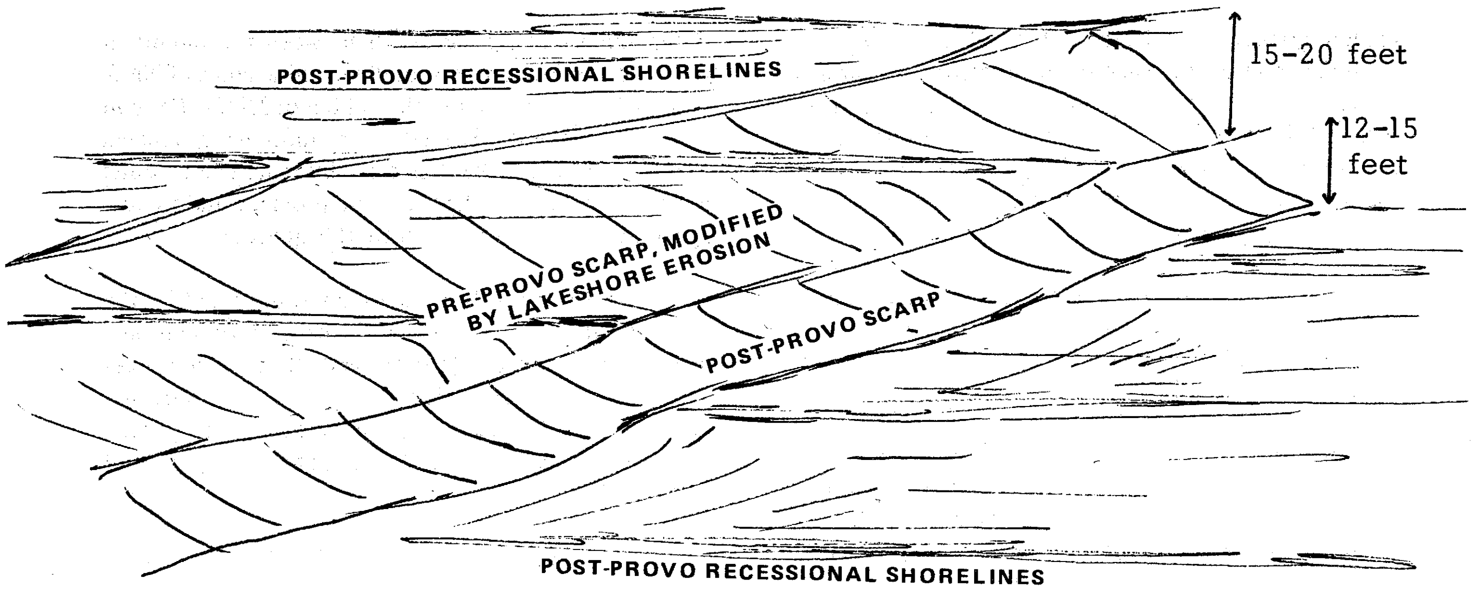


Figure 13. Interpretive sketch of a 2-stage fault scarp below the Provo shoreline, eastern Tooele Valley, Utah, Site 420.

scarp cuts alluvial fans for 16 miles between Deadman Canyon on the south and Box Canyon on the north (Plate I). Offsets of Quaternary alluvial fans amount to about 80 feet in the central part opposite Deseret Peak. Total displacement is estimated at 10 to 12 thousand feet (Rigby, 1958, p. 77). Streams crossing the scarp show prominent nickpoints only a short distance back from the scarp, in contrast to the streams crossing scarps of the Oquirrh and Sheeprock Mountains, suggesting that this may be one of the most recently active of the faults observed. Scarp morphology suggests a Holocene age (table 2).

The fault branches northward in the vicinity of Salt Mountain, and discontinuous scarps are evident along the western foot of the range northward to its northern end, including what Rigby has labeled separately as the Timpie Ridge Fault (op. cit., p. 77).

A few poorly preserved scarps appear below the Bonneville shoreline, but there is no conclusive evidence of post-Lake Bonneville offset.

GENERAL CONCLUSIONS ON SEISMIC ACTIVITY AND THE CHRONOLOGY OF SURFACE FAULTING

1. One site in Rush Valley (531) has confirmed the existence of post-Lake Bonneville surface faulting (probably less than 18,000 years B.P.), and the same is suspected for two other sites (705 and 1106) from geomorphic evidence (table 2). At one site in Tooele Valley (420) there is post-Provo (less than 12,000 B.P.) surface faulting, and at another a Holocene shoreline has been offset by about 5 feet (site 216). The Rush Valley site showing post-Bonneville faulting (Site 531) is on a fault which shows a relatively small amount of Quaternary activity, by comparing scarp heights and slopes with other faults in the study area. This suggests that most mapped Quaternary faults have probably been active in post-Bonneville time, and that many have probably been active during the Holocene (table 2). The entire area therefore may be considered to be seismically active, with no part of the valleys more than ten miles from a potentially active fault.

2. Caution is needed, however, in applying this information to the calculation of seismic risk. The pattern and history of normal faulting in the Tooele and Rush Valleys is far more complex than might be assumed. The variety of morphologies and geologies expressed by the different fault zones suggests that they are not all of the same age or degree of activity. Although there are many examples of repeated movement on individual faults during the late Quaternary, there is nothing which would suggest that this regularity can be extended back beyond the late Pleistocene; rather, some evidence suggests otherwise. Likewise there is no evidence to suggest a spatial regularity of fault movement; on the contrary, total throw and rate of displacement vary greatly along the length of individual faults and fault zones.

3. Examination of the best-known of the fault zones in the study area, the OBT, shows that in general range-

front faulting cannot be taken as a simple case of linear breakage between an upthrown mountain block and a downthrown valley block. In the case of the OBT at 40° 20′ north latitude a zone of faulting 10 miles wide extends from near the crest of the Oquirrh Mountains westward to the center of the valley, comprising some dozen individual parallel faults (Plate III-b; figure 6). Although there are no means of assessing the Quaternary activity of the faults known only from bedrock exposure, it is logical to assume, without evidence to the contrary, that they are as active as the faults which have disturbed Quaternary alluvial surfaces in the basin. Individual faults can be traced from bedrock into alluvium as they intersect the range front at acute angles, implying a complex mechanism for the uplift of the mountain range. Therefore, rather than uplift of a "mountain block" relative to a "valley block" we have innumerable small blocks or slices which have been jostled every which way. Therefore an assessment of the OBT fault zone as a source of seismic energy will be a difficult and time-consuming enterprise.

4. In Table 3 a fault density has been calculated for each of the 3 areas of Plate III: Tooele Valley, northern Rush Valley, and southern Rush Valley, as the ratio of the length of mapped Quaternary fault scarps divided by the valley area. Although the modern microseismic activity increases northward to Tooele Valley (Plate I), Table 3 shows a much lower density of Quaternary faults in Tooele Valley than in Rush Valley. Since a much greater percentage of the surface of Tooele Valley is Bonneville age or younger, it seems reasonable to assume that the actual density of Quaternary faults is as great or greater in Tooele Valley as it is in Rush Valley, and that there is a large number of undetected potentially active faults in Tooele Valley.

Table 3

Length and Density of Quaternary
Fault Scarps in Tooele and Rush Valleys

Location	Length of Quaternary Fault Scarps (miles)	Valley Area (sq. mi)	Ratio (mi/mi^2)
Tooele Valley Plate III a	9.0	296	0.03
Rush Valley Plate III b	14.7	181	0.08
Plate III c	18.8	301	0.06
Total	42.5	778	0.05

5. Fault densities of all three areas of Table 3 are significantly less than the density of 0.15 miles of surface fault per square mile computed for neighboring Salt Lake County by Kaliser (1974, p. 1). This difference in fault density correlates well with the fact that historic seismic activity (Richins, 1979) and the height and age of scarps (Swan and others, 1979) is greater along the Wasatch Front than observed in the Tooele and Rush Valleys. These data suggest that the frequency of strong earthquakes will be significantly less in the subject area than it is along the Wasatch Front.

