Geologic Hazards in Morgan County with Applications to Planning

by B.N. Kaliser

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah

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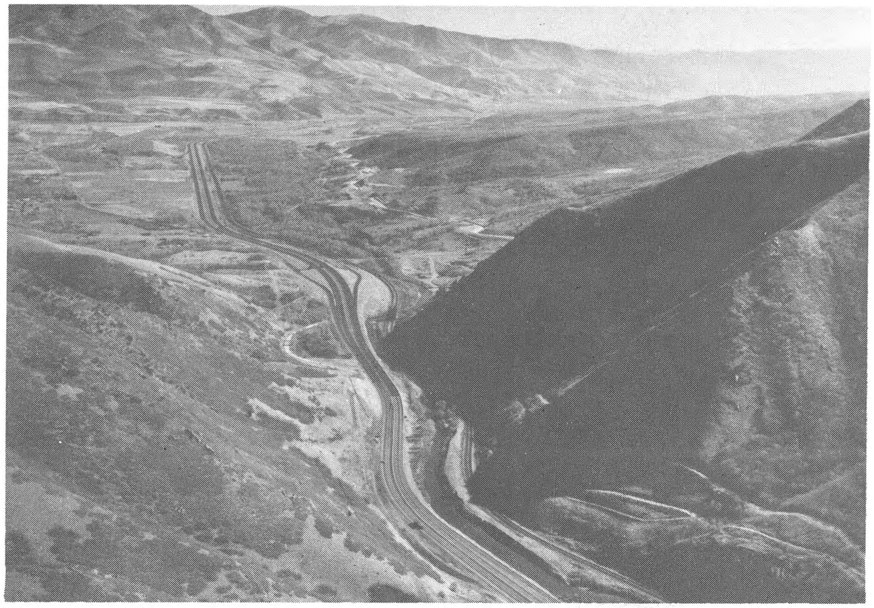

East view across Weber Canyon from Morgan-Weber County line.

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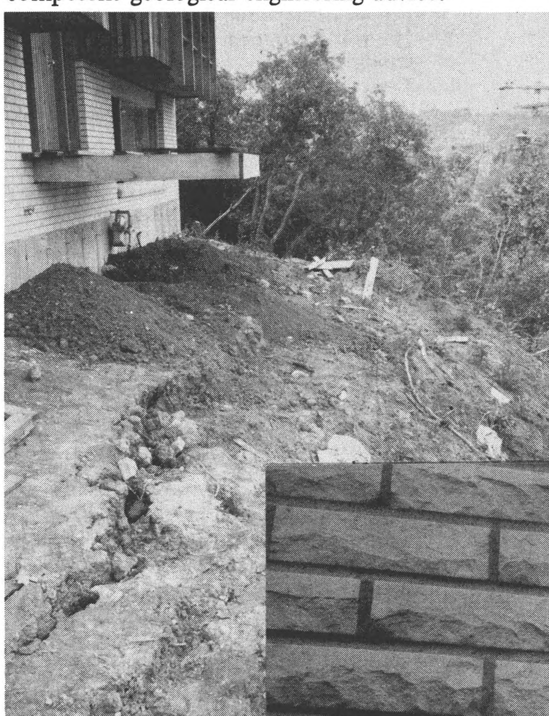
FOREWORD

The important initial step to development is the recognition of potentially unstable areas; some, by proper distribution of homes and ancillary utilities, by removal of unstable forces within the mass or by utilization of proper engineering design, can be subdivided safely. Others, for the protection of the rights of society, should be condemned.

A study of soil-stability conditions of Morgan County's mountainous terrain is the basis for this bulletin. It was requested by the Morgan County Commission, supported by appropriations from the county and from the budget allocated the Utah Geological and Mineralogical Survey by the State Legislature and reported to the Morgan County Commission in Report of Investigation No. 57, "Geologic Hazards in Morgan County with Applications to Planning" (June 17, 1971). That study and its results are a first step.

This report, however, is not a cure-all. All proposed sites for subdivisions should be field checked and those who subdivide should use this report in conjunction with competent geological engineering advice.



It is our belief that Morgan County, through its concern for natural hazards, will be recognized as among the first political entities of the State to promote the orderly subdivision of foothill and mountainous terrain. It is also our belief that Morgan County's full potential remains to be realized and the Utah Geological and Mineralogical Survey is pleased to have had this role in the future development of the County.

W. P. Hewitt
Director, UGMS

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WITH APPLICATIONS TO PLANNING

by Bruce N. Kaliser[1]

INTRODUCTION

With the greater accessibility afforded by the construction of Interstate 80 through Weber Canyon has come an opportunity for the economic rejuvenation of Morgan County.

Residential communities will continue to be developed to serve an indigenous working population and an increasingly greater number of Wasatch Front commuters. The 1970 census indicates that Morgan County gained second most in the state in population percentage (40.4 percent) for the previous decade when 13 of Utah's 29 counties lost population during the same period.

Directly proportionate with the growth of the county will come an increase in hillside development. Subdivision of the relatively gentle slopes is inevitable; *proper* subdivision is, unfortunately, not inevitable. In the interest that development take place under the best possible conditions, the Utah Geological Survey undertook this study to expose hazards of the physical environment and to examine them sufficiently so that ignorance of them no longer prevails.

Tests and analyses performed in conjunction with this study are in no way intended to replace on-site examination and testing for a specific area and project; conditions over an area as large as Morgan County may be expected to differ significantly. It is hazardous to extrapolate data from a limited area to a larger area or to one some distance away.

ACKNOWLEDGEMENTS

The assistance of G. C. Toland, W. J. Gordon and R. E. Versaw with soils engineering data is gratefully acknowledged. Arlo Richardson, state climatologist, provided table 1. Roy Zaugg of Mountain Green monitored the landslide strain gage. Clay mineral determinations were made by Raymond Kerns, Utah State University. A. P. Plummer, U. S. Forest Service, assisted in compiling a list of plant types which resist erosion.

[1]Engineering geologist, Utah Geological and Mineralogical Survey, Salt Lake City, Utah.

GEOLOGY

Geologic formations with similar engineering characteristics were mapped as a single unit. The areal extent and engineering characteristics of each of the seven units are outlined on the Engineering Geology Map of Morgan County (plate 1).

The most hazardous terrain consists of mudstone, sandstone, marl and conglomerate of the Tuffaceous Member of the Salt Lake Formation. The beds of this formation contain varying amounts of volcanic debris, some of which has broken down to clay minerals. The clay content of the formation most frequently creates problems of mass movement, slope stability, expansiveness and sewage effluent removal. The rock is generally soft to medium hard, possibly with no clear distinction between weathered material (soil) and bedrock. Weathered material has moved downslope by the process of creep aided by water and gravity. The material, termed colluvium, varies widely in thickness as a cover over *in situ* material. It is generally a bouldery, silty clay soil; its soil parameters are remarkably uniform over a wide area.

Bouldery and cobbly conglomerate and sandstone also may have a thick colluvial cover with similar characteristics to the colluvium materials above. Strata may be interbedded with tuffaceous material of significant clay content which could pose problems of slope stability and sewage effluent removal. Much of the sandstone and conglomerate may not be readily rippable.

Crystalline rocks of gneiss, schist and pegmatite are hard and stable except where highly fractured. Some slopes were oversteepened during the Ice Age in the high elevations. Thicknesses of loose soil may vary considerably, even over short distances.

Limestones and dolomites are normally quite resistant except where highly fractured locally. They may store groundwater which should be protected from individual sewage systems. Soils are likely to be clayey with no great thickness. Terrain is generally steep.

Shale formations with alternating sandstone beds are normally rippable to the depth of residential foundations. Shale may yield a soil which is not satisfactory for sewage effluent absorption. Soil erosion also could be a potential problem.

Sandstone and quartzite are resistant and blasting may be required. Problems in this terrain are minimal other than with relatively steep topographic slopes.

Loose alluvial and lacustrine deposits of gravel, sand and silt are most satisfactory for development. Topographic gradients are low. The water table when shallow is the major hazard and the seasonal fluctuation of the water table should be determined prior to a land-use decision. The shallow soil may be coarse and excessively permeable, permitting sewage effluent to readily reach the water table. Lake Bonneville deposits, a source of sand and gravel and satisfactory fill material, may occur as a cover of variable thickness up to about elevation 5,200 feet. Organic soil thickness, especially near drainages, may be great necessitating removal of considerable material for foundation placement.

In general the foothill areas of most favorable topographic gradients and subtle relief are those in which the geology is least favorable. Landslides have occurred in the past and problems of slope stability are anticipated in the future. Existent landslides are shown on plate 1 and in Appendix I in greater detail on large-scale maps. Plate 2 indexes the larger-scale maps.

CLOUDBURST FLOOD HAZARD

Between May and September high intensity, short duration summer storms affect land use by the tremendous release of water that follows such cloudburst activity. The runoff is frequently of sufficient volume and velocity to cause considerable damage and destruction to ill-placed works of man. Debris carried by the runoff is ultimately redeposited downslope.

Cloud bursts are localized in their extent and only flooding of small normally dry watersheds may be involved; neighboring drainages often remain unaffected.

Historical Account

Relatively fresh-looking alluvial fans at the mouths of dry drainages attest to debris movement prior to the relatively recent pioneer settlement in the county. Several damaging flash floods are recorded in Morgan County. Four cloudburst floods in Morgan are plotted on Woolley's map (1946, plate 6) which shows cloudburst occurrences over the state from 1850 to 1938. These occurrences are plotted over Mountain Green, Morgan, Devils Slide and Croydon on the 1:750,000 map. Four more events in Morgan County are listed in a subsequent publication dealing with the period from 1939 to 1969 (Butler, 1971).

Deseret News (8/19/89) reported a downpour caused landslide problems that halted rail traffic through Weber Canyon on August 16, 1889; fruit crops in Morgan County suffered from a cloudburst on June 15, 1892 (*Deseret News*, 6/16/92).

On July 28, 1917, the town of Morgan was directly affected by a two-hour thunderstorm which swept boulders and gravel out of a dry hollow north of town. Damage to lawns, gardens, orchards and buildings was estimated at $2,000 (*Deseret News*, 7/28/17).

Another cloudburst reported at Morgan on April 17, 1951 (Butler, 1971) was not recorded at the Morgan Weather Observation Station, which illustrates the spotty nature of the phenomenon.

Several thousand dollars damage resulted in Richville from flooding on July 18, 1954; about 3 to 4 feet of water inundated the Waldron farm demolishing an implement shed and heavy farm equipment. The 1-mile wide by several miles long storm system dumped approximately ½ inch of water in one hour. Precipitation recorded at Morgan for the 24-hour period of July 18th was .42 inches.

On August 16, 1958, a deluge centering on Round Valley about 2½ miles east of Morgan carried hundreds of tons of boulders and mud onto farms and blocked the highway at the lower end of Round Valley for several hours with debris 4 feet thick and 40 feet wide. Water stood to a depth of several feet on the highway. Debris was deposited in corrals, hay fields and irrigation ditches of the farm at the mouth of Yence Hollow (figure 1). Up to 3 or 4 feet of mud and boulders were deposited around the barn and across the fields which sit upon an alluvial fan (Rees, 1971). Erosion up Yence Hollow was extensive. Indications are that two coinciding storms

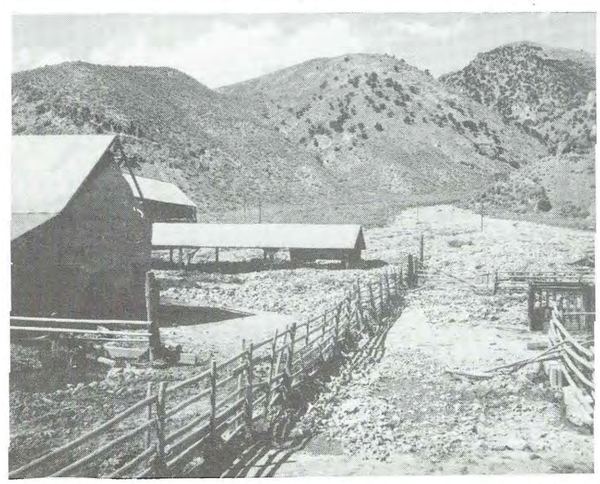


Figure 1. Debris deposited on alluvial fan at mouth of Yence Hollow (north) after storm of August 18, 1958 (Soil Conservation Service photo).

Table 1. Estimated return periods for short-duration precipitation, town of Morgan (Morgan Station, 41°02′ lat., elevation 5,000 feet).

	Minutes				Hours					
Return Period (years)	5	10	15	30	1	2	3	6	12	24
1	.17	.27	.34	.47	.59	.64	.68	.79	.89	.99
2	.19	.30	.38	.53	.67	.74	.81	.97	1.12	1.27
5	.22	.35	.44	.61	.77	.88	.98	1.23	1.46	1.69
10	.26	.40	.51	.70	.89	1.01	1.12	1.41	1.66	1.93
25	.28	.43	.55	.76	.96	1.13	1.28	1.68	2.03	2.40
50	.30	.47	.60	.83	1.05	1.24	1.42	1.88	2.29	2.71
100	.33	.51	.64	.89	1.13	1.35	1.56	2.08	2.55	3.03

created this situation, one from the southeast, the other from the northwest. Covering an area about 3 miles wide, up to 10 inches of rain may have dropped locally in the one-hour-duration event. A "bucket survey" indicated 2½ inches in Morgan. Five inches of water accumulated in each of two gas cans at Como Springs and 6½ inches in a third. At the Rees farm 10 inches of water in a tilted milk pail were estimated to represent 7 inches of precipitation for the one-hour storm (Butler, 1971). Some of these measurements of precipitation are believed to be the greatest ever measured in the state for a storm of one-hour duration. Peak flow for one small drainage basin (75-acre area) was determined to be 450 cfs (3,840 cfs/sq. mile; Butler, 1971).

Prediction

Estimated return periods, or recurring event frequency, for short-duration precipitation for localities across the country are important for the purposes of prediction and for design of drainage structures. At the request of the author, E. A. Richardson, state climatologist, prepared table 1 for the town of Morgan for durations between 5 minutes and 6 hours and return periods from 1 to 100 years, using a computer program.

For coverage of the entire county, figures 2, 3 and 4 show durations of 6 hours and return periods of from 2 to 100 years. The 6-hour duration map is the minimum short-period precipitation record available to date. One-hour duration maps would be still more useful were they available. Nevertheless, an idea of flooding magnitude for short-duration precipitation periods can be derived from the 6-hour precipitation maps.

Table 2, in conjunction with table 1 and figures 2, 3 and 4, estimates the number of years for given probability levels that an event with various return periods could occur for the *first* time.

The following example illustrates the use of the tables and figures. Consider the one-hour precipitation amount at Morgan that can be expected once in 5 years. Refer to table 1 under the column labeled "1 hr." and the row labeled "5"; the amount is .77 inches. This means that .77 inches of rain can be expected to fall in 1 hour at Morgan once in every 5 years. This result can be further interpreted with the use of table 2 to show that with a return period of 5 years, the event could occur for the first time in seventeen months (1.4 years) with a probability of 25 percent or within 42 months (3.5 years) with a probability of 50 percent or within 8 years with a probability of 80 percent. There is a 50-50 chance, then, that a cloud burst in Morgan will yield .77 inches for the first time in 3.5 years.

From figure 3b showing a 25-year return period for a 6-hour precipitation, Mountain Green falls under the 1.80 isopluvial line (i.e., may expect precipitation of

Table 2. Estimated number of years for given probability levels that an event with varying return periods will occur for the *first* time.

	Return Period (years)						
Percent Probability	1	2	5	10	25	50	100
5	0.1	0.1	0.3	0.5	1.3	2.6	5.1
10	0.1	0.2	0.5	1.1	2.6	5.3	10.5
20	0.2	0.5	1.1	2.2	5.6	11.2	22.3
25	0.3	0.6	1.4	2.9	7.2	14.4	28.8
30	0.4	0.7	1.8	3.6	8.9	17.9	35.7
40	0.5	1.0	2.6	5.1	12.8	25.6	51.1
50	0.7	1.4	3.5	6.9	17.3	34.7	69.3
60	0.9	1.8	4.6	9.2	22.9	45.8	91.6
70	1.2	2.4	6.0	12.0	30.1	60.2	120.4
75	1.4	2.8	6.9	13.9	34.7	69.3	138.6
80	1.6	3.2	8.0	16.1	40.2	80.5	160.9
90	2.3	4.6	11.5	23.0	57.6	115.2	230.3
95	3.0	6.0	15.0	30.0	74.9	149.8	299.6

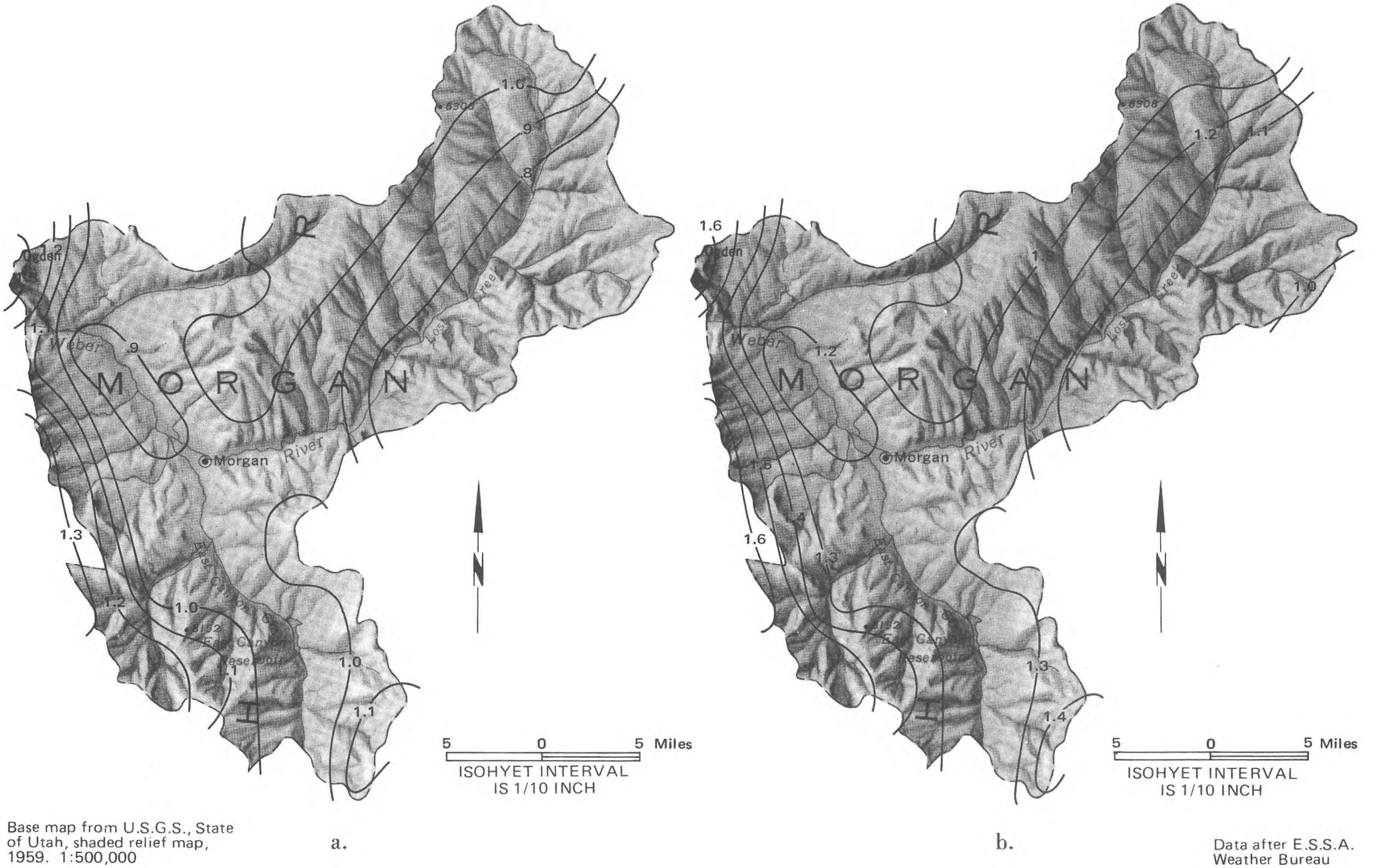
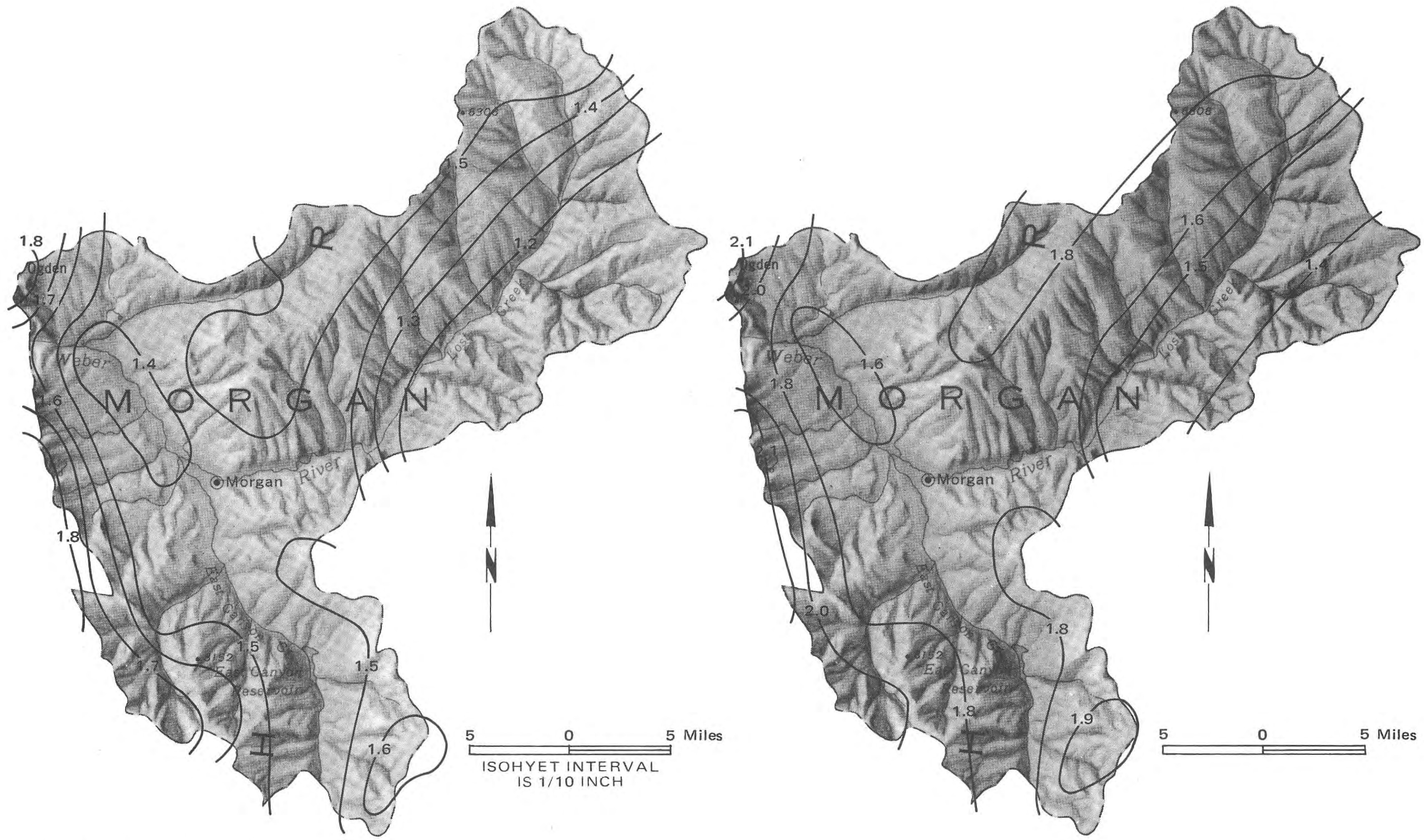


Figure 2. Short duration rainfall maps: (a) 2-year return period; precipitation for 6-hour duration and (b) 5-year return period; precipitation for 6-hour duration.



Base map from U.S.G.S., State of Utah, shaded relief map, 1959. 1:500,000

a.

b.

Data after E.S.S.A. Weather Bureau

Figure 3. Short duration rainfall maps: (a) 10-year return period; precipitation for 6-hour duration and (b) 25-year period; precipitation for 6-hour duration.

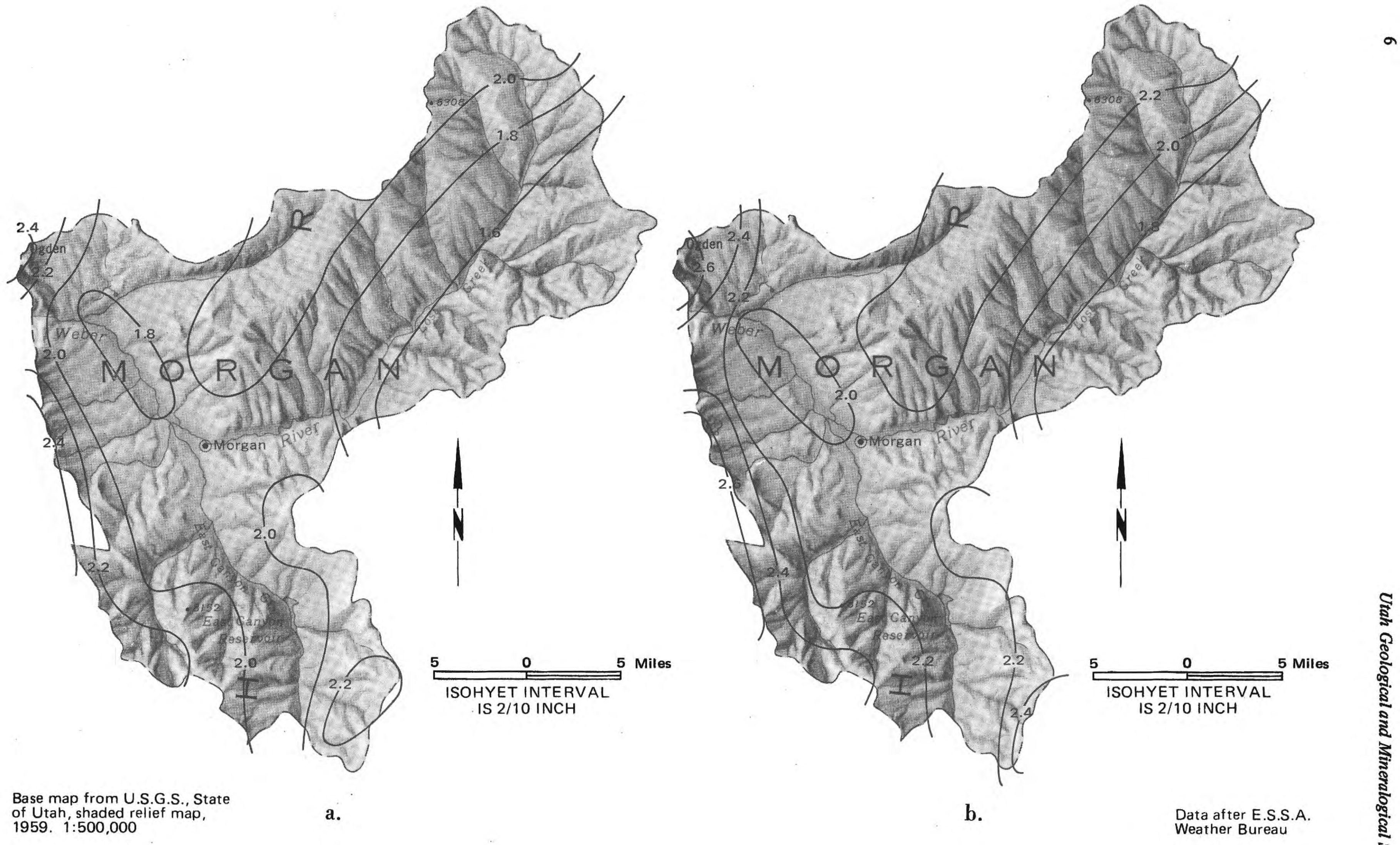


Figure 4. Short duration rainfall maps: (a) 50-year return period; precipitation for 6-hour duration and (b) 100-year return period; precipitation for 6-hour duration.

