ENGINEERING GEOLOGY OF PARK CITY, SUMMIT COUNTY, UTAH

By Harold E. Gill and William R. Lund

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
Utah Department of Natural Resources

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Gill and Lund – Engineering Geology of Park City, Summit County, Utah
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ENGINEERING GEOLOGY OF PARK CITY, SUMMIT COUNTY, UTAH

By Harold E. Gill [1] and William R. Lund [2]

ABSTRACT

Park City began as a mining community in the late 1860s and mining continued actively in the area for more than 100 years. In the 1970s skiing surpassed mining as the major industry in the area. Due to a rapid increase in population and tourism, and subsequent need for additional facilities, pressure for development in possible problem areas, such as flood plains and steep hillsides, has increased. Development in these relatively hazardous areas requires early recognition of geologic constraints on construction. It is the purpose of this report to provide general information on geologic conditions and hazards in Park City for use in making planning decisions.

Park City is on the eastern slope of the Wasatch Range in north-central Utah. Bedrock in the study area consists of Pennsylvanian to Jurassic quartzite, limestone, sandstone, shale, siltstone, mudstone, and conglomerate, as well as Tertiary volcanic and intrusive rocks. The area is on the north flank of the westward extension of the Uinta arch, and beds dip gently to the north-northwest. Quaternary glacial and alluvial deposits (gravel, sand, silt, and clay) cover approximately 25 percent of the area. The major structural features in Park City are the north-trending Park City anticline on the west and the Frog Valley thrust fault on the east. Numerous northeast-southwest trending normal faults are found in the southern half of the study area.

Soils are predominantly gravelly, but fine-grained materials (silts and clays) are found in valley bottoms and along drainage channels. Expansive clays occur locally in the alluvium-filled valleys. Rock materials are resistant quartzite and limestone in the south and less resistant shale, siltstone, and mudstone in the north. Flood-prone areas are limited to land adjacent to stream channels and to valley bottoms such as Deer Valley and Park Meadows, where both flood and shallow ground-water hazard are high. To the present time, slope failure and erosion have not been major problems. However, as development continues, especially on steeper slopes, care should be taken to assure that grading and wetting of the slopes, as well as removal of natural ground cover, do not increase the hazard.

The rapid development of Park City as a recreational area has resulted in the urbanization of mined areas. Hazards associated with mining include open shafts and adits, increased loading on slopes due to waste piles, contamination of soil and water by toxic elements in old mill tailings, and subsidence resulting from collapse of abandoned underground workings.

Park City lies within a north-south trending belt of seismicity known as the Intermountain seismic belt. Although the city has not experienced a large earthquake in historic time, an earthquake of Richter magnitude 6 is considered possible.

Snow avalanches occurred in the Park City area between 1884 and 1897, primarily because trees which stabalize snow on slopes were removed for use by the mining industry. At present, the slopes have revegetated and no avalanches have been reported on slopes near the city since Park City Resort opened in 1963.

INTRODUCTION

Background and purpose

Park City is located on the eastern slope of the Wasatch Range in north-central Utah, about 20 miles (32 km) east of Salt Lake City (fig. 1). It originated as a silver mining community in the late 1860s. Mining activity peaked in 1929 and has decreased since that time (Economics Research Associates, 1981). However, considerable ore remains and may be mined in the future. The first ski resort was devel-

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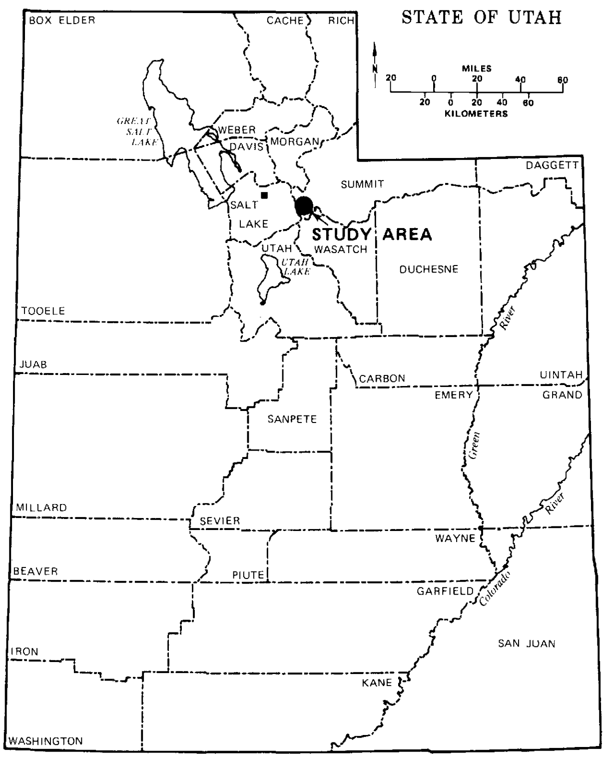


FIGURE 1.—Location of study area.

oped in 1963 (Park City Ski Resort), and during the 1970s skiing replaced mining as the major industry in Park City. All mines are idle at present, but Park City and the Snyderville Basin are experiencing renewed growth with the opening of additional winter recreational facilities such as Park West Ski Resort and most recently Deer Valley Resort. The mild summer climate and spectacular mountain scenery attract many summer visitors and full-time residents as well.

The 1980 census shows that the population of Park City increased from 1193 in 1970 to 2823 in 1980. It is estimated that the population will nearly quadruple between 1980 and the year 2000 (Economics Research Associates, 1981). The number of full-time residents, however, is not an accurate indication of the importance of Park City as a growing Utah community. During a peak month of the winter recreation season, the average population of the Park City and Snyderville Basin area was reported as 14,400 in 1981/1982, and is estimated to reach 23,470 by 1985/1986 and 47,180 by the year 2000 (Economics Research Associates, 1981). On a percentage basis, the number of housing units is expected to increase faster than resident population due to rapid construction of condominiums for visiting skiers.

Portions of Park City are characterized by steep mountain slopes, expansive soils with moderate to high shrink/swell potential, and shallow ground water. As population grows, land suitable for development will become more scarce and expansion into possible problem areas is likely. For this reason, the Utah Geological and Mineral Survey entered into a cooperative agreement with Park City to investigate engineering geologic conditions within the established boundaries of the town which may have an effect on future growth and development. This was accomplished by preparing a series of maps that identify geologic, hydrologic, and soil conditions of importance to development, and provide an assessment of slope stability, erosion, flood, seismic, and mining-related hazards. The maps and accompanying text are intended for general planning purposes, and do not preclude the necessity for site-specific investigations. A geologic time scale and glossary of terms is included in the appendix.

Previous work

Since the discovery of silver in the late 1800s, the Park City area has been of interest to geologists. Boutwell (1912) published the first extensive geologic study of the Park City mining district and it remains the standard reference for the area. Published reports by Wilson (1959), Eardley (1968), and Bromfield (1968) also discuss the geology of the Park City mining district. The U.S. Geological Survey has mapped the geology of the Park City East and West and Heber 7.5 minute topographic quadrangles, portions of which cover the study area (Bromfield and others, 1970, 1971; Crittenden and others, 1966). A great deal of geologic and hydrologic information has been gathered by various mining companies, but these data are available only through a contract/fee arrangement with United Park City Mines. Baker (1970) published the only hydrologic report pertaining to the study area. The U.S. Geological Survey is currently studying surface and ground-water hydrology in the Park City area, but the report will not be complete for several years. A map of flood-prone areas in Park City has been prepared by the U.S. Department of Housing and Urban Development Federal Insurance Administration (1976) which shows the extent of the 100-year flood (flood with a one percent chance of occurring annually) on major streams. A more comprehensive study, including newly developed areas, is scheduled to begin during the summer of 1984, with completion in about 16 months (James Harvey, oral commun., 1984). The USDA Soil Conservation Service and others (1977) have mapped soils in the area and have made engineering interpretations regarding erosion hazard, slope stability, and land-use.

Scope of work

To accomplish the objectives of this study the following work was undertaken:

1. Review of available published and unpublished reports, well and test pit logs, and maps pertaining to geology, hydrology, and soils.
2. Contact with planners, building inspectors, homeowners, and geologists familiar with local conditions and hazards.
3. Monitoring of surface hydrology and flooding between early spring and late summer 1983.
4. Detailed field mapping using 1:12,000 and 1:20,000 scale black and white stereo aerial photographs and 1:2,400 scale photo enlargements.
5. Field inspection of existing excavations with description of 20 soil profiles to gather data on soil types, erosion hazard, and slope stability.
6. Inspection of adits, shafts, and waste piles at 49 mine workings.
7. Drilling of ten 4-inch (10 cm) diameter auger holes from 2 to 11 feet (0.6 - 3.4 m) deep in the Prospector Square area of Park City to determine depth and lateral extent of mill tailings. Soil samples collected were analyzed for toxic elements.
8. Analysis of data and preparation of maps and accompanying text.

GENERAL GEOLOGY

Physiography and Climate

The study area lies in the Wasatch Range section of the Middle Rocky Mountains physiographic province in north-central Utah (Stokes, 1977). The Wasatch Range trends north-south through central Utah and includes high alpine terrain with peaks above 10,000 feet (3050 m). Much of the higher elevations were glaciated during the Pleistocene. Elevations in Park City range between 6760 and 8495 feet (2062-2591 m) above sea level. Silver Creek (also known as Poison Creek), which heads in Empire Canyon, is the principal drainage in Park City. It flows from the southern boundary of the study area northward to Masonic Hill where it turns to the northeast, eventually joining the Weber River at Wanship about 12 miles (19 km) north of Park City.

Terrain in the study area ranges from broad alluvial valley bottoms and low hills in the north to steep, rugged mountains cut by deep valleys in the south. Most of the mountainous area is underlain by resistant quartzite and limestone bedrock. Deep canyons such as Woodside Gulch, Empire Canyon, and Ontario Canyon have been cut where faulting and folding have made the bedrock less resistant to erosion. These canyons were glaciated and show evidence of scour by glacial ice. To the north, hills are rounded with gentle slopes and low relief because of the less-resistant bedrock (shale, mudstone, and siltstone) found there. Alluvium and glacial outwash from the mountains to the south were deposited along streams forming broad alluvial valleys.

The climate is sub-humid, with annual precipitation ranging from 20 to 25 inches (51-64 cm) in the valley to 25 to 30 inches (64-76 cm) in the mountains (Baker, 1970). The majority of precipitation falls as snow during November through April. The dryest period is generally May through September, when less than 8 inches (20 cm) of precipitation falls.

Stratigraphy

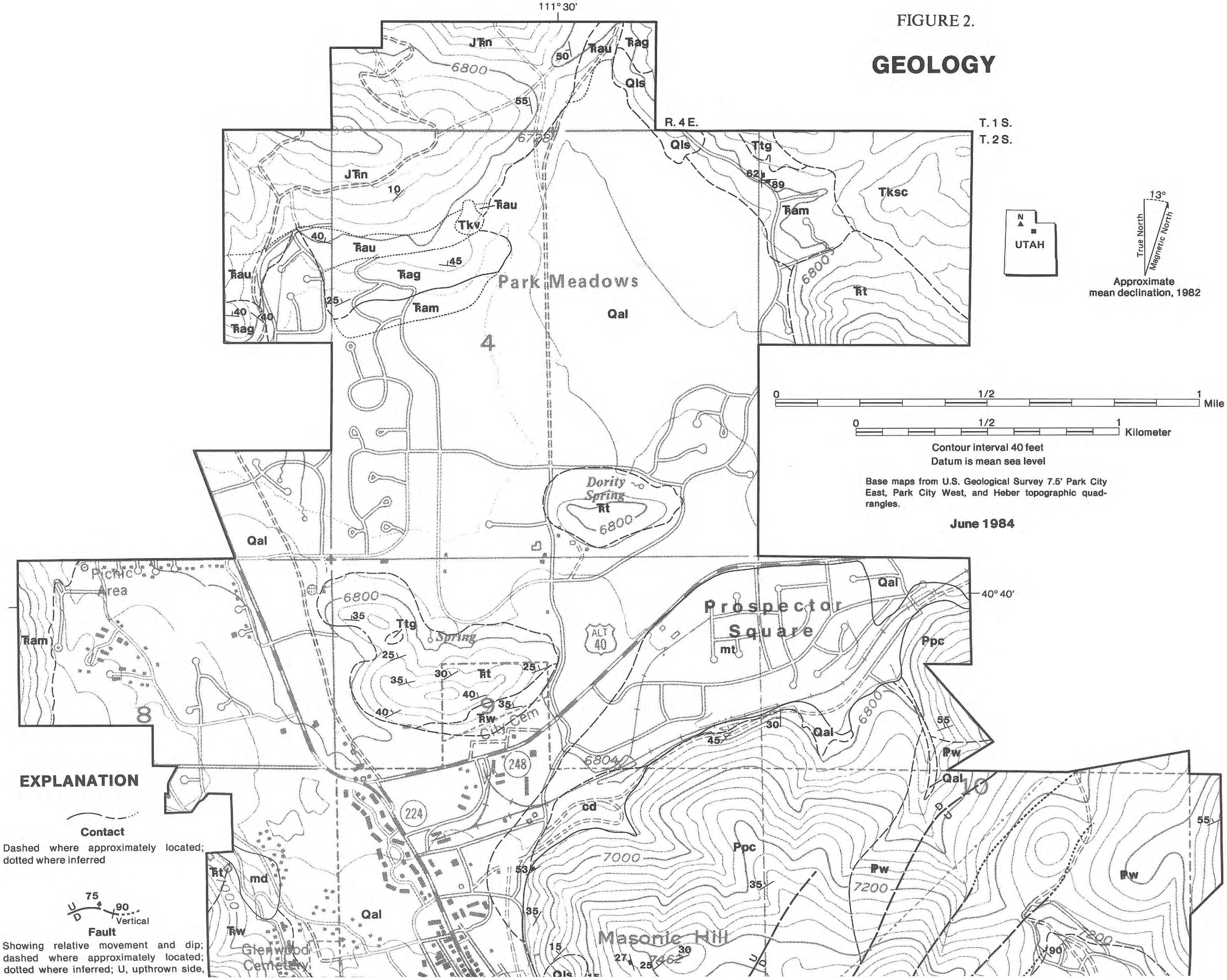
Geologic units range in age from Pennsylvanian to Holocene in the study area (geologic time scale, appendix). Bedrock consists of Pennsylvanian to Jurassic quartzite, limestone, sandstone, siltstone, mudstone, and shale, and Tertiary volcanic and intrusive rocks. Unconsolidated materials consist of Tertiary gravels and Quaternary glacial deposits, landslide deposits, alluvium, and colluvium. A geologic map of the area is shown in figure 2.

Pennsylvanian — The oldest rock unit in the Park City area is the Weber Quartzite. It crops out in the southern half of the study area where numerous resistant ridges consisting of medium- to thin-bedded, pale gray, tan-weathering, fine-grained quartzite and sandstone are found. The character of the rock indicates a shoreline deposit, and its homogeneity shows that conditions remained constant during its deposition (Boutwell, 1912). Limestone forms a subordinate but significant part of the formation. The Weber Quartzite is the principal water source in mines of the Park City mining district (Baker, 1970, p. 18).

Permian — The Park City Formation is a sequence of limestone, chert, sandstone, and phosphatic shale. The formation was deposited during a transitional period between stable conditions during the Pennsylvanian period and the more erratic conditions associated with deposition of the overlying Triassic red beds. The most extensive and characteristic exposures trend southwest-northeast across the center of the study area and form portions of Treasure Hill and

FIGURE 2.

GEOLOGY



0 — 1/2 — 1 Mile

0 — 1/2 — 1 Kilometer

Contour interval 40 feet
Datum is mean sea level

Base maps from U.S. Geological Survey 7.5' Park City East, Park City West, and Heber topographic quadrangles.

June 1984

EXPLANATION

Contact

Dashed where approximately located; dotted where inferred

75 90 U D Vertical

Fault

Showing relative movement and dip; dashed where approximately located; dotted where inferred; U, upthrown side, D, downthrown side

Thrust fault

Dashed where approximately located, dotted where inferred. Sawteeth on upper plate. R denotes reverse fault and upthrown side

Anticline

Showing direction of plunge

md

Mine dump

Dashed where approximately located

25

Strike and dip of bedding

mt

Mill tailings

Dashed where approximately located

70 90 Vertical

Strike and dip of joints

cd

City refuse dump

Dashed where approximately located

QUATERNARY

Qal	Qls	Qm

Surficial deposits

Qal, stream deposits and valley fill
Qls, landslide deposits
Qm, glacial moraine

TERTIARY

Tkv	Tksc

Keetley Volcanics

Tkv, Keetley Volcanics undifferentiated, andesitic volcanic rocks, includes pyroclastics, mudflows, and lava flows. Pale-gray pumiceous tuff present locally.

Tksc, breccia of Silver Creek, chiefly light-gray rhyodacitic to andesitic volcanic breccia, also a few interbedded tuffs.

Tp	To	ind

Intrusive rocks

Tp, small intrusive bodies of porphyry, probably granodioritic in composition; altered and poorly exposed
To, Ontario stock; light-gray quartz monzonite porphyry
ind, dikes of intermediate composition

Ttg

Gravel

Gravelly deposit composed principally of well-rounded boulders, cobbles and gravel, chiefly of quartzite and sandstone; boulders of Nugget Sandstone common. Occurs locally immediately beneath the Keetley Volcanics. In part may be equivalent to or derived from the Wasatch Formation (Knight Formation) to the north.

UNCONFORMITY

TRIASSIC(?) and JURASSIC(?)