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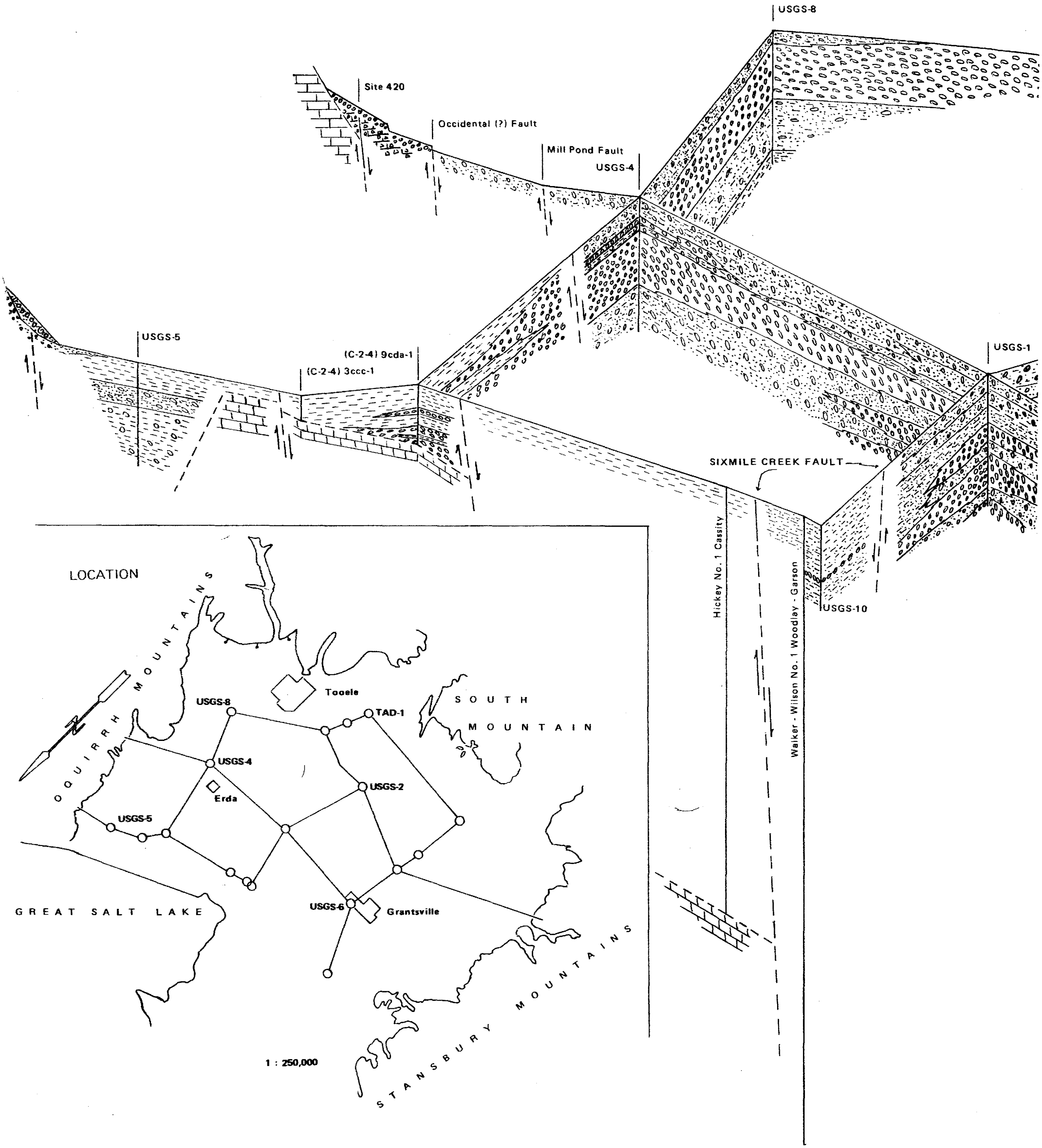
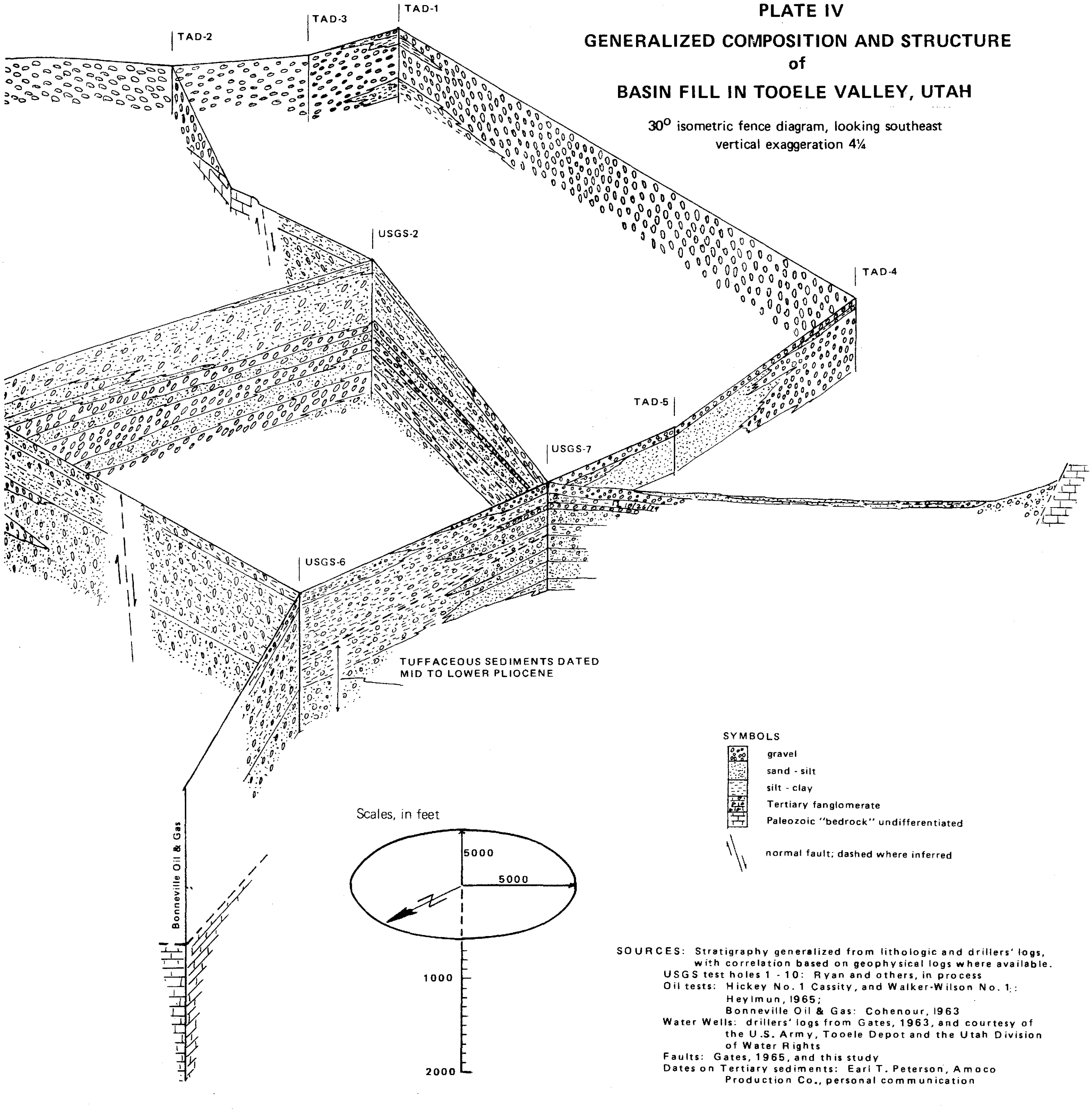

USGS-8
Site 420
Occidental (?) Fault
Mill Pond Fault
USGS-4
USGS-5
(C-2-4) 9cda-1
(C-2-4) 3ccc-1
USGS-1
SIXMILE CREEK FAULT
Hickey No. 1 Cassity
Walker - Wilson No. 1 Woodley - Garson
USGS-10
LOCATION
OQUIRRH MOUNTAINS
Tooele
USGS-8
TAD-1
SOUTH MOUNTAIN
USGS-4
Erda
USGS-2
USGS-5
GREAT SALT LAKE
USGS-6
Grantsville
STANSBURY MOUNTAINS
1 : 250,000

PLATE IV
GENERALIZED COMPOSITION AND STRUCTURE of BASIN FILL IN TOOELE VALLEY, UTAH

30° isometric fence diagram, looking southeast
vertical exaggeration 4¼



SOURCES: Stratigraphy generalized from lithologic and drillers' logs, with correlation based on geophysical logs where available.
USGS test holes 1 - 10: Ryan and others, in process
Oil tests: Hickey No. 1 Cassity, and Walker-Wilson No. 1: Heylmun, 1965;
Bonneville Oil & Gas: Cohenour, 1963
Water Wells: drillers' logs from Gates, 1963, and courtesy of the U.S. Army, Tooele Depot and the Utah Division of Water Rights
Faults: Gates, 1965, and this study
Dates on Tertiary sediments: Earl T. Peterson, Amoco Production Co., personal communication