1.8 inches). From table 2, a 50-50 chance exists that a 6-hour storm could yield 1.8 inches of rainfall for the first time in 17.3 years.

EROSION POTENTIAL

The soils comprising the hillsides which are most likely to be developed in Morgan County fall into the classification CL/ML (Unified Soil Classification System Designation: CL = low plasticity clay; ML = low plasticity silt). This means they largely fall on the borderline between easily eroded (ML) and erosion-resistant (CL) soils. On-site determination of soil type is desirable. With increasing clay binder in the soil, resistance to erosion generally increases.

Erosion Control

Erosion results from drag forces caused by wind, water, snow and ice acting on the surface particles of a slope. Through proper engineering, drag forces may be reduced by (1) dispersion of runoff on the surface of the slope, (2) reduction of total water discharge on the slope and (3) provision of drainage channels of appropriate gradients and shapes to minimize velocity of flow.

The most important force in Morgan County, flowing water, increases proportionately with the velocity of flow. To reduce water flow, the maximum rainfall that may be expected over a short duration of time must be considered (tables 1 and 2 and figures 2, 3 and 4). Maximum discharge determinations must include water reaching the slope from higher tributary areas as well as precipitation falling over the actual slope in question. Allowances for the effects of the anticipated residential construction on runoff and drainage must be made.

Preventing erosion by increasing the resistance of the slope with structural devices, soil stabilization of flow channels, mulching, wattling, contour trenching and use of suitable vegetation is equally important. Table 3 lists suitable shrubs, forbs and grasses for erosion prevention and slope stability. The table was compiled with the help of A. P. Plummer, U. S. Forest Service scientist (Plummer and others, 1968). The clayey nature of the soil has considerable advantage in planting because of its moisture retaining capacity.

The importance of vegetation is exemplified by Los Angeles' Green Hills law which requires that plantings be established on slopes immediately after they are created in the cutting or filling operations by the contractor. Shrubs must be placed at most 10 feet apart and trees 20 feet; groundcovers can be planted no more than 18 inches apart. Groundcovers are used on a low slope and on the lowest 15 feet on all slopes. Shrubs and trees may be used above 15 feet. Along terraces shrubs must be planted 2 feet apart. Temporary plantings of forbs may be desirable between trees and shrubs until the latter provides adequate cover.

The removal of moisture from the ground by plant transpiration helps eliminate an agent of sliding, subsurface water.

Maximum permissible velocities for earth slopes without vegetation is between 2 and 4 feet per second.

LANDSLIDING AND SLOPE STABILITY

Most landsliding occurrences predate man's occupation of the area and have gone unrecorded, but evidence of landsliding in the past in Morgan County is ample. *The Standard* (8/19/89) recorded one slide which interfered with rail traffic in the vicinity of Devil's Gate and aerial photographs revealed landslides which are plotted on the topographic base maps (Appendix I, figures 9 to 35). No time of occurrence has been established for these ancient landslides but some are still active presently. A portion of the slide in the northeast corner Sec. 27, T. 5 N., R. 1 E. is still moving; recent scars are visible from the hillside on the other side of the Gordon Creek drainage to the east. Nothing that man has done has affected this particular slide to date. Developments have, however, rejuvenated slides nearby and herein lies one of the most serious hazards to future subdivision. Tampering with terrain that has failed before is obviously serious. Grading for lots and streets, trenching for utilities and later water from lawn irrigation, septic tank filter fields and leaking water lines all modify the original environment—and most frequently in a detrimental manner.

Numerous landslides in Morgan County indicate the potential instability of a considerably larger portion of the county. Terrain modification, in many cases, will trigger additional failures unless proper caution is exercised. Conspicuous sliding along the Weber Basin canal on the south side of the valley provides ample proof of this. One culvert tunnel observed by the author beneath the canal had approximately 2 inches of displacement along a single joint in the pipe. In single residences, once sliding begins, it is normally not economically feasible to try to correct the situation.

Field Investigation

Landslides were investigated in the field to determine at what slope angles failures ensued. All the slides investigated were in Salt Lake Formation colluvium and soils. Failures were observed in reactivated landslides and previously unfailed slopes; most of the failures were man induced. The results of the field investigation are given below:

a. Natural slopes greater than 1-1/2 (33-2/3°) are mostly unstable;

b. The maximum allowable cut-slope angle should be 2:1 (26-1/2°);

Table 3. Ratings of suitability, by species characteristics, for use in erosion and slope stability control.

Species	Initial establishment	Growth rate	Final establishment	Persistence	Germination	Seed production and handling	Ease of planting	Natural spread	Herbage yield	Availability of current growth	Soil stability	Range of adaptation	Resistance to disease & insects	Compatibility with other plants	Ease of transplanting	Composite suitability index[1]
							SHRUBS									
Apache-plume	2[3]	2	3	4	4	3	4	4	3	4	4	2	4	5	3	71
Bitterbrush, antelope[2]	4	3	4	4	5	5	5	2	4	4	4	4	4	5	3	80
Bladdersenna, common	3	4	4	3	5	4	5	1	3	3	3	2	3	3	4	62
Ceanothus, Martin	3	3	5	5	3	1	3	4	4	3	5	4	5	4	4	75
Chokecherry, black	2	3	4	5	4	5	4	4	5	4	5	3	3	4	3	78
Cinquefoil, bush	2	3	4	5	2	2	3	3	3	3	4	2	4	4	4	65
Cotoneaster, Peking	2	2	3	4	2	4	4	2	3	4	4	3	4	3	4	65
Currant, golden	4	4	4	4	3	3	5	4	4	5	4	3	3	4	4	78
Cypress, Arizona	3	3	4	4	3	3	4	1	3	3	3	3	4	3	4	67
Elder, blueberry	2	5	5	5	1	3	4	3	5	4	4	4	5	5	4	79
Ephedra, green	4	2	4	5	5	3	5	3	3	4	4	4	5	4	3	80
Honeylocust	3	3	4	5	3	3	4	3	3	3	3	3	3	3	5	63
Honeysuckle, bearberry	1	3	4	5	2	2	2	3	4	4	4	2	4	4	5	71
Juniper, Rocky Mountain[2]	1	2	4	4	2	3	5	5	3	4	3	4	4	2	3	70
Lilac, common	1	3	4	5	3	3	3	2	4	4	4	3	5	3	5	72
Maple, Manchurian[2]	1	2	2	2	3	3	3	2	1	3	2	2	3	2	4	48
Maple, mountain	1	2	2	2	2	3	2	3	2	3	3	2	3	2	2	48
Matrimony-vine	2	4	4	4	3	2	4	4	3	3	5	4	4	3	5	69
Mt.-mahogany, curlleaf	2	1	3	4	4	3	3	3	2	3	3	2	3	2	2	61
Mt.-mahogany, true or birchleaf	3	2	2	4	4	3	4	4	3	4	4	2	3	2	2	64
Rabbitbrush, rubber	3	5	4	4	4	3	3	5	5	5	5	5	3	4	4	83
Sagebrush, big	4	5	5	5	4	4	4	5	5	5	4	5	3	3	5	86
							FORBS									
Alfalfa	5	5	4	4	5	5	5	2	4	3	4	5	3	5	4	82
Bouncing-bet	4	4	4	5	5	4	5	3	4	3	5	4	5	3	5	82
							GRASSES									
Bluegrass, Kentucky	3	2	4	5	4	5	5	4	3	3	5	4	4	3	5	80
Brome, smooth (Southern)	3	4	5	5	5	5	4	4	5	4	5	4	4	3	5	86
Orchardgrass	4	5	3	3	5	5	5	4	4	4	4	3	4	5	3	78
Wheatgrass, bluestem	3	3	5	5	3	4	4	5	3	3	5	4	5	4	2	78
Wheatgrass, crested (fairway)	5	5	4	4	5	5	5	5	4	4	4	5	4	4	5	87
Wheatgrass, intermediate	5	5	5	5	5	5	5	4	5	4	5	5	4	3	5	90
Wheatgrass, pubescent	5	4	5	5	5	3	4	4	4	4	5	5	4	3	5	84

[1] 100 is possible
[2] Suggested as particularly suitable
[3] Key to ratings: 1. Very poor, 2. Poor, 3. Medium or fair, 4. Good, 5. Very good

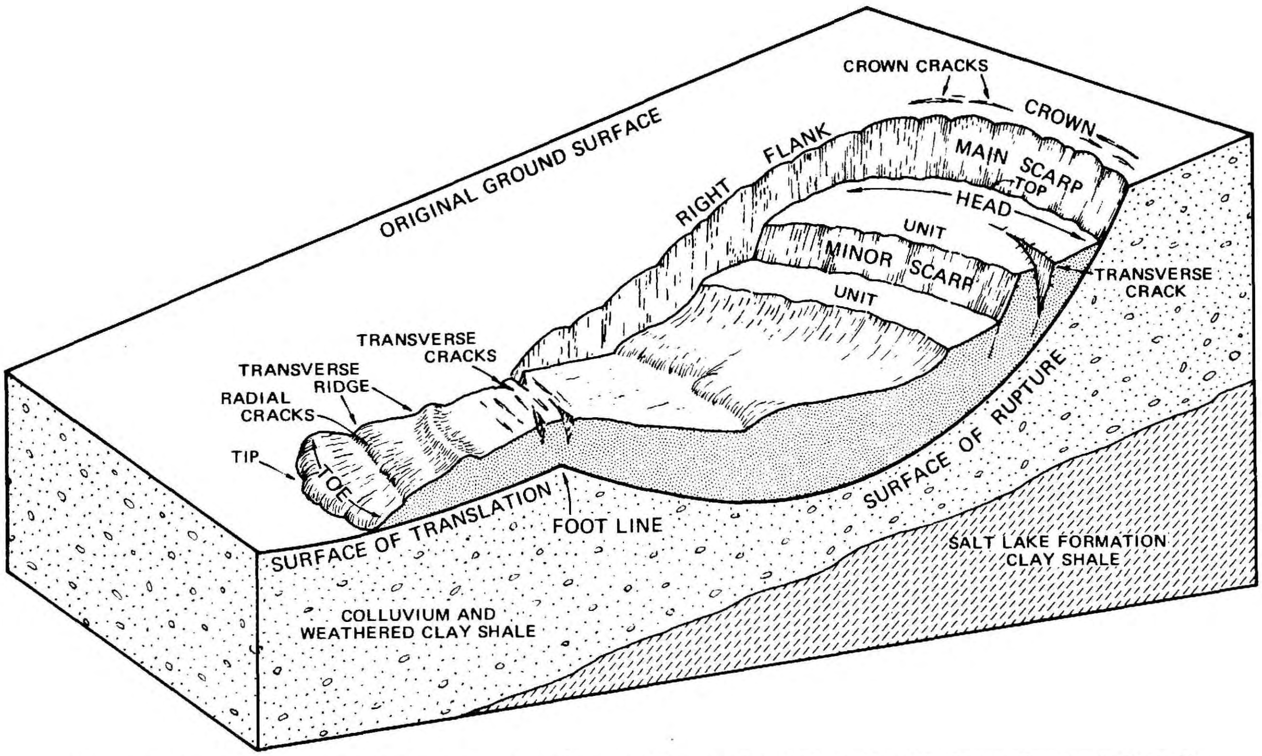


Figure 5. Typical form of slides occurring in Morgan County (modified after Highway Research Board).

c. The maximum allowable cut-slope angle without further geologic and soils analysis should be 2-1/2:1 (22°) and

d. The maximum allowable cut-slope on an old landslide should be 3:1 (18°).

These conclusions were derived from slides on north-, south-, west- and east-facing slopes. Geologic structures (fractures, faults, etc.) were judged not to have been involved, even in the few instances in which bedrock (Salt Lake Formation) may have been involved. To cut bedrock, however, attitude of bedding and jointing and faults, if any, must be considered. Adverse dips of beds, for example, could cause bedding plane failures.

Two landslides, both reactivated old slides in colluvium, were studied in considerable detail. An extensometer was placed to span the main scarp (figure 5) of a 100-foot-long slide in the northeast corner of Sec. 27, T. 5 N., R. 1 E. Figure 6 shows the vertical displacement of the slide head as recorded by the extensometer and also the record of precipitation. A correlation is evident between precipitation and movement of the slide mass. Total vertical displacement during the 5-month period was slightly greater than ¼ inch. Several months prior to the instrument installation, a drainage system was placed in the slide. This study demonstrated the creep-type failure that can occur in the colluvium.

A second landslide, 94 feet long and 180 feet wide, was given a soil mechanics treatment for determination of slope stability. Data on this slide were fed into a computer for analysis. Soil parameters were C (cohesion) equal to 650 pounds per square foot and ϕ (angle of internal friction) equal to 0°. The minimum factor of safety (the maximum possible resistive force divided by the driving forces), utilizing the circular mode of failure, was determined by the computer to be 1.3. For the slide to fail (factor of safety of 1.0), a cohesion of 500 pounds per square foot is required rather than the value of 650 pounds per square foot which was derived from the laboratory test data. Using the figure 500 psf, a graph was prepared (figure 7) which shows the height of slope versus maximum slope angle for a factor of safety of 2.0. This graph provides data which serve as a guideline for establishing the steepness and height of slopes in Salt Lake Formation soils and colluvium.

In addition to soil parameters, other considerations of slope stability follow.

Shrinkage cracks filled with water from surface runoff exert hydrostatic pressure on the sides of the

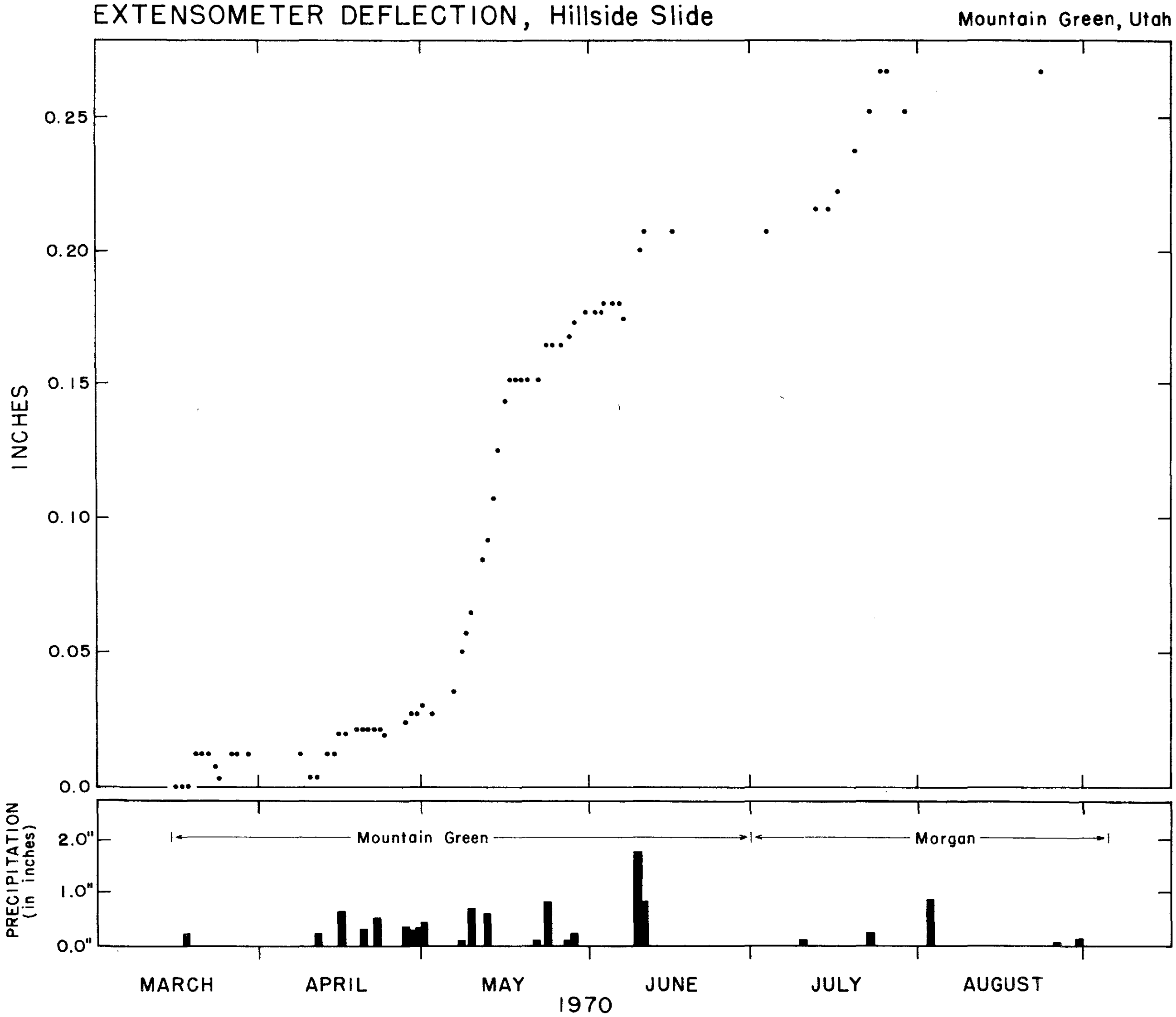


Figure 6. Extensometer deflection indicating rate of vertical displacement of landslide mass.

crack. Even healed shrinkage cracks may act as hidden planes of weakness which have a much lower strength than the clay. On swelling, clays also tend to lose strength.

In some slopes, seepage forces of subsurface water act in the direction of flow, which is generally towards the face of the slope. Seepage forces reduce resistance of the slope to failure.

Loading the slope by placing fill on it (figure 8a) also may be critical, particularly on the head or foot of an old slide, because it increases the driving force. Slope height is also relevant (figure 7). To remove support from a slope by undercutting at the toe creates certain instability.

Vegetative cover also plays a significant part. Roots act as a mechanical reinforcer and they dry out surface layers. Transpiration depletes soil moisture and produces negative pore-water pressure which is conducive to slope stability. Water is also intercepted by above-ground growth and ground litter. Snow accumulation also may be affected.

A landslide may be avoided by relocation of structures, eliminated by complete excavation and flattening of the slope or subjected to measures for correction: (1) surface and subsurface drainage, (2) selective removal of slide material and replacement with properly compacted fill to increase the soil strength and (3) structural retention by properly designed and constructed retaining walls, buttresses, etc.

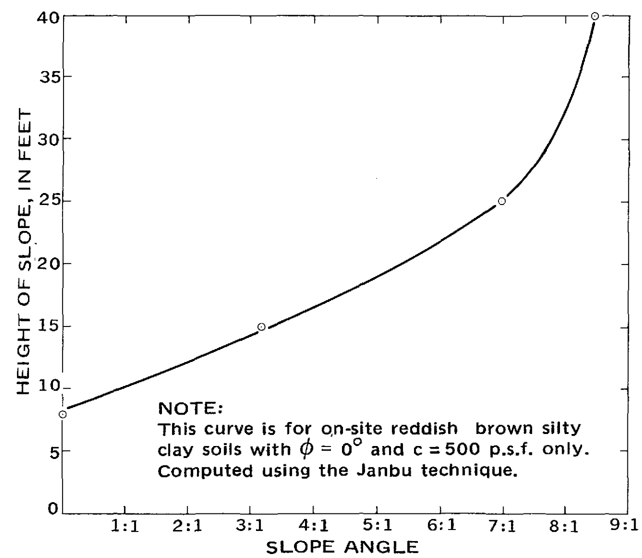


Figure 7. Height of slope versus slope angle for factor of safety of 2.0.

Drainage Modification

With a cloudburst flood potential it appears obvious that modification of any stream course, whether perennial or intermittent, is hazardous to riparian interests.

Another facet must be given consideration as well. Any change in a channel may alter the eroding or load carrying capacity of a stream, at least over some length of the channel. An increase in erosive capacity can undermine the toe of an old slide or a precarious slope and thereby accelerate landsliding. This acceleration may create an instantaneous failure which might block the entire channel. A subsequent surge over or through the damming slide could cause a flood downstream, which might trigger increased mass movement.

A landslide intruding into a stream channel will cause aggradation of sediment upstream from the point of incursion; the stream rises from its incised valley which leads to latteral corrasion and, therefore, greater slope instability. A man-made embankment across a channel would have the same effect.

It is not known what part of the total sediment load carried by Morgan County streams is contributed by debris from sliding slopes; some is certain, however. Certain types of land-use aggravates these mass movements and increases the stream load. The sediment yield may affect fish habitat or loss of reservoir storage capacity downstream.

Clearly, any degree of drainage modification must involve considerable forethought, especially in the vicinity of or upstream from old landslides or marginally unstable slopes.

EARTHQUAKE EFFECTS

A recurrent threat to Morgan County, particularly in hillside developments, may be earthquakes that originate along the Wasatch Front. A medium- to high-magnitude quake in the Ogden vicinity, for example, easily shakes houses in Morgan; earthquakes originating some distance from the county line have been felt in Morgan town. Hillside slope failures likely would be triggered by such a tremor, especially where slopes are presently only marginally stable. Many of the landslides mapped (Appendix I, figures 9 to 35) probably were triggered in this fashion.

In the state of Utah instrumentation to measure earthquakes has been available since 1950. Prior to that year only earthquakes felt by man were recorded. The lowest magnitude[1] tremor that can be felt is about 2.0, and then only locally. No quakes originating in Morgan County are listed prior to 1950; since then, however, some seismic activity has been recorded on U. S. Coast and Geodetic Survey and University of Utah network seismographs:

Year	Month	Day	Magnitude	Intensity	Remarks
1955	June	25	3.7	IV	Morgan
1964	Feb.	15	2.2		4 mi. NW of Morgan
1965	May	11	4.1		12 mi. NE of Morgan
1965	May	24			23 mi. NE of Morgan
1969	Feb.	26	2.0		South of Morgan
1970	Nov.	27			Near Morgan
1970	Dec.	4	1.9		Near Morgan
1971	Jan.	30	2.0		Near Morgan

Generally, earthquakes in Utah are associated with *active* faults in the earth. None of the faults in the county have been definitely determined to be *active* by geologists or seismologists. Nevertheless, several faults have displaced geologic materials of Pliocene or Pleistocene age. These latter faults (East Canyon fault, Cottonwood Creek fault and Morgan fault) are not conclusively determined to be inactive and, therefore, have been shown on the Engineering Geology Map of the county (plate 1).

Design for cut and fill slopes and foundations for large structures definitely should provide for the dynamic loading that an earthquake imparts.

SOIL EXPANSION

Expansive or swelling soils undergo volume changes in the field that cause large differential movements within a structure and hence excessive cracking of

[1]Magnitude refers to the Richter Scale; the numbers are instrumentally derived and related to the total energy released by an earthquake.

walls, floors and pipes. The degree of expansiveness, as well as the cause, varies greatly from area to area.

Shrinkage and swelling usually are related and reversible processes; any soil showing signs of shrinkage in dry weather has a potential for swelling in wet weather.

It is important to recognize swelling soils and to design to minimize damage from them. Some design requirements for residential foundations include: continuous footings, two No. 4 bars in footings, 6 x 6-10/10 welded wire mesh in slabs, moisture content above optimum and controlled exterior drainage.

Results of the expansion tests (Appendix II, figures 41 and 42) indicate that the samples are moderately expansive, ranging from 3 to 5 percent under a pressure of 100 pounds per square foot. In the event of a long dry period followed by saturation, however, this amount of expansion could increase considerably.

The Uniform Building Code (1970 edition, Sec. 2903) classifies soils that swell more than 3 percent from air dry to saturation under a surcharge load of 60 pounds per square foot as expansive.

The clay mineral montmorillonite in the soil is most responsible for expansiveness. Its structure permits significant quantities of water to be taken in, expanding its lattice structure.

Table 4 shows X-ray diffraction analyses of samples taken at five locations; soil mechanics tests were performed on the same samples (compare sample numbers). Figure 41 shows expansivity tests on sample 2b. Swelling and shrinkage were recorded for this sample despite a montmorillonite content of less than 1 percent. All other samples measured montmorillonite with greater quantities, up to 65 times more in the clay fraction. Accordingly, expansion potential is expected to be much greater in most instances.

From sample size analyses, generally between one-third and one-half of each sample falls within the clay fraction[1]. From table 4, up to 22 times more montmorillonite occurs in the clay than in the silt fractions. This is as one would expect.

Damage from swelling is common in areas where the potential evaporation (evaporation from a free surface-water body) greatly exceeds the annual or monthly rainfall so that a moisture deficiency normally exists in the ground. From April through October a deficit of 38½ inches accumulates in Morgan (table 5).

[1]Clay fraction=particle sizes less than .005 to .002 mm, depending on classification system used.

Table 4. Mineralogic analyses by X-ray diffraction of Salt Lake colluvium samples.

Sample No.	Mineral	Percent					
		Quartz	Calcite	Dolomite	Illite	Kaolinite	Montmorillonite
2 b, c	Silt	55	25	5	10	5	<1
2 b, c	Clay	4	1		75	20	<1
3 b	Silt	70	15	5	5	<3	<3
3 b	Clay	5		65	20	10	
4 c	Silt	55	20	10	5	5	5
4 c	Clay	8	2		20	5	65
5 b	Silt	70	15	5	3	3	3
5 b	Clay	8	2		20	5	65
6 a	Silt	65	20	5	6	2	2
6 b	Clay				45	10	40

Buildings occasionally are placed incorrectly on desiccated soils. The physical environment of the soil is immediately changed by the building; the most important change is the reduced rate of water evaporation from the foundation soil. Thus if water moves to the foundation soil, it is imbibed by the desiccated soil rather than evaporated.

Water movement to the foundation soil occurs for the following reasons: (1) concentrated periods of high precipitation, (2) poor drainage around the structure, (3) seepage of water from water mains, plumbing facilities, etc., (4) infiltration from lawn irrigation, (5) infiltration from septic tank filter field lines, (6) capillary rise of water from the water table, which may lie at several tens of feet depth and (7) water vapor flow due to cooler temperatures beneath buildings than in the surrounding uncovered soil.