JTRn

Nugget Sandstone

Pale-orange medium-grained crossbedded sandstone

TRIASSIC

TRau	TRag	TRam

Ankareh Formation

TRau, upper member: moderate-red, grayish-red, and grayish-purple mudstone and fine-grained sandstone

TRag, Gartra Grit Member: white to pale-purple massive crossbedded coarse-grained to pebbly quartzite

TRam, Mahogany Member: purplish-gray and pale-red ripple-laminated sandstone, interbedded with olive-green mudstone, and a few thin limestone beds

TRt

Thaynes Formation

Brown-weathering fine-grained limy sandstone and siltstone, interbedded with olive-green to dull-red shale and gray fine-grained fossiliferous limestone

TRw

Woodside Shale

Dark- and purplish-red shale, siltstone, and very fine-grained sandstone

PERMIAN

Ppc

Park City Formation

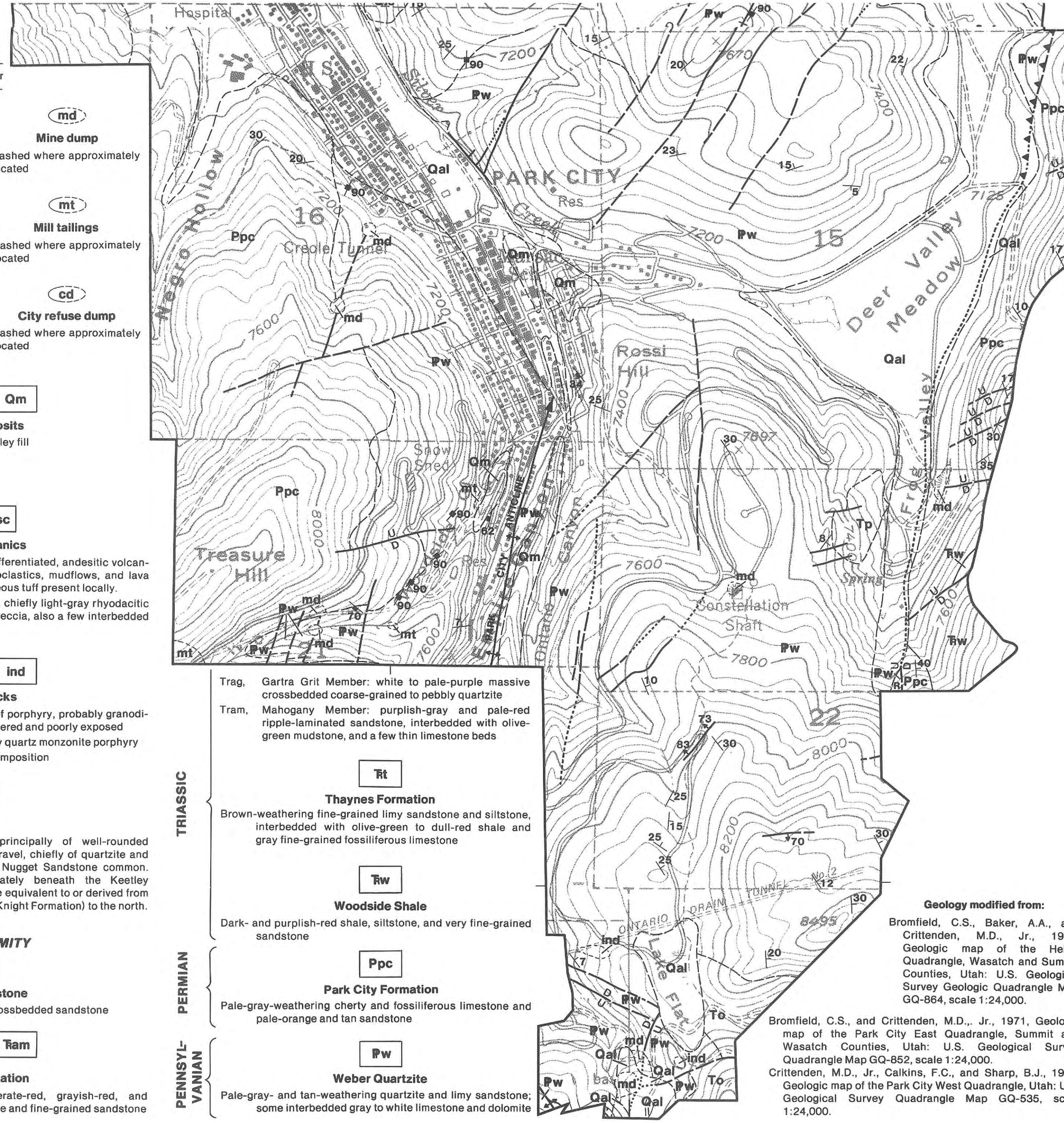
Pale-gray-weathering cherty and fossiliferous limestone and pale-orange and tan sandstone

PENNSYLVANIAN

Pw

Weber Quartzite

Pale-gray- and tan-weathering quartzite and limy sandstone; some interbedded gray to white limestone and dolomite



Geology modified from:

Bromfield, C.S., Baker, A.A., and Crittenden, M.D., Jr., 1970, Geologic map of the Heber Quadrangle, Wasatch and Summit Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-864, scale 1:24,000.

Bromfield, C.S., and Crittenden, M.D.,. Jr., 1971, Geologic map of the Park City East Quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Quadrangle Map GQ-852, scale 1:24,000.

Crittenden, M.D., Jr., Calkins, F.C., and Sharp, B.J., 1966, Geologic map of the Park City West Quadrangle, Utah: U.S. Geological Survey Quadrangle Map GQ-535, scale 1:24,000.

Masonic Hill. No single exposures of the entire formation can be found in the study area and only the upper Franson Member was observed in outcrop. That member consists of light gray, buff-weathering limestone and dolomite and tan calcareous sandstone. The Park City Formation is one of the major ore-bearing units in the Park City mining district (Boutwell, 1912).

Triassic — The majority of rocks exposed in the northern half of the study area are of Triassic age. They include, from oldest to youngest; the Woodside Shale, Thaynes Formation, and Ankareh Formation.

The Woodside Shale is a sequence of interbedded red shale, siltstone, and fine-grained sandstone representing an offshore deposit laid down during a period of relative tectonic quiescence. The unit contains no ore, but its capacity for ground-water storage reportedly makes it an important factor in mining operations (Boutwell, 1912). The formation crops out in a northeast-southwest band approximately through the center of the study area in the vicinity of the Glenwood Cemetery and the new City Cemetery.

The Thaynes Formation is a calcareous sequence of marine limestone, sandstone, and clastic sedimentary rocks. It is comprised of an upper interbedded limestone, limy sandstone, and siltstone unit; a middle red shale and siltstone unit; and a lower green micaceous shale. Its deposition was probably characterized by crustal instability with frequent marine transgressions and regressions. Only the upper limestone and sandstone sequence and middle red shale unit are in the study area. Some units within the Thaynes Formation are fossiliferous and the fossils plus the middle red shale unit distinguish the Thaynes Formation from the otherwise similar Park City Formation. The unit occurs in two small hills immediately north of Utah State Alternate Highway 40 in the north-central portion of the study area. Dority Spring and two unnamed springs discharge from this formation.

The Ankareh Formation overlies the Thaynes Formation in the far northern portion of the study area and is comprised of three members; the lower Mahogany Member, the middle Gartra Grit Member, and the upper (unnamed) red member. The formation is comprised of shallow-water detrital sediments representing flood-plain, mud flat, and channel deposits. The Mahogany Member consists of purplish-gray and pale-red, ripple-laminated, fine-grained sandstone and purplish mudstone. Rock from this unit has been used for landscaping in the Park City area. The middle Gartra Grit Member consists of a white to pale-purple, massive, crossbedded, coarse-grained to pebbly quartzite and conglomeratic sandstone. The member occurs in channels in the underlying Mahogany Member, indicating a period of erosion after deposition of the lower unit. The contact between the Gartra Grit and the upper red beds is gradational. Due to its extent and characteristic appearance, the Gartra Grit is considered an excellent marker unit for stratigraphic studies. The upper member consists of red and grayish-purple mudstone and fine-grained sandstone. This member weathers to gentle slopes and few outcrops can be found.

Triassic - Jurassic — The Nugget Sandstone overlies the Ankareh Formation in the northwest corner of the study area where it caps Quarry Mountain. The age of the unit is uncertain, and is considered to be transitional between the Triassic and Jurassic (Bromfield, 1968). The Nugget Sandstone consists of fairly uniform pale-red to reddish-orange, fine-grained to very fine-grained sandstone. Large-scale crossbeds occur throughout the unit, indicating an eolian dune depositional environment. The formation has been utilized for landscaping and as building stone.

Tertiary — Tertiary gravel deposits consisting of well-rounded boulders, cobbles, and gravels, chiefly of quartzite and sandstone, unconformably overlie the Ankareh Formation. The deposits are localized and very thin. Cobbles of Nugget Sandstone are common and the unit may be equivalent to or derived from the Wasatch (Knight) Formation to the north (Bromfield and Crittenden, 1971).

Oligocene intrusive rocks are found in the southern portion of the study area. A small granitic intrusive is located immediately east of the Deer Valley Resort lower lodge, at the southern end of Frog Valley (fig. 2). A much larger intrusive, the Ontario Stock, is located immediately east of the Deer Valley upper lodge at Lake Flat. This intrusive consists of light-gray quartz monzonite porphyry. Small dikes of intermediate composition are also found near this location (Bromfield and Crittenden, 1971).

The Keetley Volcanics of Oligocene age unconformably overlie sedimentary rocks at the north end of the study area. Rock types include flows, tuffs, and volcanic breccias of andesitic to rhyodacitic composition. Residual soils have attained thicknesses of several feet in many locations and outcrops of unweathered rock are rare.

Quaternary — Glacial moraines comprised of boulders, cobbles, gravel, and finer material underlie Ontario Ridge and are also found at the mouth of Woodside Gulch and at the northwest end of Rossi Hill (fig. 2). Apparently only in Empire Canyon did ice reach the canyon mouth (Boutwell, 1912). The moraines in Park City have not been dated, but possible correlation with glacial deposits mapped by Madsen and Currey (1978) in Little Cottonwood Canyon approximately 7 miles (11 km) southwest of Park City across the Wasatch Range indicates a late Pleistocene age.

Two landslides of Quaternary age (fig. 2) are found in Park City. The largest is located near the northeast corner of the study area on a moderate slope underlain by the Ankareh Formation. It appears to have involved both residual soil and weathered bedrock. The smaller landslide is on the west slope of Masonic Hill and is an earth slump in colluvium on a steep slope. The failure is underlain by the Park City Formation. A series of mudflows and debris flows of late Pleistocene to Holocene age occurred in Iron Canyon immediately west of the study area (Schroder, 1971). The toe of the flow deposits, termed the Iron Canyon landslide, terminates near the picnic area north of Snow Summit Ranch. Failure occurred in the argillaceous upper red member of the Ankareh Formation.

Holocene sediments are found over much of the study area (fig. 2). The deposits consist chiefly of alluvial gravel, sand, silt, and clay. Fine-grained sediments in Park Meadows and Deer Valley Meadow reach a maximum thickness of about 100 feet (31 m) and an average thickness of approximately 60 feet (18 m) (Baker, 1970). These sediments represent alluvial material and local residual soil of silt and clay derived from shale, siltstone, and mudstone bedrock. Silt and clay are also found adjacent to stream channels where they were deposited during periods of overbank flooding. Holocene silty and sandy gravels cover much of the remaining area. They occur predominantly as colluvium and alluvium at the base of mountain slopes, and as clean gravel in stream channels.

Structure

The Park City region lies on the north side of a broad east-west trending uplift, generally considered to be the westward extension of the Uinta arch. This structure cuts across the north-south orientation of the Wasatch Range (Bromfield, 1968). The dip of bedding in the study area is generally to the north-northwest, but has been altered by folding and faulting in the southern part. The dominant structural feature in the area is the Park City anticline, which is transverse to the east-trending Uinta arch. The axis of the anticline plunges to the north and trends parallel with and immediately east of Ontario Ridge. It terminates slightly north of the mouth of Empire Canyon (fig. 2). In the study area the limbs of the anticline dip gently northeast and west at angles between 15 and 25 degrees. The anticline and associated folding are thought to be of Tertiary age and may be associated with the intrusion of porphyries in late Eocene or Oligocene time (Wilson, 1959).

A major structural feature on the east side of the study area is the Frog Valley thrust fault which trends north-south along the east side of Frog Valley and Deer Valley Meadow (fig. 2). On the ridge north of McHenry Canyon (south of the study area) the fault is mapped as a reverse fault placing Weber Quartzite on the west against beds of Woodside Shale on the east (Bromfield and others, 1970; Bromfield and Crittenden, 1971). North of Frog Valley, the fault trace is concealed by alluvium where it runs along the east side of Deer Valley Meadow. No evidence for displacement of the alluvium was observed. The fault is again exposed north of Deer Valley Meadow where the Weber Quartzite has been thrust along a low-angle fault over the Park City Formation (Bromfield, 1968). Weber Quartzite north of the fault strikes northeast and dips northwest while the Park City Formation and the Woodside Shale south of the fault strike north and northwest and dip eastward (Bromfield, 1968). The Frog Valley thrust fault is believed to be contemporaneous with other thrusting in the area (F. Davis, oral commun., 1984) which has been dated as late Cretaceous and early Tertiary (Crittenden, 1976).

A number of southwest-northeast trending normal faults found almost exclusively in the Park City Formation and Weber Quartzite were observed in the southern half of the study area. No evidence of Quaternary offset along those faults has been identified. The nearest fault on which offset during the Quaternary is known is the Wasatch fault located approximately 16 miles (26 km) to the west (Anderson and Miller, 1979).

ENGINEERING GEOLOGY

Various geologic considerations are important in the location, design, construction, and maintenance of engineered structures. These include rock type and structure, soil characteristics and thickness, topography, hydrology (both surface and groundwater conditions), and seismicity. These factors were used to evaluate slope stability, foundation conditions, erosion hazard, seismic hazard, and mining-related hazards that affect the Park City area.

Soils

Soils in the area range from relatively thin colluvial gravel usually found on or at the base of mountain slopes to thick, fine-grained alluvial soil generally restricted to valley bottoms. The soil units identified by the USDA Soil Conservation Service and others (1977) in Park City have been modified based on geologic mapping, air photo interpretation, and boring/test pit logs. They have been combined on the basis of soil type and engineering characterestics into four major groups (fig. 3). The groups are further subdivided into deep and shallow soils based on a depth to bedrock of 60 inches (152 cm). The major soil groups consist of (a) gravel, silty gravel, and clayey gravel (Group I), (b) silty clay and clay (Group II), (c) a mixture of clay, silt, and gravel (Group III), and (d) a layer of silty clay overlying silty and clayey gravel (Group IV). An "r" attached to the group number designates an area of shallow bedrock (e.g. Ir). Soil descriptions conform to the Unified Soil Classification System (table 1).

Gravelly soils consist primarily of silty, clayey, and sandy gravels (GM, GC, GP). Silty and clayey gravels have permeabilities ranging from 0.6 to 6.0 inches/hour (4.2 x 10^{-4} to 4.2 x 10^{-3} cm/sec), while clean gravels can have permeabilities as high as 20 inches/hour (1.4 x 10^{-2} cm/sec). Fines forming the matrix for the clayey gravels exhibit low to moderate shrink-swell characteristics and may have low shear strengths (USDA Soil Conservation Service and others, 1977). Gravelly soils occur on or near the base of mountain slopes or as clean sandy gravel in stream channels.

Fine-grained soils consist of silt and clay (ML, CL, CH). These soils have permeabilities of 0.06 to 2.0 inches/hour (4.2 x 10^{-5} to 1.4 x 10^{-3} cm/sec), low to high shrink-swell characteristics, and low shear strength (USDA Soil Conservation Service and others, 1977). Fine-grained soils are found primarily in valley bottoms and along some stream channels where they represent overbank flood deposits.

Both gravelly and fine-grained materials have developed as residual soils over bedrock. Resistant formations such as the Weber Quartzite and the limestone of the Park City Formation generally have only a thin residual soil cover. Less resistant rock units in the northern half of the study area develop variable thicknesses of residual soil depending on rock type and slope. The Woodside Shale and Ankareh Formation have the deepest residual soils, commonly up to several feet thick. Soil texture (grain size) depends on the rock type from which the soil is derived. Residual soil on quartzite will be sandy or gravelly,

TABLE 1.—Unified Soil Classification System.

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS More than 50% retained on No. 200 seive*	GRAVELS 50% or more of coarse fraction retained on No. 4 seive	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS More than 50% of coarse fraction passes No. 4 seive	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS 50% or more passes No. 200 seive*	SILTS AND CLAYS Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS AND CLAYS Liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
HIGHLY ORGANIC SOILS			PT	Peat, muck, and other highly organic soils

*Based on the material passing the 3-in. (75-mm) seive.

while soil developed on shale and siltstone will normally be fine grained.

Hydrology

Surface water and flooding — The principal drainage in Park City is Silver Creek (fig. 4). The stream course has been altered by man at several locations to accomodate the railroad and city expansion. Most tributaries to Silver Creek are small, but thick alluvial fans have formed at the mouths of the larger tributary canyons. At present most surface drainage is collected in storm drains that empty into Silver Creek. In addition, several surface water impoundments used as retention basins for excess surface runoff have been constructed in the study area. In Deer Valley Meadow, the impoundments are small lakes and ponds used for landscaping in and around residential structures (fig. 5). Excess surface water from the ponds flows along Heber Avenue and eventually empties into Silver Creek. At Park Meadows and the Park City Golf Course, impoundments are used as water hazards on the golf courses. Excess surface water from the city golf course flows to the north along Utah State Highway 224. Surface flow from Park Meadows enters a canal which eventually empties into Silver Creek east of Prospector Square.