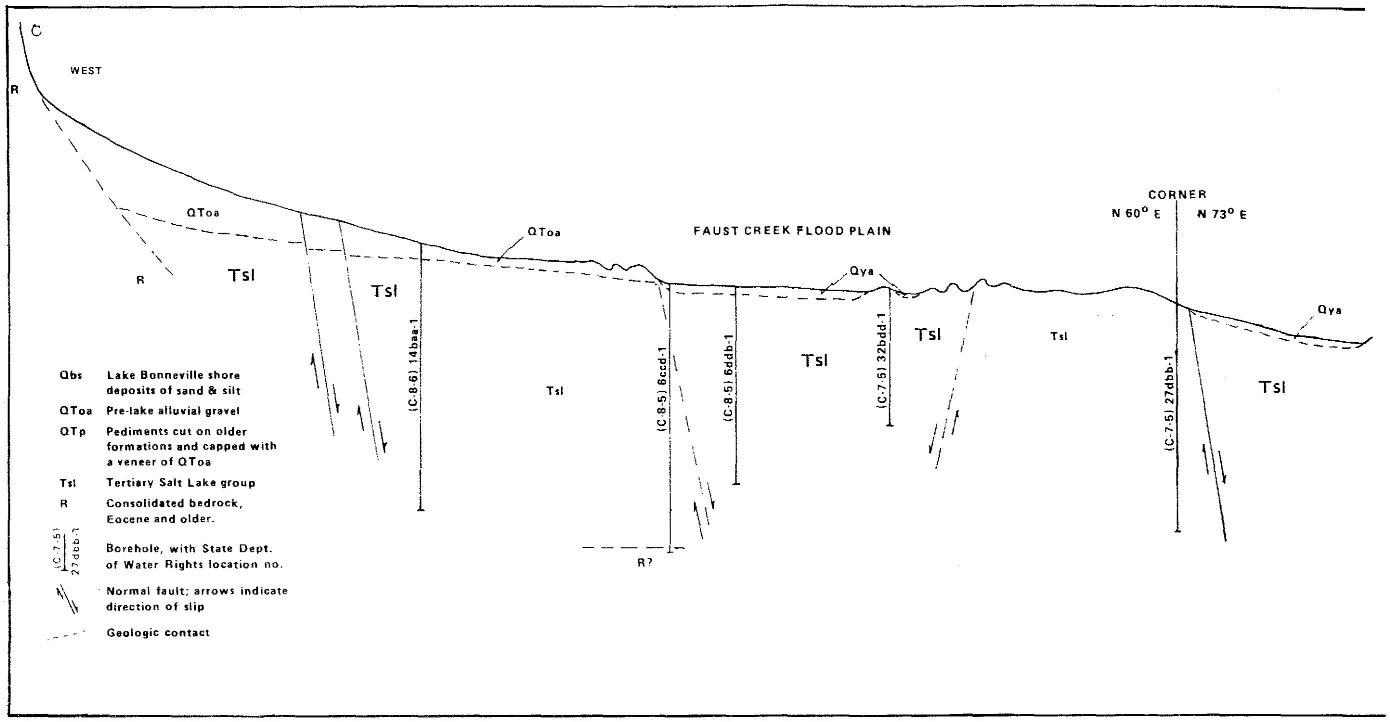
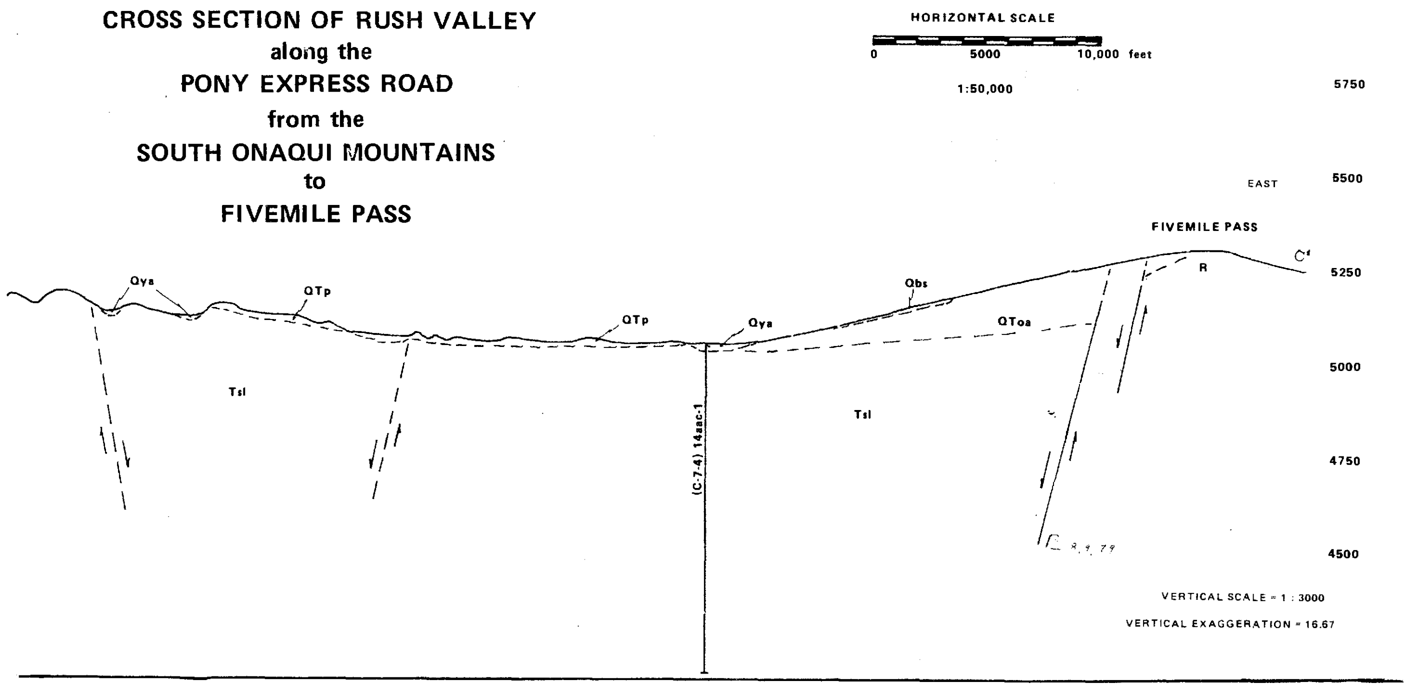


Plate V. Cross section of Rush Valley along the Pony Express road from the south Onaqui Mountains to Fivemile Pass. (see Plate III-c for location).

PLATE V

CROSS SECTION OF RUSH VALLEY along the PONY EXPRESS ROAD from the SOUTH ONAQUI MOUNTAINS to FIVEMILE PASS



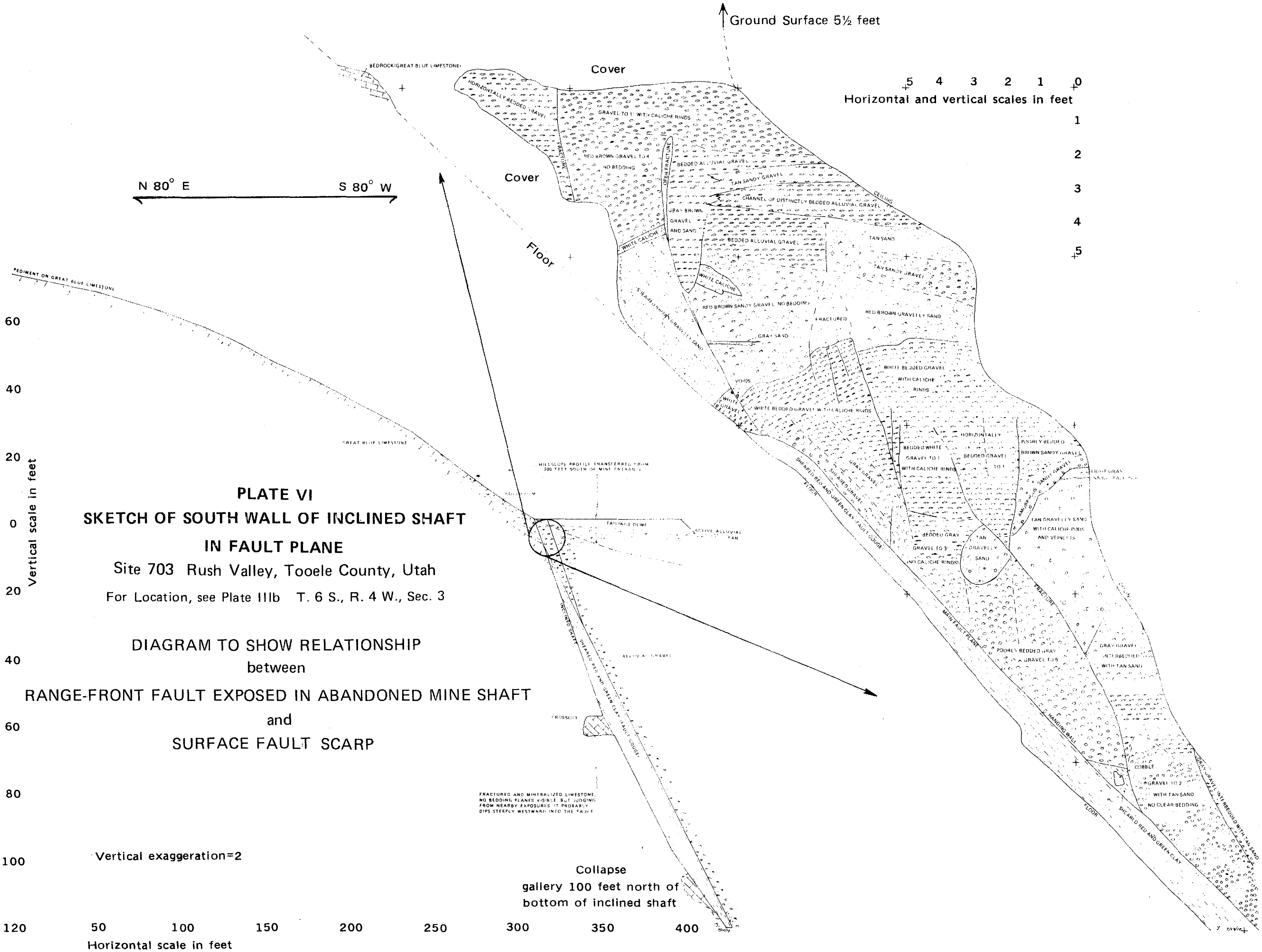
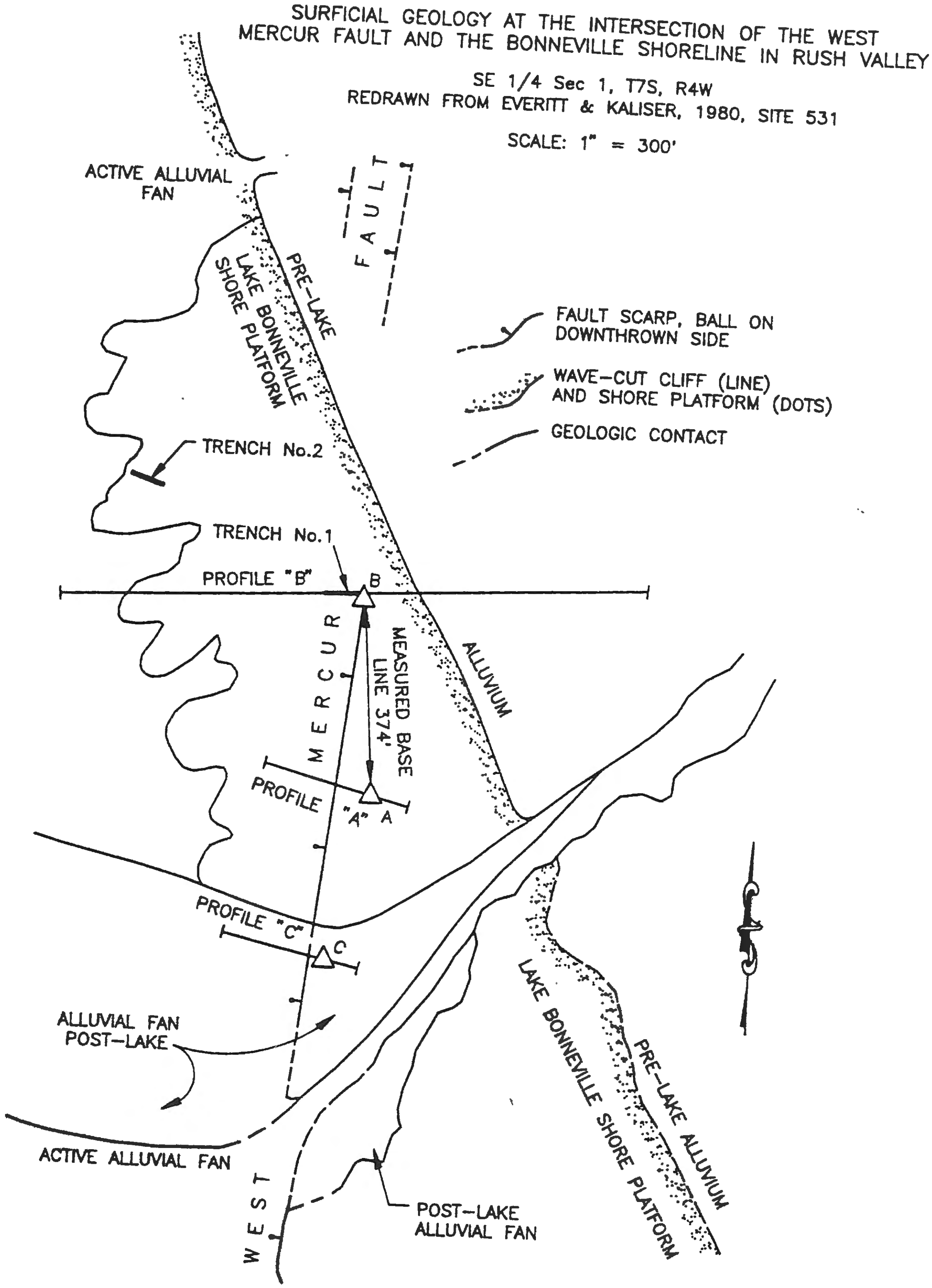