A cyclic shrink-swell effect corresponding to normal seasonal weather changes appears likely in Morgan County; several accounts of the disappearance and reappearance of desiccation cracks in the ground were given to the author. These cracks normally assume a polygonal pattern on the ground surface.

Deep excavations for major structures in the Salt Lake Formation materials conceivably could rebound (move upward following unloading). In addition, slaking is likely on exposure and air drying of the Salt Lake Formation in excavations and road cuts.

Because much of the material comprising the Salt Lake Formation and overlying colluvium is still susceptible to expansion when used as fill, it is advisable to use these compacted soils in nonstructural areas only. If the material is used, however, in structural areas, such as beneath floor slabs, foundations and driveways, it should be compacted to 90 percent of its maximum dry density and conditioned to a moisture content at optimum or up to plus 3 percent optimum to reduce the effects of sub-

Table 5. Potential evaporation and precipitation data for station at Morgan.

	April	May	June	July	Aug.	Sept.	Oct.	7-month Total
Evaporation Potential[1]	4.94[2]	6.52[3]	7.03[3]	8.76[3]	8.28[4]	6.10[4]	3.80[5]	45.43
Precipitation[6]	1.38	1.37	1.03	0.48	0.83	0.64	1.22	6.95
Deficit	3.56	5.15	6.00	8.28	7.45	5.46	2.58	38.48

[1]As measured in 4-inch pan at Morgan, elevation 5,070 feet.
[2]Based on one-year record.
[3]Based on four-year record.
[4]Based on seven-year record.
[5]Based on six-year record.
[6]Mean monthly, as measured at Morgan.

sequent moisture changes. In nonstructural areas, such as yards and slopes, a compaction of 85 percent of maximum dry density is necessary (see pages 49, 54-56 for additional fill requirements).

Proper evaluation of potential swell at any given site includes:

(a) Expansive properties of the soil and possible drying shrinkage,

(b) Thickness and depth of the various underlying soil and geologic material layers,

(c) Moisture content and density at time of construction,

(d) Local climate and hydrology and

(e) The floor-foundation system's ability to accommodate and tolerate action of the soil and geologic material.

FROST HEAVE HAZARD

Unless foundations are constructed to a minimum depth of 3½ feet in Morgan County a potential exists for heaving because of ground frost. This is easily overlooked, especially on hillsides where it appears expeditious to have the footings on the downslope side as shallow as possible (figure 8).

With increase in elevation, penetration of ground frost increases so that footings must be placed deeper. In the foothills a minimum depth of 4 feet is suggested.

In areas of high water table, water conducted upward by capillarity may form ice lenses. The worst soils for permitting upward migration of water are silts. Determinations based on samples of Salt Lake Formation colluvium indicate a range of capillary rise of from 3 to 15 feet. In Salt Lake Formation terrain (see plate 1 for areal extent) in the few areas where a water table exists at depths of less than about 15 feet, foundation design requires extra consideration.

SETTLEMENT POTENTIAL

The settlement potential of structures is determined by performing consolidation tests on soil samples. The results of these tests for Morgan County (figures 41 and 42) indicate that the soils are moderately compressive. For nominally sized residential units where foundation loads are one kip (1,000 pounds dead weight) per square foot or less, settlement resulting from consolidation of the soils beneath the foundations approximates ½ to ¾ inch, which alone should not cause structural damage to the existing buildings.

Topsoil is particularly compressible material and eventual excessive settlement is expected for homes built on it (figure 8). Thickness of topsoil varies considerably depending largely on geomorphologic aspects of a site. Near drainages at lower elevations, for example, perhaps several feet of highly organic black soil occur which, on adjacent hillsides, may diminish to a few inches or less. This organic material must be removed so that foundations for structures sit on underlying inorganic material or settlement will follow. Building on variable thicknesses of organic soils leads invariably to differential settlement.

Differential settlement may also ensue where various materials underlie separate footings for the same structure. If two footings for a home rest on Salt Lake Formation clay-shale and two footings on loose, colluvial silty clay, depending on the type of construction of the home, the differential settlement may be reflected in tight doors and windows or even cracks.

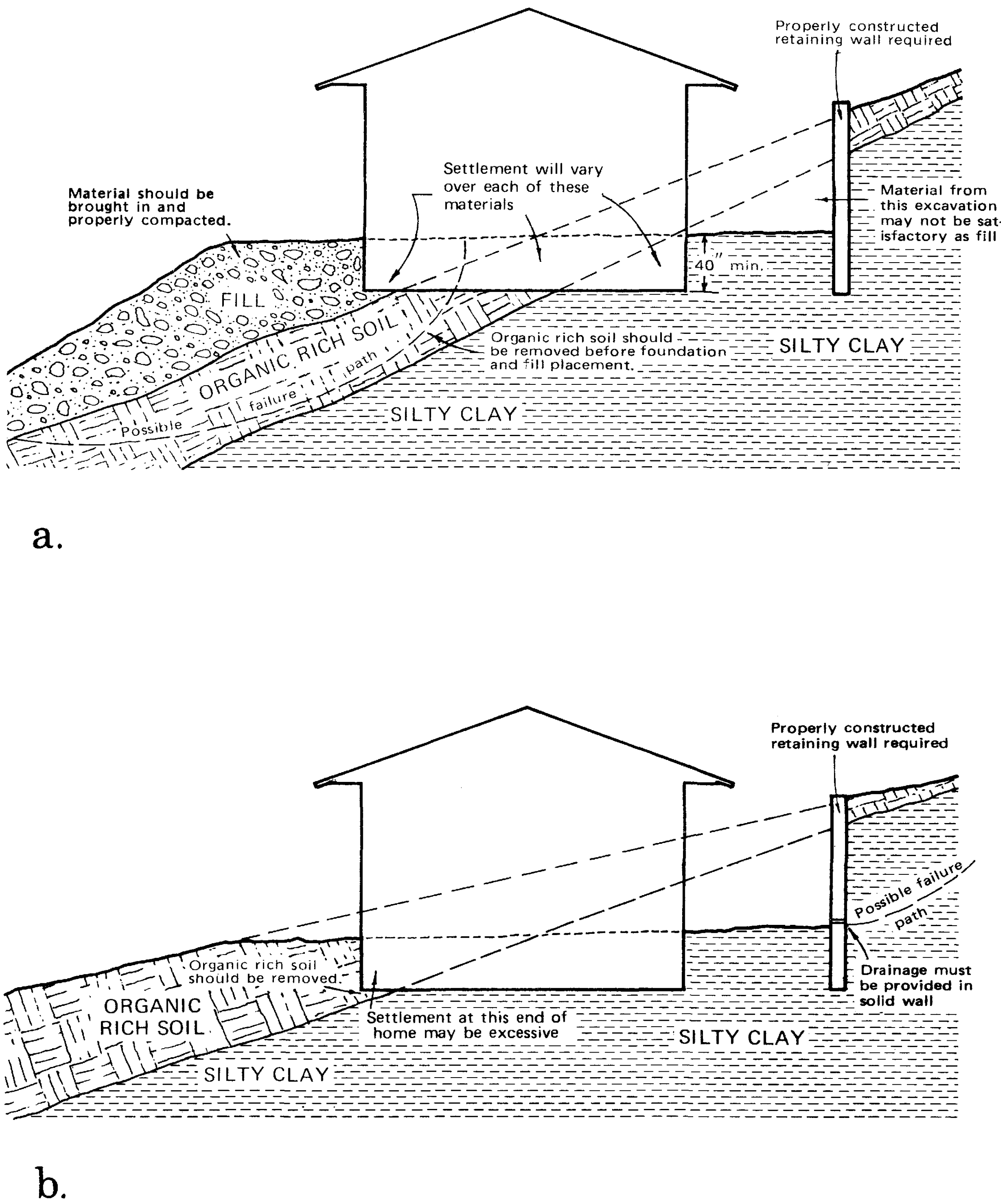


Figure 8. Schematic drawing of common mistakes in hillside subdivisions: (a) fill atop organic rich soil on site under foundation and (b) organic rich soil on site under foundation.

HEALTH HAZARD

Conditions for removal of effluent from septic tanks are unsatisfactory to only marginally satisfactory over a considerable part of the county.

Most of the Tuffaceous Member of the Salt Lake Formation and its overlying colluvium and soil (see plate 1 for areal extent) do not accept effluent because of their low to negligible permeability. The few strata of the member that prove satisfactory comprise a small percentage of the total formation. Some volcanic ash, sandstone and conglomerate beds may be permeable. Most of the formation, however, has sufficient clay binder and compaction to make it entirely unsatisfactory for discharge of fluid waste. Despite the presence of considerable gravel and larger particles, a matrix of clay and silt acting as a binder largely seals the voids in colluvium and soil overlying the Salt Lake Formation. Each prospective building lot in this material should be tested individually.

Many of the factors which make for unsatisfactory conditions for individual fluid effluent removal in the above terrain may be just the requisite elements for sewage lagoons.

The bouldery and cobbly conglomerates and sandstone and shales with interbedded sandstone also may have only marginal utility for fluid effluent removal. Conditions vary considerably in areas where these materials outcrop.

Where loose soils of gravel, sand and silt (alluvium and Lake Bonneville sediments) occur, the water table may be shallow posing a pollution hazard. In some areas effluent could discharge into surface streams with minimal subsurface conductance and, therefore, minimal filtration. This must be borne in mind also when locating sanitary landfill sites.

Another potential pollution hazard exists in limestone and dolomite terrain. These rocks may store groundwater and permit ready ingress of polluting effluent. Soil cover over bedrock, both in vertical and lateral extent, will have to be investigated. Fortunately the areal extent and topographic relief of geologic materials is such that development on this terrain is not likely.

Aquifers in bedrock are not surficial nor likely to yield significant quantities of water to future developments in the county. Where thicknesses of sand and gravel (alluvium and lacustrine sediments) exist, however, the potential of aquifers in these materials has yet to be exploited. This fact emphasizes the importance of strict control of sewage systems in the latter terrain, especially where the water table is high (even seasonally).

CONCLUSIONS

Public agencies, developers, builders, money lenders and homeowners must be informed of the geologic hazards expressed in this report; no development should begin without adequately considering each of the hazards. Basic determinations should be made early as to what control over hazardous terrain should be exercised:

(a) Whether the land should remain as undisturbed open space,

(b) Whether only minimal nonstructural modification should be permitted, such as a golf course or park,

(c) Whether soil or rock material correction should be attempted,

(d) Whether strengthening of the foundation structure is properly and economically feasible or

(e) Whether individual sewage systems should be permitted.

Neglect, insufficient regard or inadequate design and construction for each of the hazards may be manifested in a completed structure in one of the following ways: (a) cracked plaster, (b) cracked foundations, (c) cracked floor slabs, (d) jammed windows, (e) jammed doors, (f) separation in masonry, (g) out-of-plumb structural elements, (h) backed-up sewer lines and/or surfacing of sewage effluent, (i) undermined walls and (j) polluted groundwater. Repairs to a damaged residence are inordinately high compared to initial preventative costs and careful control of construction.

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APPENDIX I

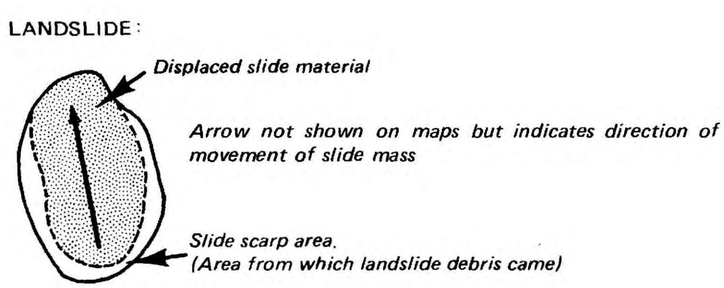
Utilization of Maps Showing Landslides

On figures 9 to 35 landslides have been plotted on topographic maps (scale: 1 inch = 2,640 feet = ½ mile). Plate 2 is an index map (scale: 1 inch = 10,560 feet = 2 miles) showing the geographic relationship of the topographic maps. Plate 1 illustrates the overall distribution of landslides in the county. The landslides were interpreted from U. S. Department of Agriculture aerial photographs at the scale 1 inch = 1,667 feet. Small slides capable of occupying one or more housing lots are observable at this scale. Some distortion of features in aerial photography is inevitable; shapes of the slides as they appear on the map, therefore, may not be precise. Field checking of landslides was undertaken only in the area of the Snow Basin 7½-minute quadrangle (figures 9 and 10). Without a field check a terrain feature that appears to be a landslide and has been plotted as such may not in fact be a landslide. In high elevations, for example, glacial topography is often confused for landslide morphology. Some landslides may have been missed but the opposite is probably true.

The solid line on the map delineates the entire slide; the dashed line approximately separates the main scarp from the head and foot of the slide (see figure 5 for clarification of landslide terms). The main scarp of the slide frequently remains as a scar on the terrain. It is an oversteepened slope. The head and foot of the slide, denoted by stipling (figure 5), is the mass of displaced material, soil and rock that has broken away from the hillside and has moved downslope. Where this downslope movement has encroached or blocked a natural channel, the drainage is diverted around it.

Each individual slide will have to be investigated to determine the utility of its area. It may be necessary or most economical to leave landslide areas as open space. Other slopes adjacent to or removed from known landslides may pose just as great or perhaps a greater threat to development.

EXPLANATION FOR MAPS (figures 9 to 35)



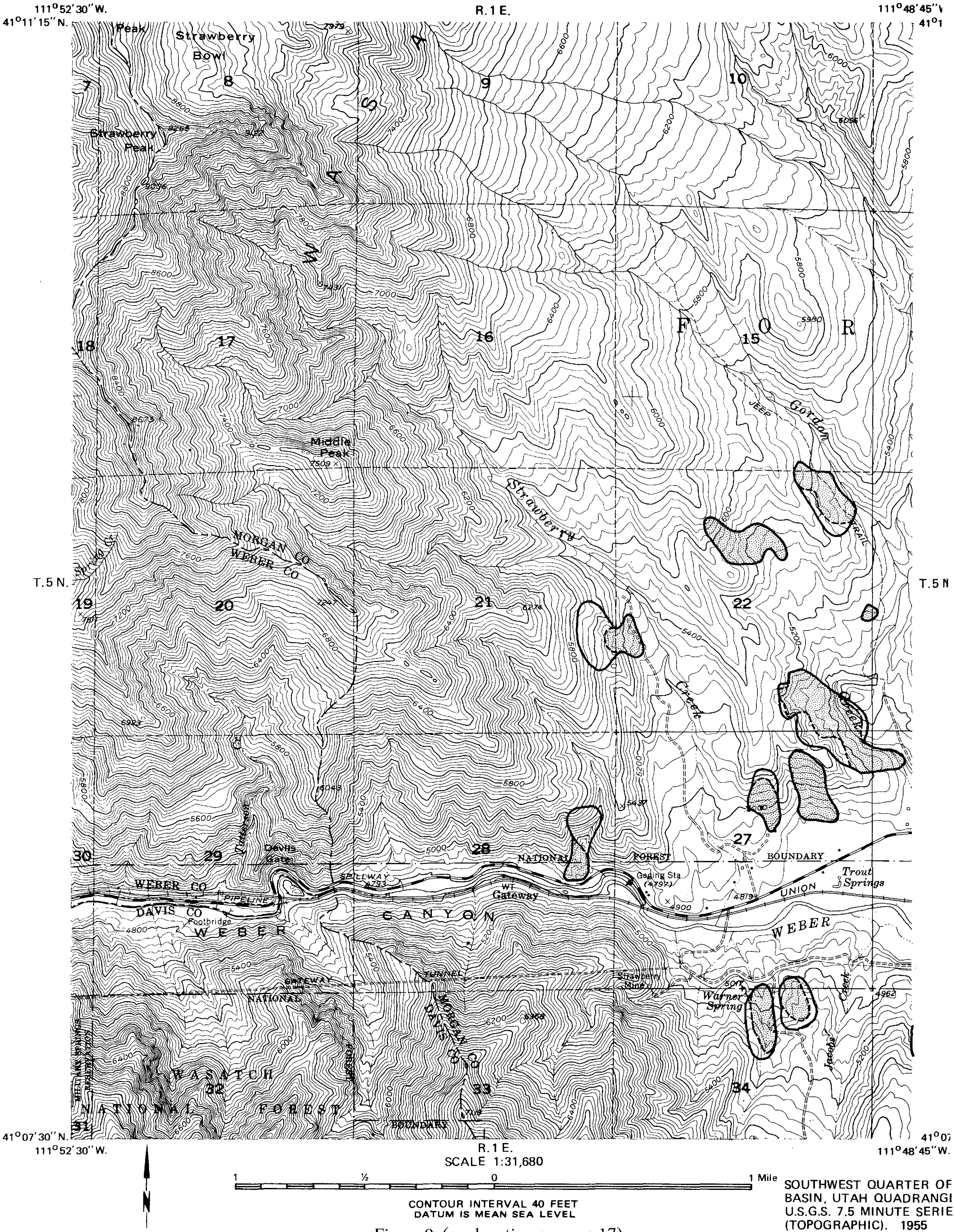


Figure 9. (explanation on page 17)

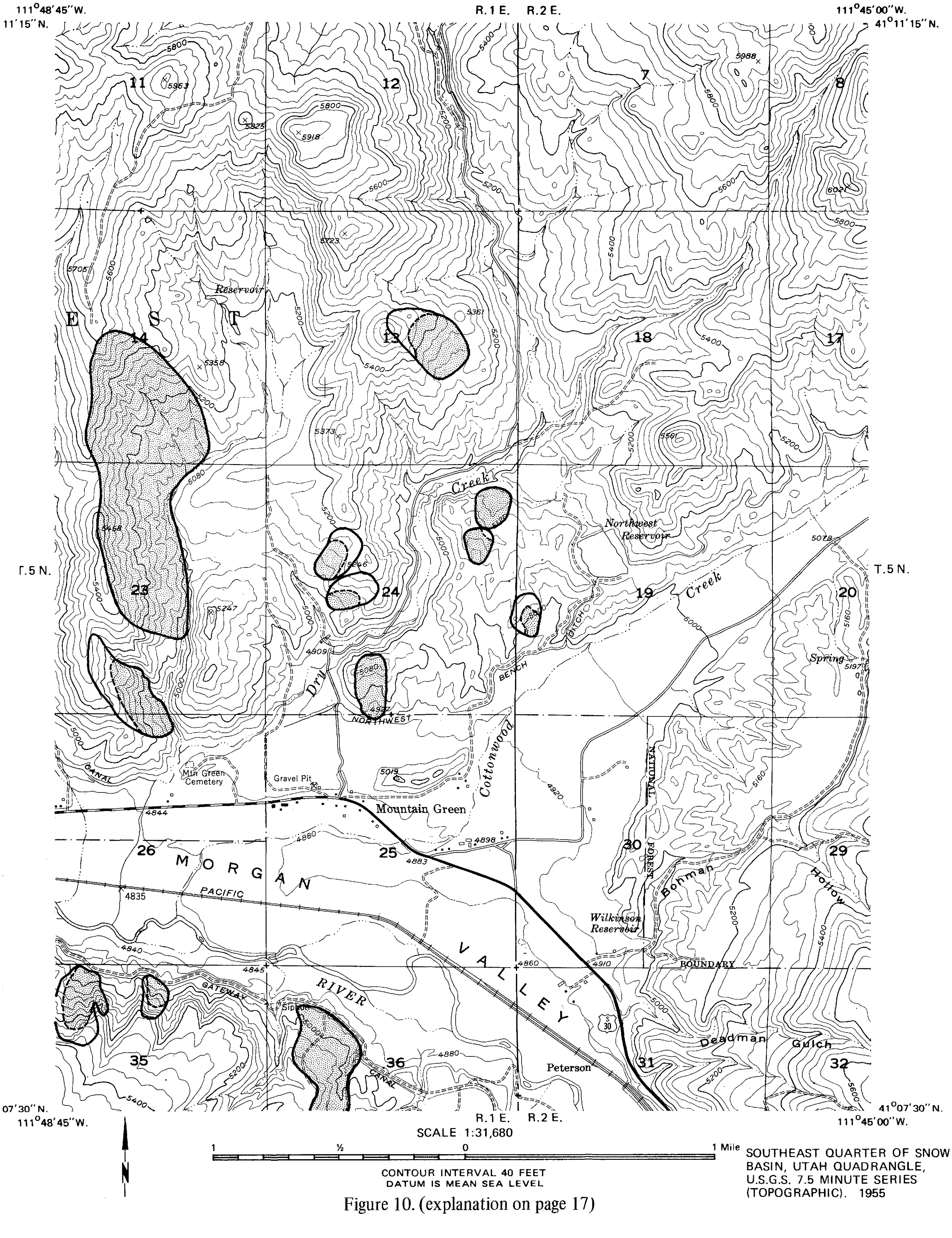
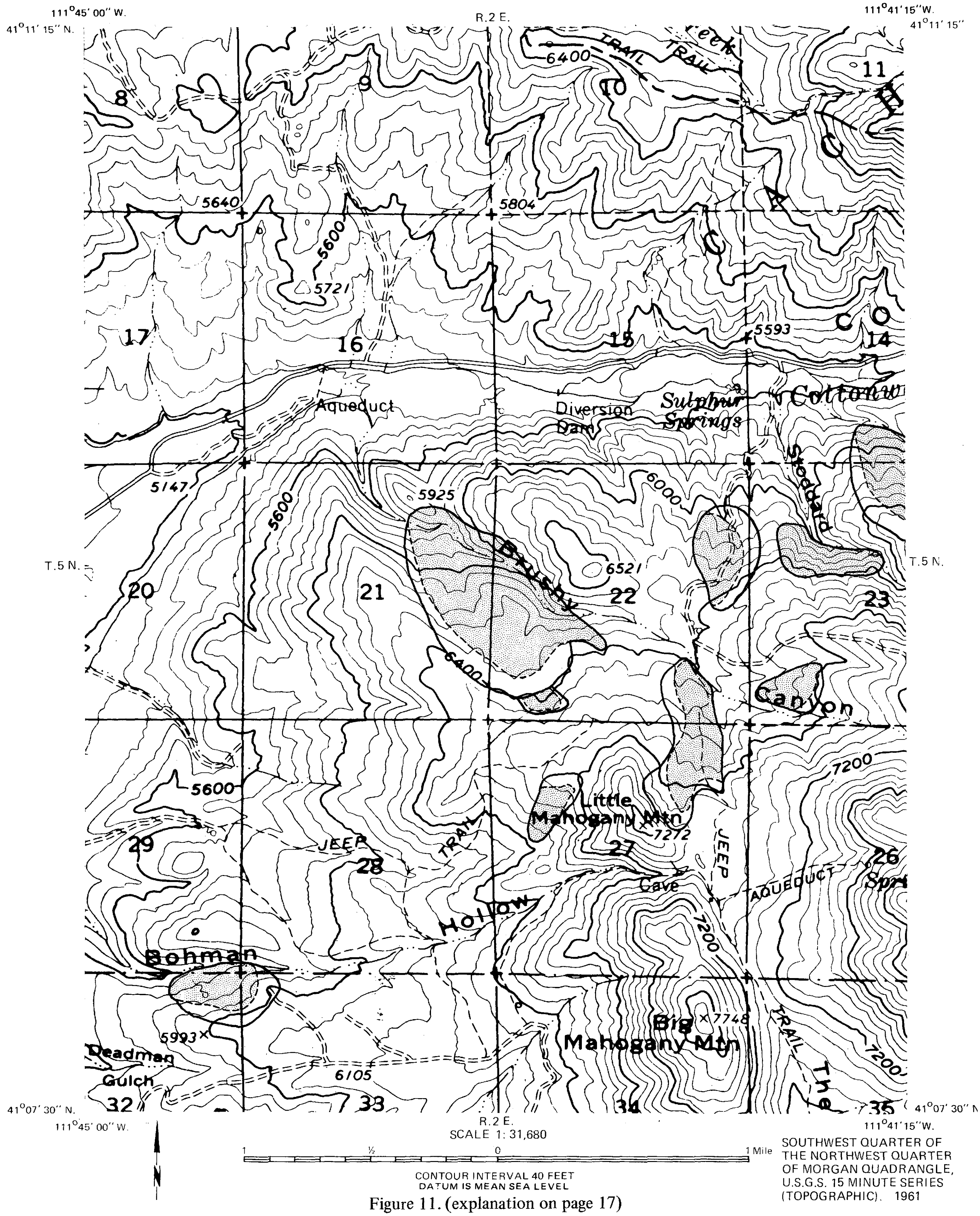


Figure 10. (explanation on page 17)



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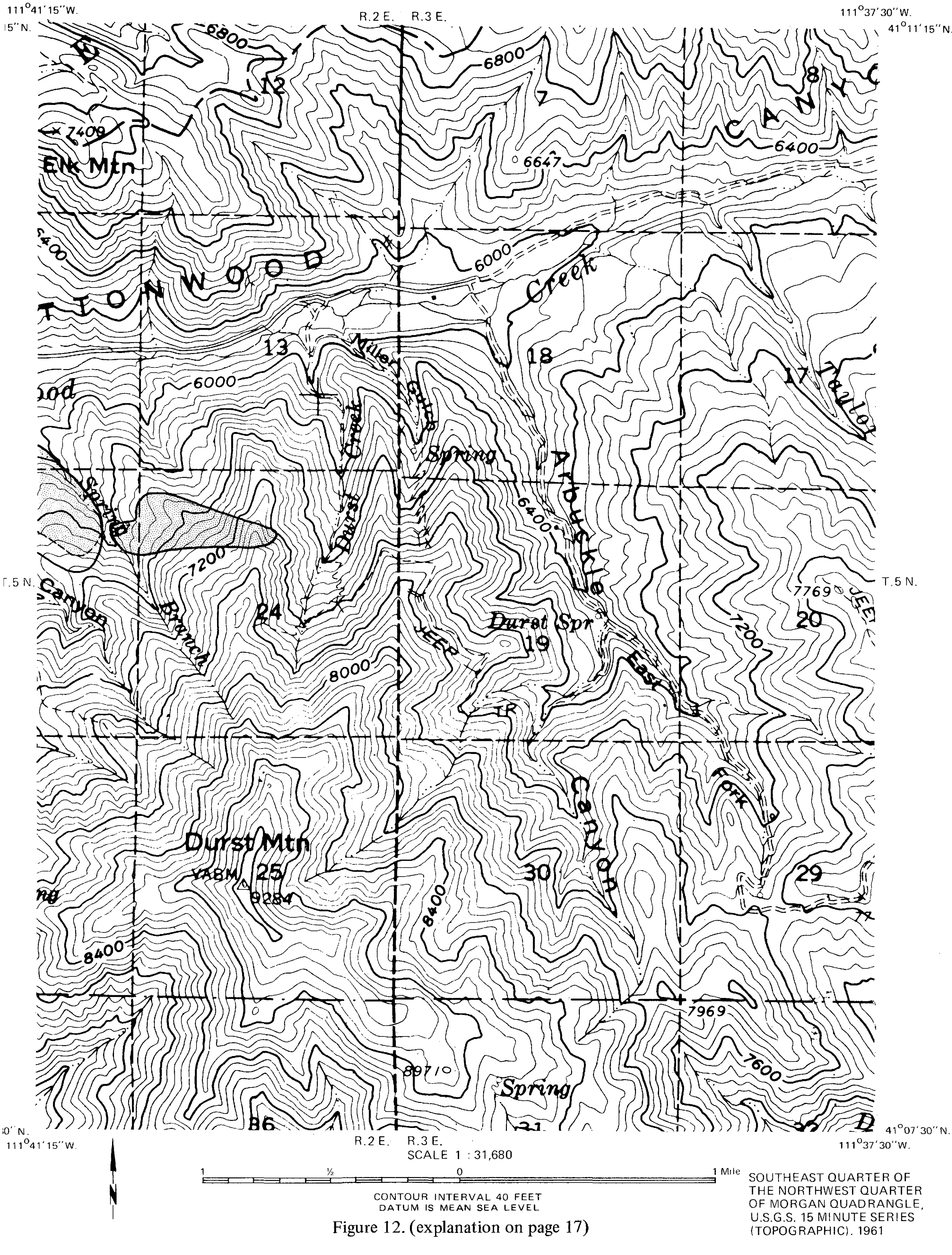