Only four historical floods have been recorded in Park City since the late 1800s (Wooley, 1946; Butler and Marsell, 1972; Utah Division of Comprehensive Emergency Management, 1981). The most damaging (July, 1913) occurred when heavy rains flooded homes and streets, crippled the electrical system, and washed mud and boulders from the hillsides into the town. The other instances of flooding were relatively minor with heavy rain and hail causing road damage and severe sedimentation in streams (Butler and Marsell, 1972). In 1983 flood damage occurred in Empire Canyon where Silver Creek overflowed its banks (fig. 6). The bridge over Silver Creek at Heber Avenue was also damaged, and a thick layer of debris was deposited on the road. The flooding observed during 1983 resulted from the rapid melt of an extremely heavy snowpack. Flood control improvements have been made since publication of the map of flood-prone areas in Park City outlining the extent of a 100-year flood on major streams. In particular, a large diameter storm drain has been installed in Empire Canyon to handle excess flow from Silver Creek.

Ground water — Nearly all rock units and unconsolidated basin-fill deposits in the study area yield water to springs (fig. 4). Major exceptions are the Nugget Sandstone, the Keetley Volcanics, and Tertiary gravel deposits that cap ridges in the area. Two large springs discharge from the Thaynes Formation in the northern half of the study area (Dority Spring and an unnamed spring). During periods of snowmelt, numerous small springs and seeps appear, especially in the highly fractured Weber Quartzite. A detailed discussion of aquifer characteristics of rock units in the Park City area is presented by Baker (1970).

During this study, emphasis was placed on the occurrance of shallow ground water because of its importance to construction. Structures built in areas of shallow ground water run the risk of flooding and foundation instability, especially near springs on steep slopes and/or in clayey soils that exhibit high shrink-swell characteristics.

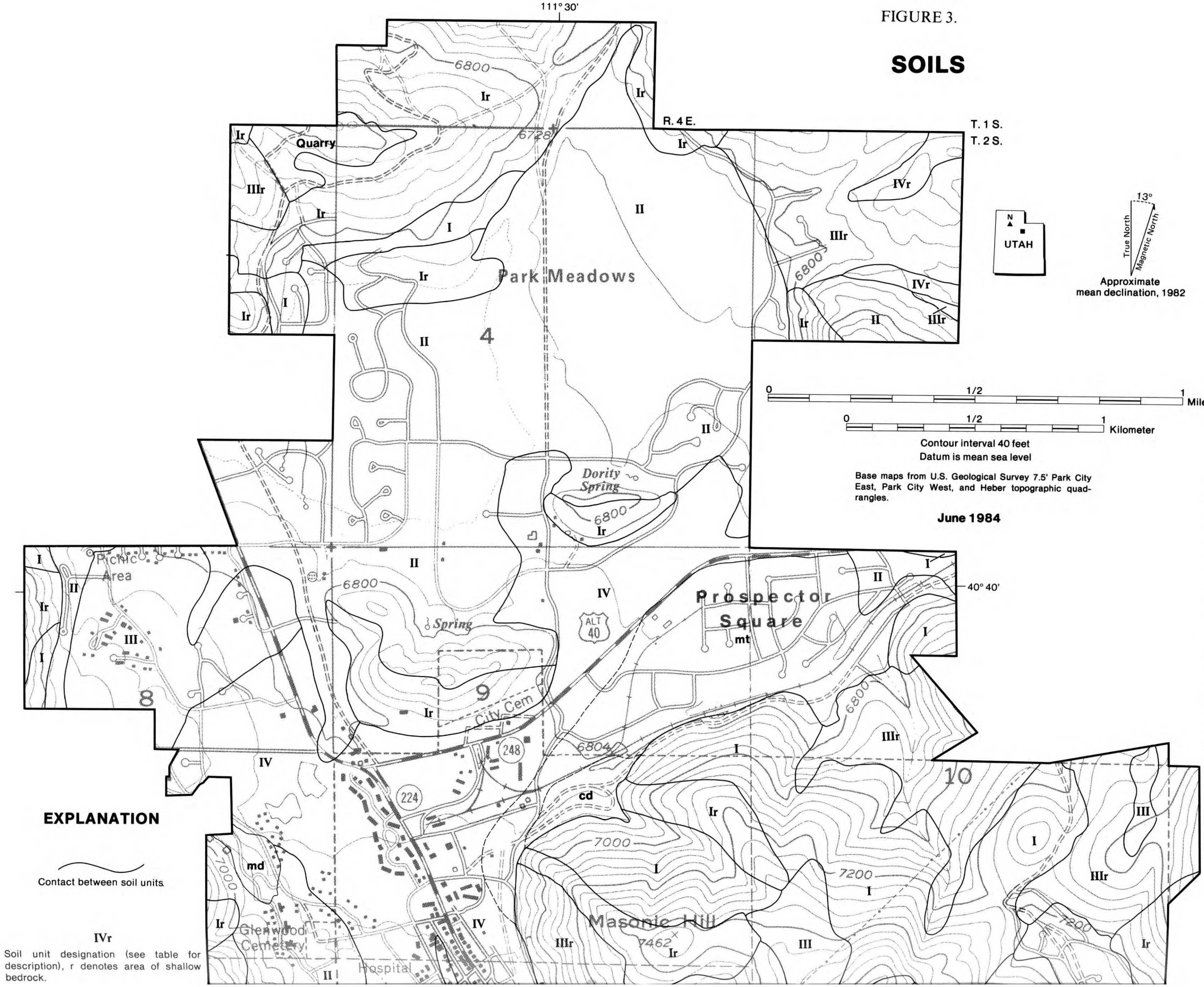
Areas of shallow ground water were identified from boring and test pit logs covering a 10-year period (1972-82) and from field observations. Figure 4 shows those areas where the estimated seasonal high stand of the shallow water table is from 0 to 10 feet (3 m) below ground surface. High ground water occurs principally in alluvium in valley bottoms and in colluvium at the base of slopes where springs discharge and large areas of marshy or boggy ground are found. Two such areas are Park Meadows and Deer Valley Meadow. At the northern end of Deer Valley Meadow several marsh and pond areas fed by ground water are quite large and standing water remains throughout the year (fig. 7, p. 16). Surface water impoundments in low areas further increase the water table by trapping runoff which then infiltrates into shallow aquifers. Site-specific investigations of ground-water levels, including consideration of seasonal variations, should be performed prior to construction in areas shown on figure 4 as subject to shallow ground water.

Slope stability

Natural slope stability depends on material type, slope angle, spacing and attitude of discontinuities (e.g. faults, joints, bedding, soil fissures), and moisture content. Dynamic processes such as erosion, ground vibration, and human activity also affect the stability of slopes. Slope failures result from either a reduction of the resisting forces (shear strength) that hold an earth mass in place, or an increase in the driving forces (shear stresses) that promote failure. Expansive soils, rock/soil discontinuities, high pore pressures, frost action, and breakdown of intergranular cement (weathering) are all factors that contribute to decreased shear strength. Increased shear stress may result from undercutting or removal of lateral

FIGURE 3.

SOILS



mt

Mill tailings

Soils highly variable, may contain elevated levels of toxic elements; recommend thorough site investigation prior to development. Contact dashed where approximately located.

md

Mine dump

Rock fragments and crushed rock from underground workings. Angular, loose, range in size from sand to boulders. Contact dashed where approximately located.

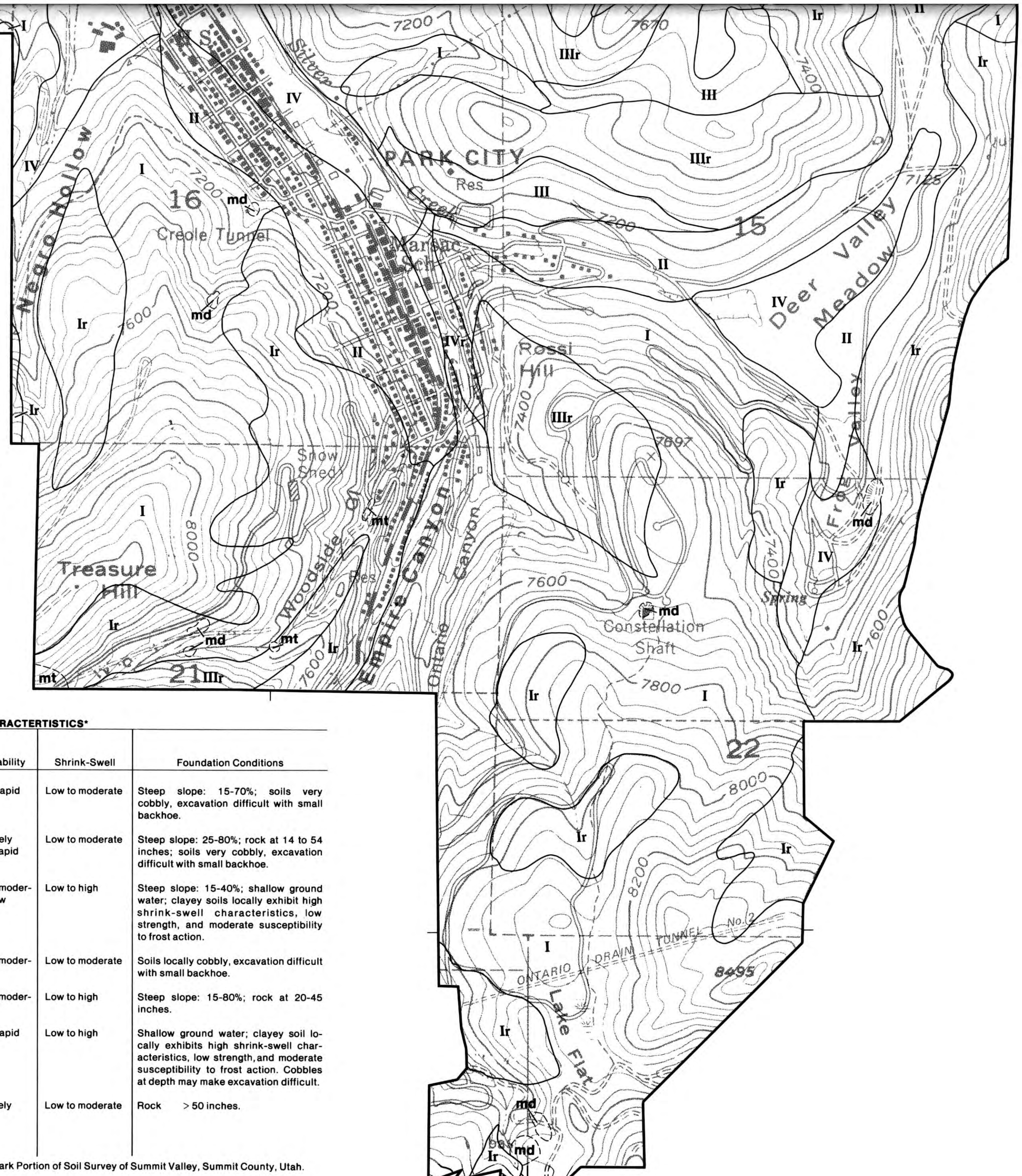
cd

City refuse dump

Old dump site possibly underlain by mill tailings. Contact dashed where approximately located.

The soils information shown on this map has been adapted from the USDA Soil Conservation Service (SCS) report entitled "Soil Survey and Interpretations Parleys Park Portion of Soil Survey of Summit Valley Summit County, Utah." The numerous soil units identified by the SCS have been grouped according to the Unified Soil Classification System on the basis of their characteristics as engineering materials. Additional soil data were obtained from 20 soil profiles described during this study, and from a review of soil/foundation reports prepared by engineering and geological consultants for structures in the Park City area. Fifty five such reports, including a total of 352 test pit and 33 boring logs, were examined.

Although modifications have been made based on geologic mapping, air photo interpretation, and boring/test pit logs, the soil boundaries shown are primarily those of the SCS. Contacts between soil units are generally irregular and gradational and represent zones of transition rather than distinct contacts. Therefore; the same cautions concerning the accuracy of soil contacts and included soil units that apply to SCS maps also apply to this one. This map is intended for general planning purposes, and does not preclude the need for site-specific investigations.



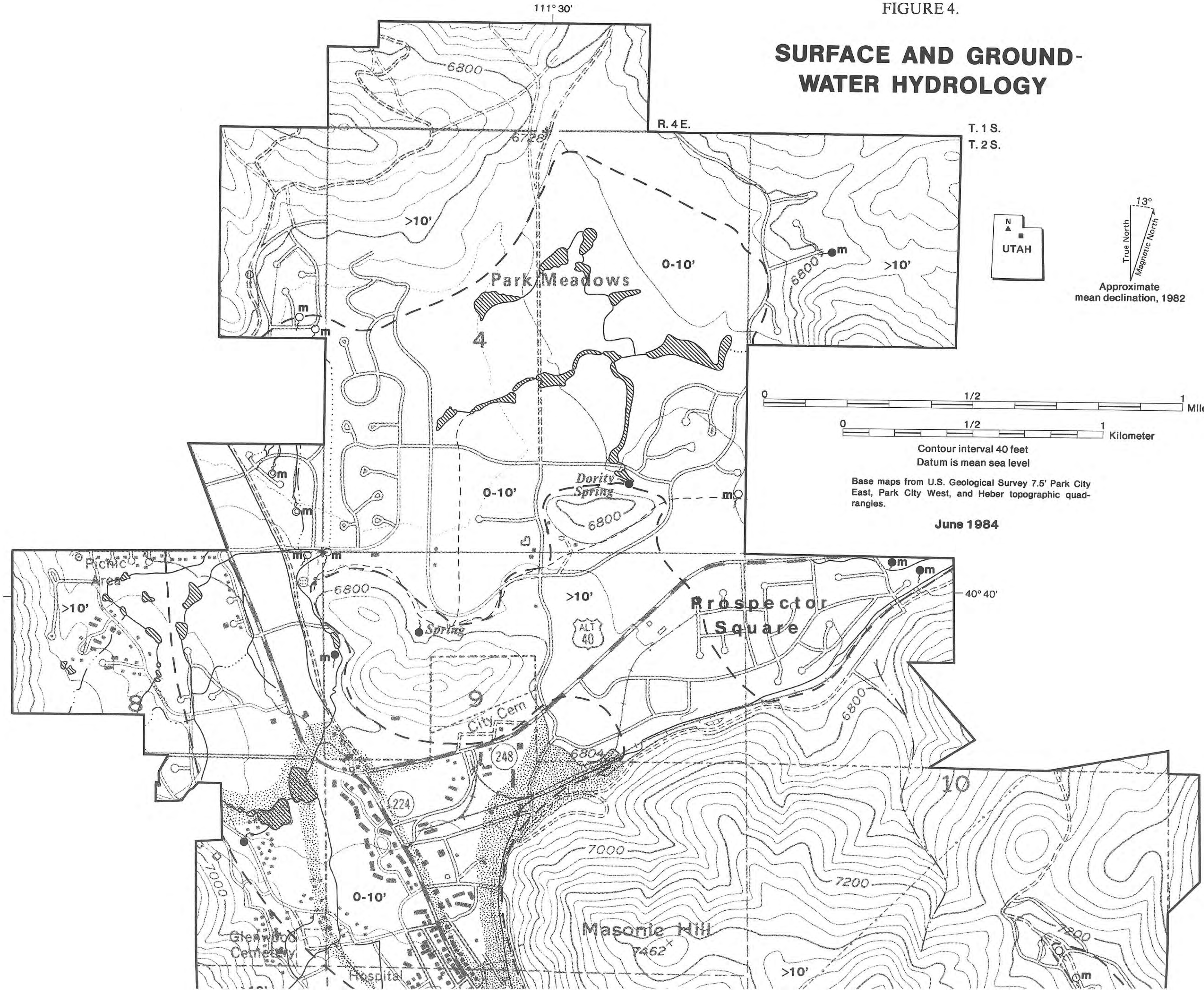
SOIL CHARACTERTISTICS*

Soil Grp	USCS Group Symbol	% Gravel	% Sand	% Silt & Clay	Permeability	Shrink-Swell	Foundation Conditions
I	GM,GP,GC	10-70	<5-60	<5-55	Slow to rapid	Low to moderate	Steep slope: 15-70%; soils very cobbly, excavation difficult with small backhoe.
Ir	GM,GP,GC	10-40	<5-60	<5-37	Moderately slow to rapid	Low to moderate	Steep slope: 25-80%; rock at 14 to 54 inches; soils very cobbly, excavation difficult with small backhoe.
II	CL,CH	<5-45	<5-70	21-46	Slow to moderately slow	Low to high	Steep slope: 15-40%; shallow ground water; clayey soils locally exhibit high shrink-swell characteristics, low strength, and moderate susceptibility to frost action.
III	CH,CL,ML, GC,GM	10-75	<5-66	20-45	Slow to moderate	Low to moderate	Soils locally cobbly, excavation difficult with small backhoe.
IIIr	CH,CL,ML, GC,GM	5-50	<5-65	5-45	Slow to moderate	Low to high	Steep slope: 15-80%; rock at 20-45 inches.
IV	CL at 30-48 inches over GM, GC at 60-75 inches	<5-65	<5-90	<5-44	Slow to rapid	Low to high	Shallow ground water; clayey soil locally exhibits high shrink-swell characteristics, low strength, and moderate susceptibility to frost action. Cobbles at depth may make excavation difficult.
IVr	CL at 26 inches over GM at 50 inches	<5-45	37-75	18-32	Moderately slow	Low to moderate	Rock >50 inches.