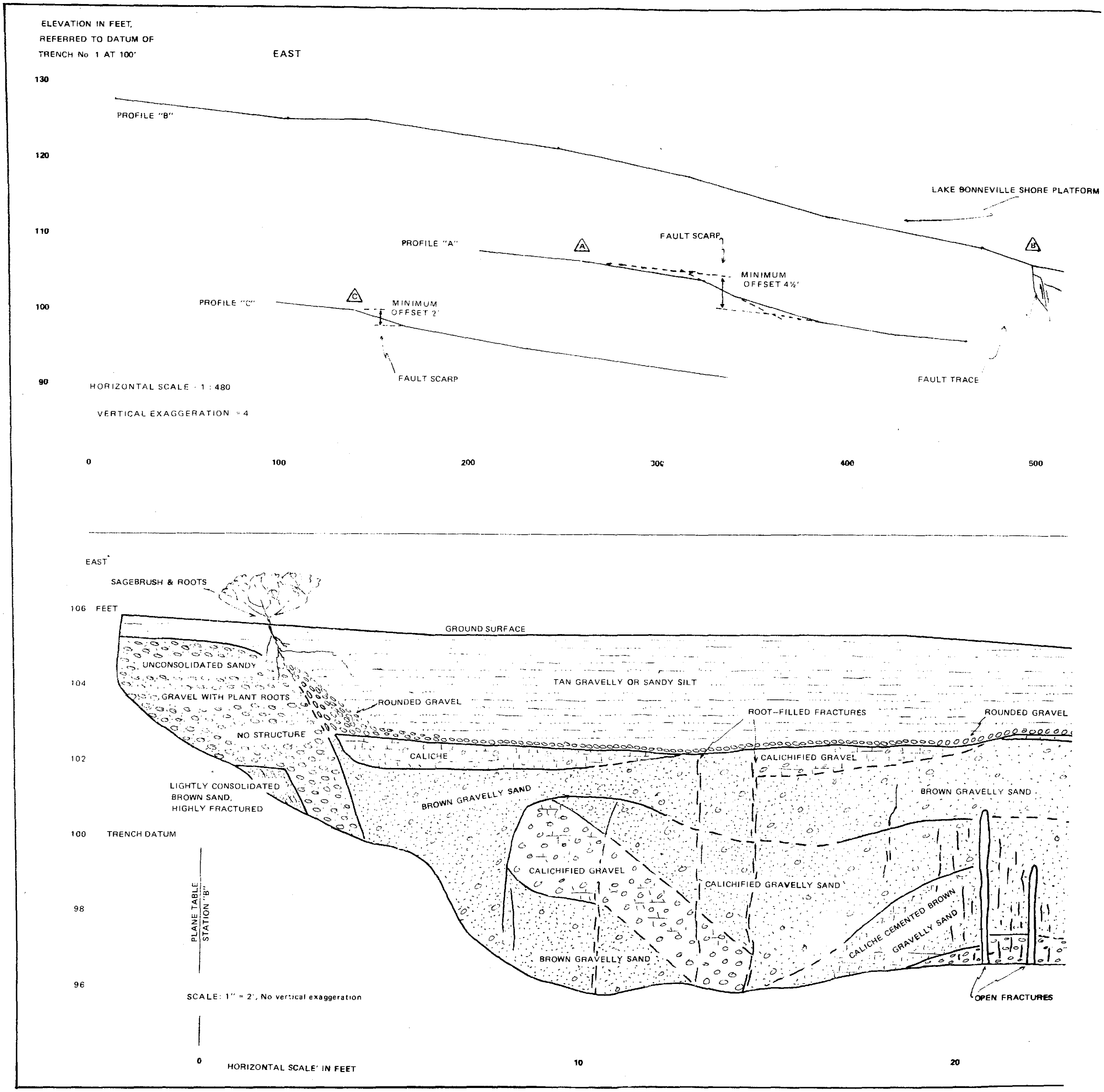
PLATE VI
SKETCH OF SOUTH WALL OF INCLINED SHAFT IN FAULT PLANE
Site 703 Rush Valley, Tooele County, Utah
For Location, see Plate IIIb T. 6 S., R. 4 W., Sec. 3

DIAGRAM TO SHOW RELATIONSHIP
between
RANGE-FRONT FAULT EXPOSED IN ABANDONED MINE SHAFT
and
SURFACE FAULT SCARP

Correct figure



B 11/25/91



Geology of a faulted Lake Bonneville shoreline, site 531, SE¼ Sec. 1, T. 7 S., R. 4 W., Tooele County, Utah. Geology by Ben Everitt and Bruce Kaliser, June 1, 1979.

PLATE VIIb

TOPOGRAPHIC PROFILES OF THE FAULT SCARP WITH THE GEOLOGY EXPOSED BY TRENCHING

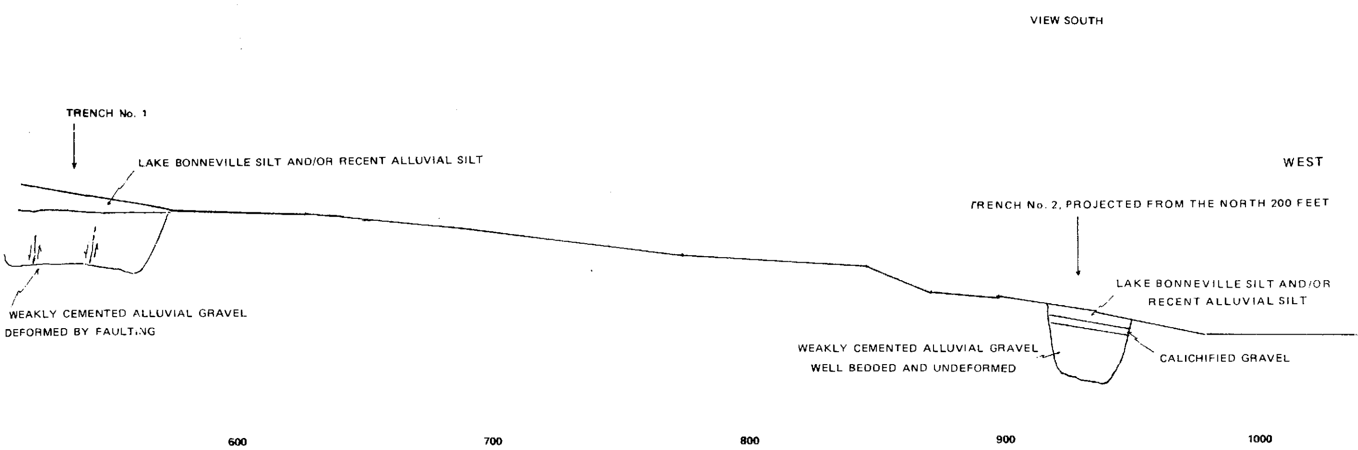
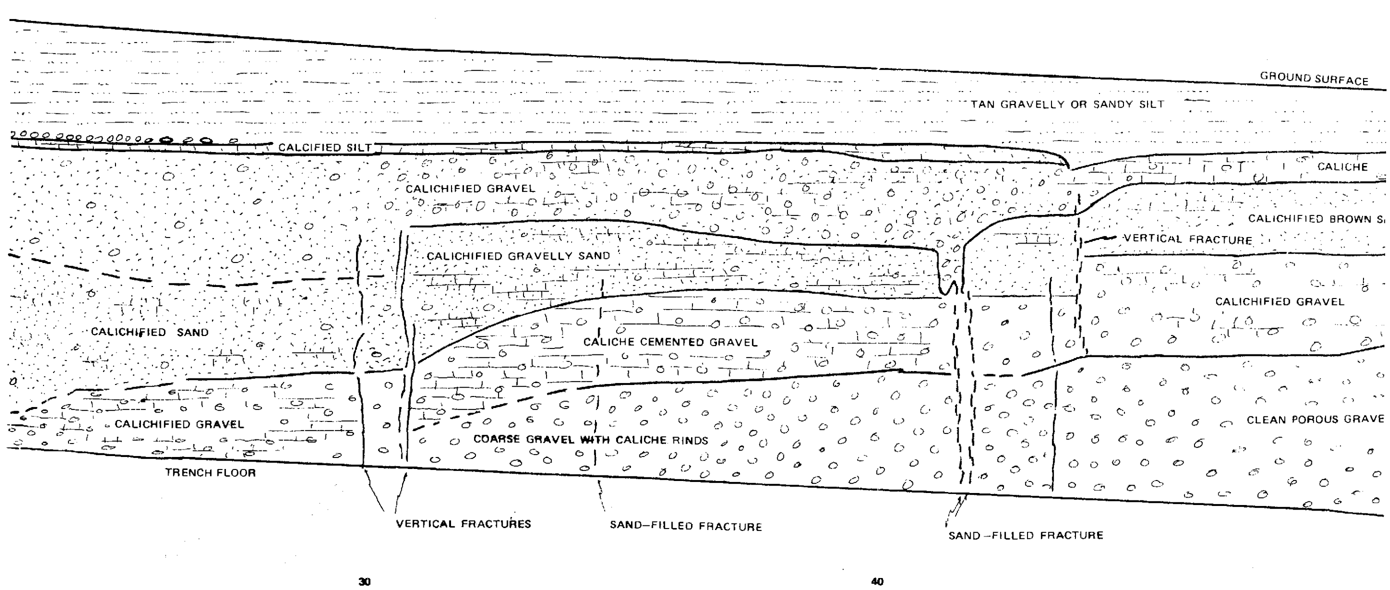