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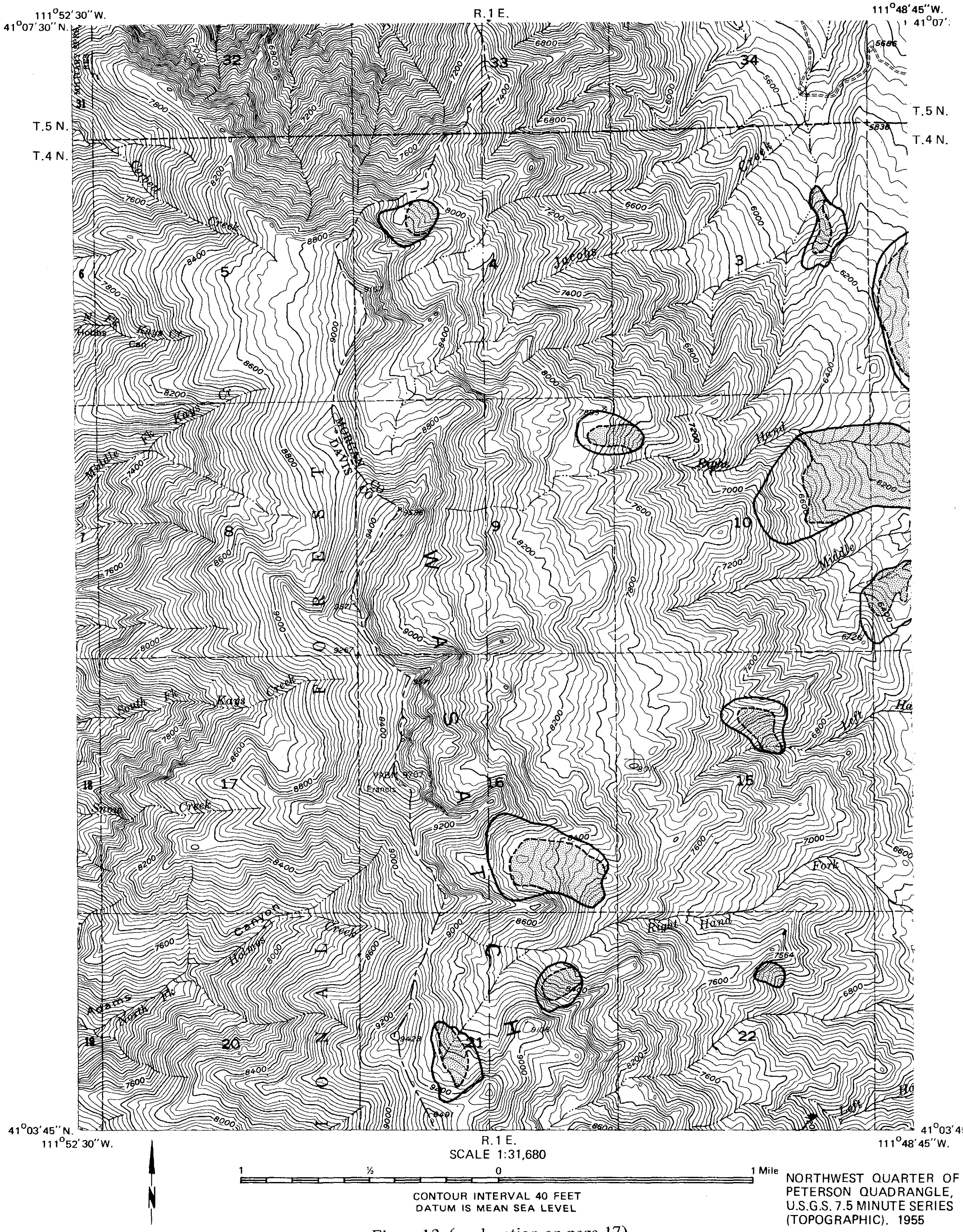

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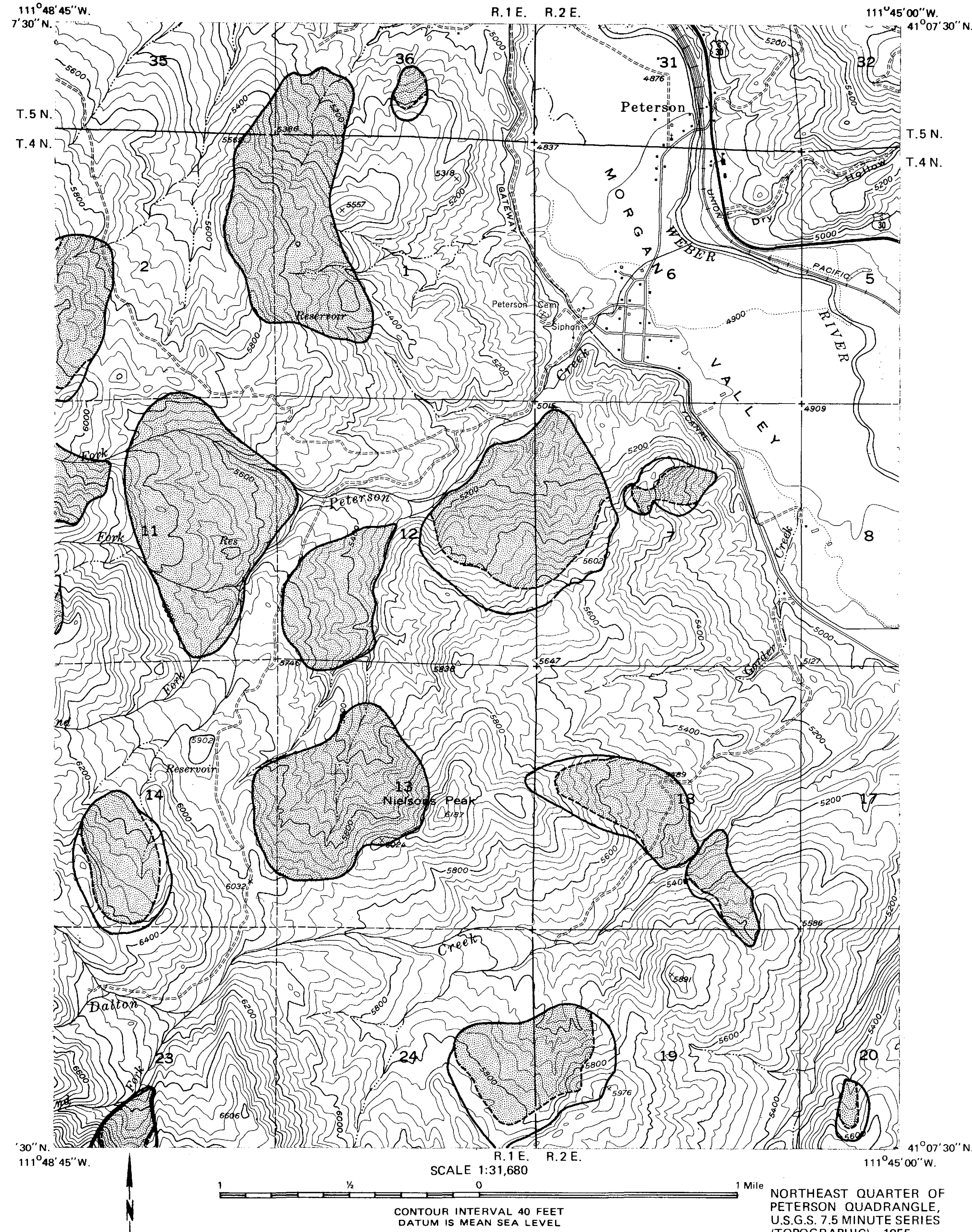

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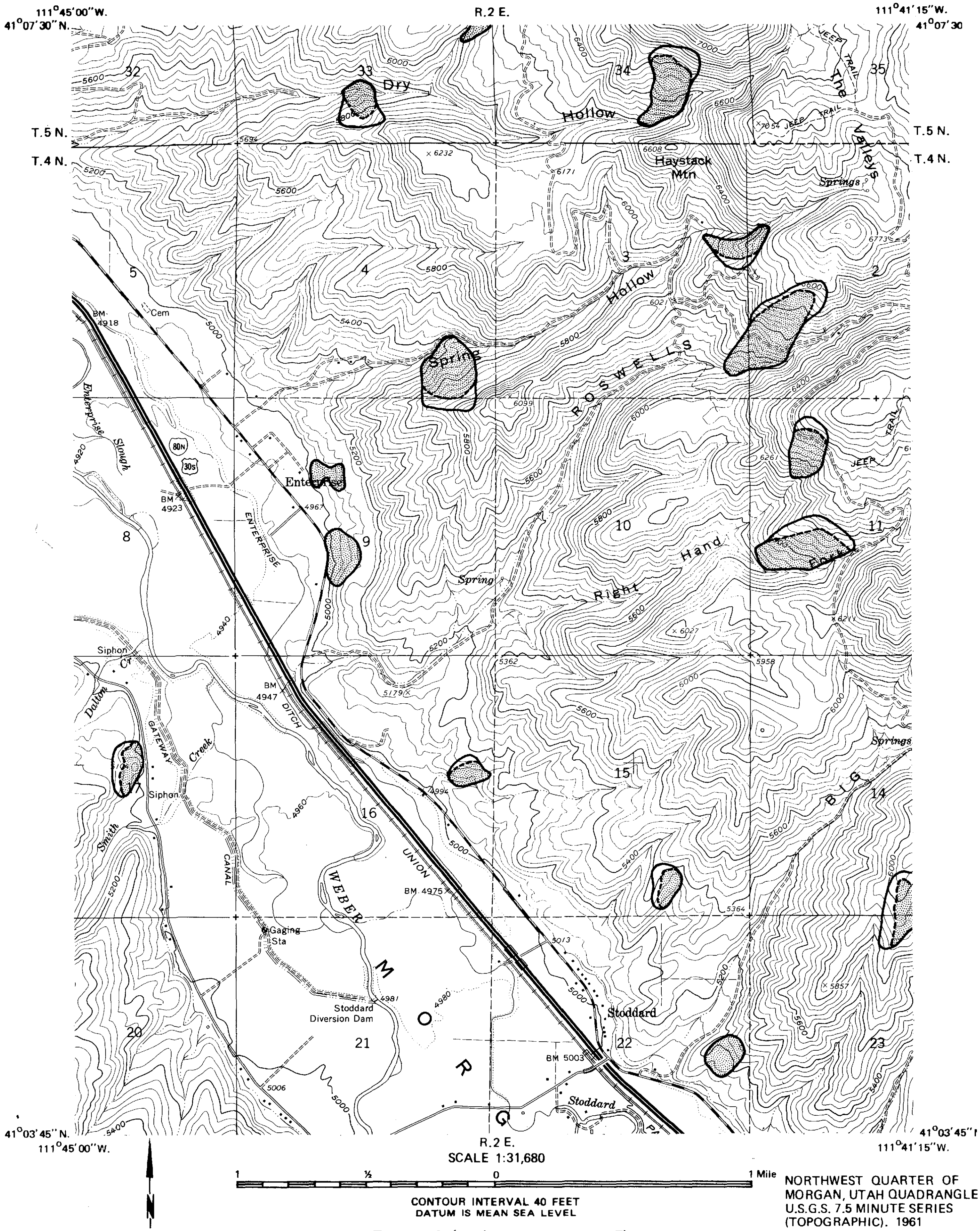

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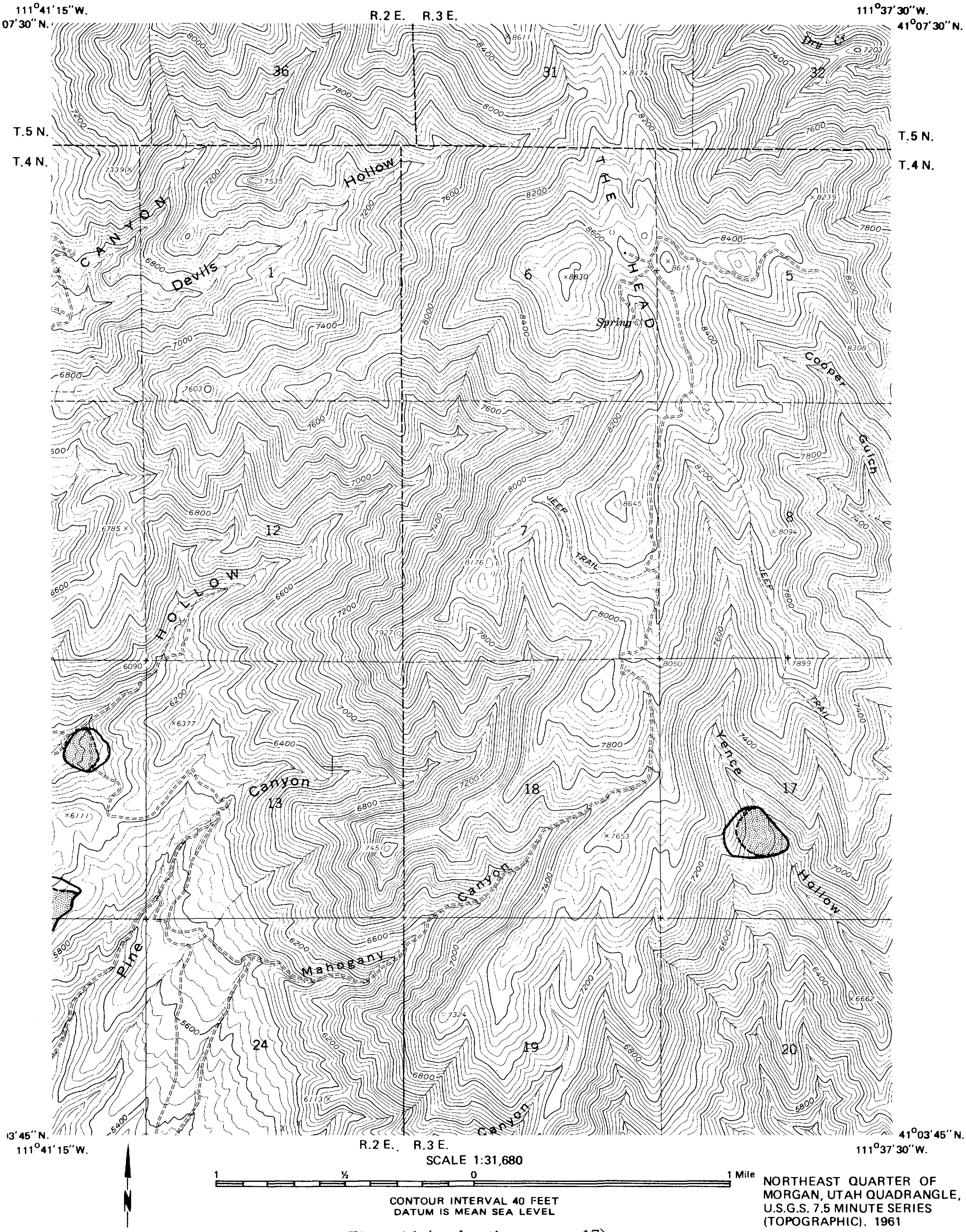

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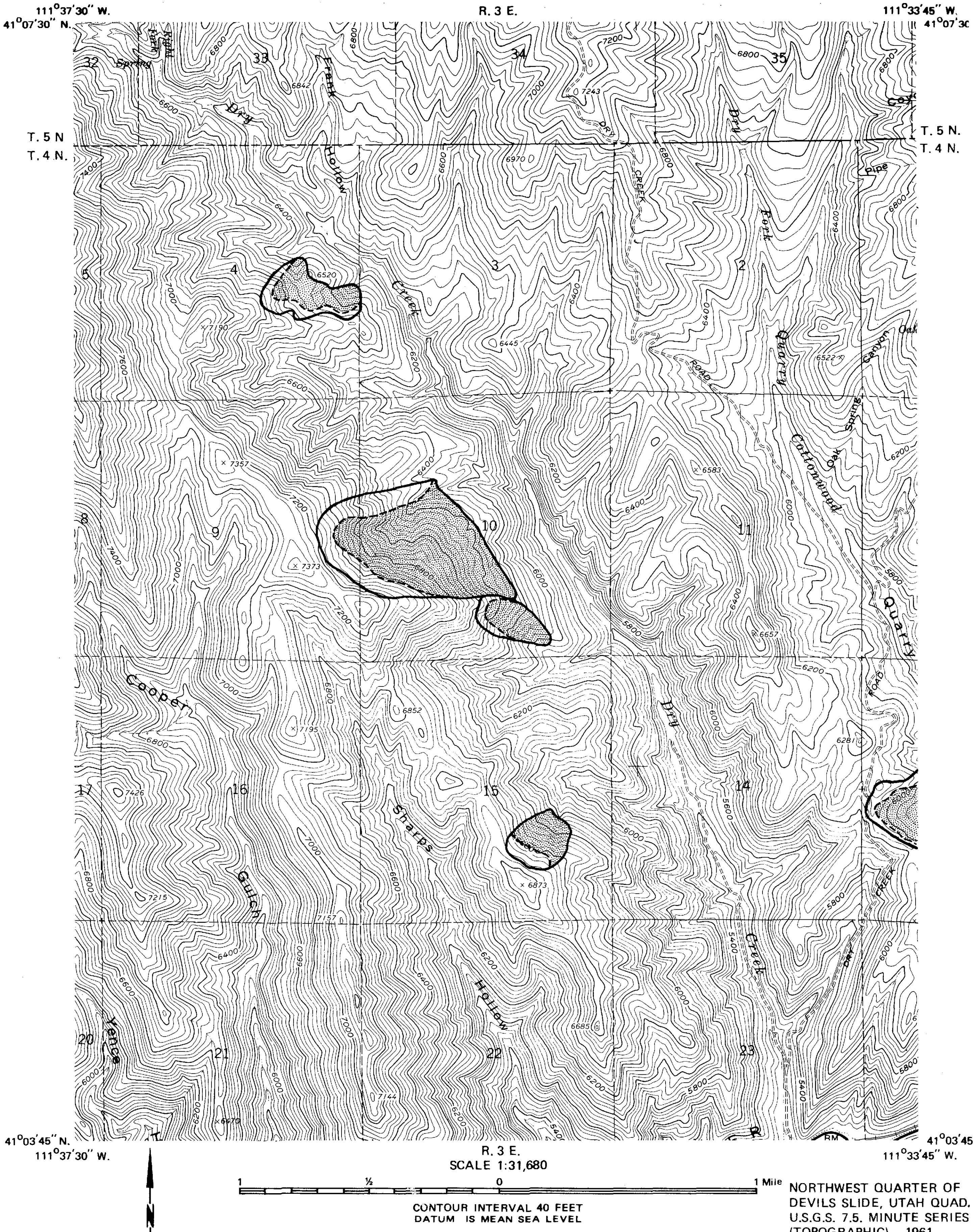
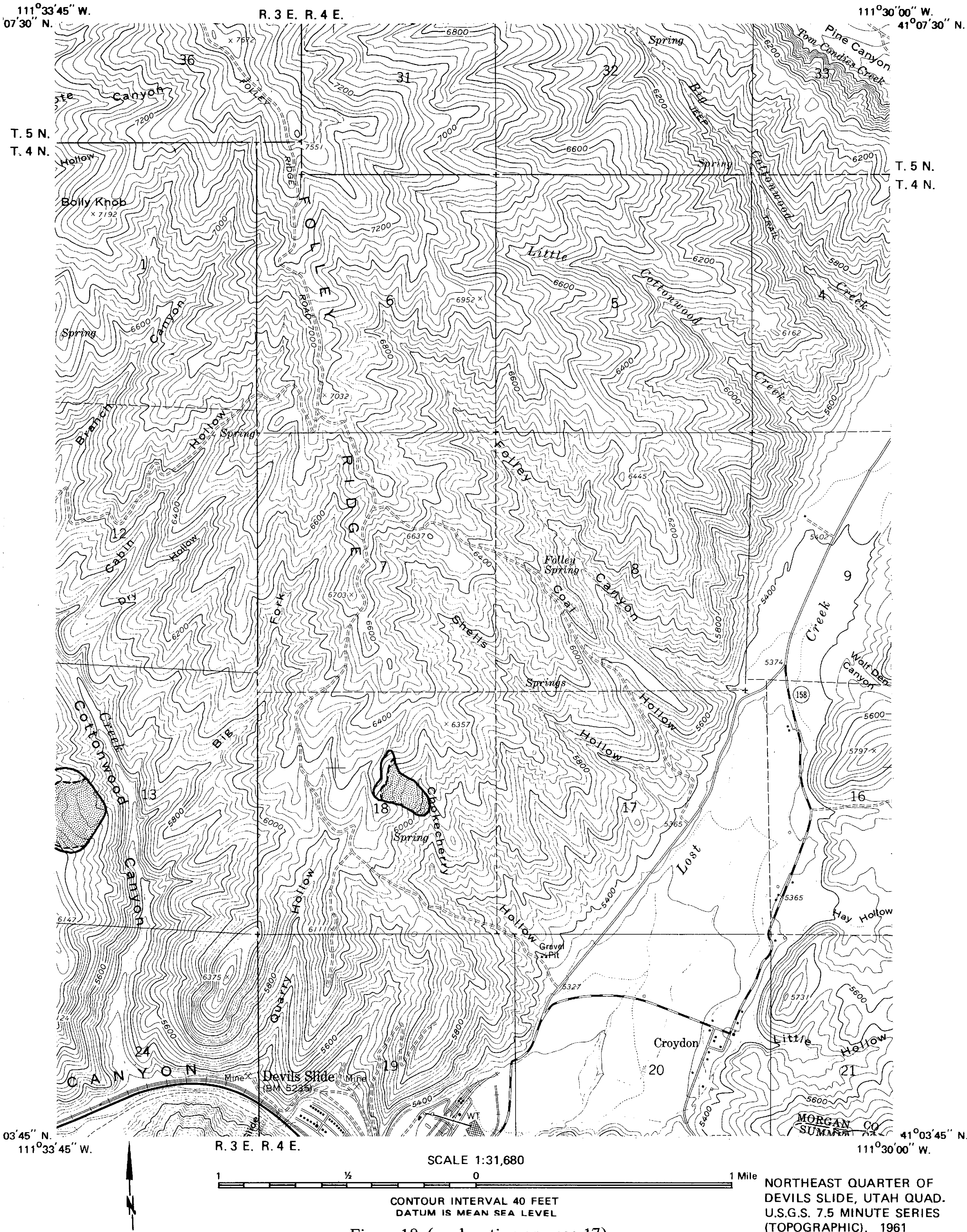
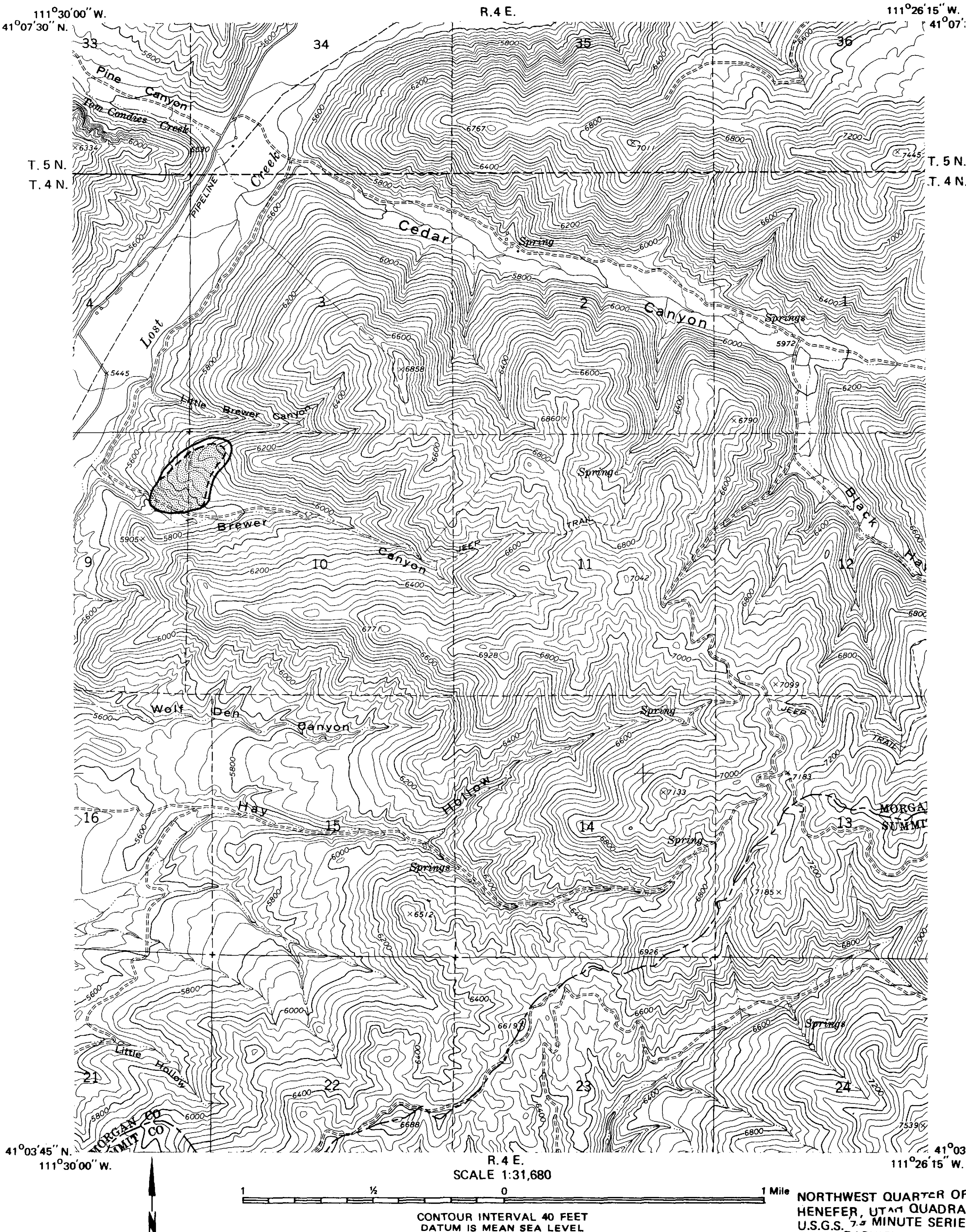