*Adapted from SCS Soil Survey and Interpretations Parleys Park Portion of Soil Survey of Summit Valley, Summit County, Utah.

FIGURE 4.

SURFACE AND GROUND-WATER HYDROLOGY



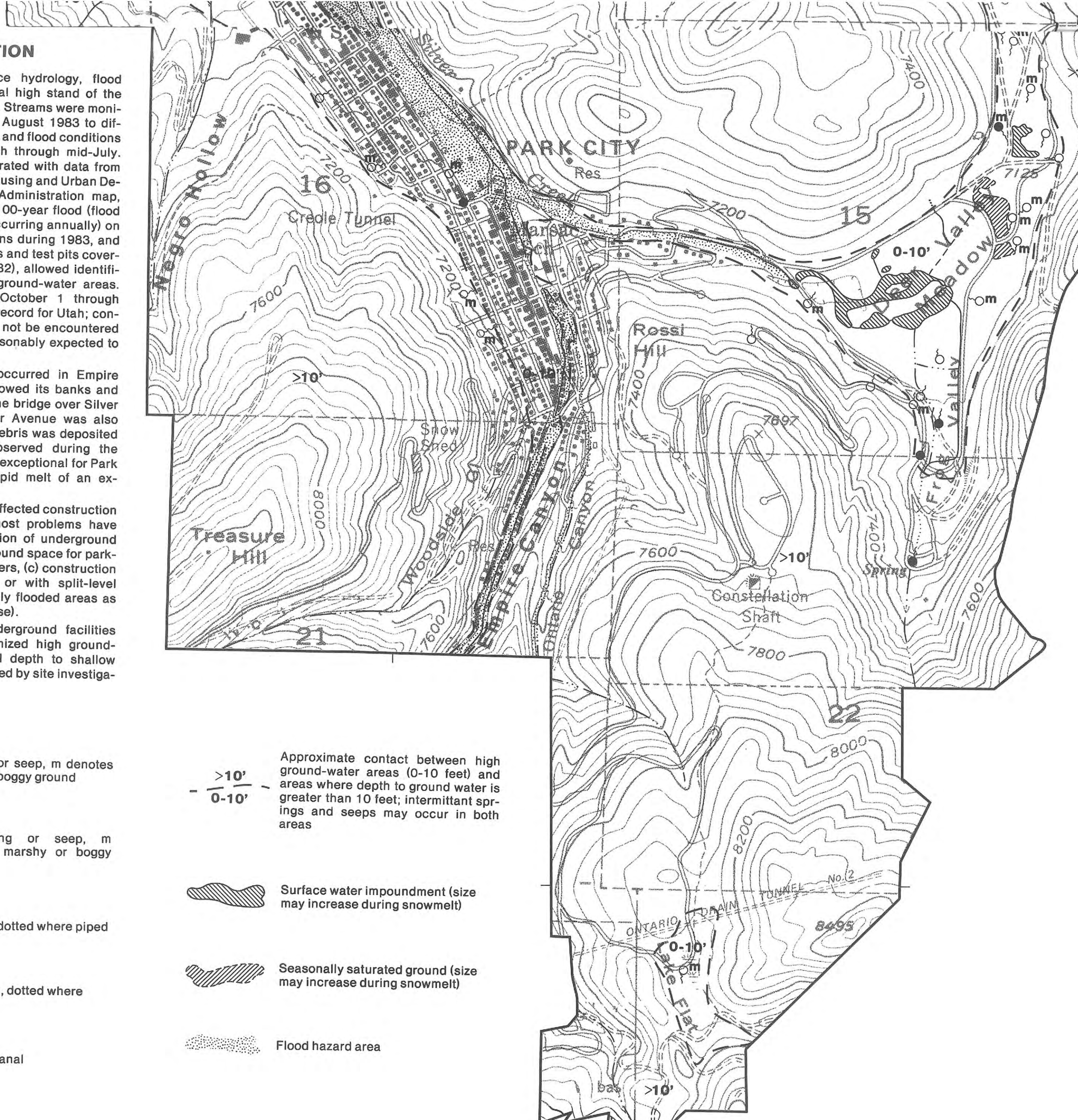
EXPLANATION

This map depicts surface hydrology, flood hazard, and estimated seasonal high stand of the shallow water table in Park City. Streams were monitored from late March through August 1983 to differentiate base flow from runoff, and flood conditions were observed from late March through mid-July. The observations were incorporated with data from the 1976 U. S. Department of Housing and Urban Development Federal Insurance Administration map, which outlines the extent of a 100-year flood (flood with a one percent chance of occurring annually) on major streams. Field observations during 1983, and analysis of data from boring logs and test pits covering a ten-year period (1972-1982), allowed identification of shallow (0-10 feet) ground-water areas. The 1982-1983 water year (October 1 through September 1) is the wettest on record for Utah; conditions shown on this map may not be encountered in a normal year but can be reasonably expected to recur.

Extensive flood damage occurred in Empire Canyon where the creek overflowed its banks and inundated nearby structures. The bridge over Silver Creek (Poison Creek) at Heber Avenue was also damaged, and a thick layer of debris was deposited on the road. The flooding observed during the monitoring period is considered exceptional for Park City, and resulted from the rapid melt of an extremely heavy snowpack.

Shallow ground water has affected construction in the study area. However, most problems have been mitigated by: (a) installation of underground drains, (b) utilization of underground space for parking areas rather than living quarters, (c) construction of homes without basements, or with split-level design, and (d) use of seasonally flooded areas as recreational sites (i.e. a golf course).

Basements and other underground facilities may become flooded in recognized high groundwater areas. Flood hazard and depth to shallow ground water should be determined by site investigations prior to construction.



m Perennial spring or seep, m denotes area of marshy or boggy ground

m Intermittant spring or seep, m denotes area of marshy or boggy ground

Perennial stream, dotted where piped

Intermittant stream, dotted where piped

Irrigation ditch or canal

>10' / 0-10' Approximate contact between high ground-water areas (0-10 feet) and areas where depth to ground water is greater than 10 feet; intermittant springs and seeps may occur in both areas

Surface water impoundment (size may increase during snowmelt)

Seasonally saturated ground (size may increase during snowmelt)

Flood hazard area

FIGURE 5.—Surface water impoundments in Deer Valley Meadow, used for landscaping in and around residential structures.

support by erosion or man-made cuts, loading by fills or structures, increased weight from water, and ground vibrations.

Natural slopes in Park City are stable under present conditions. Two prehistoric slope failures were identified (fig. 8) but neither shows evidence of recent movement. Both appear to be slump-earth flow failures (Varnes, 1978), but their surface morphology has been modified by erosion and vegetative cover. One failure occurred in weathered shale bedrock and residual clay soil; the other in deep colluvial soils. Soil creep is active to varying degrees in colluvium on steep slopes throughout Park City. It is most rapid during the spring snowmelt when near surface soils are saturated.

Numerous small slope failures related to construction activity have occurred throughout the study area (fig. 8). The largest was an earth slump involving several hundred cubic yards of material in a road cut excavated for Deer Valley Drive (fig. 9). The cut is almost 1000 feet (300 m) long and passes through a combination of bedrock (Weber Quartzite) and colluvium. The colluvium is thickest at the south end of the cut and it was there that the failure occurred. Excavated at a steep angle (1:1 or greater), the cut was nearly 30 feet (9 m) high and had been standing for approximately a year before it failed. Undercutting of the slope and increased weight due to pore water are thought to have caused the failure. Extensive regrading of the slope and construction of a retaining wall were undertaken to correct the problem. Other construction-related slope failures have been small (tens of cubic yards or less) and have occurred in colluvium in road cuts and in fill placed for roads and building lots. One small earth slump developed in a road cut excavated in the toe of the larger of the two prehistoric slope failures (fig. 10). There is no evidence to indicate that either the cut or the earth slump have caused the older failure to reactivate, but additional uncontrolled development there may lead to slope stability problems.

Stability of cuts in bedrock largely depends on the number and orientation of discontinuities in the rock mass. Numerous closely spaced faults in portions of Park City (fig. 2) have fractured the surrounding bedrock to a high degree. Fracture intensity is greatest near the fault and decreases outward away from the fault trace. Figure 8 shows the faults in Park City along which considerable rock fracturing has occurred. The widths indicated for the fracture zones are estimated from limited exposures in outcrops and road cuts and should be confirmed by trenching if development is planned for those areas. Where faults are closely spaced their fracture zones may overlap. Bedding planes and major joint sets also control rock cut stability. Rock fall, rock topple, and rock slide fail-

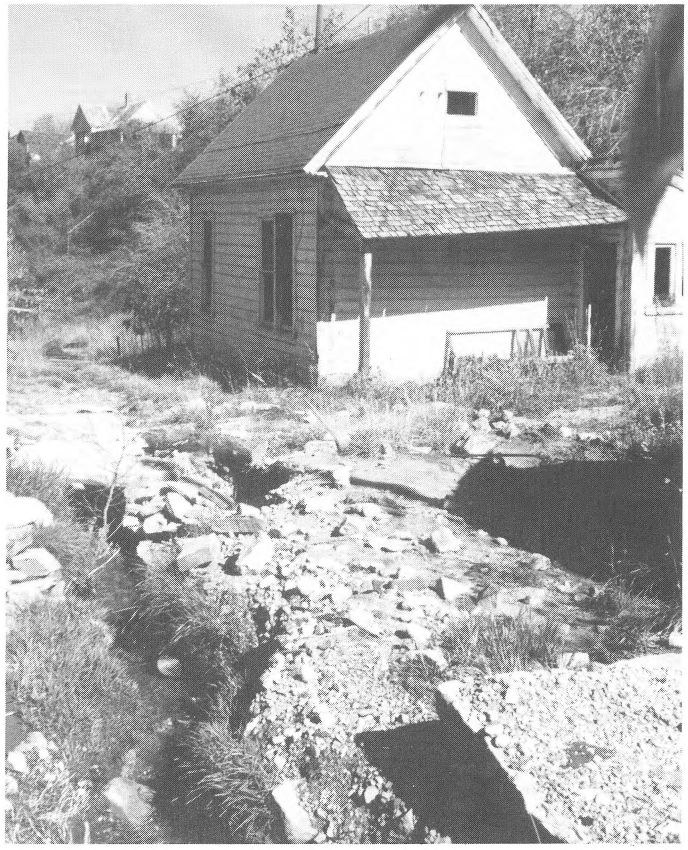


FIGURE 6.—Flood damage in Empire Canyon from Silver Creek. Note damaged sidewalk, gravel and cobble deposits, and abandoned structures.

ures (Varnes, 1978) occur where bedding or joint planes dip toward and are exposed in cuts. For a discussion of slope stability problems related to mining activity, see the Mining-related hazards section (page 26).

Results of the field investigation show a correlation between material type and slope failures in Park City. The slope stability map of the study area (fig. 8) groups hillsides steeper than 15 percent into one of three categories based on underlying material type. The groups are:

1. slopes comprised of unconsolidated material (alluvium, colluvium, residual soil),
2. slopes underlain by soft bedrock (shale, mudstone, siltstone, poorly cemented sandstone, volcanic breccia, and tuff), and
3. slopes underlain by hard rock (limestone, sandstone, quartzite and igneous intrusives).

The greatest number of slope failures in Park City have occurred in unconsolidated materials on slopes steeper than 15 percent. The smaller of the two prehistoric slope failures developed on a steep slope in colluvium. The majority of construction-related slope failures that are not in artifical fill are either in colluvium or residual soils. Most slopes in Park City are covered by a layer of loose unconsolidated material of variable thickness. Only slopes where depth to bedrock is more than 5 feet (1.5 m) are shown on figure 8 as being comprised of unconsolidated material. Thick unconsolidated deposits too small to be shown on the map exist in other areas, and may be subject to slope failure if not recognized and accounted for in project planning and design.

The Ankareh Formation, Thaynes Formation, Woodside Shale, and some tuffs and breccias of the Keetley Volcanics are relatively soft (less resistant) bedrock formations. Mudstone, siltstone, and shale are common rock types in most of these formations and are interbedded with more resistant strata of limestone, sandstone, and quartzite. The fine-grained rocks generally have lower shear strength and weather more quickly than the more resistant layers, and as a result form planes of weakness in the rock mass.

FIGURE 7.—High water table creates a large area of marshy ground at the north end of Deer Valley Meadow. Fill is placed on the wet area and structures are constructed without dewatering the site.

The larger of the two prehistoric failures probably occurred along such a plane of weakness in the upper red member of the Ankareh Formation. In addition, the large (5 million cubic yard, $3.8x10^6$ m^3) Iron Canyon landslide immediately west of the study area is also in the weathered upper member of the Ankareh Formation (Schroder, 1971). Failure is most likely to occur when the planes of weakness dip toward and are exposed in excavation cuts. Failure types include rock fall, rock topple, or rock slide, and the size of the failed mass will be influenced by the presence of other joints and discontinuities in the rock. When highly weathered, the rock begins to assume the characteristics of soil and there will be a continual gradation from fresh rock at depth to weathered residual soil at the ground surface. Slope failures in such material display features typical of both soil and rock. Rock slump, earth slump, soil creep, and debris flow are possible failure types.

Because soft bedrock is less resistant to erosion, the areas of Park City where it occurs are characterized by low rounded hills and generally subdued topography. The absence of steep slopes accounts for the generally low number of slope failures found there. However, site conditions in areas of soft bedrock can be extremely variable over short distances, and grading for roads or building lots may cause stability problems unless construction slopes are designed to accommodate natural conditions.

Slopes underlain by hard rock are usually steep and covered by a thin veneer of colluvium. Hard rock has high shear strength and is susceptible to large slope failures only where extensively fractured by faulting and folding. Areas of highly fractured hard rock are found in Park City (fig. 8) but no large slope failures have been identified. Road cuts through those areas experience rockfall problems. The most common type of failure observed in hard rock areas does not involve rock at all, but the thin colluvial material that overlies it. Road cuts in hard rock can stand at steep angles, but the colluvial soils exposed at the top of the cuts cannot, and often fail after short periods of time. The resulting debris slides are small, but represent a continuing maintenance problem for the roads.

The areas of most concern regarding slope stability in Park City are the two prehistoric slope failures (fig. 8). Both show evidence of long term stability, but a potential exists for renewed movement if they are disturbed. Detailed studies will be required before development to ensure that these slopes are not destabilized. Elsewhere in Park City a slope stability analysis is needed for all construction sites and rights of way on slopes steeper than 15 percent. Factors affecting slope stability on a site-specific level are many and varied, and for that reason, slope design must be based on individual site investigations. Because conditions vary from site to site, no recommendation is made for a slope angle beyond which development should not take place. Conditions at one location may be such that maintainance of slope stability for a construction site on 15 percent slopes is prohibitive; while at another location, hard unfractured rock produces slopes stable at twice that grade.

Foundation conditions

The structural integrity and longevity of engineering works depends to a large extent on how well they are adapted to their geologic surroundings. A critical factor for all structures is the nature of the material on which they are founded. The factors that determine the suitability of soil and rock materials for foundations include bearing capacity, settlement and uplift, ease of excavation, stability, and ground water.

Bearing capacity is the ability of the foundation material to support a load without failing. It is usually evaluated in terms of shear strength and compressibility, and can be increased by mechanical compaction of the soil. Soils are all compressible to some degree, and are weak when compared to rock. Therefore, some settlement should be expected for all structures not founded on solid rock, and accommodations made in the foundation design. Methods used to reduce settlement include compacting subgrade materials to a predetermined optimum density and moisture content and spreading the base or footings of the structure so the foundation pressures are small and evenly applied. Where settlement-prone foundation materials exist it may be necessary to support the structure on piles, or to overexcavate and recompact the unsuitable material. Settlement caused by collapse of underground mine workings is discussed in the Mining-related hazards section (p. 26). Uplift of foundations may result from hydrostatic pressure, expansive soils, and frost action. Preventive measures include careful control of subgrade moisture and density, overexcavating and recompacting unsuitable material, directing surface drainage away from structures, and using special foundation designs. Ease of excavation has a direct bearing on construction costs. Excavation difficulty in bedrock depends on hardness, degree of weathering, and fracture spacing. Textural (grain size) characteristics are the most important consideration for soil excavatability. Stability refers to the foundation material's ability to stand in an open cut, either temporary or permanent, without failing. Cut slope stability is a function of material type, slope angle, and cut height. Ground water increases pore pressure and reduces shear strength, both of which are detrimental to slope stability. Water's ability to alter the physical and chemical nature of soil and rock makes it a primary factor in most types of ground movement. It initiates swelling of expansive soils, is essential to frost heaving, causes hydrocompactive soils to collapse, and is a major factor in slope instability. A high ground-water table limits land use and may require special construction techniques to prevent basement flooding and foundation damage.