PLATE VIIc LOG OF TRENCH No. 1, SOUTH WALL



UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108

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The Survey publishes bulletins, maps, a quarterly newsletter, and a biannual journal that describe the geology of the state. Write for the latest list of publications available.

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GEOLOGICAL AND MINERAL SURVEY
UTAH

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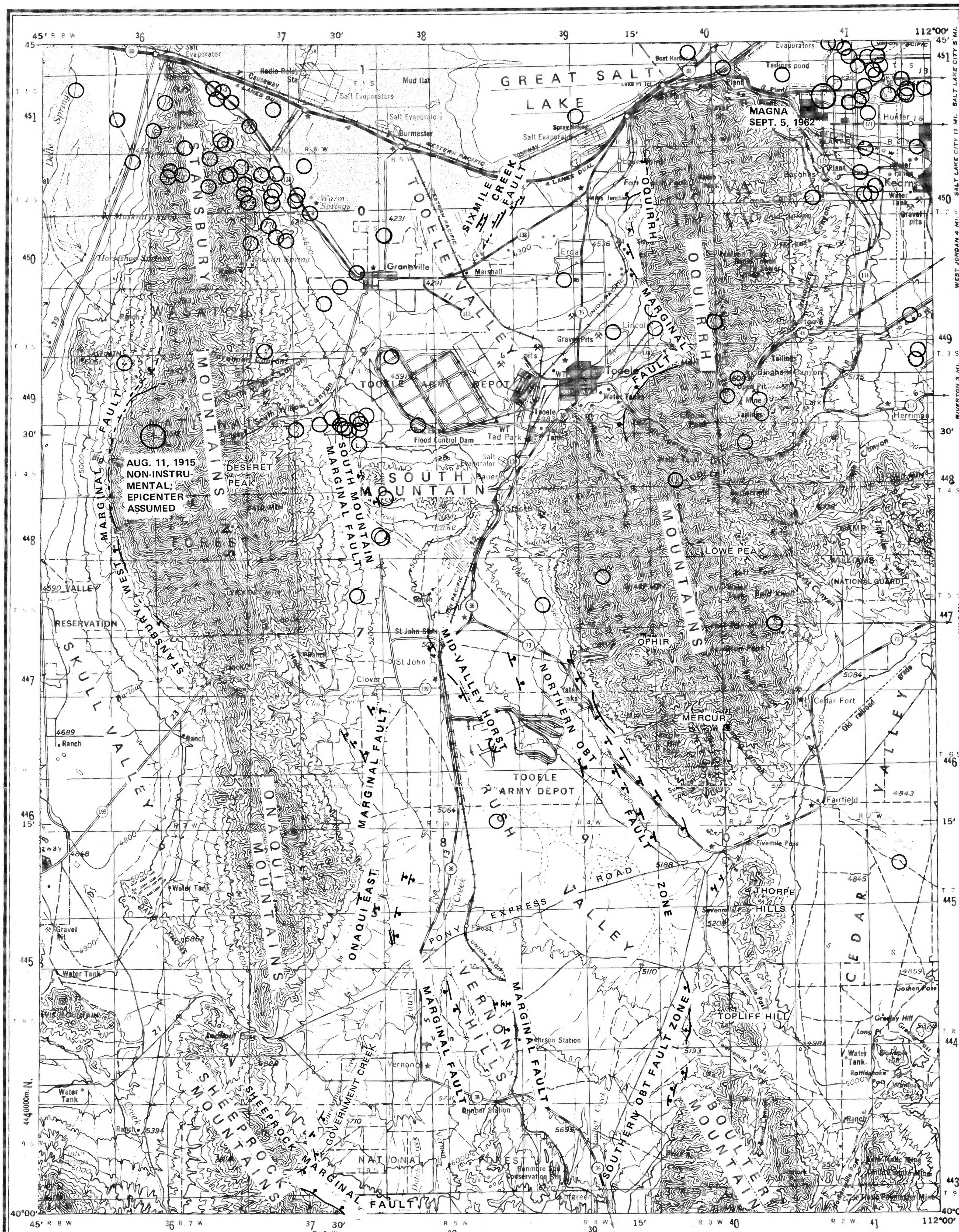
Urban and Engineering Geology Section
1979

EARTHQUAKE EPICENTERS, 1850 - 1979
and
ZONES OF QUATERNARY FAULTING

PLATE I

SPECIAL STUDIES 51



Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles

N

BASE: TOOELE, UTAH
2 degree AMS sheet
Revised 1970

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

INSTRUMENTAL EARTHQUAKES, JUNE 1962 THROUGH MARCH 1979
(UNIVERSITY SEISMOGRAPH STATION)
RICHTER MAGNITUDE LESS THAN 3

HISTORIC EARTHQUAKES OF MODIFIED MERCALLI INTENSITY V
OR GREATER (ARABASZ & OTHERS, 1979;
ROGERS & OTHERS, 1976)

POTENTIALLY ACTIVE FAULTS AS MAPPED FROM QUATERNARY
FAULT SCARPS

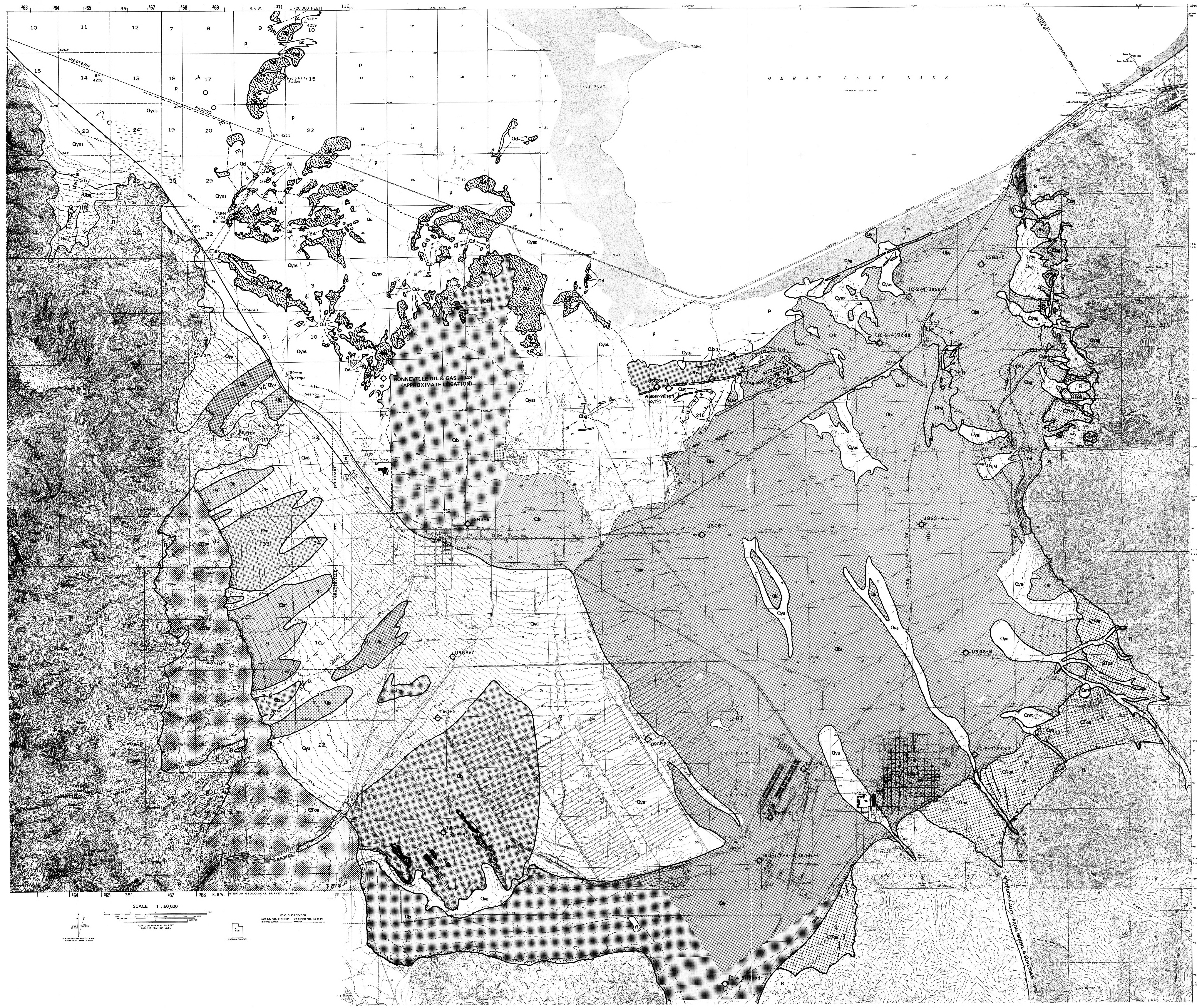
SOURCES

1850 - 1962	Arabasz, W. J., R. B. Smith, and W. D. Richins, Eds., 1979, Earthquake studies in Utah. University of Utah Seismograph Stations Special Publication, 552 p.
	Rogers, A. M., S. T. Algermissen, W. W. Hays, and D. M. Perkins, 1976, A study of (potential) earthquake losses in the Salt Lake City, Utah area: U. S. Geological Survey Open File Report 76-89, 357 p.
1962 - 1977	University of Utah Seismograph Station, 1978, Plot of epicenters, preliminary Tooele 2° sheet, 1:250,000
1978 - 1979	University of Utah Seismograph Station, 1979, Print-out of Utah earthquakes, June 1962 through the present for the Tooele area