Figure 17. (explanation on page 17)



NORTHEAST QUARTER OF DEVILS SLIDE, UTAH QUAD. U.S.G.S. 7.5 MINUTE SERIES (TOPOGRAPHIC). 1961

Figure 18. (explanation on page 17)



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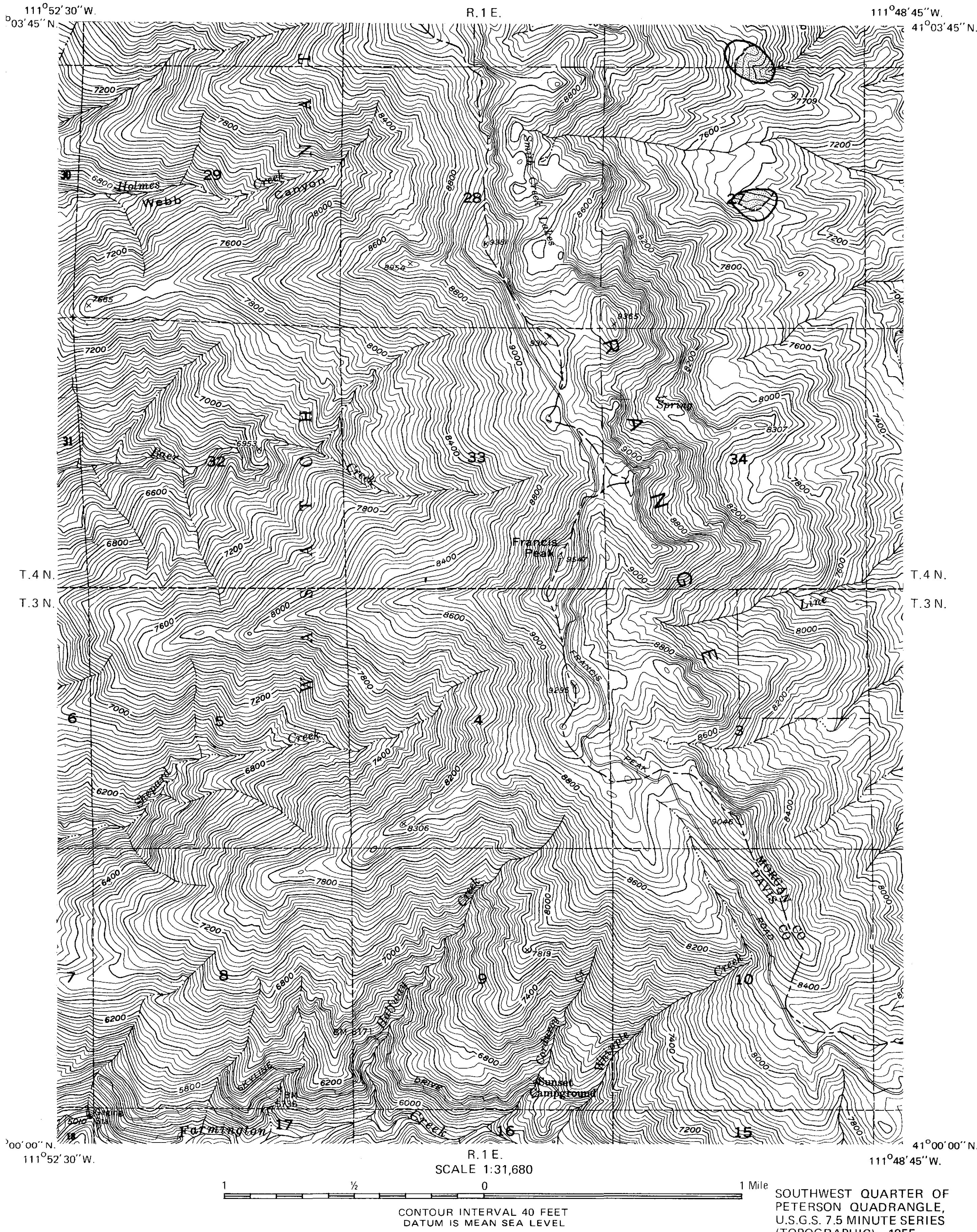

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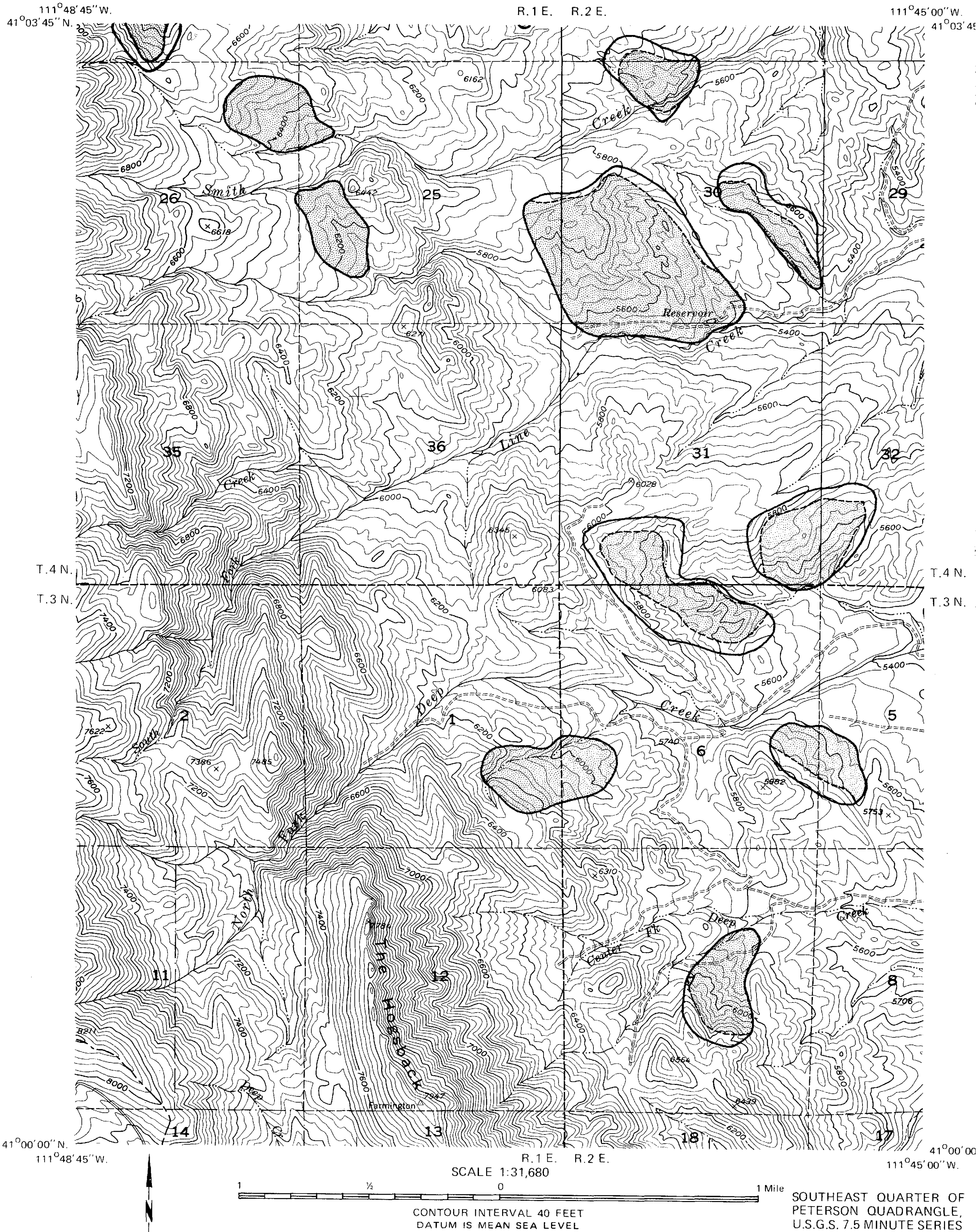

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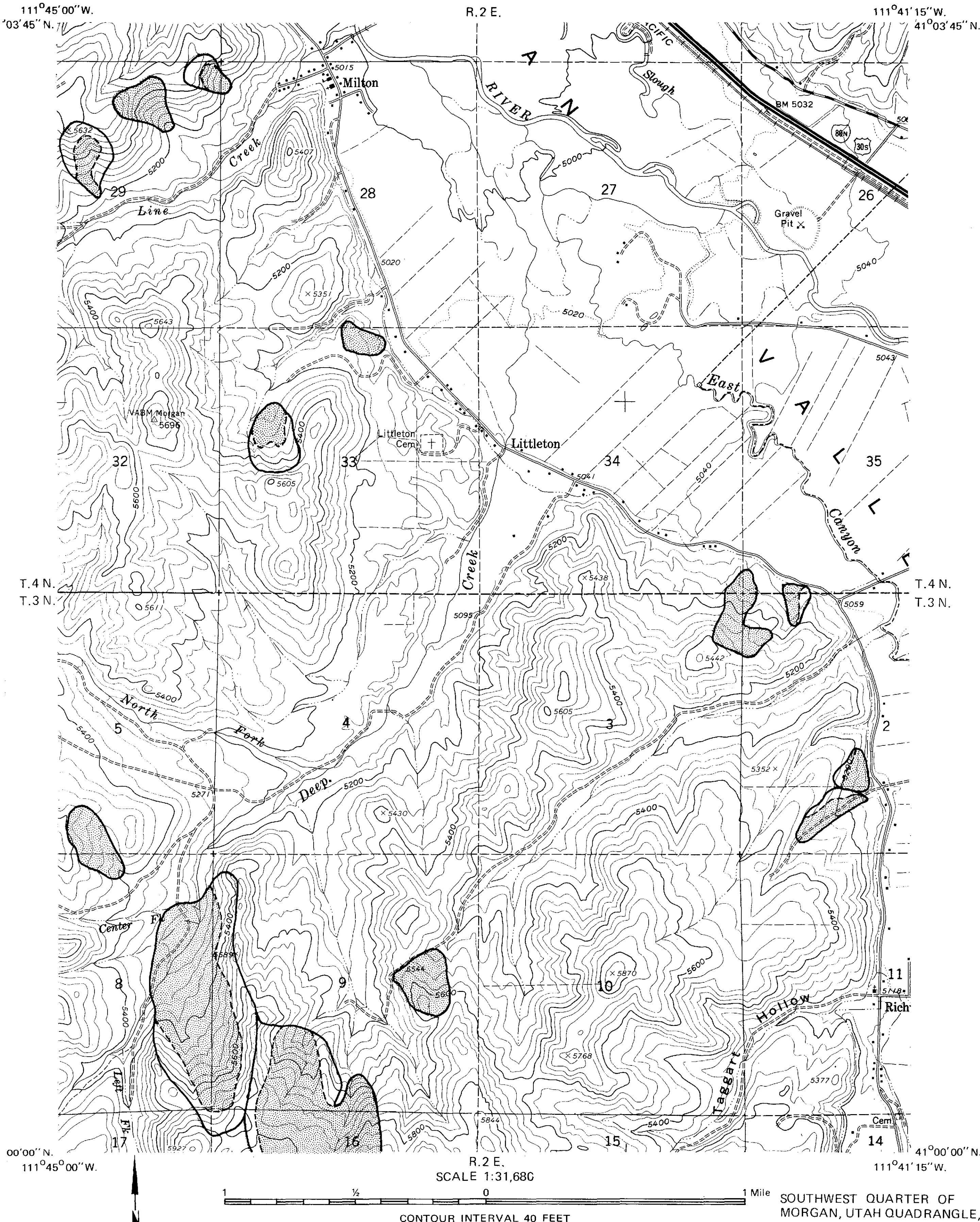

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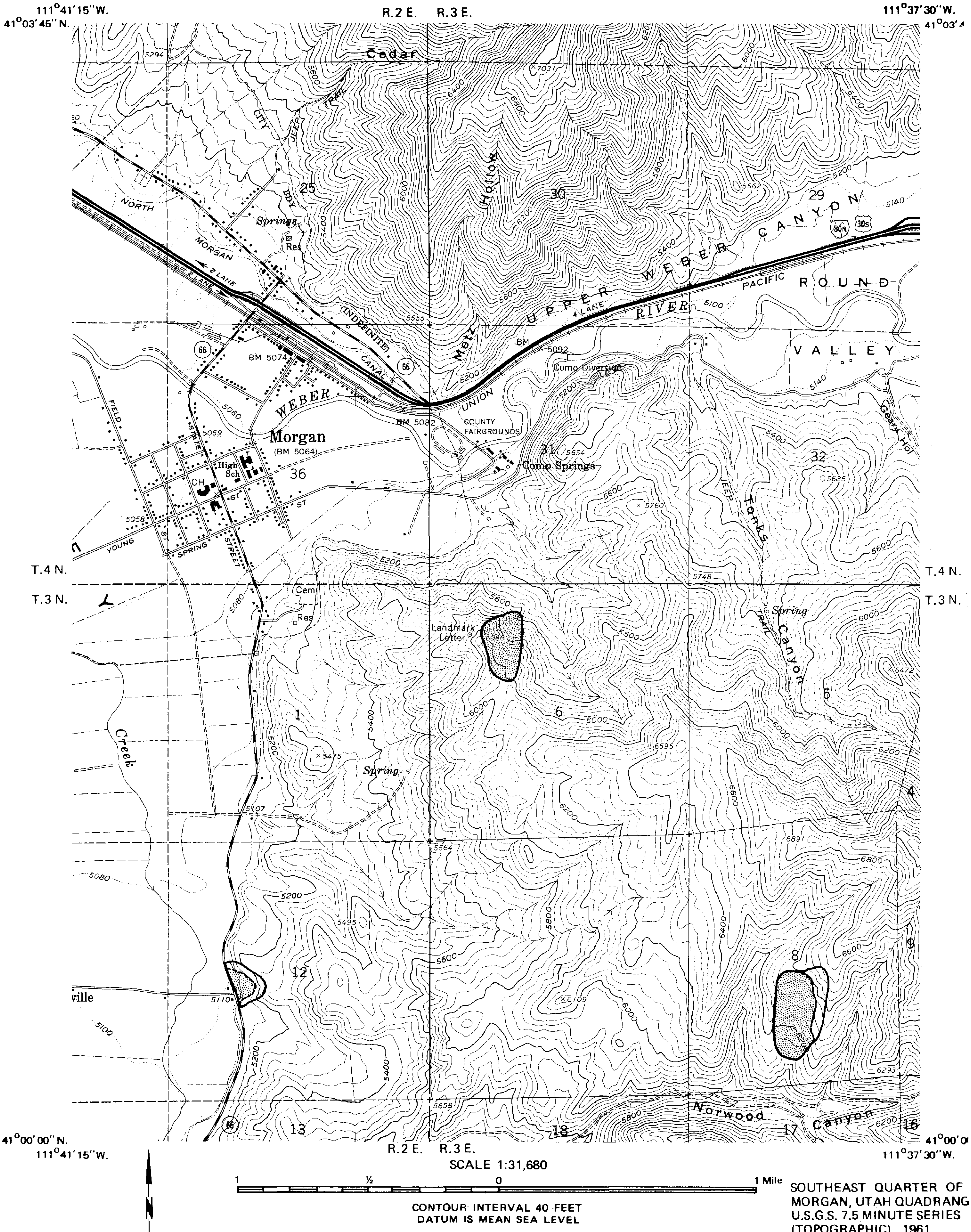

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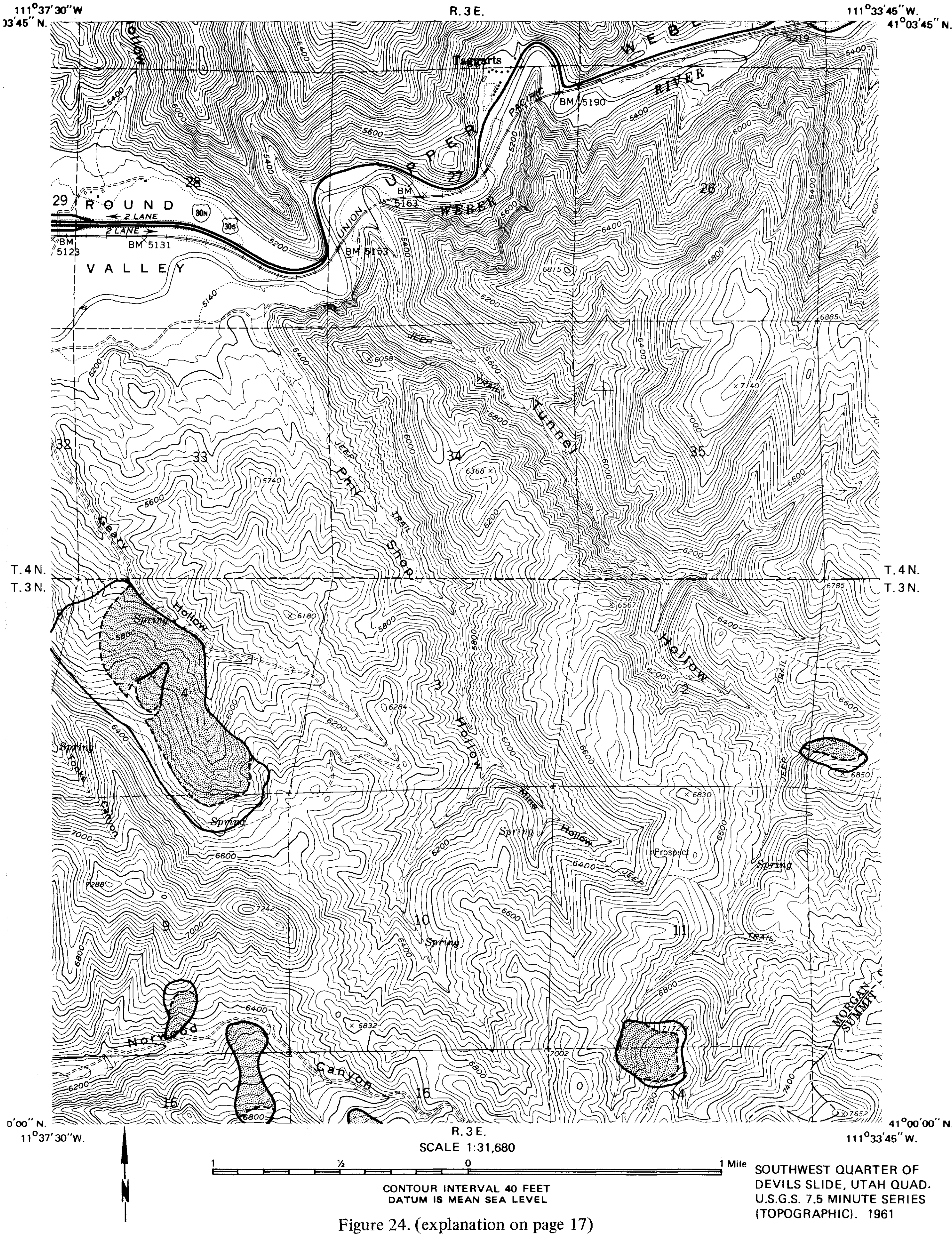

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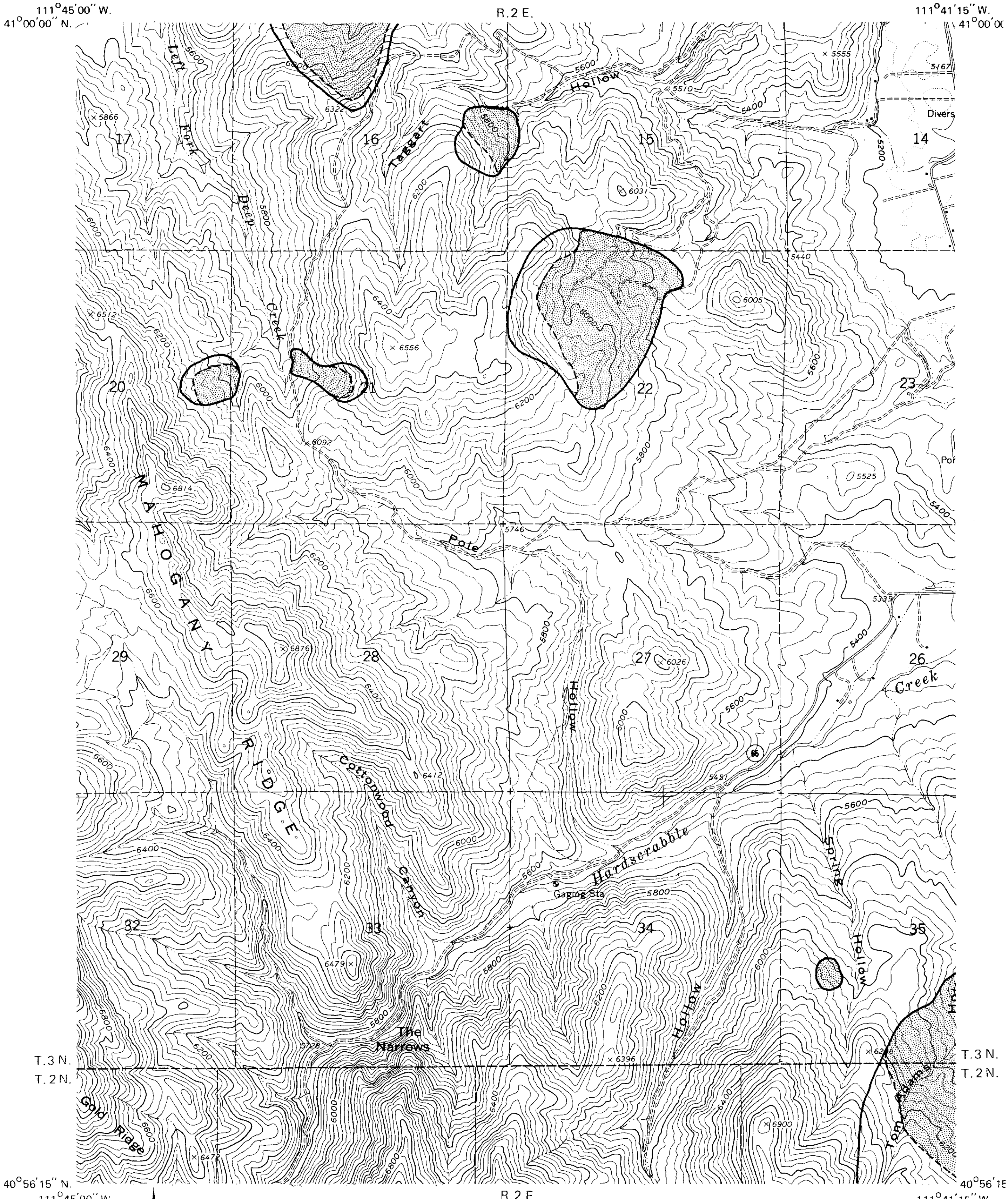


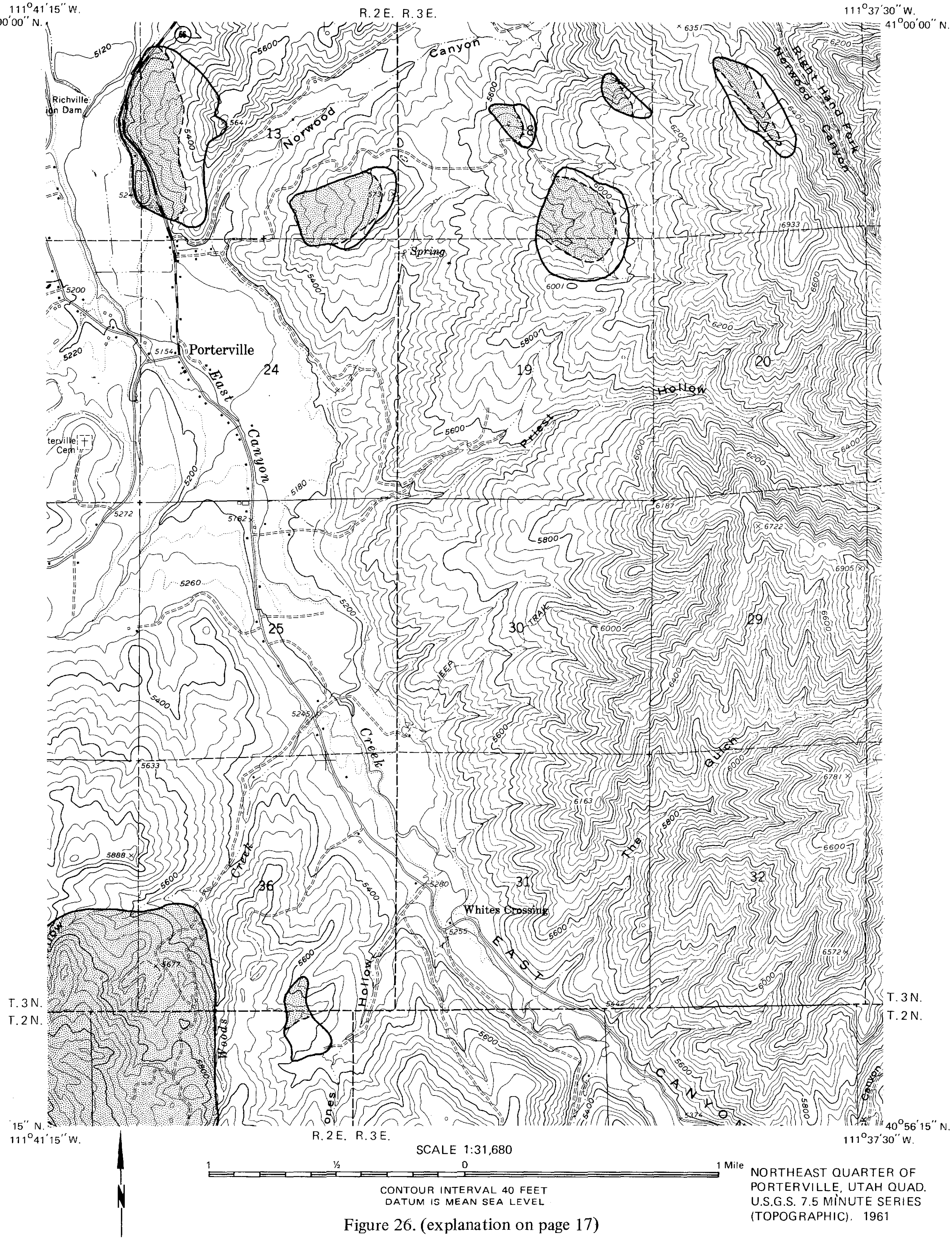
SCALE 1:31,680

1 ½ 0 1 Mile

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

NORTHWEST QUARTER OF PORTERVILLE, UTAH QUAD. U.S.G.S. 7.5 MINUTE SERIES (TOPOGRAPHIC). 1961

Figure 25. (explanation on page 17)