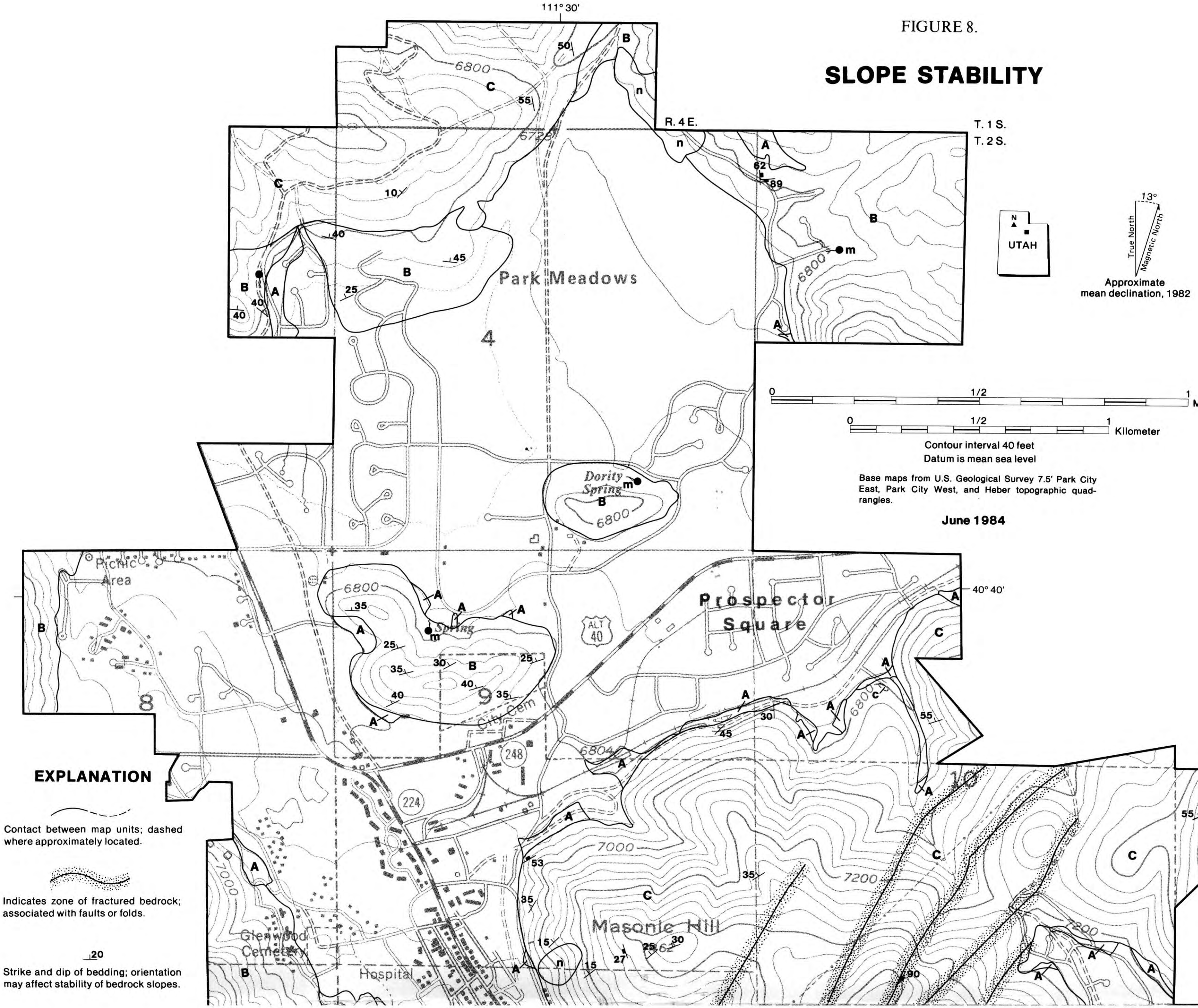
The most common foundation problems encountered in Park City are: (a) expansive soils with moderate to high shrink/swell potential, (b) frost susceptible soils, (c) difficult excavation conditions, (d) shallow ground water, and (e) soil creep. Soils exhibiting moderate to high shrink/swell potential are widespread in Park City. Most are located in Deer and Frog Valleys and in Park Meadows where clay and clayey silt soils are common (fig. 3). However, coarse-grained soils containing as low as 15 percent clay may also be expansive. When recognized during the planning and design phase of a project, expansive soils can be adequately managed and are usually not a factor in land-use decisions.

Frost action causes uplift of subgrade soils that can be particularly damaging to roads and lightly loaded structures. The susceptibility of soil to frost action depends on soil texture, temperature conditions, and water supply. Most soils are affected to a greater or lesser degree, with only coarse-grained clean sands and gravels (SW, SP, GW, GP) being immune. The soils in Park City are generally susceptible (USDA Soil Conservation Service, 1970) and when combined with the cold temperatures and wet conditions that prevail during the winter months create a high potential for frost-related problems. The most severe problems can be expected where soils receive a continuous supply of water to feed growing ice lenses and where the proportion of silt in the soil is high compared to other size fractions (U.S. Bureau of Reclamation, 1974).

Bedrock crops out or lies close to the ground surface in many areas of Park City. Unweathered rock generally has high shear strength and low compressibility, making it an excellent foundation material. The primary foundation problem associated with bedrock is difficulty of excavation. Resistant rock units in the study area include granitic intrusives, the Nugget Sandstone, limestone of the Park City Formation, and quartzite and sandstone of the Weber Quartzite. Unweathered rock from those formations is very hard and, unless highly fractured, requires blasting to excavate. The Ankareh and

FIGURE 8.

SLOPE STABILITY



0 1/2 1 Mile

0 1/2 1 Kilometer

Contour interval 40 feet
Datum is mean sea level

Base maps from U.S. Geological Survey 7.5' Park City East, Park City West, and Heber topographic quadrangles.

June 1984

EXPLANATION

Contact between map units; dashed where approximately located.

Indicates zone of fractured bedrock; associated with faults or folds.

20

Strike and dip of bedding; orientation may affect stability of bedrock slopes.

40 90 Vertical

Strike and dip of joints; orientation may affect stability of bedrock slopes.

m

Spring or seep; m denotes area of marshy or boggy ground; wet conditions may affect slope stability, particularlarly during seismic shaking.

Existing slope failures

n — Failure of natural slope.

c — Failure of cut slope; dashed where approximately located.

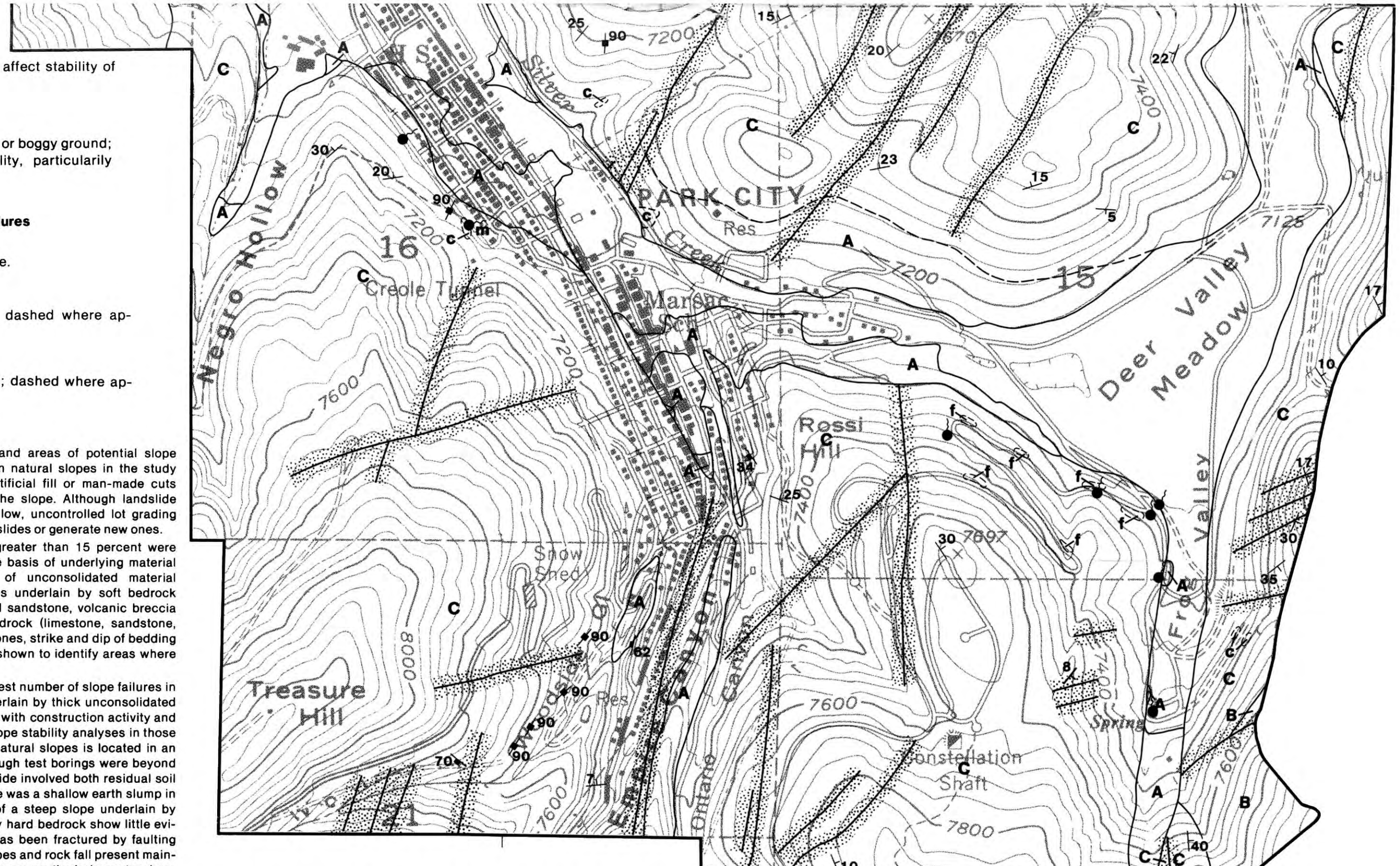
f — Failure in artificial fill; dashed where approximately located.

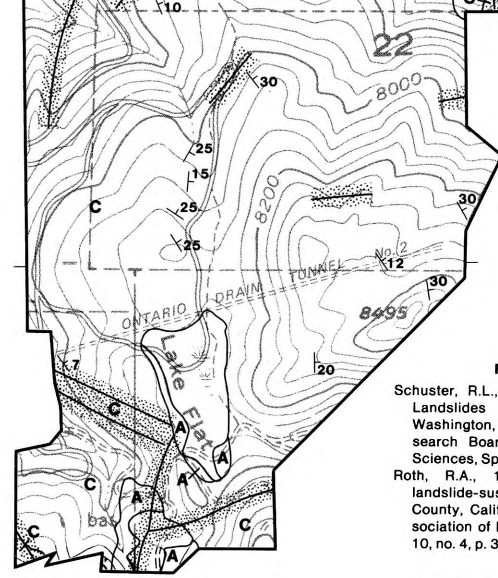
This map shows existing slope failures and areas of potential slope instability. Two landslides were identified on natural slopes in the study area; the remaining failures occurred in artificial fill or man-made cuts where grading has removed support from the slope. Although landslide potential on natural slopes in Park City is low, uncontrolled lot grading and/or road building could reactivate old landslides or generate new ones.

For purposes of this study, only slopes greater than 15 percent were evaluated. Slopes have been grouped on the basis of underlying material into three categories: slopes comprised of unconsolidated material (alluvium, colluvium or residual soil), slopes underlain by soft bedrock (shale, mudstone, siltstone, poorly cemented sandstone, volcanic breccia and tuff), and slopes underlain by hard bedrock (limestone, sandstone, quartzite, and igneous intrusives). Fracture zones, strike and dip of bedding and joints, and spring or seep locations are shown to identify areas where potential for slope failure may be increased.

Field observation has shown that the greatest number of slope failures in the study area have occurred on slopes underlain by thick unconsolidated materials. All of those failures are associated with construction activity and demonstrate the need for pre-construction slope stability analyses in those areas. The largest of the two landslides on natural slopes is located in an area underlain by shale (soft) bedrock. Although test borings were beyond the scope of this study, it appears that the slide involved both residual soil and weathered bedrock. The second landslide was a shallow earth slump in colluvium that accumulated near the base of a steep slope underlain by hard bedrock. In general, slopes underlain by hard bedrock show little evidence of instability except where the rock has been fractured by faulting and folding. In those areas, raveling of cut slopes and rock fall present maintenance problems along roads. Such problems are particularly acute where bedding or joint planes parallel the slope and daylight in cut faces.

Due to the large number of site-specific factors that can effect slope stability, and the tendency for slope failures to occur in colluvial materials even over shallow bedrock, a slope stability analysis is recommended for all construction sites (including road rights-of-way) where slopes exceed 15 percent.





A Slopes comprised of unconsolidated material (alluvium, colluvium, or residual soil)

These slopes have the greatest potential for failure in the study area. The potential increases with removal of vegetation, grading, or other disturbance. The addition of water may cause both an increase in shear stress (added weight) and a decrease in strength (increased pore pressure). Therefore, sites near springs or seeps should be evaluated carefully. Removal of lateral support (i.e. by road construction) is the most common cause of instability and has produced the greatest number of earth slumps in this unit.

B Slopes underlain by soft bedrock (shale, mudstone, siltstone, poorly cemented sandstone, volcanic breccia, and tuff)

Slopes underlain by soft bedrock exhibit a wide range of slope stability characteristics; some similar to those in unconsolidated materials and others similar to those in hard bedrock. The residual soils derived from soft bedrock commonly have a high clay content. When saturated, increased pore pressure can weaken intergranular bonds within the soil and reduce shear strenth. Lateral pressure caused by swelling of the clay can further reduce soil strength and lead to slope failure. In some areas residual and colluvial soils have attained sufficient thickness (at the base of slopes and adjacent to drainages) for earth slumps and slump-earth flows to occur independent of the underlying bedrock.

Zones of weathered bedrock can attain thicknesses of several feet, and failures common to earth slopes (earth slumps, slump-earth flows, and debris slides) may occur in this material. Weak horizons within shale or mudstone units can form slip surfaces, especially when wet, that allow block slides or rock slumps to occur. Rock fall, rock topple, and/or block slides can occur due to frost wedging or where bedding or joint planes parallel the slope and daylight in cut faces.

C Slopes underlain by hard bedrock (limestone, sandstone, quartzite, and igneous intrusives)

Slopes in exposed hard bedrock are the most stable in the study area. Local areas of potential instability are found along faults which create zones of fractured and crushed rock; the extent of which depend on the length of the fault, the amount of movement, and the rock type. Roads crossing these zones may encounter ravelling, rockfall, or rock topple problems in cut areas. Fractured rock provides access for water entering the subsurface and slope failure due to frost wedging may result. Rock fall, rock topple, and/or block slides can occur where bedding or joint planes parallel the slope and daylight in cut faces.

Colluvium and residual soils greater than 5 feet thick have accumulated locally in hard bedrock areas. Shallow earth slumps and soil creep can occur in these areas.

References

Schuster, R.L., and Krizek, R.J., 1978, Landslides analysis and control: Washington, D.C., Transportation Research Board, National Academy of Sciences, Special Report 176, 234 p.

Roth, R.A., 1983, Factors affecting landslide-susceptibility in San Mateo County, California: Bulletin of the Association of Engineering Geologists, v. 10, no. 4, p. 353-372.

FIGURE 9.—Large earth slump in road cut excavated for Deer Valley Drive. Failure probably caused by undercutting of the slope and increased weight due to pore water. Extensive regrading is underway in an attempt to correct the problem.

FIGURE 10.—Small earth slump developed in a road cut excavated in the toe of a prehistoric slope failure. The remainder of the older failure has not been reactivated. Note outline of prehistoric slope failure.

Thaynes Formations, Woodside Shale, and tuff and volcanic breccia of the Keetley Volcanics contain alternating hard and soft layers that make excavatability of fresh rock highly variable. When weathered, these formations normally can be ripped and removed without blasting. Difficult excavation conditions may also be encountered in areas of very coarse- and fine-grained soils (fig. 3). Coarse-grained soils in the study area commonly contain cobbles and boulders. While not a major consideration in large excavations where heavy earthmoving equipment can be used, boulders may cause problems in smaller utility excavations. High plasticity clay soils are very hard when dry and can be nearly as difficult to excavate as shale bedrock. Clays also pose problems when wet because they are difficult to work and almost impossible to compact.

All known springs and seeps and areas of shallow ground water in Park City are shown in figure 4. Projects proposed for these areas should determine what effect the ground water will have on foundation materials. A second important consideration is the effect that the project will have on ground water. Changes accompanying development that may either raise or lower the water table include concentration and ponding of roof and pavement runoff, land grading, installation of sewers and other underground utilities, landscaping, and irrigation of lawns. Unanticipated changes in the shallow ground-water table can result in flooded basements, foundation settlement or uplift, soil collapse, and water system failure.

Soil creep is the gradual but steady downhill movement of soil and loose rock material on a slope. It is manifested by the tipping of fence posts and other rigid objects embedded in the soil, and signifies a quasi-equilibrium state that can be easily upset and turned into a landslide by construction activities such as a deep cut or heavy fill. Creep is active on many of the steeper slopes in Park City underlain by colluvial material. Its effect on retaining wall and building foundations is particularly evident along Woodside and Norfolk Avenues south of Sixth Street. Creep cannot be completely stopped, but its rate of movement can be materially decreased by providing adequate drainage to increase soil strength and prevent periodic swelling and shrinking. The absence of storm sewers and an integrated surface drainage system in much of Park City contributes directly to soil creep.

Two special foundation conditions affect small areas of Park City. They are old mill tailings and municipal refuse. Development has occurred on both materials. The primary concern with mill tailings is the possible presence of chemical residues which may be detrimental to concrete and other construction materials. The concern with municipal refuse is that it is a low density material which is difficult to compact and subject to deterioriation over time. Excessive settlement may be a problem under moderate to heavy foundation loads, and special construction techniques (piles, cassions, removal of refuse) may be required. Methane gas produced by decomposition of organic matter in the refuse also poses a hazard to enclosed structures placed over such material.

Foundation conditions in Park City are variable and need to be investigated on a site-specific basis for all major construction projects. A complete soils/foundation investigation should include:

1. nature of the deposits (geology, recent history of filling or excavation on site),
2. depth, thickness, composition, and areal extent of soil and rock strata,
3. depth, location, and seasonal/annual fluctuations of ground water,
4. location and description of any underground workings,
5. engineering properties of soil and rock strata affecting the proposed project,
6. site preparation and foundation design recommendations (including mitigation of frost action, high ground-water conditions, and soil creep) where appropriate, and
7. stability evaluation of natural and construction slopes.