UTAH GEOLOGICAL AND MINERAL SURVEY
Urban and Engineering Geology Section
1979

SURFICIAL GEOLOGY OF TOOELE AND RUSH VALLEYS

TOOELE VALLEY



Special Study 51

PLATE III a

Tooele Valley, Tooele County, Utah

EXPLANATION

SURFACES

p — Playa: flat, featureless, poorly drained unvegetated plains of silt or clay; mostly marginal to the Great Salt Lake below the historic high water contour of 4211 feet, and in the bottom of Rush Valley.

pc — Historic playa washover channels, sec. 9 & 10, T1S, R6W.

UNCONSOLIDATED DEPOSITS

Qmt — Modern mill tailings

Qya — Post-Lake Bonneville alluvium; mostly very thin sheets of sand or silt; boulder mudflow deposits near mountain fronts; shoreline features of the underlying Qb are obscured; 5-15 feet in thickness.

- Qyag — Sand-gravel facies.
- Qyas — Silt-clay facies.

Qd — Dunes or features modified by wind drift; those near present lake level are composed of calcareous oolitic sand, sometimes with a core of lake silt; up to 15 feet in thickness.

UNCONSOLIDATED TO PARTLY CONSOLIDATED DEPOSITS (Plio-Pleistocene)

Qb — Lake Bonneville shore deposits (Bonneville Group): mostly a thin veneer of gravel, sand, and silt, on which shoreline features are visible. Deposits of unconsolidated to weakly cemented gravel up to 200 feet thick occur primarily at the Bonneville shoreline (5200 to 5250 feet elevation), the Provo shoreline (4800 to 4850), and the Stansbury shoreline (4400 feet).

- Qbg — Sand-gravel facies 0 to 200 feet thick
- Qbs — Clay-silt facies 0 to possibly 100 feet thick

QToa — Older (pre-Lake Bonneville) alluvium, ranging from coarse rounded gravel near mountain footslopes to sand and silt toward basin centers; locally cemented by caliche or travertine; exposed mostly above the Lake Bonneville shoreline; thicknesses are not well known but range to 500 feet in some areas, and may extend to 1000 feet in parts of Tooele Valley. Superscripts 1, 2, 3, indicate local relative age of remnants, where locally separable by age.

QTp — Pediments cut on Salt Lake group rocks and capped with a veneer (5 to 30 feet) of QToa.

UNCONSOLIDATED TO CONSOLIDATED DEPOSITS (Tertiary)

Tsl — Tertiary Salt Lake group; conglomerate, sandstone, siltstone, limestone, and tuffaceous deposits of estimated Miocene and Pliocene age. A section more than 8000 feet thick is exposed in Rush Valley (Heylmun, 1963). Some unconsolidated gravel, sand, and silt at depth in Tooele Valley is also of Salt Lake age.

CONSOLIDATED DEPOSITS

R — Bedrock pre-dating the major period of Basin & Range Formation (Eocene & older).

OTHER SYMBOLS

- Fault showing displacement of Quaternary surfaces; ball on downthrown side; dashed where inferred.
- Beach cliff (line) and shore platform (dots)
- Scarp of erosional or undetermined origin.
- Bedrock normal fault, with direction of offset indicated. (D, U)
- Vegetation lineation of possible tectonic origin
- Geologic boundary, dashed where inferred or approximately located
- 703 — Field location with identification number
- Location of selected wells and boreholes,

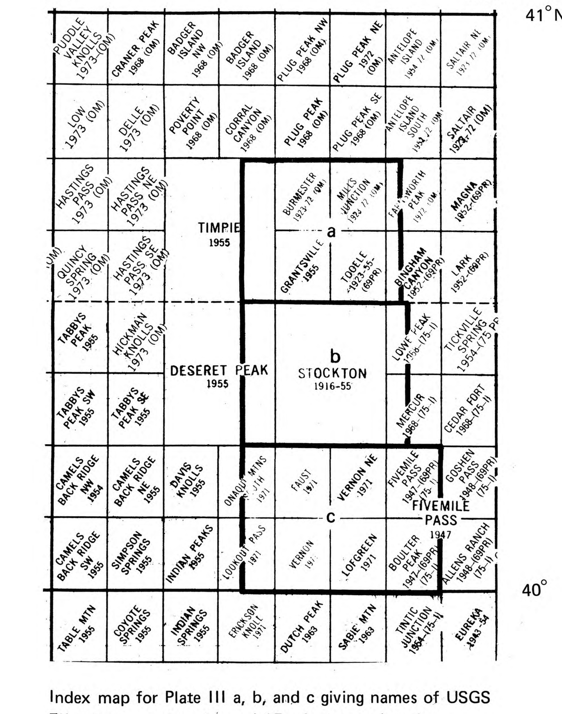
Sources:

The base map was mosaicked and reduced from U.S. Geological Survey 7½' and 15' topographic quadrangles.

Most of the area was mapped from 1953 U.S. Army 1:63,000 aerial photography (VVASM 15 to 21 AMS). A strip along the OBT fault zone was mapped in greater detail from 1959 U.S. Department of Agriculture 1:20,000 aerial photography (CYO), including parts of townships 7 & 8 south, Ranges 3 & 4 west on map IIIc, and parts of Townships 5 & 6 south, Ranges 4 & 5 west on map IIIb.

Selected bedrock faults are shown as mapped by Gilluly, 1932; Groff 1959; and Moore and Sorensen, 1978.

Parts of map IIIa were adapted from Tooker & Roberts, 1971: Geologic maps of the Garfield and Mills Junction Quadrangles; and from Davis, F. D., 1978, Surficial geology of western Bingham Canyon and Tooele 7½' Quadrangles, unpublished manuscript, UGMS.



Index map for Plate III a, b, and c giving names of USGS 7½ minute quadrangles and 15 minute quadrangles.

SURFICIAL GEOLOGY OF TOOELE AND RUSH VALLEYS

UTAH GEOLOGICAL AND MINERAL SURVEY
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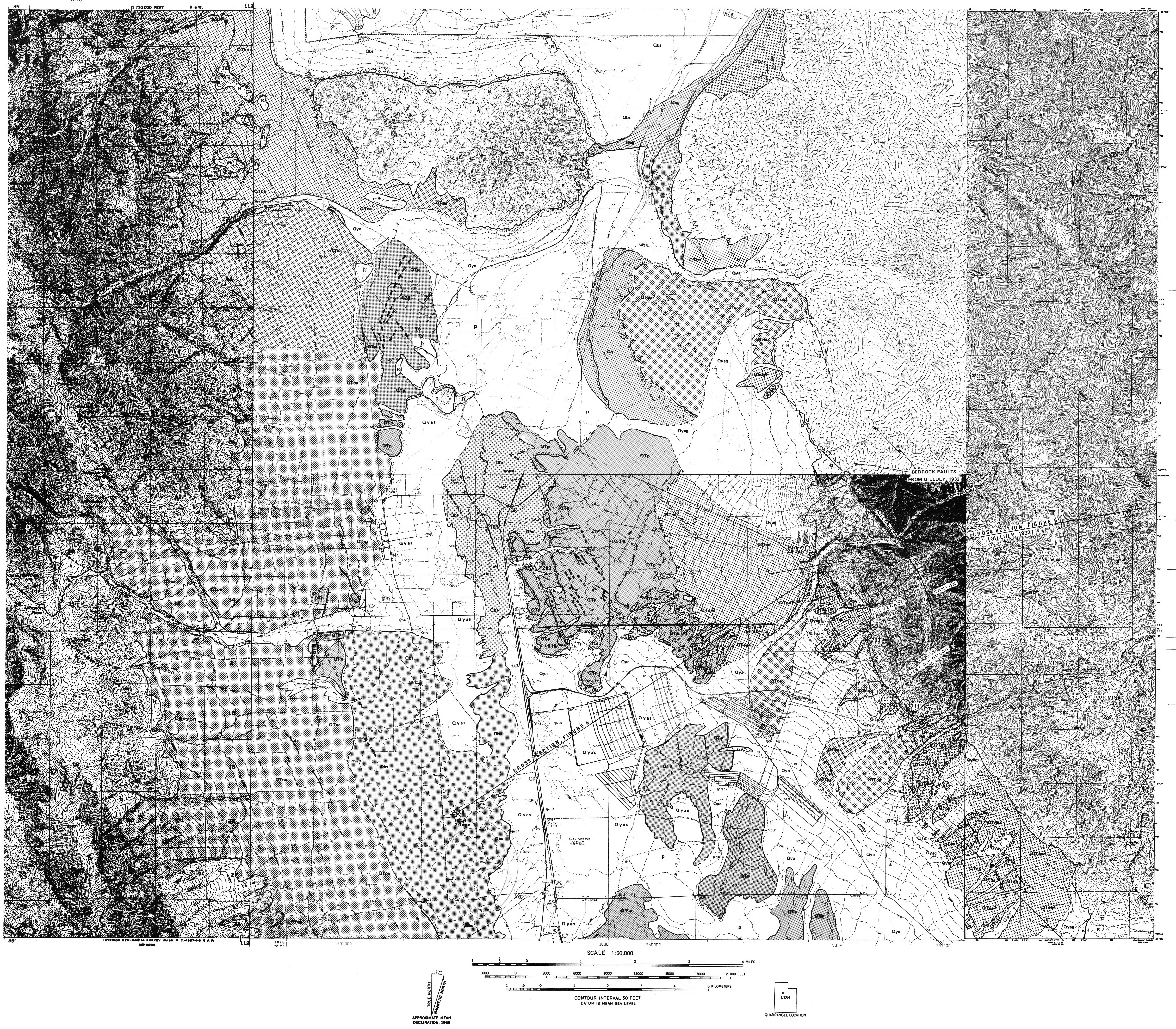
1979



Special Study 51

PLATE III b

Northern Rush Valley, Tooele County, Utah

EXPLANATION

SURFACES

p — Playa: flat, featureless, poorly drained unvegetated plains of silt or clay; mostly marginal to the Great Salt Lake below the historic high water contour of 4211 feet, and in the bottom of Rush Valley.

pc — Historic playa washover channels, sec. 9 & 10, T1S, R6W.