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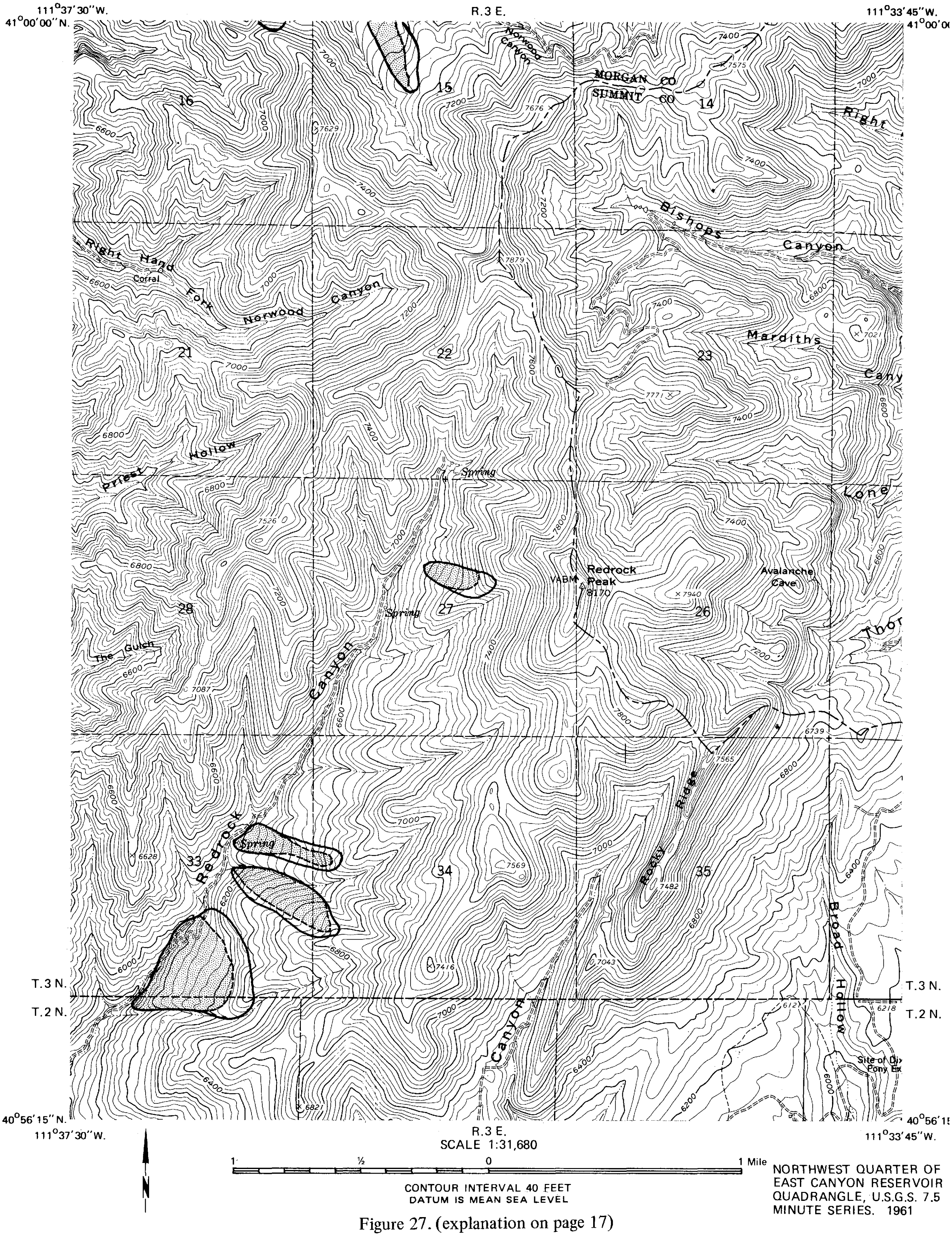

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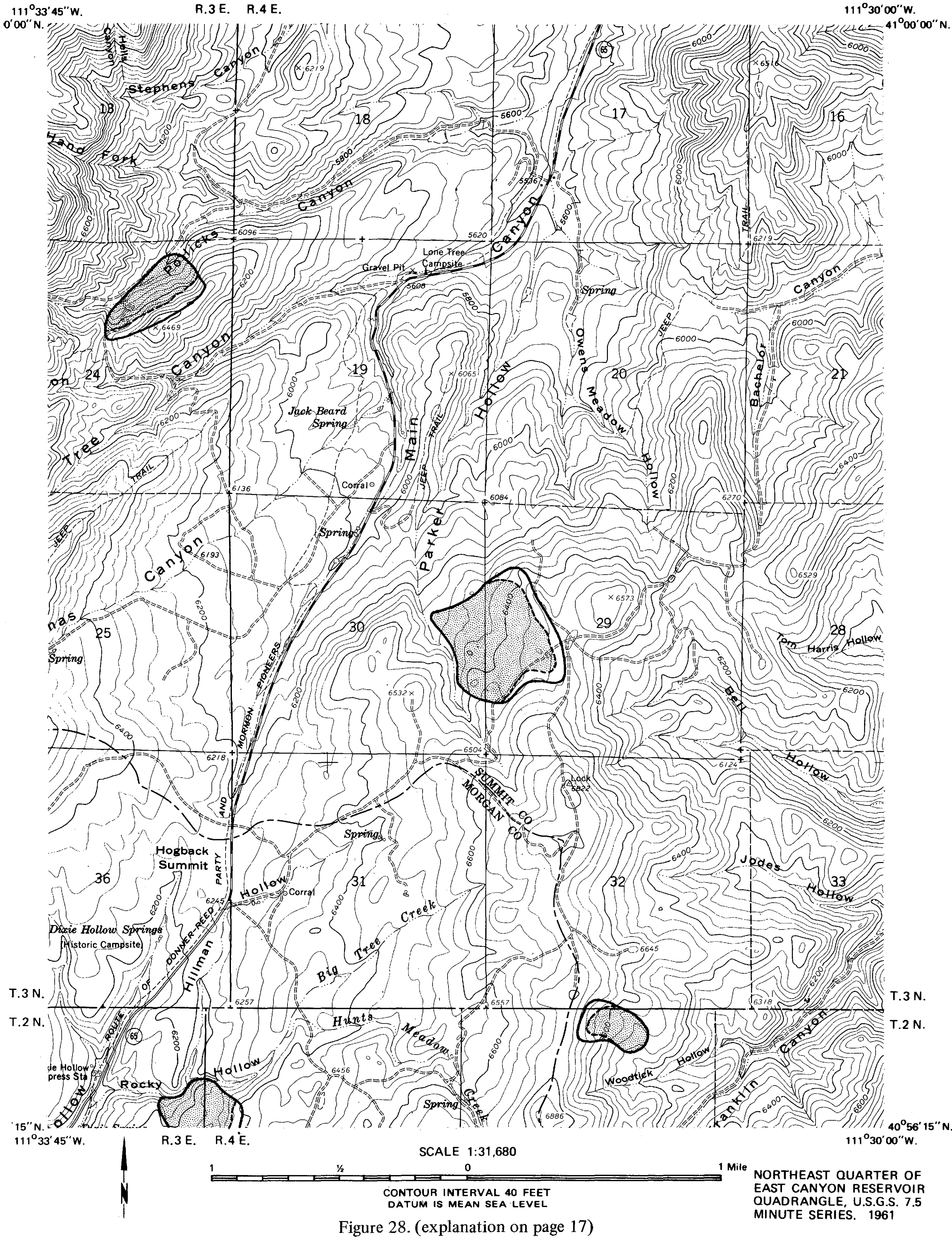

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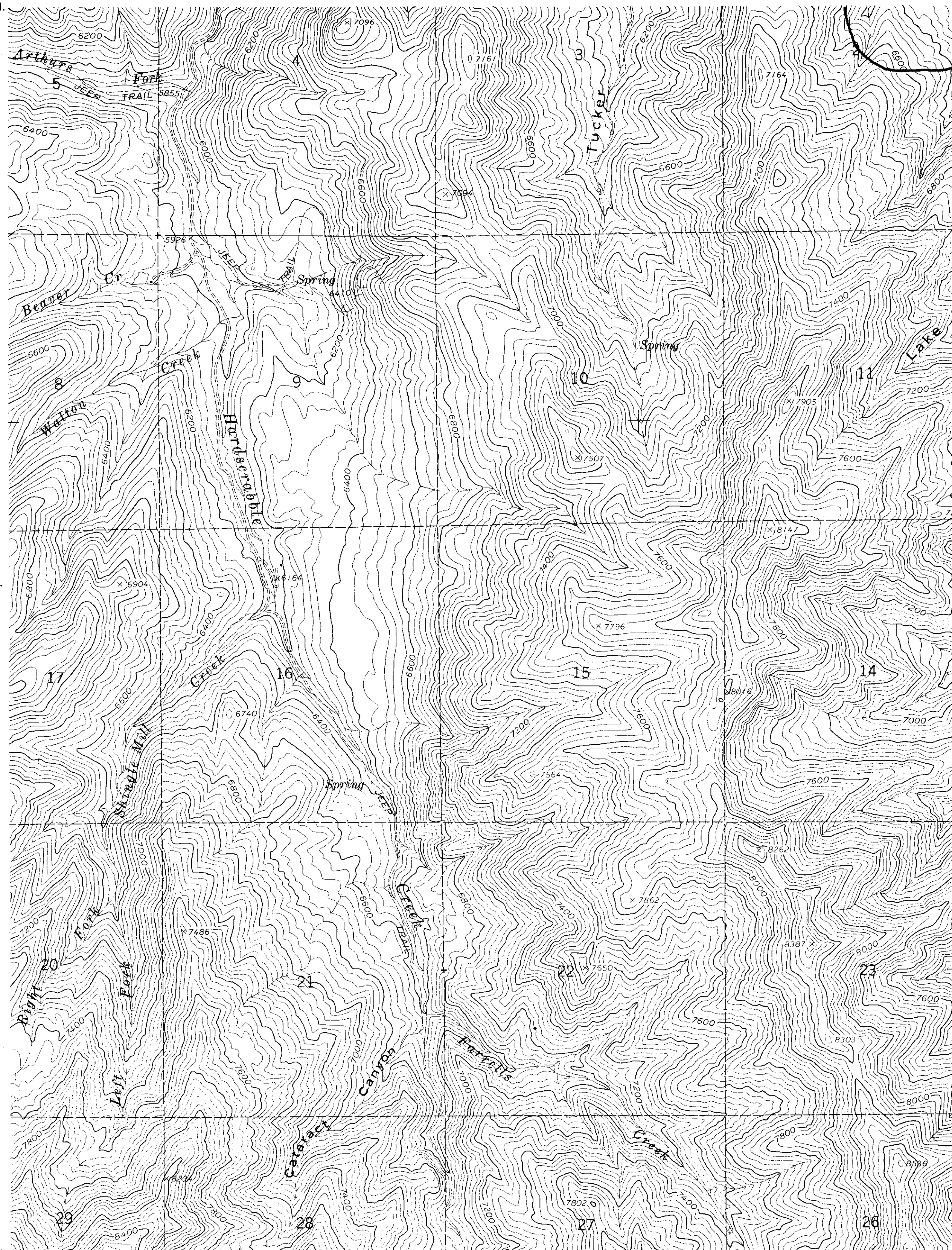


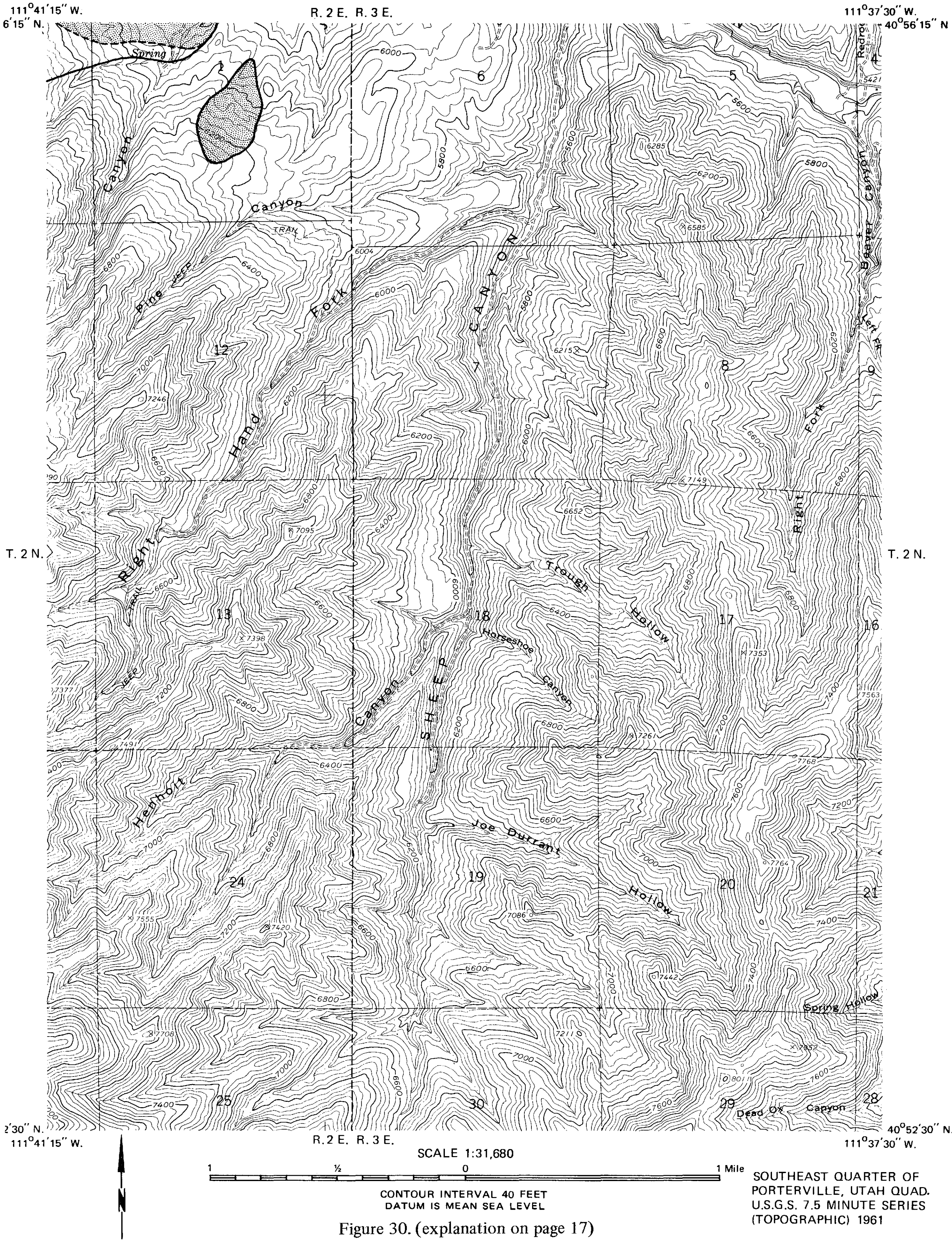
SCALE 1:31,680

1 ½ 0 1 Mile

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

SOUTHWEST QUARTER OF
PORTERVILLE, UTAH QUAD
U.S.G.S. 7.5 MINUTE SERIES
(TOPOGRAPHIC). 1961

Figure 29. (explanation on page 17)



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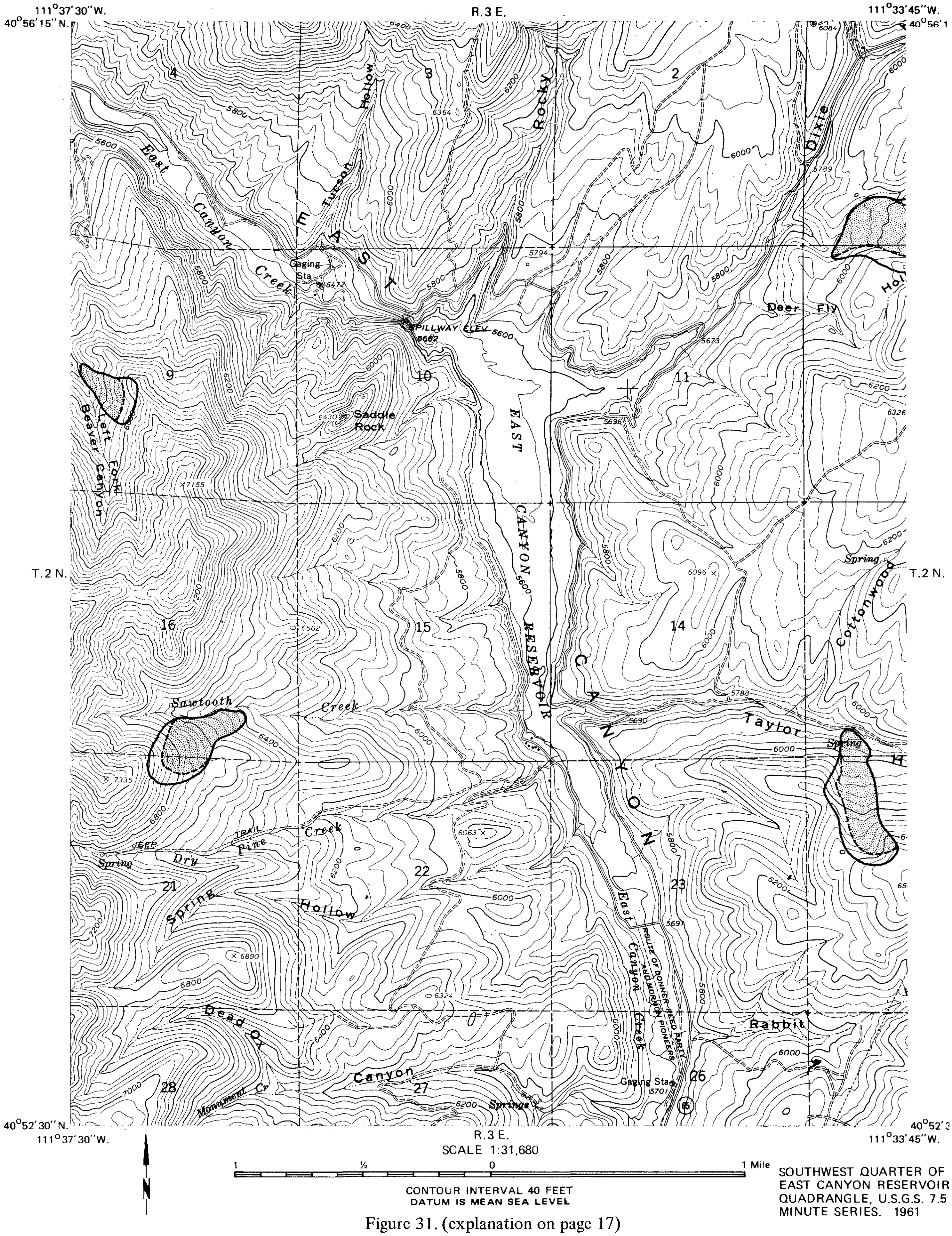


Figure 31. (explanation on page 17)

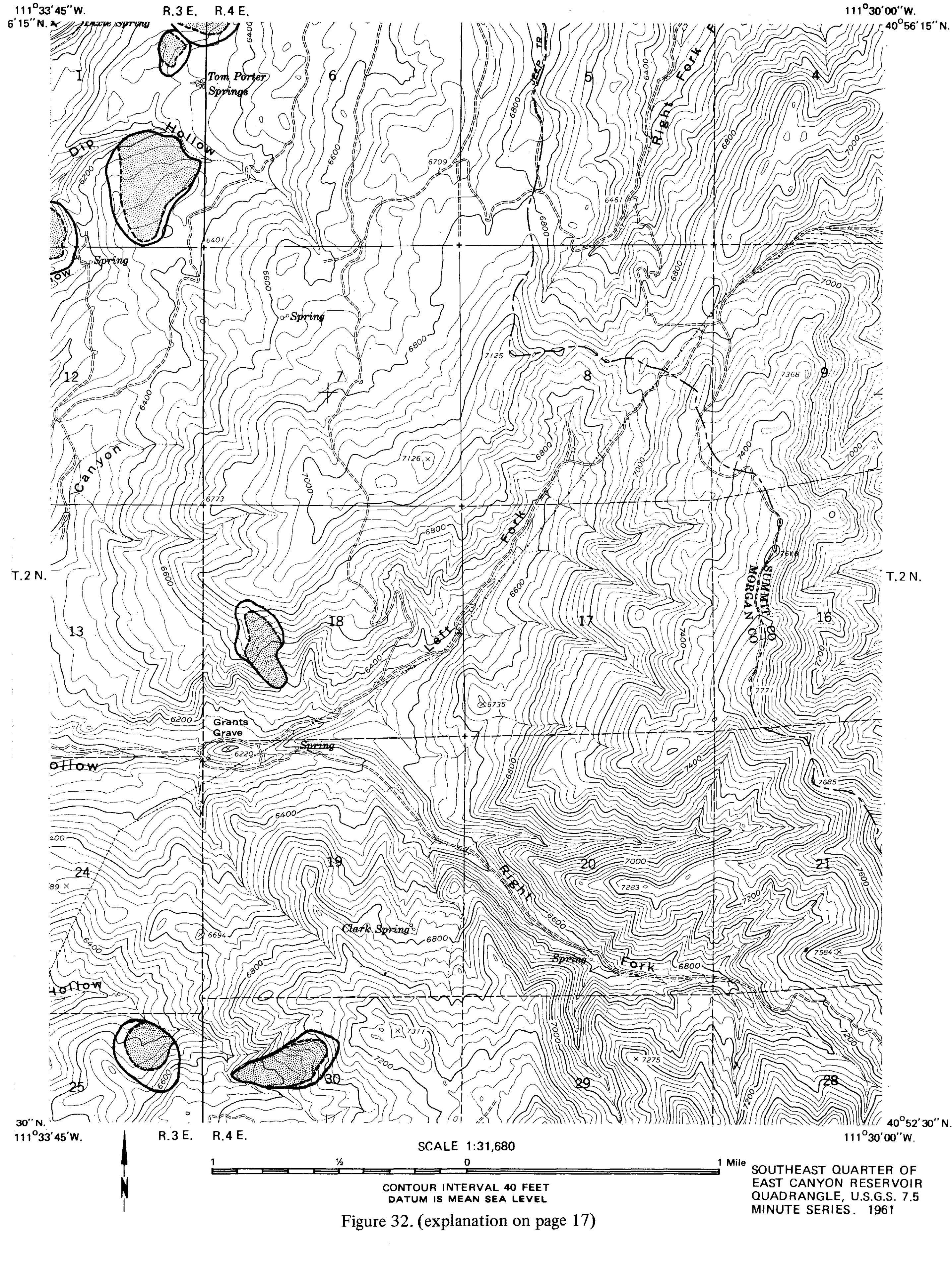


Figure 32. (explanation on page 17)

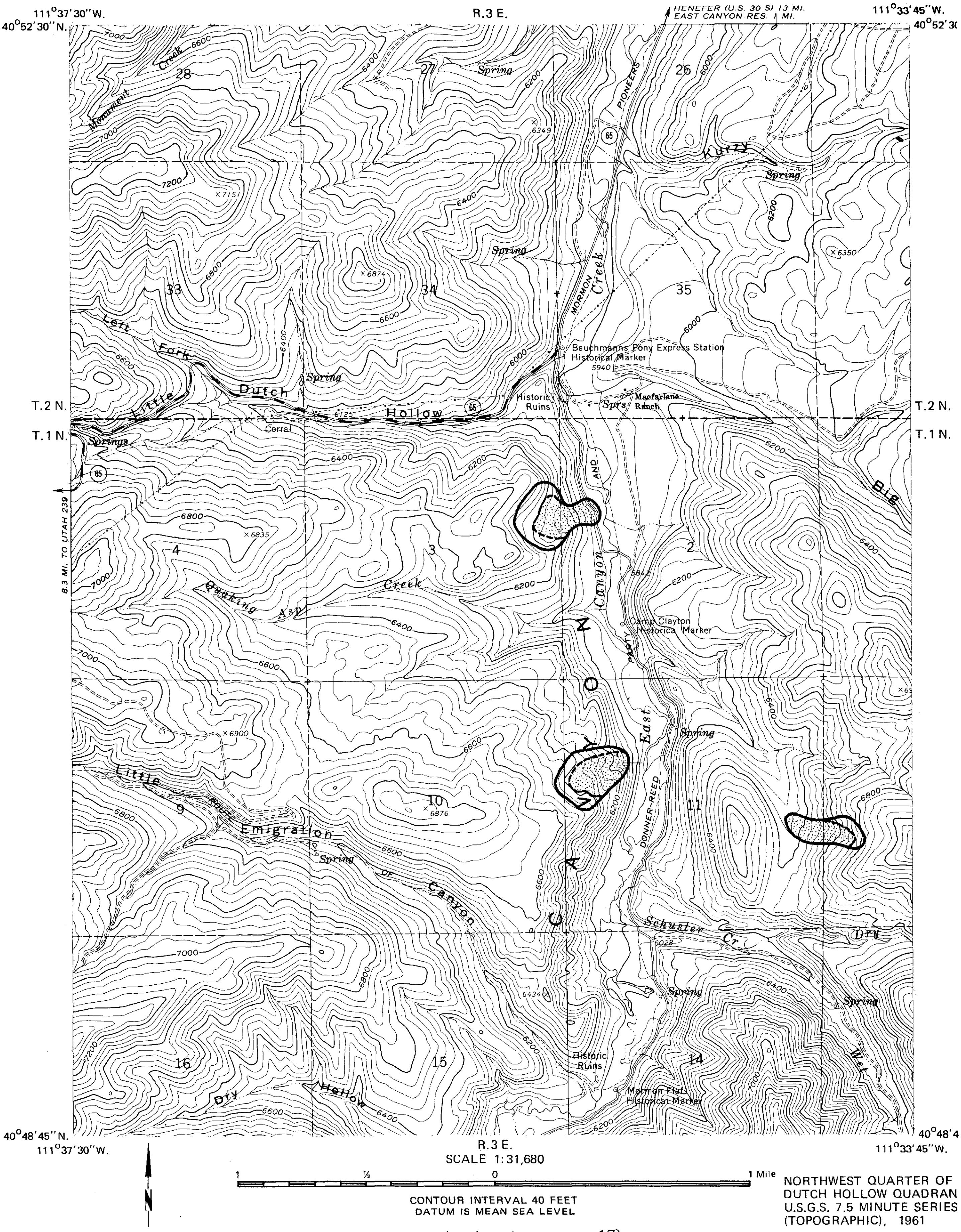
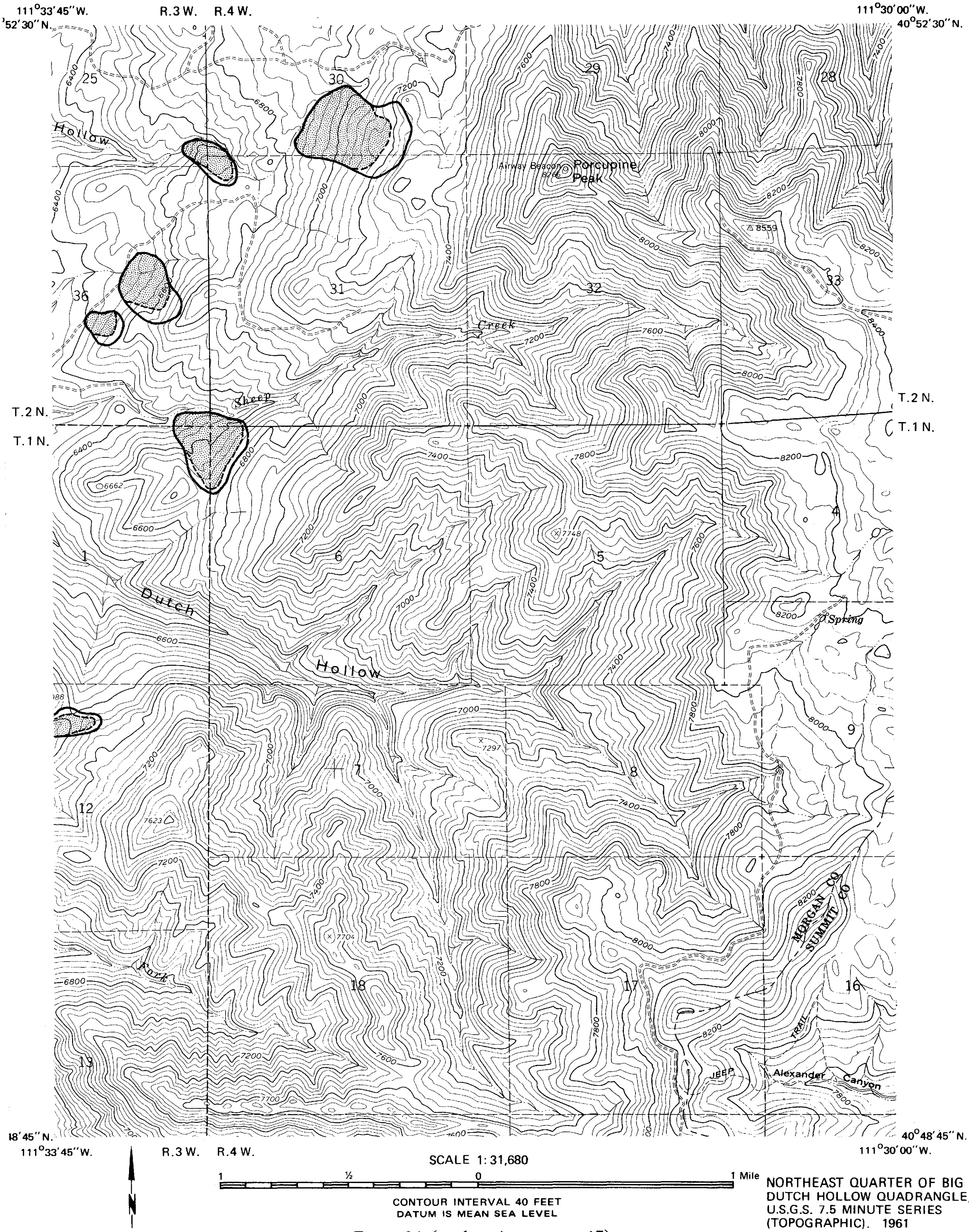