Soils/foundation reports should be submitted to the city for review and approval before building permits are issued and construction is allowed to proceed.

Erosion hazard and erodibility

Background — Erosion and associated sedimentation can damage construction sites, degrade water quality, carry polluting chemicals, reduce the capacity of water conveyance and storage structures, and cover downstream areas with layers of unwanted sediment. Water is the primary erosional process active in Park City. Erosion and sedimentation by water involve the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water. The force of raindrops falling on bare or sparsely vegetated soil detaches soil particles (raindrop erosion). Water running as a thin sheet across the ground surface picks up the particles and carries them along as it flows (sheet erosion). As the water gains velocity and becomes concentrated, it detaches more soil particles, cutting first narrow and then wider channels in the ground surface (rill and gully erosion) and adding to its load of sediment. When runoff reaches a stream, it increases the stream's volume and velocity and may cause erosion of the banks and channel (stream bank and bed erosion). Sediment is deposited when the water is slowed sufficiently to allow the soil particles to settle out.

The susceptibility of a soil to erosion independent of vegetative cover, topography, and rainfall energy, is termed erodibility. Erodibility is determined by size and gradation of soil particles, percentage of organic matter, soil structure, and soil permeability (USDA Soil Conservation Service, 1977). Clean, well-drained, granular soils that allow runoff to infiltrate rapidly usually have low erodibility. Clayey soils also have low erodibility because the clay acts as a binder to prevent detachment. Soils containing high percentages of silt and fine sand are generally the most erodible because the small, noncohesive particles are easily detached and transported.

Factors other than soil erodibility which are important to erosion are vegetative cover, topography, and climate. Vegetation inhibits erosion by shielding the soil from raindrop impact and reducing runoff velocity. Root systems help maintain the capacity of soil to absorb water and hold soil particles in place. Slope length and steepness (gradient) directly affect runoff. As length and gradient increase, the amount and rate of runoff also increase. Slope orientation influences vegetation type and density, depth of snowpack, and rate of snowmelt. The frequency, intensity, and duration of precipitation events are fundamental to determining runoff amounts. Seasonal changes of temperature also help define periods of high erosion risk. During the winter, precipitation falls mostly as snow and little erosion takes place. In the spring, the melting snow adds to runoff at a time when the ground is still frozen and its absorptive capacity reduced.

These factors (soil erodibility, vegetation, topography, and climate) taken together determine susceptibility to erosion and therefore define erosion hazard. Erosion hazard is not a static condition, but changes as the factors that influence it change. For example, removal of vegetation and above-normal precipitation both tend to increase erosion hazard and may lead to serious erosion problems in formerly stable areas. Conversely, slope terracing reduces slope length and gradient and decreases erosion hazard. It is the ability to manipulate the factors affecting erosion hazard that makes the control of erosion possible.

Erosion potential in Park City — The erosion hazard and soil erodibility map of Park City (fig. 11) presents erosion hazard at the ground surface both with and without vegetative cover. The map was developed by grouping the 41 soil types identified in the study area by the USDA Soil Conservation Service and others (1977) according to similarities in their erosion hazard and soil erodibility ratings. Because soil erodibility, and particularly erosion hazard, are determined by a variety of factors, the map units shown on figure 11 do not necessarily coincide with soil map units on figure 3. Because of the many variables involved, the effect of site grading on erosion hazard is not shown on the map. However, removing vegetation, disturbing the ground surface, increasing slope gradient, and exposing deeper, possibly more erodible soils, all serve to increase the hazard from erosion.

Soils in Park City exhibit low to moderate erodibility. No high erodibility soils were identified in the study area (USDA Soil Conservation Service and others, 1977). Coarse-grained gravelly soils (GP, GM-GC) generally have low erodibility ratings. Clayey silt and clay soils (CL-ML, CL) are moderately erodible. In many areas of Park City mixed profile soils containing both coarse- and fine-grained horizons are common. In those areas, the erodibility of the surface horizon is shown on figure 11, but because the soil characteristics change with depth, the soil erodibility ratings also change. Such changes can be significant where extensive site grading is planned.

The erosion hazard for Park City soils was evaluated with natural vegetative cover, and with vegetation removed (USDA Soil Conservation Service and others, 1977). With vegetative cover, erosion hazard for all soils ranked low to moderate. Coarse-grained soils protected by vegetation generally have low erosion hazard. Moderate hazard occurs only on steep slopes (25 to 60 percent) where sufficient silt and clay are present to reduce permeability and increase runoff. Most fine-grained soils in the study area are found where slopes are gentle or nearly flat (fig. 3). The combination of subdued topography, cohesive soil, and vegetative cover produces low to nearly nonexistent erosion hazard in those areas. Where fine-grained soils occur on steeper slopes (greater than 15 percent), their lower permeability results in increased runoff and erosion hazard becomes moderate.

When vegetation is removed, the erosion hazard for Park City soils ranges from low to high. Most coarse-grained soils without vegetative cover have a high erosion hazard. Moderate hazard is found only where enough clay is present to act as a binder, or where the proportion of 3-inch (8 cm) plus material (cobbles) is high enough (50 percent or greater) to inhibit erosion. When vegetation is removed from fine-grained soils, the erosion hazard ranges from low to high and is directly related to slope gradient. The steeper the slope, the greater the erosion hazard.

For mixed profile soils, the erosion hazard rating represents the soil type at the ground surface both with and without vegetative cover. Where bedrock is very shallow (15 inches or less, 38 cm), it often acts as an impermeable horizon increasing both the amount and rate of runoff, and the erosion hazard is correspondingly increased for all soil types and vegetative conditions. Erosion hazard from mine waste piles and mill tailings are disscussed in the Mining-related hazards section (p. 26).

Erosion and sediment control — Erosion and sedimentation can be controlled in urbanizing areas if certain principles and practices are adhered to as the land is developed. Five basic principles for minimizing soil erosion from construction sites identified by the USDA Soil Conservation Service (1970) are: (a) use soils that are suited for development and avoid those that are not, (b) leave soil bare for the shortest time possible, (c) reduce the velocity and control the flow of runoff, (d) detain runoff on site to trap sediment, and (e) release runoff slowly and safely to downstream areas. General practices that have proven effective in applying these principles include:

1. selecting land where drainage, topography, and soil are favorable for the intended use, and then carefully fitting the development to the site,
2. using areas not suited for urban development for open space and recreation,
3. developing large tracts in small units to keep grading and vegetation removal at a minimum,
4. scheduling construction activities to minimize the time bare soils are exposed, and to avoid site grading during high precipitation or snowmelt periods,
5. controlling runoff and conveying it in a manner that does not erode the land surface,
6. constructing sediment basins on site to trap sediment and then safely releasing runoff to off-site areas,
7. utilizing mulch, temporary cover crops, and engineered structures to protect critical areas during construction, and
8. establishing permanent vegetation and erosion control structures as soon as possible following construction.

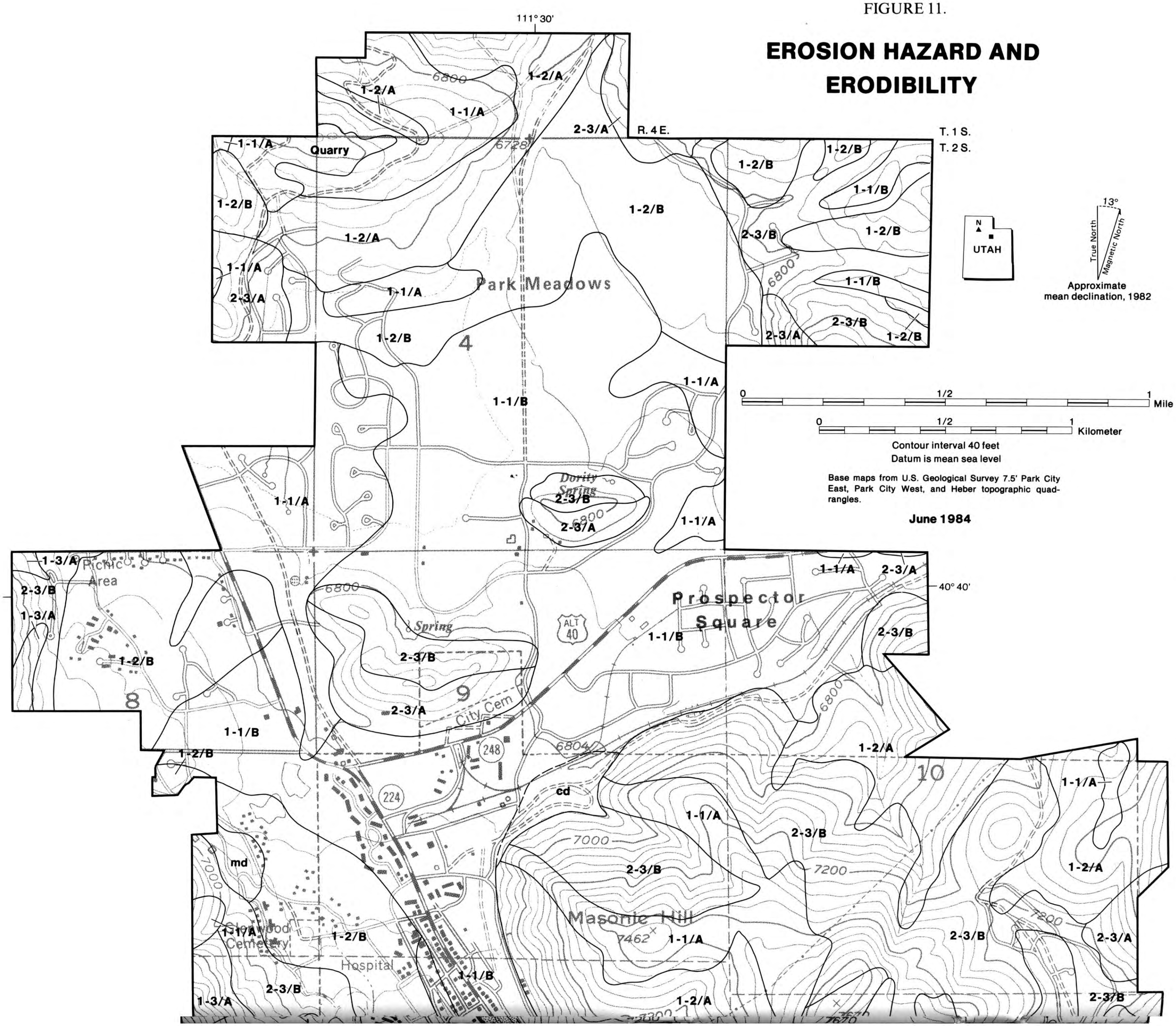
The methods and techniques used to control erosion and sedimentation on construction sites are varied and often complex. It is not the intent of this report to examine them in detail, except to note that they fall into two broad categories, mechanical (engineered) and vegetative (agricultural) (USDA Soil Conservation Service, 1970). Mechanical measures include special land grading, bench terraces, subsurface drains, storm sewers, diversions, berms, lined channels, waterway stabilization structures, and sediment basins. Vegetative measures include mulching and planting temporary or permanent cover crops. A combination of mechanical and vegetative techniques are often required to effectively control erosion and sedimentation in developing areas.

The erosion hazard and erodibility map shown in figure 11 is intended to serve as a general planning guide for future development in Park City. However, before erosion control measures can be effectively applied on a site-specific basis, the actual factors contributing to the erosion hazard for the site must be accurately assessed and a plan developed to guide the control effort. An erosion control report should be prepared and submitted to the City for review and approval prior to issuing building permits for new construction projects. The requirement could be waived for projects involving minimal site grading and for projects proposed in areas having low erodibility and erosion hazard ratings (fig. 11, map unit 1-1/A). The erosion control plan should include the following information:

1. General location map; showing the site in relation to nearby features such as waterbodies, drainages, structures, roads, and utilities. Recommended scale 1:1000 or larger.
2. Existing conditions site plan; showing topographic contours, drainage, bodies of water, soil types and distribution, vegetation, and cultural features on the site. Scale would vary with size of site, but generally not smaller than 1:100.
3. Grading plan and construction time schedule; showing final as-graded topographic contours, limits of proposed soil disturbance, limits of cut and fill areas, areas of various construction phases, location of proposed structures and utilities, and a chart detailing the construction time schedule.
4. Erosion control site plan and time schedule; showing location of areas to be seeded or mulched, type

FIGURE 11.

EROSION HAZARD AND ERODIBILITY



N
UTAH

13°
True North
Magnetic North
Approximate mean declination, 1982

0 1/2 1 Mile

0 1/2 1 Kilometer

Contour interval 40 feet
Datum is mean sea level

Base maps from U.S. Geological Survey 7.5' Park City East, Park City West, and Heber topographic quadrangles.

June 1984

EXPLANATION

This map depicts erosion hazard and erodibility. It was compiled using data from the USDA Soil Conservation Service and others (1977), field observations, and air photo interpretation

Erosion hazard is an evaluation of erosion potential that takes into consideration the inherent soil erodibility, rainfall energy, topography, and vegetative cover. Soil erosion is directly related to permeability of the soil. If permeability is high, excess moisture passes through rather than over the soil. Any restriction or impedance of this flow, such as an increase in clay content, compacted layers, or shallow soil over bedrock, increases erosion potential. Surface erosion in sheet, rill, or gully form can take place only where overland flow occurs. Removal of vegetation and/or presently stable topsoil may accelerate soil loss depending on soil characteristics in the subsurface (Bailey, 1974).

Erodibility is the ability of the soil to resist detachment and transport by rainfall and/or runoff. Some soil properties affecting soil erodibility are: texture (grain size), percent sand greater than 0.10 mm diameter, organic content, permeability, clay mineralogy, and coarse fragments in the soil.

A dual classification system has been developed to show both erosion hazard and erodibility on a single map. Erosion hazard is given a rating of 1, 2, or 3, which equates to low, medium, or high hazard. Two hazard ratings are assigned to each map area, the first represents the hazard with vegetative cover and the second with vegetation removed. Erodibility is assigned a rating of A for low or B for medium; there are no highly erodible soils in the study area. A typical ranking would be 1-3/A, which represents a soil with a low erosion hazard prior to vegetation removal and a high hazard after, and in both cases low erodibility. Because erosion hazard may increase with removal of vegetation and both erosion hazard and erodibility may change with removal of upper soil layers, an erosion hazard assessment should be performed on a site by site basis, except in areas designated 1-1/A.

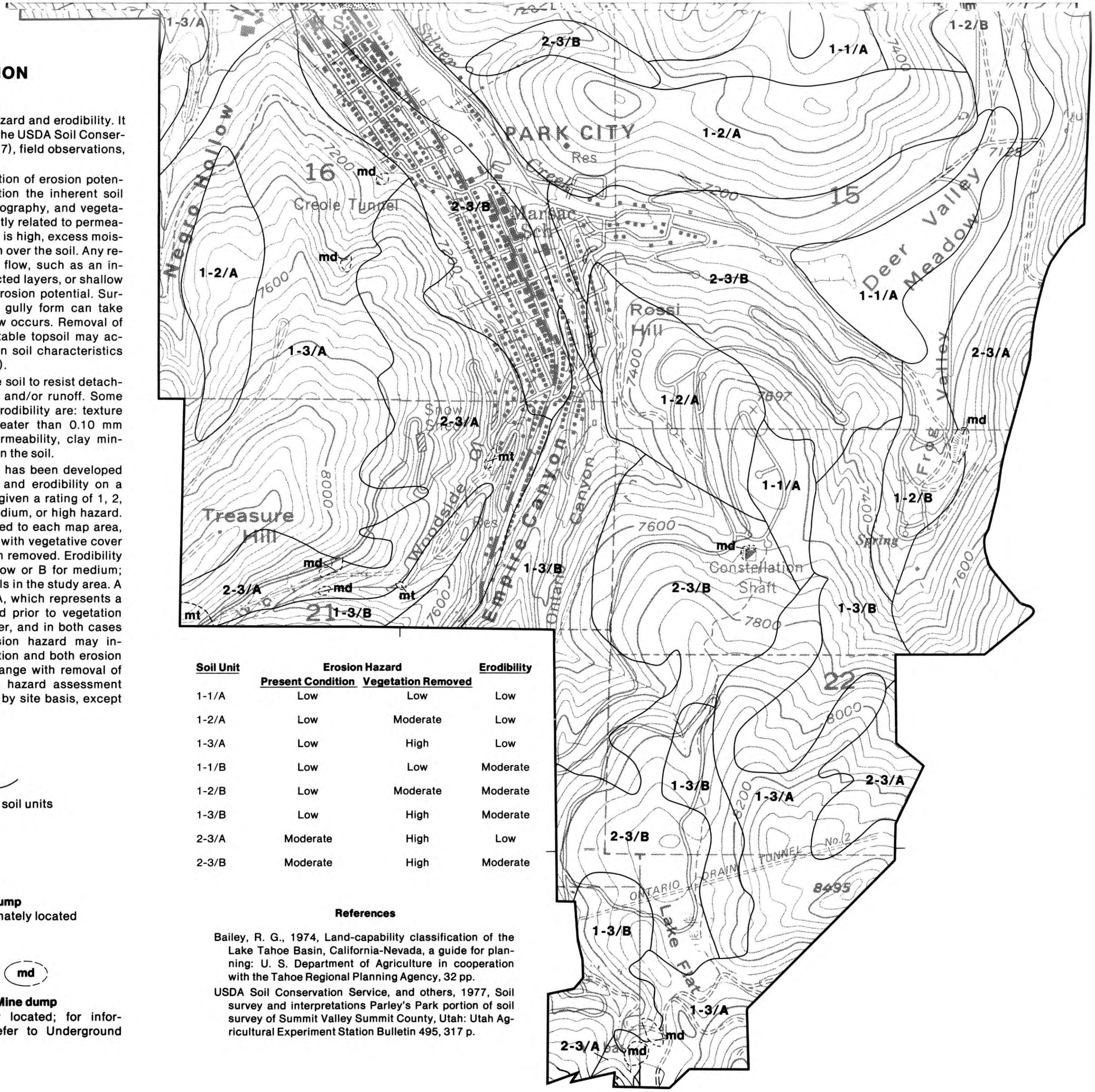
Contact between soil units

cd

City refuse dump
Dashed where approximately located

mt md

Mill tailings **Mine dump**
Dashed where approximately located; for information on erosion hazard refer to Underground Workings map



Soil Unit	Erosion Hazard		Erodibility
	Present Condition	Vegetation Removed	
1-1/A	Low	Low	Low
1-2/A	Low	Moderate	Low
1-3/A	Low	High	Low
1-1/B	Low	Low	Moderate
1-2/B	Low	Moderate	Moderate
1-3/B	Low	High	Moderate
2-3/A	Moderate	High	Low
2-3/B	Moderate	High	Moderate

References

Bailey, R. G., 1974, Land-capability classification of the Lake Tahoe Basin, California-Nevada, a guide for planning: U. S. Department of Agriculture in cooperation with the Tahoe Regional Planning Agency, 32 pp.