UNCONSOLIDATED DEPOSITS

Qmt — Modern mill tailings

Qya — Post-Lake Bonneville alluvium; mostly very thin sheets of sand or silt; boulder mudflow deposits near mountain fronts; shoreline features of the underlying Qb are obscured; 5-15 feet in thickness.

- Qyag — Sand-gravel facies.
- Qyas — Silt-clay facies.

Qd — Dunes or features modified by wind drift; those near present lake level are composed of calcareous oolitic sand, sometimes with a core of lake silt; up to 15 feet in thickness.

UNCONSOLIDATED TO PARTLY CONSOLIDATED DEPOSITS (Plio-Pleistocene)

Qb — Lake Bonneville shore deposits (Bonneville Group): mostly a thin veneer of gravel, sand, and silt, on which shoreline features are visible. Deposits of unconsolidated to weakly cemented gravel up to 200 feet thick occur primarily at the Bonneville shoreline (5200 to 5250 feet elevation), the Provo shoreline (4800 to 4850), and the Stansbury shoreline (4400 feet).

- Qbg — Sand-gravel facies 0 to 200 feet thick
- Qbs — Clay-silt facies 0 to possibly 100 feet thick

QToa — Older (pre-Lake Bonneville) alluvium, ranging from coarse rounded gravel near mountain footslopes to sand and silt toward basin centers; locally cemented by caliche or travertine; exposed mostly above the Lake Bonneville shoreline; thicknesses are not well known but range to 500 feet in some areas, and may extend to 1000 feet in parts of Tooele Valley. Superscripts 1, 2, 3, indicate local relative age of remnants, where locally separable by age.

QTp — Pediments cut on Salt Lake group rocks and capped with a veneer (5 to 30 feet) of QToa.

UNCONSOLIDATED TO CONSOLIDATED DEPOSITS (Tertiary)

Tsl — Tertiary Salt Lake group; conglomerate, sandstone, siltstone, limestone, and tuffaceous deposits of estimated Miocene and Pliocene age. A section more than 8000 feet thick is exposed in Rush Valley (Heylmun, 1963). Some unconsolidated gravel, sand, and silt at depth in Tooele Valley is also of Salt Lake age.

CONSOLIDATED DEPOSITS

R — Bedrock pre-dating the major period of Basin & Range Formation (Eocene & older).

OTHER SYMBOLS

- Fault showing displacement of Quaternary surfaces; ball on downthrown side; dashed where inferred.
- Beach cliff (line) and shore platform (dots)
- Scarp of erosional or undetermined origin.
- Bedrock normal fault, with direction of offset indicated.
- Vegetation lineation of possible tectonic origin
- Geologic boundary, dashed where inferred or approximately located
- 703 — Field location with identification number
- Location of selected wells and boreholes,

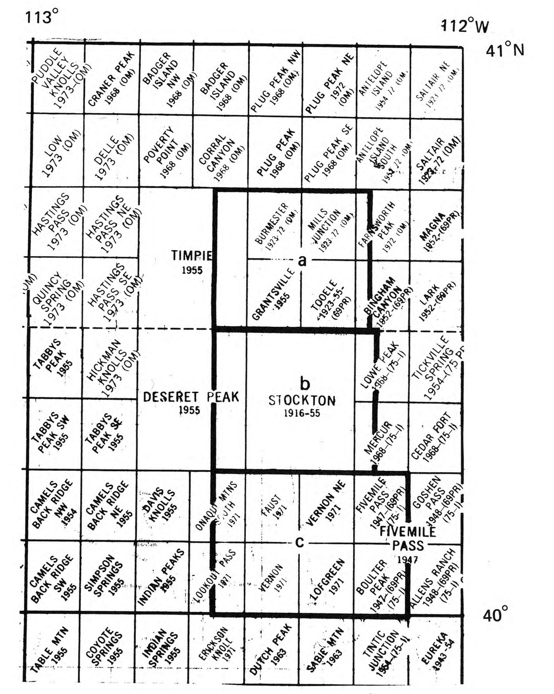
Sources:

The base map was mosaicked and reduced from U.S. Geological Survey 7½' and 15' topographic quadrangles.

Most of the area was mapped from 1953 U.S. Army 1:63,000 aerial photography (VVASM 15 to 21 AMS). A strip along the OBT fault zone was mapped in greater detail from 1959 U.S. Department of Agriculture 1:20,000 aerial photography (CYO), including parts of townships 7 & 8 south, Ranges 3 & 4 west on map IIIc, and parts of Townships 5 & 6 south, Ranges 4 & 5 west on map IIIb.

Selected bedrock faults are shown as mapped by Gilluly, 1932; Groff 1959; and Moore and Sorensen, 1978.

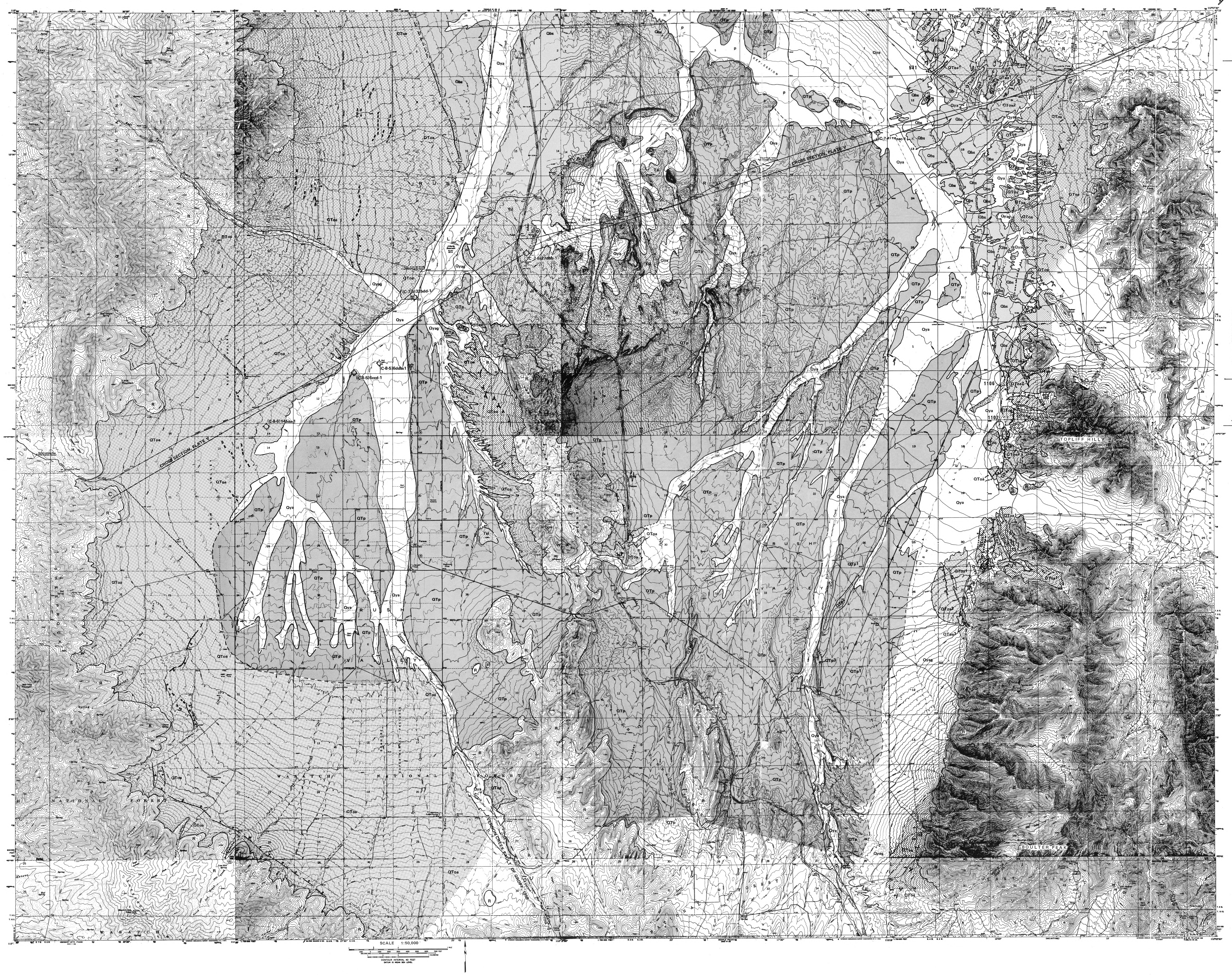
Parts of map IIIa were adapted from Tooker & Roberts, 1971: Geologic maps of the Garfield and Mills Junction Quadrangles; and from Davis, F. D., 1978, Surficial geology of western Bingham Canyon and Tooele 7½' Quadrangles, unpublished manuscript, UGMS.