Figure 33. (explanation on page 17)



NORTHEAST QUARTER OF BIG DUTCH HOLLOW QUADRANGLE, U.S.G.S. 7.5 MINUTE SERIES (TOPOGRAPHIC). 1961

Figure 34. (explanation on page 17)

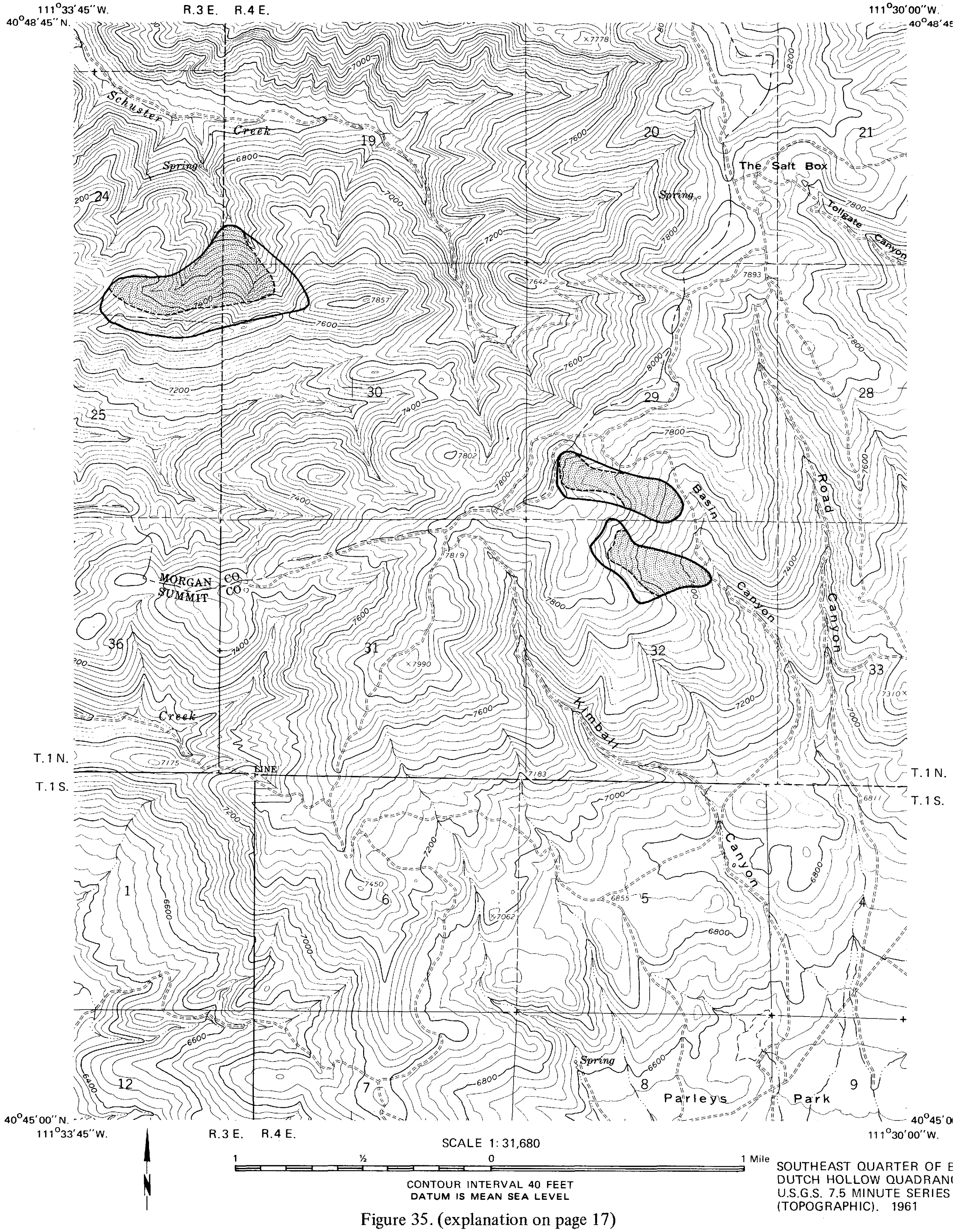


Figure 35. (explanation on page 17)

APPENDIX II

SOIL SAMPLING AND TESTING

Limited soil sampling of Salt Lake Formation materials was undertaken in the Mountain Green area at sites representative of the formation and its overlying colluvium. Much of the terrain that appears most likely to be subdivided consists of these materials; therefore, there is every need to appreciate its limitations at this early stage.

Disturbed and undisturbed samples were taken, the latter by hand driving either a 2.42-inch diameter thin wall bit or a 2.4-inch diameter Shelby tube into the soil. Samples were sealed in the field and transmitted to the laboratory where they were tested under contract for the Utah Geological Survey.

Samples obtained by utilizing the thin wall bits ranged in height from 2.0 to 5.5 inches while samples obtained utilizing the Shelby tubes ranged in height from 6 to 10 inches.

Six sites were sampled and test results indicate the material to be relatively uniform as was perceived from first field observations.

MOISTURE AND DENSITY DETERMINATIONS

Moisture and density determinations were performed to determine the degree of saturation of the *in situ* soils and to correlate strength and consolidation-expansion data.

Table 6 shows the results of the determinations. Since a principal concern of this study is slope stability, several samples were obtained from within active slides.

Figures 36, 37 and 38 are zero air voids curves with moisture and density determinations plotted. The plots indicate that nearly all of the *in situ* samples tested are at or nearly at saturated moisture contents.

ATTERBERG LIMITS

To classify the soils, Atterberg Limit determinations were performed on two representative samples. The results of the tests are presented below.

The Atterberg Limit determinations were performed in accordance with ASTM (American Society for Testing Materials) designations D423-66 and D424-59.

Site	Sample designation	Soil type	Percent		
			Liquid limit	Plastic limit	Plasticity index
2[1]	A and B	CL/ML	46.0	27.8	18.2
6	A and B	CL/ML	42.4	24.5	17.9

[1]Denotes sample obtained from within slide area.

SHRINKAGE FACTORS

To determine shrinkage characteristics of the soils, shrinkage factors were determined on two representative samples. The results of the tests are presented below:

Site	Sample designation	Shrinkage limit	Shrinkage ratio
2[1]	A and B	15.5	1.92
6	A and B	14.1	1.97

[1]Denotes sample obtained from within slide area.

The shrinkage factors were determined in accordance with the ASTM designation D427-61.

SPECIFIC GRAVITY TESTS

Specific gravity determinations also were run on the samples on which Atterberg limits and shrinkage fac-

Table 6. Moisture and density determinations.

Site	Sample designation	Soil type	Natural moisture (content in percent)	Natural dry (density in pcf)
1	A	CL/ML	27.2	97
1[1]	B	CL/ML	24.6	92
2[1]	B	CL/ML	31.7	87
2[1]	C	CL/ML	28.8	94
2[1]	E	CL/ML	28.6	90
3[1]	D	CL/ML	30.0	90
3[1]	D	CL/ML	16.2	90
3[1]	E	CL/ML	25.0	97
3[1]	F	CL/ML	24.3	100
3[1]	G	CL/ML	27.8	94
3[1]	H	CL/ML	27.8	93
3[1]	I	CL/ML	26.1	97
4	A	CL/ML	24.0	97
4	B	CL/ML	28.0	92
4	C	CL/ML	26.8	94
5[1]	A	CL/ML	23.0	97
5[1]	A	CL/ML	22.9	100
5[1]	B	CL/ML	24.4	88

[1]Denotes samples obtained from within slide area.

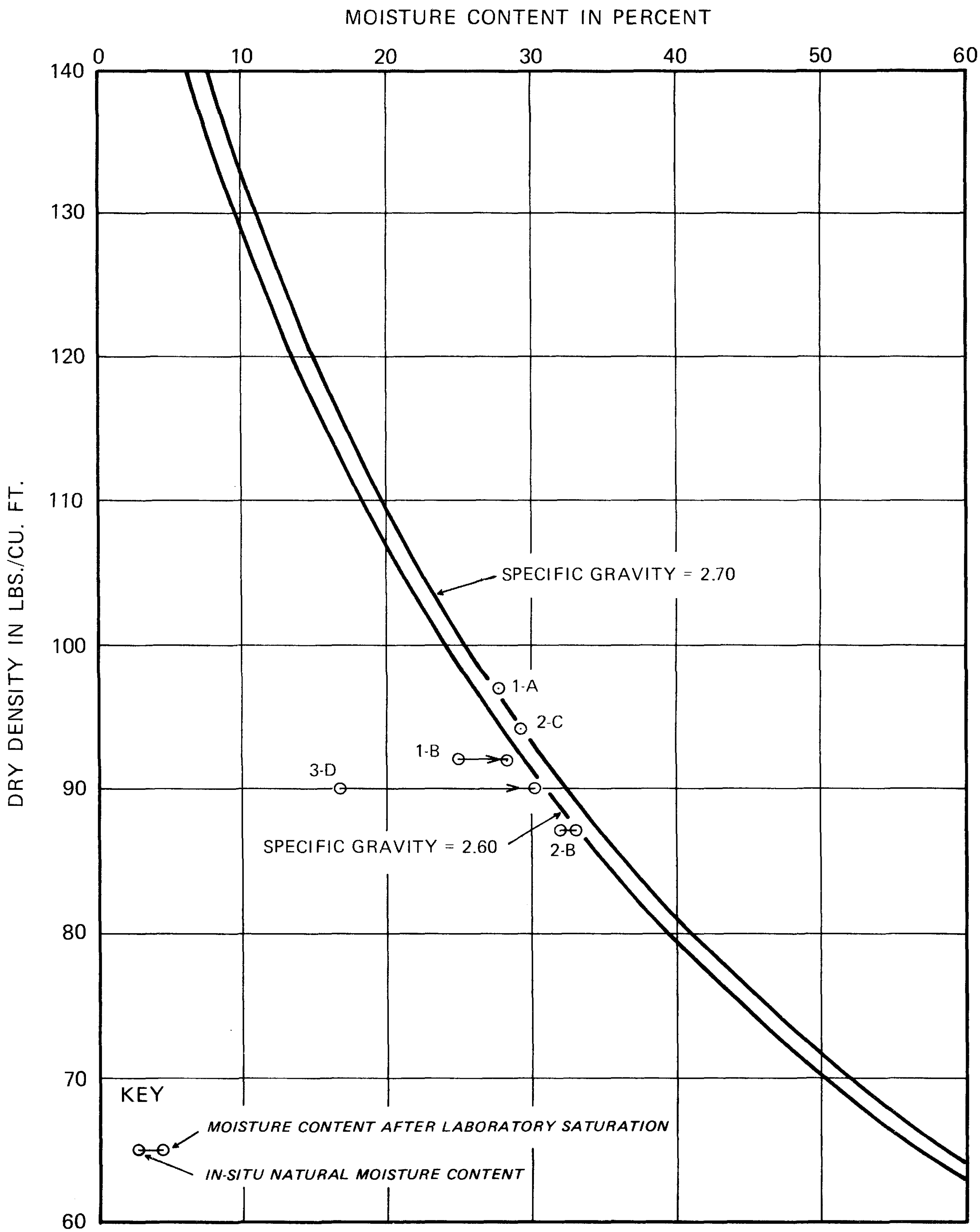


Figure 36. Zero air voids curve.

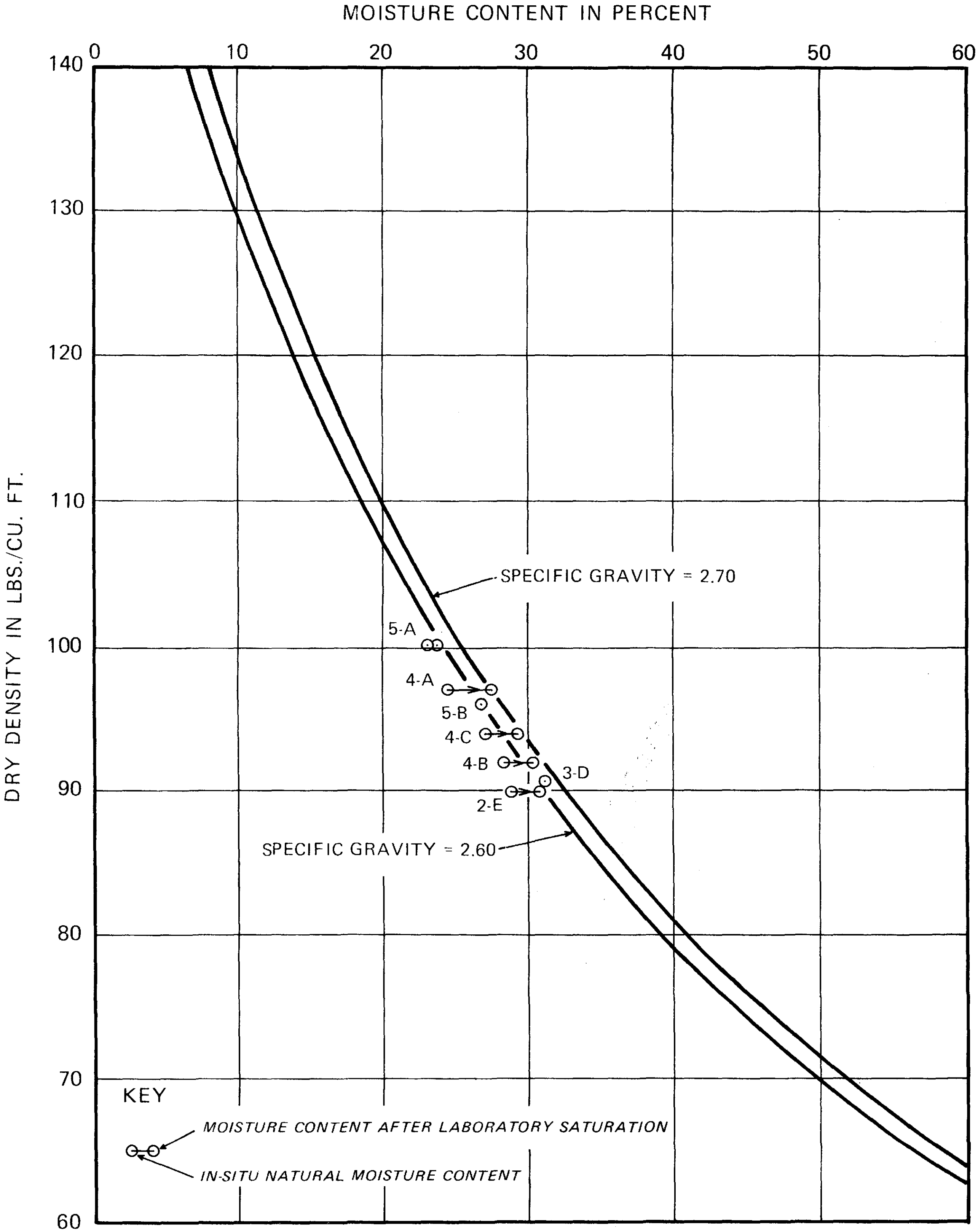
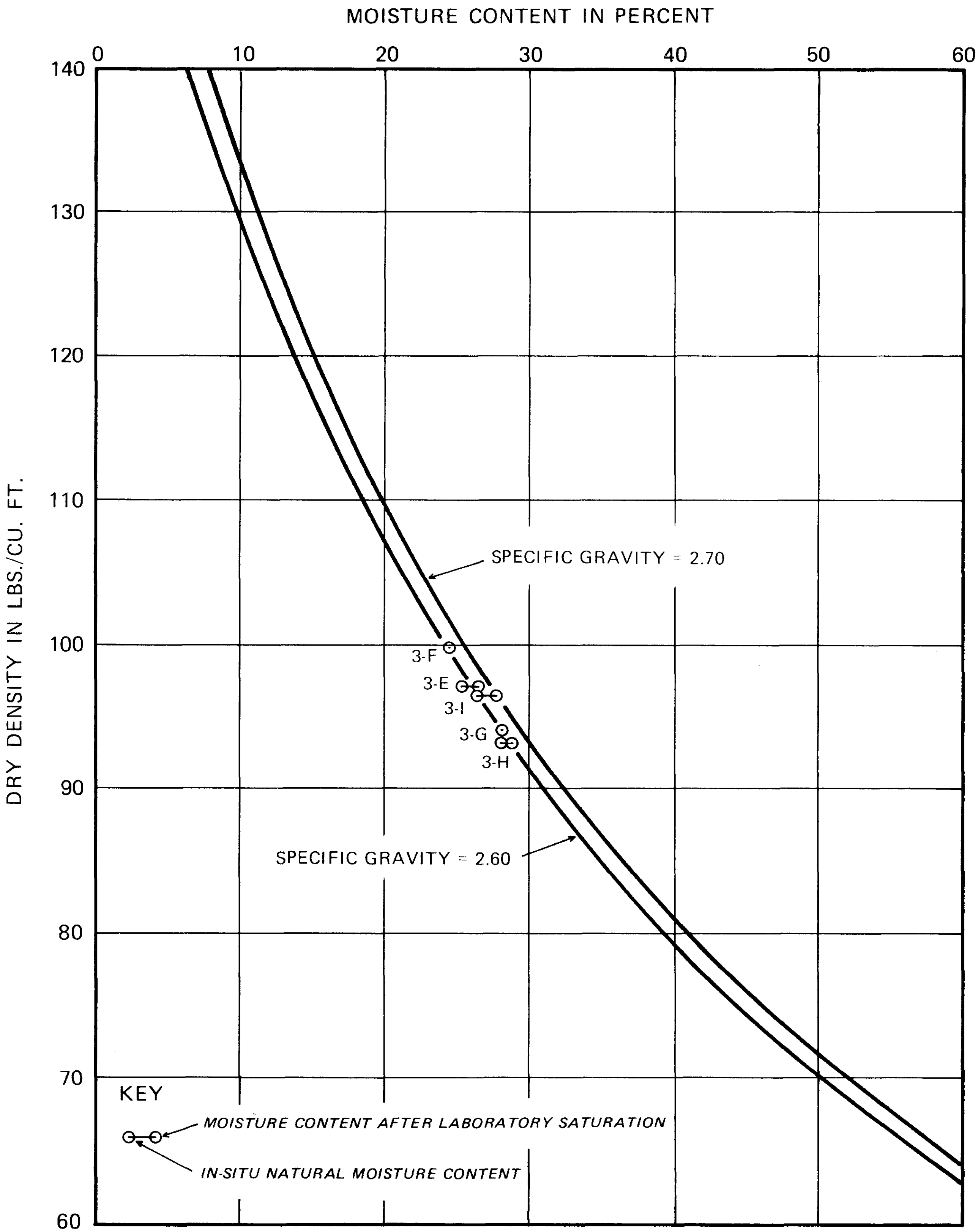


Figure 37. Zero air voids curve.


MOISTURE CONTENT IN PERCENT
0
10
20
30
40
50
60
140
130
120
110
100
90
80
70
60
DRY DENSITY IN LBS./CU. FT.
SPECIFIC GRAVITY = 2.70
SPECIFIC GRAVITY = 2.60
3-F
3-E
3-I
3-G
3-H
KEY
MOISTURE CONTENT AFTER LABORATORY SATURATION
IN-SITU NATURAL MOISTURE CONTENT

tor determinations had been performed. The results of the tests are given below:

Site	Sample designation	Soil type	Specific gravity
2[1]	A	CL/ML	2.66
6	A	CL/ML	2.60

[1]Denotes sample obtained from within slide area.

The specific gravity tests were performed in accordance with the ASTM designation D854-58.

GRAIN-SIZE ANALYSES

The fine-grained nature of the soil samples necessitated hydrometer analyses to determine the grain-size distribution of the two representative soil samples. Figures 39 and 40 present the results of the hydrometer analyses.

STRENGTH TESTS

Determination of strength characteristics of the *in situ* natural soils required a series of direct shear and unconsolidated, undrained, triaxial compression tests on a number of selected and undisturbed samples. Samples were saturated prior to testing in all cases. Various normal and confining pressures were applied to the samples to develop suitable strength parameter envelopes. Tables 7 and 8 summarize these tests.

The strength parameters of the natural soils as determined by the laboratory testing are:

$$c \text{ (cohesion)} = 650 \text{ psf}$$
$$\phi \text{ (phi angle)} = 0^\circ$$

CONSOLIDATION-EXPANSION TESTS

Two representative undisturbed samples underwent confined compression testing to develop consolidation parameters. Figures 41 and 42 show the resulting data plotted as load versus consolidation curves. These curves permit estimates to be made of the probable magnitude and rate of settlement of the tested soils under applied loads.

Table 7. Direct shear tests on undisturbed samples.

Site	Sample designation	Soil type	Normal pressure (psf)	Yield shearing stress (psf)
1	A	CL/ML	1,500	650
1	B	CL/ML	3,000	420
2	C	CL/ML	1,000	580
2	E	CL/ML	3,500	500
3	D	CL/ML	1,500	700
3	D	CL/ML	3,000	800
4	A	CL/ML	3,250	1,100
4	B	CL/ML	1,250	650
4	C	CL/ML	2,000	600
5	B	CL/ML	2,500	650

Table 8. Triaxial compression tests.

Site	Sample designation	Soil type	Confining pressure (psf)	Ultimate shearing stress (psf)
3	E	CL/ML	1,000	862
3	F	CL/ML	2,000	715
3	G	CL/ML	3,000	606
3	H	CL/ML	4,000	729
3	I	CL/ML	5,000	700

Expansion tests were performed in conjunction with the consolidation tests to determine the relative expansion characteristics which could be expected on saturation of the natural soils. Figures 41 and 42 graphically present the test results.

COMPACTION TEST

To determine the compaction characteristics of the material, a compaction test was performed on a representative sample. Figure 43 shows the resulting curve.

TESTS ON RECOMPACTED SAMPLES

The purpose of testing recompacted samples is to determine the utility of *in situ* materials as fill.

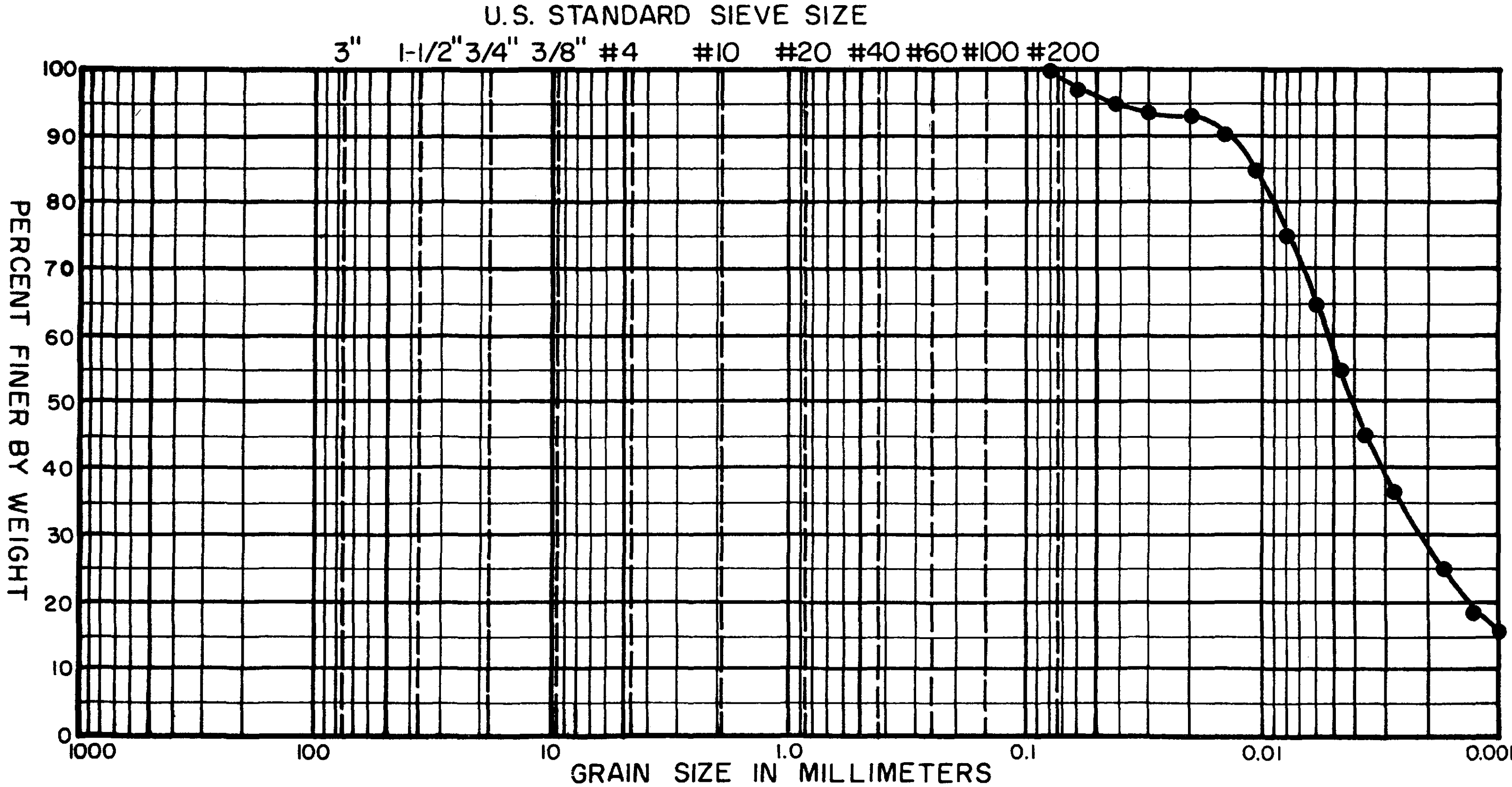
Based on figure 43, samples of on-site material were recompacted to densities of approximately 85, 90 and 95 percent of the maximum dry density. The samples were recompacted at moisture contents near optimum and above optimum and then subjected to consolidation and direct shear testing.