USDA Soil Conservation Service, and others, 1977, Soil survey and interpretations Parley's Park portion of soil survey of Summit Valley Summit County, Utah: Utah Agricultural Experiment Station Bulletin 495, 317 p.

and location of all mechanical erosion control measures, and a chart sequencing implementation of erosion control measures with the construction schedule.

5. Narrative text; providing details of the erosion hazard at the site and proposed erosion control measures.

The erosion control plan should be prepared in sufficient detail to allow the City to evaluate its effectiveness, for contractors to implement the required control measures, and for City inspectors to determine compliance in the field.

Mining-related hazards

The Park City area has been the site of underground mining since 1869, and recent rapid development as a recreation area has resulted in urbanization of many mined areas. There are four principal hazards associated with these areas: (a) subsidence or sinkhole development resulting from collapse of abandoned underground workings, (b) slope failure resulting from undercut slopes or increased surcharge from mine dumps, (c) sedimentation in stream channels, debris basins, and storm drains by mine wastes and mill tailings, and (d) potential health hazards due to contamination of ground water and soils by toxic elements in mill tailings.

A comprehensive study of mining-related hazards requires specific information on underground workings including their age, condition, depth, length, and location of adits and shafts. The Utah Geological and Mineral Survey requested this information from United Park City Mines and their response was that the data is considered proprietory but can be obtained through a contract/fee arrangement with the mining company. This study includes a detailed field reconnaissance of adits and shafts in the area. Available topographic, geologic, and mine maps and aerial photographs were utilized to locate the workings. Several shafts and adits were discovered that were not on the maps, and it is possible that others exist that could not be identified from the sources used. During the field reconnaissance each site was inspected and the condition of the portal or opening, as well as any evidence of surface subsidence or collapse was documented. Each waste pile was measured to estimate the volume of material, and evidence of erosion was noted. The results of the field reconnaissance are shown in figure 12.

Collapse, subsidence, or sinkhole development — Many older shafts were capped 50 to 80 years ago and four of those caps have failed within the past two years. Age, quality of construction, and ground saturation likely have contributed to the failures. One collapse occurred during construction of the Silver King Lodge (fig. 12, S15) immediately north of Park City Resort, and nearly resulted in the loss of heavy construction equipment. A second collapse occurred during site clearing operations at Stein's Lodge (fig. 12, S 9) in Deer Valley Resort, and once again construction equipment was nearly lost. At both locations a new cap was installed and the lodges were constructed on the site. The most spectacular collapse occurred in Empire Canyon approximately one mile (1.6 km) southwest of the study area in August 1983. A shaft 45 feet (14 m) in diameter and 1400 feet (427 m) deep was exposed (fig. 13). A chain link fence was placed around the hazardous area and backfilling is underway. This location was under consideration for future development. The fourth collapse was 45 feet (14 m) wide and 40 feet (12 m) deep and is located near the western boundary of the study area, west of Creole Shaft (fig.12, S14). The collapse is approximatly 1500 feet (458 m) from a residential area and is easily accessible. At the time of inspection only colored plastic ribbon had been strung around the opening.

In the past, the portals of many adits were purposely collapsed following closure of the mine. This resulted in ground subsidence at the entrance, and many such abandoned adits are found in residential areas in Park City. Not all adits have been closed in this manner, and some present a hazard because they are still accessible. The possibility also exists for collapse during construction above underground workings. However, to date there have been no reports of damage due to such subsidence. Because most mines are in competent rock and because they were driven into steep hillsides, where they rapidly become quite deep, the potential for collapse affecting the surface is considered low.

Slope Stability — Slope instability induced by mining activity remains a problem long after mining has ceased. Loading of slopes by mine waste piles may induce slope failure, especially on slopes subject to seasonal saturation. The waste piles themselves may fail due to saturation or undercutting (fig. 12, A-1 and A-13). Larger mine dumps, located on steep slopes, may become unstable during seismically induced ground shaking. Poorly designed roads also pose slope stability problems. Evidence of slumping and rock fall is apparent in the study area where old mine roads had removed support from the slope.

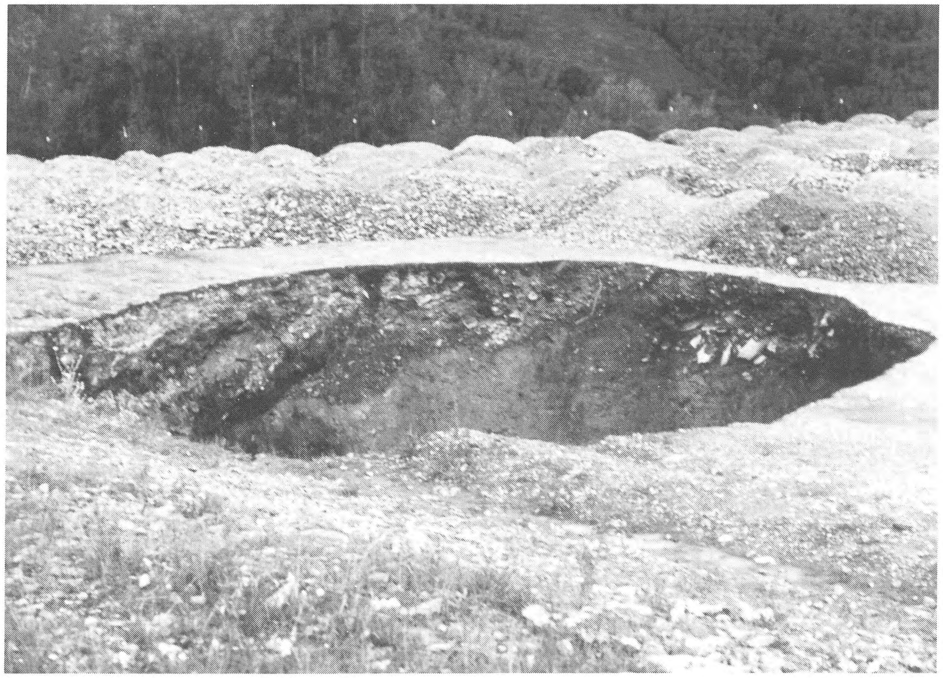


FIGURE 13.—Failure of mine shaft cap possibly caused by age and quality of construction. Collapse occurred southwest of study area in August 1983, and is 45 feet (14 m) in diameter and 1400 feet (427 m) deep.

Erosion and sedimentation — Erosion of waste piles and mill tailings may greatly increase sediment loads delivered to streams and result in sedimentation in stream channels, debris basins, and storm drains. Mill tailings pose the greatest problem because they are fine grained and more readily eroded and transported by streams than the coarse-grained materials in mine waste piles. Extensive erosion of two tailings piles and one mine dump is occurring in Woodside Gulch (fig. 14). The sediment is entering the city's storm sewer system at the mouth of the canyon, but there has been no report of sediment-related flooding to date.

Contamination of ground water and soil — Mill tailings associated with mining activity characteristically contain high levels of heavy metals and other toxic elements. The Prospector Square development near the eastern boundary of the study area is sited almost entirely on old mill tailings. A drilling program was undertaken by the Utah Geological and Mineral Survey (UGMS) to determine if toxic elements existed in these sediments. Ten 4-inch (10 cm) diameter auger borings, from 2 to 11 feet (0.6 to 3.4 m) deep, were drilled on the site (fig. 12). At each location samples were taken at 1-foot (0.3 m) intervals and then combined into a single sample representative of the entire boring. Chemical analyses were run on five of the composite samples, and high concentrations of arsenic, cadmium, mercury, and lead were found. The Utah Department of Health collected and tested samples taken from the upper 2 inches (5 cm) of soil and from a depth of 12 inches (30 cm) below the ground surface. These horizons were selected because children are more likely to come in contact with surface soils, and a comparison of analyses at depths of 2 and 12 inches (5 and 30 cm) gives an indication of the leaching that has occurred in the upper horizon. Surface water samples from Silver Creek both upstream and downstream from the Prospector Square tailings were also collected and tested. The test results on the soil samples confirmed the high concentrations of toxic elements found earlier in samples taken by UGMS, and the water samples from below Prospector Square showed elevated levels of lead. Table 2 compares the results of the UGMS and Health Department testing with the average concentration of the same elements in soils as reported by the U.S. Geological Survey (1979).

Although levels of toxic elements are high, the potential hazard to residents is unknown. The State and Summit County health departments are proceeding with additional soil and water sampling and with blood tests on residents. Their findings will assist in grading and ranking the area for possible inclusion on

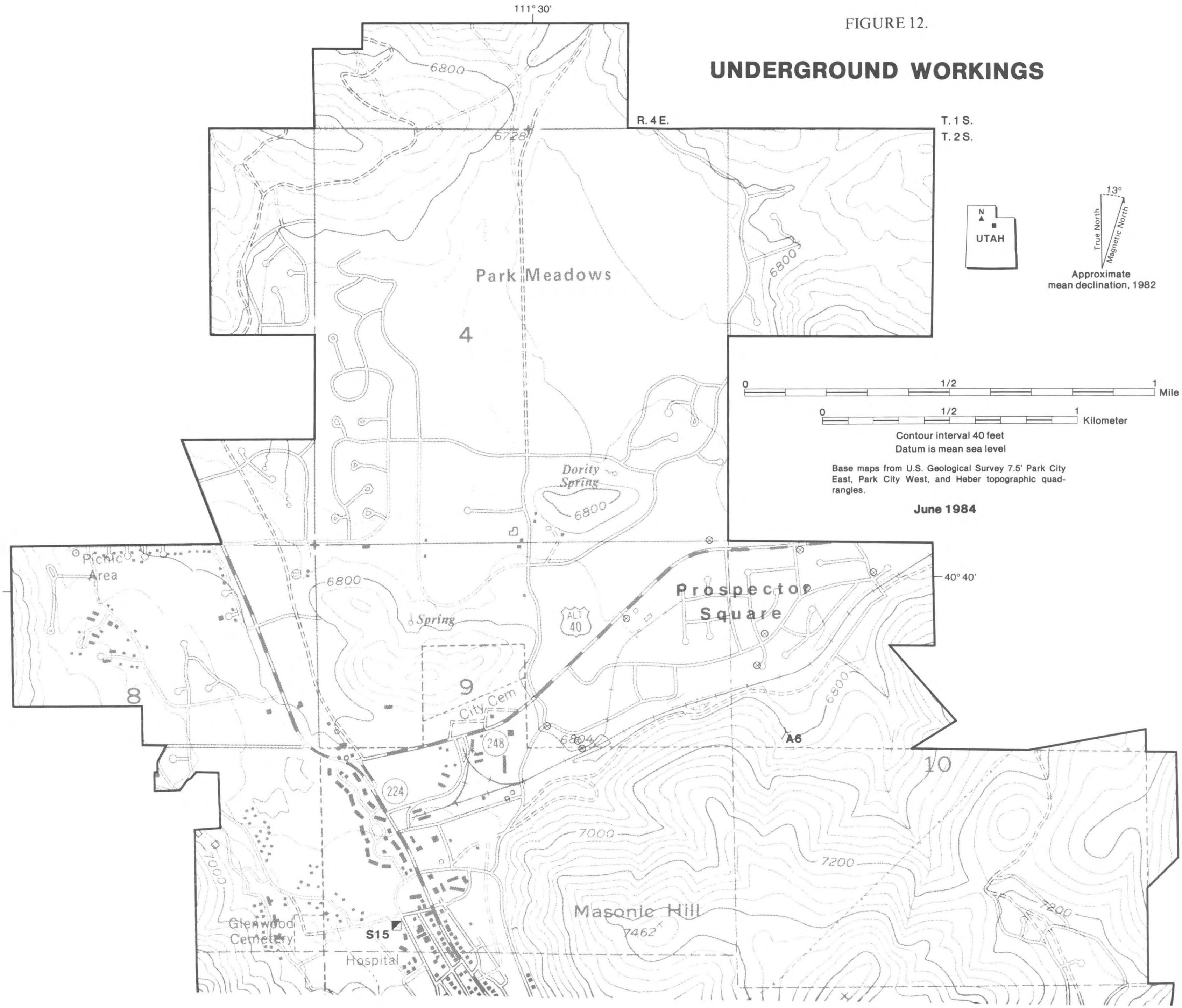
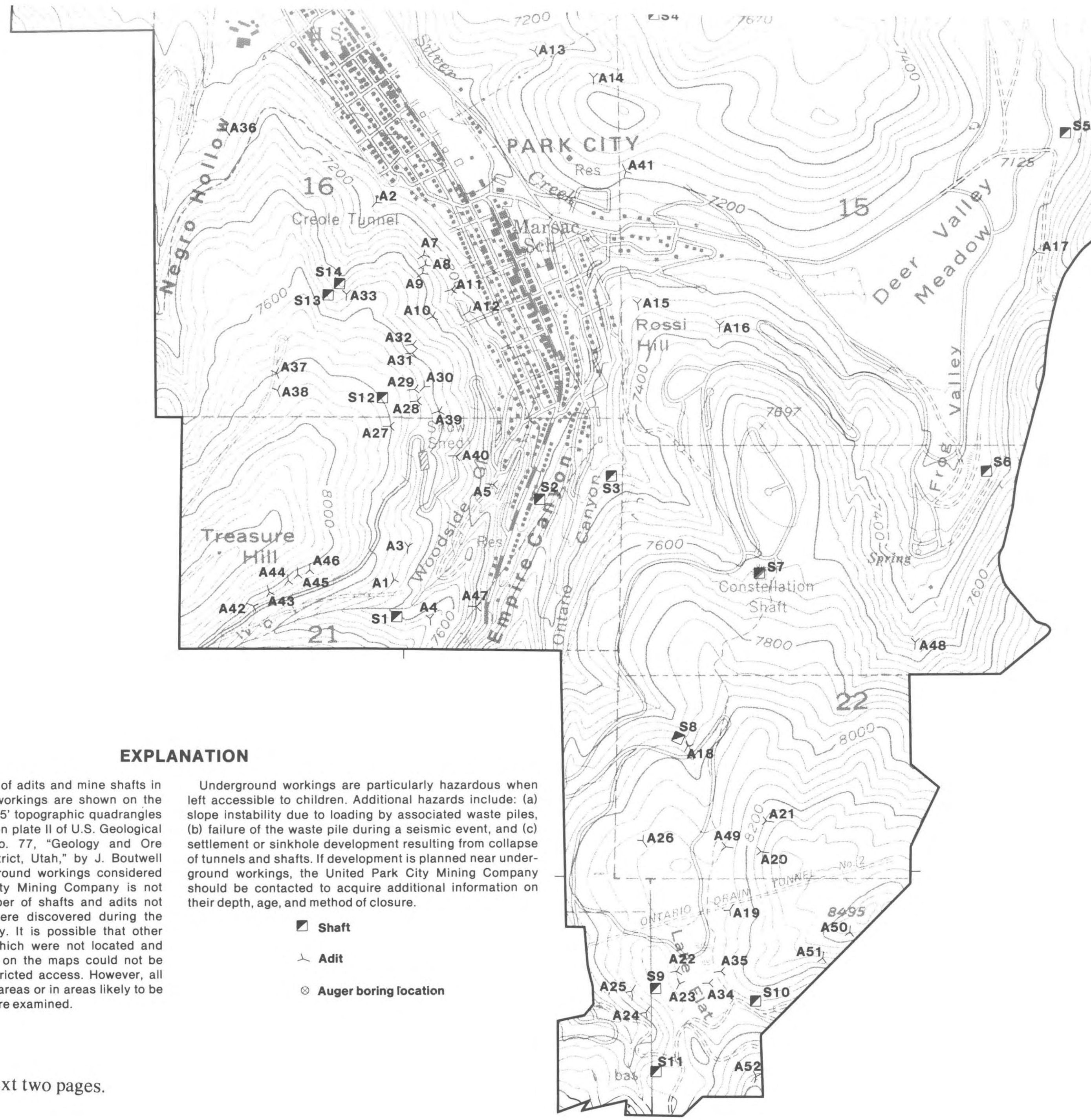


FIGURE 12.