Index map for Plate III a, b, and c giving names of USGS 7½ minute quadrangles and 15 minute quadrangles.

UTAH GEOLOGICAL AND MINERAL SURVEY
Urban and Engineering Geology Section
1979

SURFICIAL GEOLOGY OF TOOELE AND RUSH VALLEYS



531

SITE NUMBERS

1106

1107

Special Study 51

PLATE III c

Southern Rush Valley, Tooele County, Utah

EXPLANATION

SURFACES

p	Playa: flat, featureless, poorly drained unvegetated plains of silt or clay; mostly marginal to the Great Salt Lake below the historic high water contour of 4211 feet, and in the bottom of Rush Valley.
pc	Historic playa washover channels, sec. 9 & 10, T1S, R6W.

UNCONSOLIDATED DEPOSITS

Qmt	Modern mill tailings
Qya	Post-Lake Bonneville alluvium; mostly very thin sheets of sand or silt; boulder mudflow deposits near mountain fronts; shoreline features of the underlying Qb are obscured; 5-15 feet in thickness.
Qyag	Sand-gravel facies.
Qyas	Silt-clay facies.
Qd	Dunes or features modified by wind drift; those near present lake level are composed of calcareous oolitic sand, sometimes with a core of lake silt; up to 15 feet in thickness.

UNCONSOLIDATED TO PARTLY CONSOLIDATED DEPOSITS (Plio-Pleistocene)

Qb	Lake Bonneville shore deposits (Bonneville Group): mostly a thin veneer of gravel, sand, and silt, on which shoreline features are visible. Deposits of unconsolidated to weakly cemented gravel up to 200 feet thick occur primarily at the Bonneville shoreline (5200 to 5250 feet elevation), the Provo shoreline (4800 to 4850), and the Stansbury shoreline (4400 feet).
Qbg	Sand-gravel facies 0 to 200 feet thick
Qbs	Clay-silt facies 0 to possibly 100 feet thick
QToa	Older (pre-Lake Bonneville) alluvium, ranging from coarse rounded gravel near mountain footslopes to sand and silt toward basin centers; locally cemented by caliche or travertine; exposed mostly above the Lake Bonneville shoreline; thicknesses are not well known but range to 500 feet in some areas, and may extend to 1000 feet in parts of Tooele Valley. Superscripts 1, 2, 3, indicate local relative age of remnants, where locally separable by age.
QTp	Pediments cut on Salt Lake group rocks and capped with a veneer (5 to 30 feet) of QToa.

UNCONSOLIDATED TO CONSOLIDATED DEPOSITS (Tertiary)

Tsl	Tertiary Salt Lake group; conglomerate, sandstone, siltstone, limestone, and tuffaceous deposits of estimated Miocene and Pliocene age. A section more than 8000 feet thick is exposed in Rush Valley (Heylmun, 1963). Some unconsolidated gravel, sand, and silt at depth in Tooele Valley is also of Salt Lake age.

CONSOLIDATED DEPOSITS

R	Bedrock pre-dating the major period of Basin & Range Formation (Eocene & older).

OTHER SYMBOLS

Fault showing displacement of Quaternary surfaces; ball on downthrown side; dashed where inferred.

Beach cliff (line) and shore platform (dots)

Scarp of erosional or undetermined origin.

D U Bedrock normal fault, with direction of offset indicated.

Vegetation lineation of possible tectonic origin

Geologic boundary, dashed where inferred or approximately located

703 Field location with identification number

Location of selected wells and boreholes,

Sources:

The base map was mosaicked and reduced from U.S. Geological Survey 7½' and 15' topographic quadrangles.

Most of the area was mapped from 1953 U.S. Army 1:63,000 aerial photography (VVASM 15 to 21 AMS). A strip along the OBT fault zone was mapped in greater detail from 1959 U.S. Department of Agriculture 1:20,000 aerial photography (CYO), including parts of townships 7 & 8 south, Ranges 3 & 4 west on map IIIc, and parts of Townships 5 & 6 south, Ranges 4 & 5 west on map IIIb.

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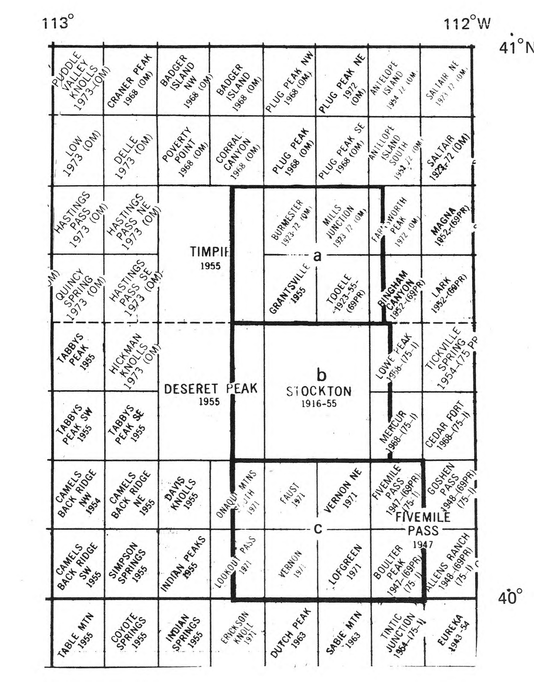

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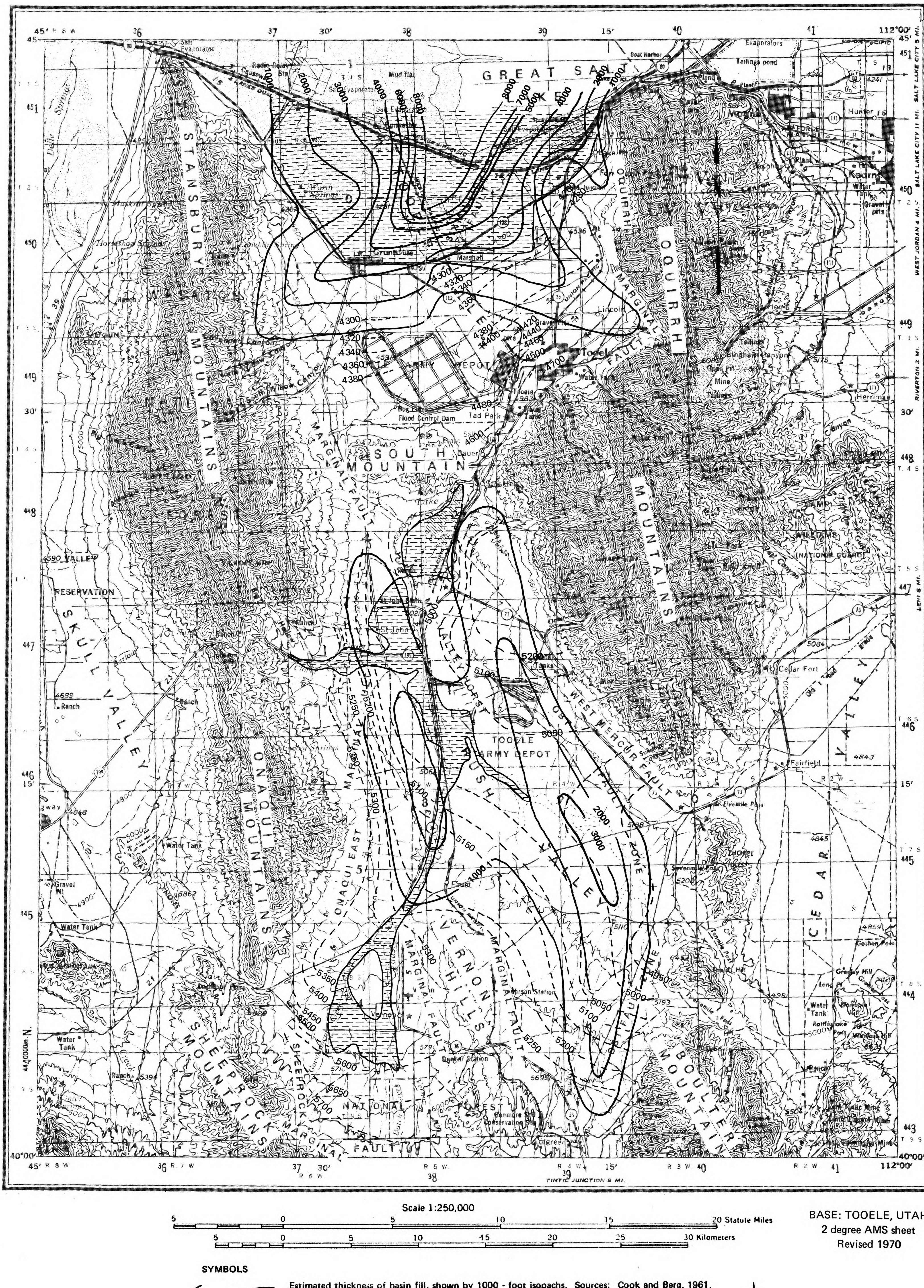

BASE: TOOELE, UTAH
2 degree AMS sheet
Revised 1970

SYMBOLS

4000 — Estimated thickness of basin fill, shown by 1000 - foot isopachs. Sources: Cook and Berg, 1961, Johnson, 1958; well logs from Gates, 1963 and Ryan and others, in preparation.

5150 - - - Piezometric surface of the principal aquifer. Source: Gates, 1965, Fig. 6.

Area occupied by phreatophytic vegetation, indicating an unconfined water table within 15 feet of the surface; coincides roughly with the area of artensian pressure. Source: Gates, 1965, Fig. 14.

N

GROUNDWATER LEVELS AND ESTIMATED THICKNESS OF BASIN FILL
Tooele and Rush Valleys, Utah