Consolidation Tests

Four consolidation tests were performed on recompacted soil samples. Figures 44 and 45 show the resulting curves.

Direct Shear Tests

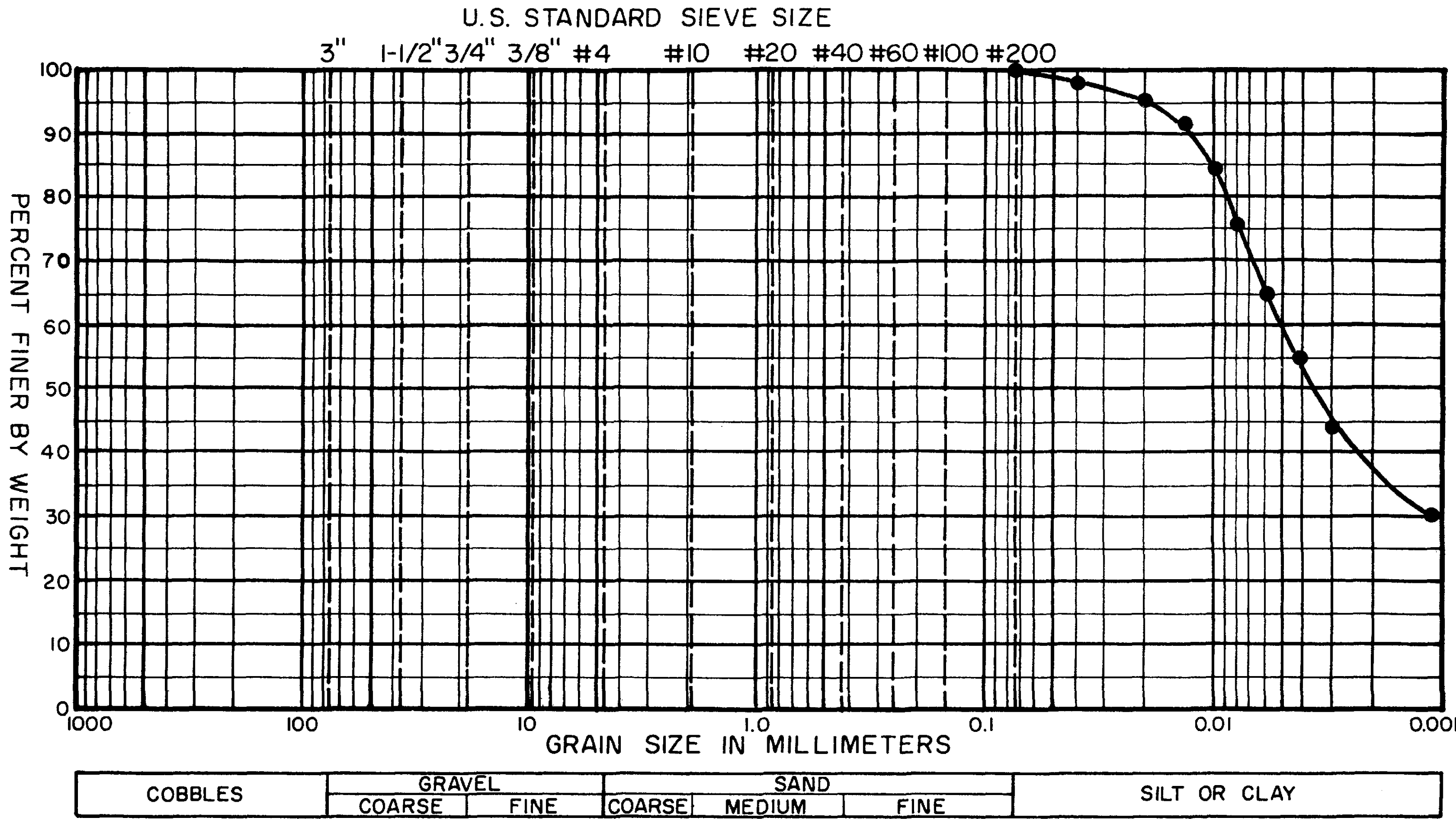
Six direct shear tests were performed on recompacted samples. The samples tested were recompacted to approximately 90 and 95 percent of the maximum dry density. Prior to testing these samples were saturated under a confining load approximating the pressures that would be encountered under field conditions. Results of these tests are presented in table 9 (p. 54).



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

LOCATION	CLASSIFICATION
MOUNTAIN GREEN UGMS (2 A&B)	REDDISH BROWN SILTY CLAY CL/ML

Figure 39. Grain-size analysis.



LOCATION	CLASSIFICATION
MOUNTAIN GREEN UGMS (6 A&B)	REDDISH BROWN SILTY CLAY CL/ML

Figure 40. Grain-size analysis.

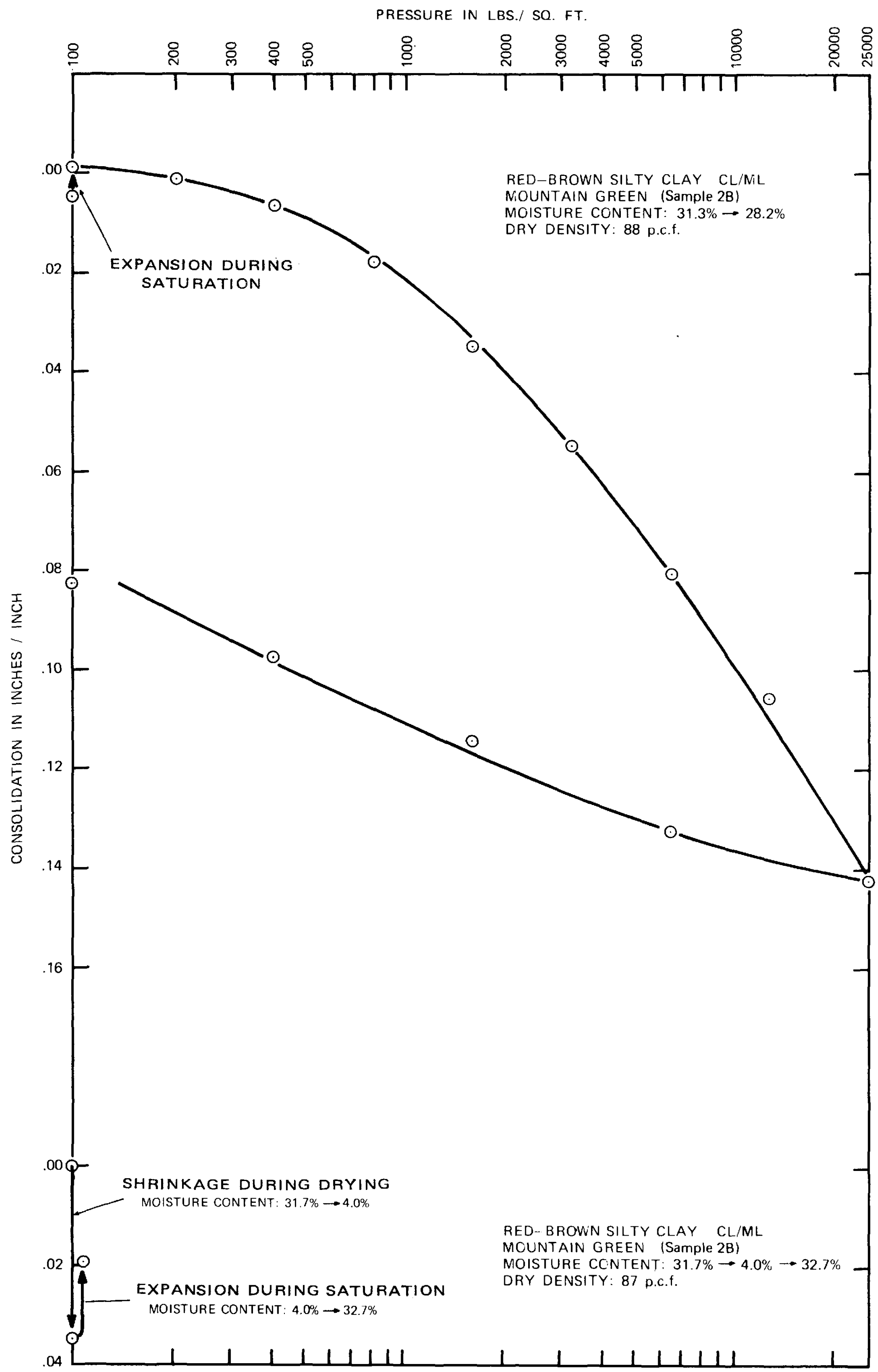


Figure 41. Consolidation and expansion tests on undisturbed samples.

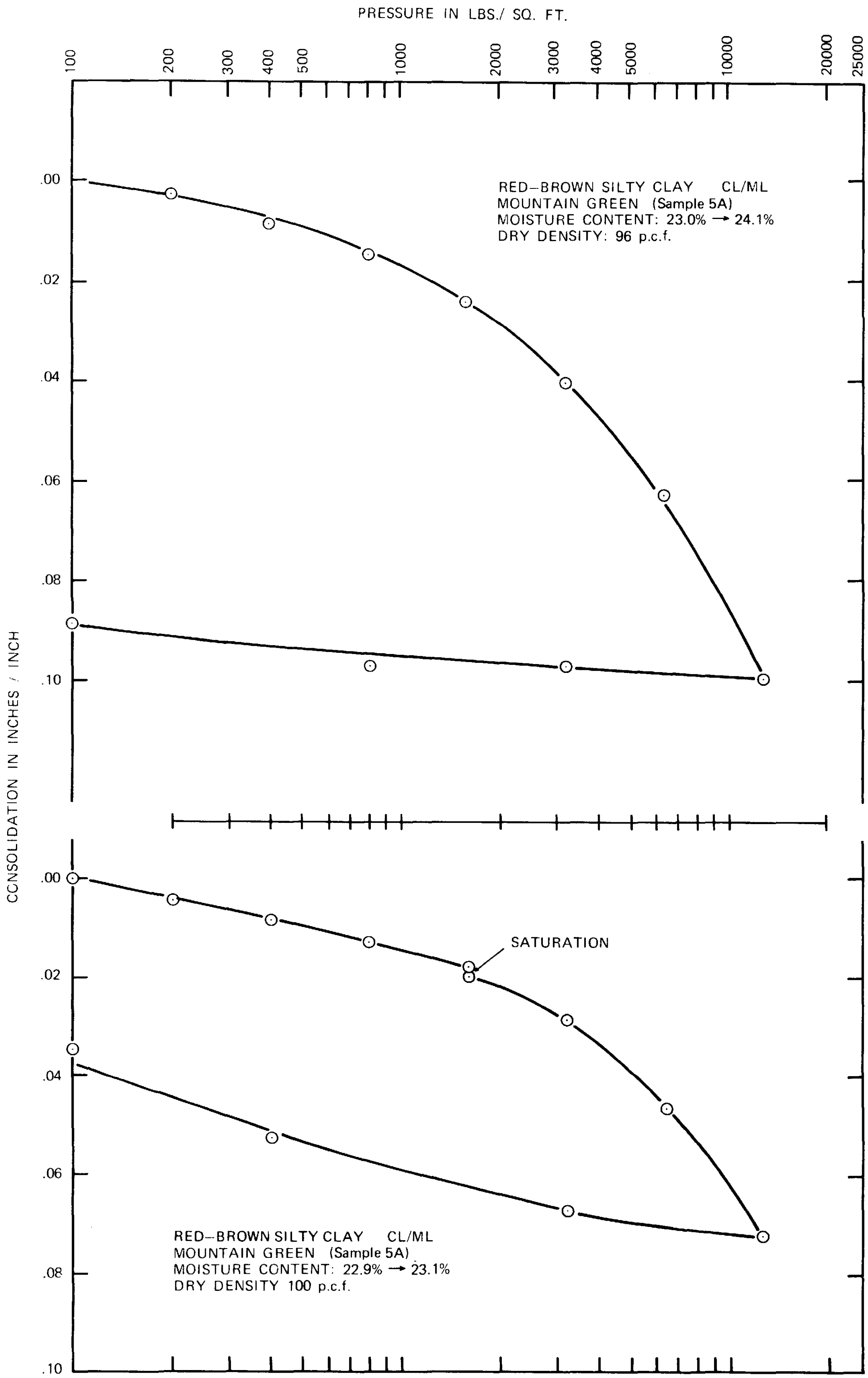


Figure 42. Consolidation and expansion tests on undisturbed samples.

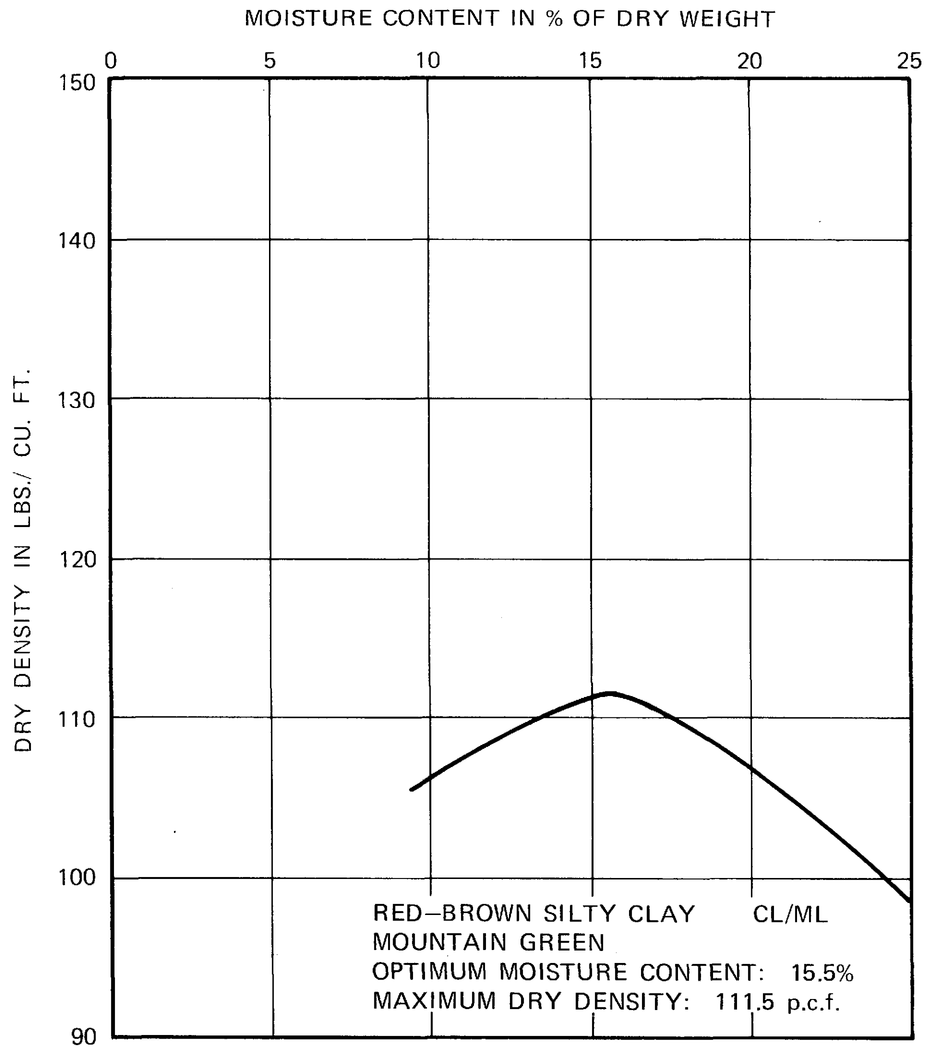


Figure 43. Compaction curve.

Table 9. Direct shear tests on recompacted samples.

Sample No.	Compaction (percent)	Soil type	Normal pressure (psf)	Yield shearing strength (psf)
1	89	CL/ML	1,500	600
2	89	CL/ML	3,000	650
3	88	CL/ML	4,500	900
4	96	CL/ML	1,500	800
5	96	CL/ML	3,000	750
6	96	CL/ML	4,500	850

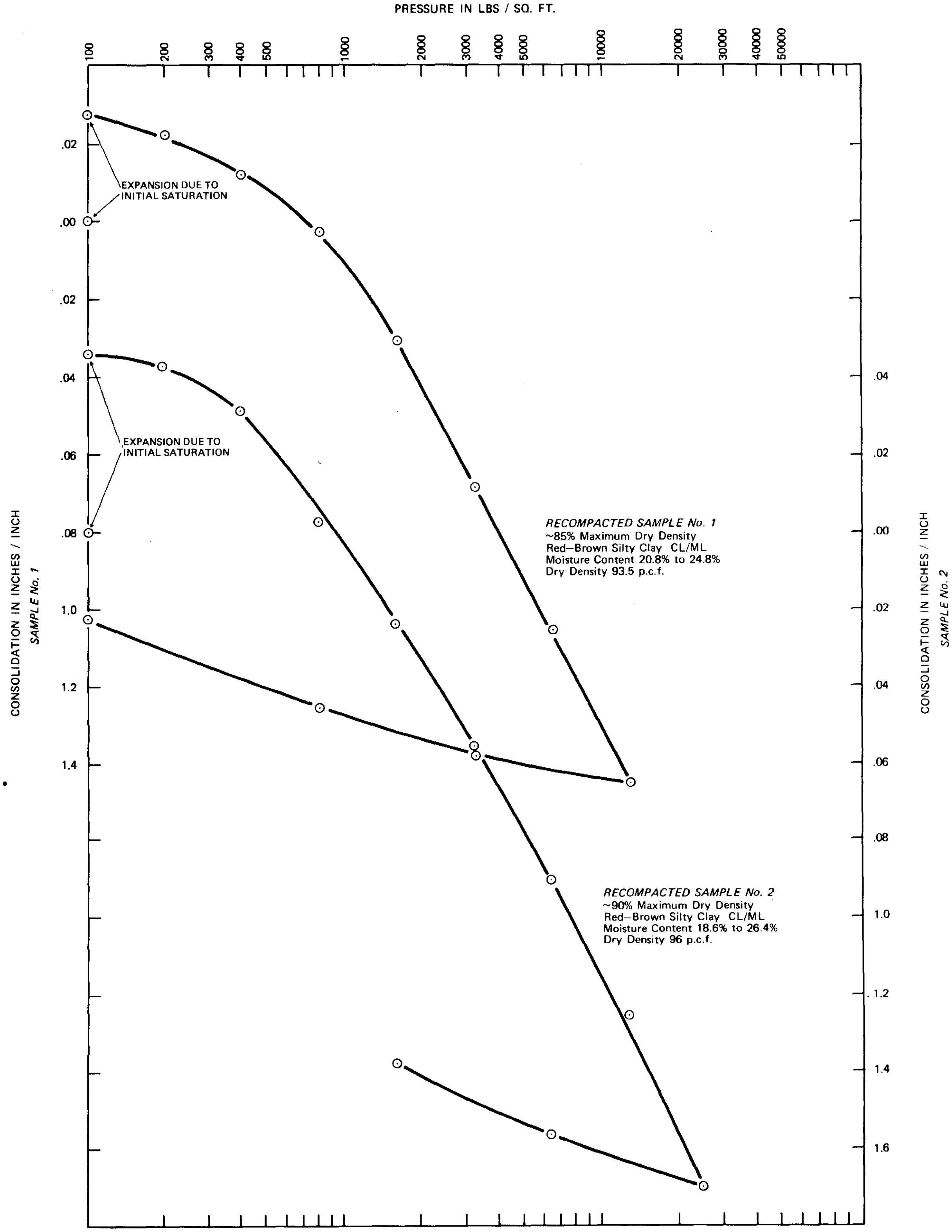


Figure 44. Consolidation and expansion tests on recompacted samples.

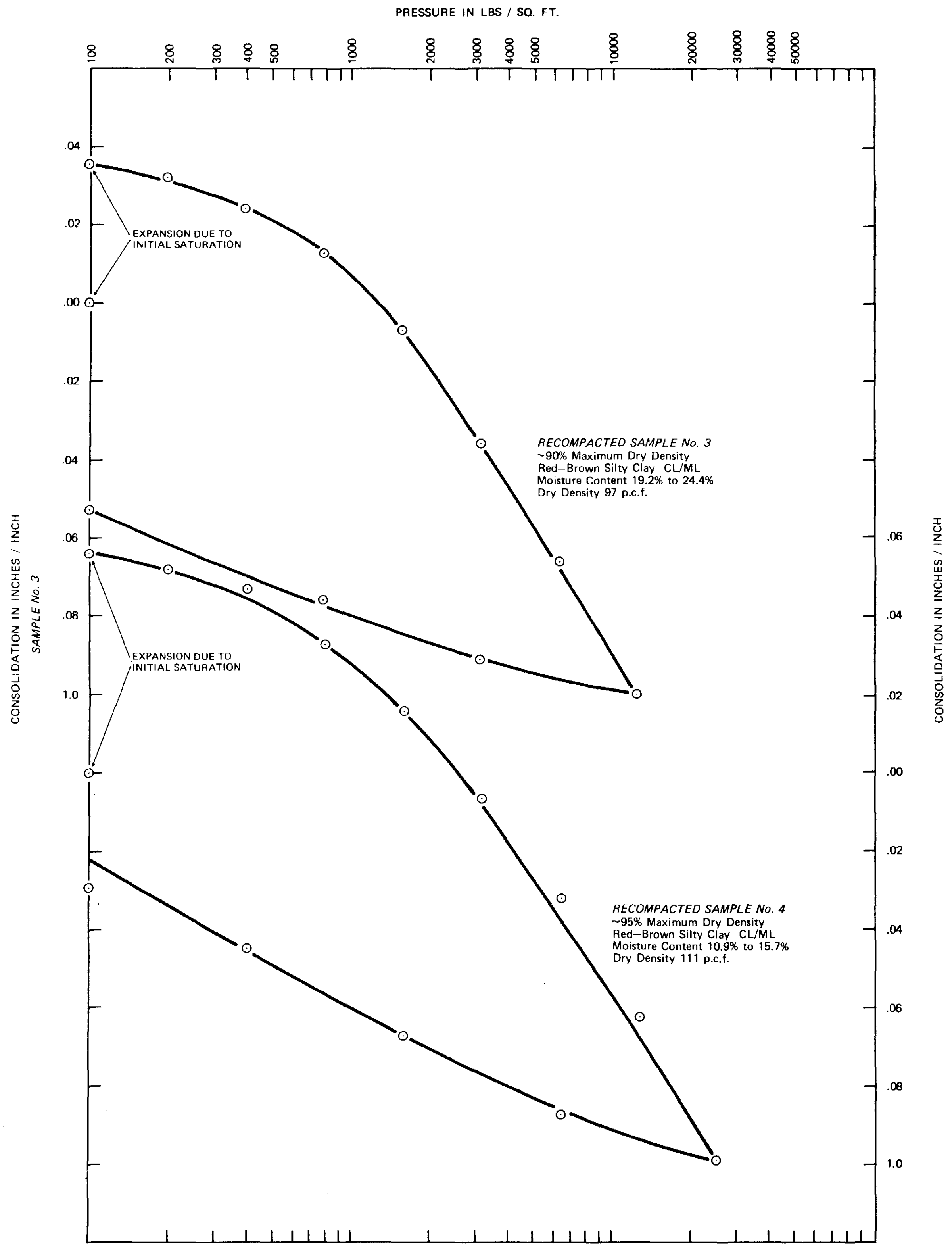


Figure 45. Consolidation and expansion tests on recompacted samples.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Utah Geological Survey Building
University of Utah
Salt Lake City, Utah 84112

THE UTAH GEOLOGICAL AND MINERALOGICAL SURVEY since 1949 has been affiliated with the College of Mines and Mineral Industries at the University of Utah. It operates under a director with the advice and counsel of an Advisory Board appointed by the Board of Regents of the University of Utah from organizations and categories specified by law.

The survey is enjoined to cooperate with all existing agencies to the end that the geological and mineralogical resources of the state may be most advantageously investigated and publicized for the good of the state. The *Utah Code, Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-2*, describes the Survey's functions.

Official maps, bulletins, and circulars about Utah's resources are published. (Write to the Utah Geological and Mineralogical Survey for the latest list of publications available).

THE LIBRARY OF SAMPLES FOR GEOLOGIC RESEARCH. A modern library for stratigraphic sections, drill cores, well cuttings, and miscellaneous samples of geologic significance has been established by the Survey at the University of Utah. It was initiated by the Utah Geological and Mineralogical Survey in cooperation with the Departments of Geology of the universities in the state, the Utah Geological Society, and the Intermountain Association of Petroleum Geologists. This library was made possible in 1951 by a grant from the University of Utah Research Fund and by the donation of collections from various oil companies operating in Utah.

The objective is to collect, catalog, and systematically file geologically significant specimens for library reference, comparison, and research, particularly cuttings from all important wells driven in Utah, and from strategic wells in adjacent states, the formations, faunas, and structures of which have a direct bearing on the possibility of finding oil, gas, salines or other economically or geologically significant deposits in this state. For catalogs, facilities, hours, and service fees, contact the office of the Utah Geological and Mineralogical Survey.

THE SURVEY'S BASIC PHILOSOPHY is that of the U. S. Geological Survey, i.e., our employees shall have no interest in Utah lands. For permanent employees this restriction is lifted after a 2-year absence; for consultants employed on special problems, there is a similar time period which can be modified only after publication of the data or after the data have been acted upon. For consultants, there are no restrictions beyond the field of the problem, except where they are working on a broad area of the state and, here, as for all employees, we rely on their inherent integrity.

DIRECTORS:

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961