UNDERGROUND WORKINGS



EXPLANATION

This map shows the location of adits and mine shafts in Park City. Most underground workings are shown on the three U.S. Geological Survey 7.5' topographic quadrangles which cover the study area or on plate II of U.S. Geological Survey Professional Paper No. 77, "Geology and Ore Deposits of the Park City District, Utah," by J. Boutwell (1912). Information on underground workings considered proprietory by United Park City Mining Company is not included on this map. A number of shafts and adits not shown on the above maps were discovered during the field-work portion of this study. It is possible that other underground workings exist which were not located and described. A few adits shown on the maps could not be found or were in areas of restricted access. However, all mine workings near developed areas or in areas likely to be developed in the near future, were examined.

Underground workings are particularly hazardous when left accessible to children. Additional hazards include: (a) slope instability due to loading by associated waste piles, (b) failure of the waste pile during a seismic event, and (c) settlement or sinkhole development resulting from collapse of tunnels and shafts. If development is planned near underground workings, the United Park City Mining Company should be contacted to acquire additional information on their depth, age, and method of closure.

Shaft

Adit

Auger boring location

Figure 12 tables on next two pages.

FIGURE 12.—Underground workings (continued).

MINE SHAFTS

	Condition of opening	Evidence of surface subsidence	Approx. waste pile volume	Remarks
S1	Open, 50-75 ft (15-23 m) deep		10 yd^3 (8 m^3)	
S2	Closed	Possible sinkhole	No measurement taken.	Rock fall hazard above opening.
S3	Open		Waste pile removed.	Old mill site; shaft enclosed by metal shed with gate.
S4	Open, apprx. 30 ft deep (9 m)		90 yd^3 (69 m^3)	Minor soil creep over edge of opening.
S5	Closed		103 yd^3 (100 m^3)	15 ft (5 m) to concrete plug.
S6	Closed		40 yd^3 (30 m^3)	
S7	Closed		Waste pile disturbed, no measurement taken.	Located on SE corner of subdivision lot.
S8	Closed		5 yd^3 (4 m^3)	
S9	Closed		No waste pile.	Stein's Lodge built over shaft.
S10	Closed	Evidence of settling, concentric cracks extend outward from opening.	No waste pile.	Standing water in opening, origin unknown; shaft 300 ft (92 m) deep, plugged at 10 ft (3 m).
S11	Closed		Extensive waste pile, no measurement taken.	Waste pile failure may occur during seismically induced ground shaking; deep gulleys cut into face of waste pile, shaft 820 ft (250 m) deep.
S12	Open, 20 ft (6 m) deep	Partially collapsed or settled.	150 yd^3 (115 m^3)	Minor soil creep over edge of opening.
S13	Open, 20 ft (6 m) deep	Appears to have collapsed or settled.	480 yd^3 (367 m^3)	Extensive waste pile in steep canyon, potential for failure during seismically induced ground shaking, minor gullying down face of waste pile.
S14	Open, 40 ft (12 m) deep	Shaft has recently collapsed; 40 ft (12 m) deep, 45 ft (14 m) in diameter; extensive sloughing of sides, entire north side appears unstable.	21,815 yd^3 (16,680 m^3)	Extensive waste pile in steep canyon, potential for failure during seismically induced ground shaking, minor gullying down face of waste pile.
S15	Closed, apprx. 800 ft (244 m) deep		No waste pile.	Silver King Lodge built over shaft.

ADITS

	Condition of portal	Evidence of surface subsidence
A1	Open into hill apprx. 30 ft (9 m)	
A2	Closed	Roof collapse, extends upslope from portal apprx. 70 ft (21 m); 10 ft (3 m) wide, 3-6 ft (.9-2 m) deep.
A3	Closed	Sinkholes extend upslope from portal 150-200 ft (46-61 m); 5-30 ft (2-9 m) long, 3-10 ft (.9-3 m) deep.
A4	Closed	Collapse apprx. 15 ft (5 m) to west and east of portal.
A5	Closed	
A6	Closed	
A7	Open	
A8	Open	
A9	Closed	
A10	Closed	
A11	Open into hill apprx. 30 ft	
A12	Closed	
A13	Closed	
A14	Open	Partially closed
A15	Closed	
A16	Open	Partially closed
A17	Closed	
A18	Closed	Settlement extends 15 ft (5 m) upslope.
A19	Closed	Possible settlement in several locations.
A20	Closed	
A21	Closed	
A22	Closed	
A23	Closed	

Approx. waste pile volume	Remarks
10 yd^3 (8 m^3)	Toe of waste pile has been removed by roadcut, sloughing onto road has occurred.
1450 yd^3 (1109 m^3	Soil moist, abundant vegetation; possibly wet in spring.
310 yd^3 (237 m^3)	
110 yd^3 (84 m^3)	Minor soil creep observed.
No measurement taken	Within 1000 ft (305 m) of residence; waste dump eroded by creek.
350 yd^3 (268 m^3)	Minor soil creep observed.
30 yd^3 (23 m^3)	Minor gullying down face of waste pile.
30 yd^3 (23 m^3)	
90 yd^3 (69 m^3)	Minor soil creep observed.
30 yd^3 (23 m^3)	
15 yd^3 (11m^3)	Located close to existing homes.
30 yd^3 (23 m^3)	Minor soil creep observed.
30 yd^3 (23 m^3)	Road removed toe of waste pile; sloughing has occurred; minor erosion around portal.
90 yd^3 (69 m^3)	
15 yd^3 (11 m^3)	Abundant vegetation, possibly wet in spring.
90 yd^3 (69 m^3)	Soil creep has obscured portal; abundant vegetation, may be wet in spring.
10 yd^3 (8 m^3)	Minor gullying down face of waste pile; animal burrows around portal.
15 yd^3 (11 m^3)	
Waste pile removed	
110 yd^3 (84 m^3)	
5 yd^3 (4 m^3)	Prospect
60 yd^3 (46 m^3)	
55 yd^3 (42 m^3)	

ADITS (cont.)

	Condition of portal	Evidence of surface subsidence	Approx. waste pile volume	Remarks
A24	Closed		Waste pile removed by erosion.	Minor soil creep near portal; slope above cut possibly unstable.
A25	Closed		15 yd^3 (11 m^3)	
A26	Closed	Settlement to within 30 ft (9 m) of a residence.	20 yd^3 (15 m^3)	Minor erosion north of portal.
A27	Closed		15 yd^3 (11 m^3)	
A28	Closed		270 yd^3 (206 m^3)	
A29	Closed		90 yd^3 (69 m^3)	
A30	Open 30 ft (9 m) into hill	Portal partially collapsed.	30 yd^3 (23 m^3)	
A31	Closed		20 yd^3 (15 m^3)	
A32	Open		30 yd^3 (23 m^3)	
A33	Closed		310 yd^3 (237 m^3)	Extensive waste pile in steep canyon, potential for seismically induced failure; minor soil creep upslope from portal.
A34	Closed	Collapsed by mining company, no surface expression observed.	Waste pile removed.	Shaft originally 1400 ft (427 m) long.
A35	Closed	Collapsed by mining company, no surface expression observed.	Waste pile removed.	Shaft originally 800 ft (244 m) long.
A36				Could not locate.
A37				Restricted access
A38				Restricted access
A39				Could not locate, possibly removed by road construction.
A40				Removed by road construction
A41				Could not locate
A42				Restricted access
A43				Restricted access
A44				Restricted access
A45				Restricted access
A46				Restricted access
A47				Could not locate
A48				Restricted access
A49				Could not locate, possibly removed by road construction.
A50				Restricted access
A51				Restricted access
A52				Restricted access

FIGURE 14.—Extensive erosion of mine waste pile in Woodside Gulch. Fine-grained sediment carried downstream enters the city's storm sewer system and may cause sediment-related flooding in the future.

the Environmental Protection Agency (EPA) Super Fund Hazardous Waste Site list. If the site is included, the EPA will institute a comprehensive study of the Park City area during which all mill tailing sites would be identified and a decision made as to their disposition (John Brink, EPA, oral communication, 1983).

Seismicity

Park City lies within a north-south trending belt of seismicity known as the Intermountain seismic belt - a zone of pronounced earthquake activity extending from northwestern Montana to southwestern Utah (Sbar and others, 1972). Although Park City has not experienced a large earthquake in historic time, an earthquake of Richter magnitude 6 is considered possible (Arabasz and others, p. 41, 1983). The complete record of historical earthquakes, within a 14- by 18-mile (23 by 29 km) rectangle centered on Park City, of Richter magnitude 2.0 or greater compiled from the University of Utah Seismograph Stations (1983) is shown in table 3. This record covers the period 1850 to September, 1983, and records 17 events, some of which consisted of more than one shock within a relatively short time period. Location of these events are shown in figure 15.

The largest magnitude events near the study area occurred in May 1953 and October 1972. Both had estimated Richter magnitudes of 4.3 with Modified Mercalli intensities (appendix) of V and VI, respectively (University of Utah Seismograph Stations, 1983). The 1953 event was located approximately 10 miles (16 km) south of Park City, and the 1972 earthquake was about 12 miles (19 km) to the south-southeast. The 1972 earthquake was felt over a large area with minor damage reported at Midway, Heber City, Wallsburg, and along the east bench of Salt Lake City (Langer and others, 1979). A maximum intensity of VI was assigned at Midway where bricks were shaken from chimneys and some cracking of plaster occurred. A total of 28 aftershocks were identified, five of which ranged from 2.0 to 2.5 estimated Richter magnitudes. The earthquake was felt in Park City but there was no damage reported (J. Wilking, publisher Park Record, oral commun., 1984). No surface faulting has been recorded during any earthquakes in the Park City area, and no faults with geologic evidence of offset during the Quaternary have been identified. However, the area is only 16 miles (26 km) east of the Wasatch fault which has a history of recurrent Holocene surface faulting accompanying moderate to large earthquakes (Langer and others, 1979), and is thought capable of generating an earthquake of magnitude 7.5 (Arabasz and others, 1979). Other faults on which Quaternary offset has occurred are found 32 miles (51 km) to the

TABLE 2.—Toxic element concentrations at Prospector Square development.

Element	Concentration (ppm - parts per million, ppb - parts per billion)				
	Prospector Square			Average soils U.S. Geological Survey (1979)	Utah public drinking water standards
	Utah Geological and Mineral Survey samples	Utah State Dept. of Health samples			
		Soil*	Water** (Silver Creek)		
Arsenic	160-550 ppm	A 250-440 ppm B 270-360 ppm	A 2 ppb B 6 ppb	less than 1-40 ppm	50 ppb
Cadmium	100-185 ppm	A 43-89 ppm B 46-85 ppm	A 5 ppb B 8 ppb	0.15-0.2 ppm	10 ppb
Mercury	0.47-1.78 ppm	A 3.9-7.4 ppm B 1.6-13.3 ppm	A 0.1 ppb B 0.2 ppb	0.071 ppm	2 ppb
Lead	approximately 10,000 ppm	A 1340-4000 ppm B 1170-2500 ppm	A 5 ppb B 112 ppb	less than 1 ppm	50 ppb

*A, surface; B, 12″ below surface.
**A, upstream from tailings; B, downstream from tailings.

southeast in Strawberry Valley. Exploration of the late Pleistocene Strawberry Valley fault by the U.S. Bureau of Reclamation has uncovered evidence which may show a history of repeated fault movement with 3.3 to 9.8 feet (1 to 3 m) of stratigraphic displacement on individual fault breaks. At least one and possibly two surface displacement events have occurred during the Holocene, the larger occurring about 3 thousand years ago (Arabasz and others, p. 51, 1983).

Earthquake hazard — In discussing earthquake hazards, it is important to differentiate between the terms risk and hazard. An earthquake hazard refers to a source of danger such as a geologic process accompanying an earthquake; whereas earthquake risk refers to the probability that peril or loss will occur in the event of an earthquake. Earthquake hazards such as ground shaking and faulting are beyond man's control, but earthquake risk can be mitigated by human intervention such as avoiding hazardous zones or engineering structures to withstand hazards.

The absence of faults showing evidence of Quaternary movement indicates that the principal earthquake hazard in Park City would be due to ground shaking caused by an earthquake outside the area. Hazards from ground shaking are produced by propagation of large-amplitude seismic waves at the earth's surface. Damage occurs to materials and structures that deform or fail from excessive strain produced by passage of the seismic waves through the material beneath the structure. If a building has a natural vibration frequency that is about the same as that of the passing wave, the building may develop natural resonance which results in amplified ground motion that can be destructive (Arabasz and others, 1979).

Other earthquake effects that may occur due to ground shaking are differential ground settlement that can deform or break building foundations; liquefaction of saturated soils that reduce their strength as foundation supports; and slope movements and snow avalanches. In the Park City area, special seismic hazards exist due to past mining activity. Ground shaking may cause collapse of underground workings and subsequent surface subsidence or sinkhole

TABLE 3.—Earthquakes of Richter magnitude 2.0 or greater in the Park City area, 1850 to September 1983.

Index to numbers in fig. 15	Date	Magnitude	Maximum intensity	Epicenter Location Latitude (N)	Longitude (W)
1	11/11/32	3.7	IV	40°31′04″	111°28′27″
2	5/24/53	4.3	V	40°30′00″	111°30′00″
3	1/23/69	2.5	—	40°43′62″	111°37′92″
4	9/22/69	2.0	—	40°33′45″	111°34′54″
5	10/1/72	4.3	VI	40°30′36″	111°20′91″
6	10/1/72	2.2	—	40°37′09″	111°19′02″
7	10/1/72	2.5	—	40°36′35″	111°20′37″
8	10/1/72	2.1	—	40°32′56″	111°21′77″
9	10/3/72	2.4	—	40°26′35″	111°21′04″
10	12/24/72	2.0	—	40°26′10″	111°24′53″
11	12/19/74	2.0	—	40°26′27″	111°26′73″
12	1/19/75	2.0	—	40°50′35″	111°39′90″
13	7/7/75	2.5	—	40°47′98″	111°35′25″
14	10/22/75	2.6	—	40°45′42″	111°37′36″
15	12/10/78	2.3	—	40°48′40″	111°33′22″
16	12/10/78	2.7	—	40°48′72″	111°33′91″
17	2/3/80	2.3	—	40°53′33″	111°36′45″

Source: University of Utah Seismograph Stations (1983).

development. Shaking could also cause downslope movement of larger mine waste piles located on steep slopes.

Due to the level of seismicity in the area, Park City is in seismic zone 3 of the Uniform Building Code (UBC) and the Utah Seismic Safety Advisory Council (USSAC) statewide seismic zonation. Utah is divided into three (UBC) or four (USSAC) seismic zones, with zone 1 being least hazardous (lowest projected earthquake probability and magnitude) and zones 3 and 4 being most hazardous (highest projected earthquake probability and magnitude). Earthquake hazard near Park City is thus considered high, with an expected Modified Mercalli intensity of VIII or higher (appendix) in UBC zone 3.

Avalanche hazard

Information on avalanche hazard in the study area was obtained through interviews with avalanche control personnel at Park City and Deer Valley Resorts, and through personal communication with long-time residents of the area (Lund, 1979). Numerous snow avalanches occurred in the Park City area between 1884 and 1897, primarily because trees which stabalize snow on slopes were removed for use by the mining industry. At least one destructive avalanche is known to have occurred on the hillside immediately west of Park City between Woodside Gulch and Creole Tunnel. It destroyed a large shed and damaged a house on Woodside Avenue in either 1910 or 1911 (Lund, 1979). At present, the slopes have revegetated and no avalanches have been reported on slopes near the city since Park City Resort opened in 1963 (limit of accurate record).

Slopes in the populated areas of Park City do not pose an imminent danger from large avalanches (Mike Spurlock, oral commun., Chief of Avalanche Hazard, Park City Resort, 1983; ski patrol personnel, oral commun., Deer Valley Resort, 1983). However, small point or slab avalanches may occur on steep slopes under extreme snow and weather conditions. Several avalanches have occurred on slopes within

FIGURE 15.—Location of earthquake epicenters listed in Table 3 (1850 to September 1983) in the Park City area.

the Park City ski area, but the location of the slides precludes any danger to the city. The slope nearest Park City with the greatest avalanche potential is located just outside the study area on the west side of Negro Hollow. An extremely heavy snowfall with a prolonged southwest wind would be required to develop an avalanche hazard there. However, there is no record of a failure at this location since the opening of Park City Ski Resort, and if one did occur it is unlikely that it could affect any area other than the ski resort (Mike Spurlock, oral commun., 1983).

CONCLUSIONS AND RECOMMENDATIONS

Growth in Park City is expected to continue at a rapid rate, and proposals for construction in areas where geologic conditions are undesirable for development are likely to increase. Development can proceed safely and efficiently if geologic constraints are recognized and incorporated into the planning process. Use of information provided in this report during initial site planning will assist in early recognition of potentially hazardous geologic conditions and mitigating measures can be instituted where appropriate. However, the data presented in this report are for general planning purposes only and do not preclude the necessity for site investigations. It is recommended that all proposed subdivisions and major construction projects include a geologic/soils report addressing all relevant site conditions. The following geotechnical conditions in Park City are of greatest importance to planners:

1. Flood hazard adjacent to major drainages and in some valley bottoms.
2. High ground water in valley bottoms and adjacent to stream channels.
3. Generally stable natural slopes, however, with a potential for instability under changed conditions resulting from development.
4. Area of fine-grained soils with high shrink-swell potential and low shear strengths.
5. Chemical residues in old mill tailings which may be detrimental to concrete and other construction materials.
6. Low density materials in the old city refuse dump which may settle under moderate to heavy loads.
7. Low to moderate soil erodibility and erosion hazard under existing conditions, and high erosion hazard on some steeper slopes if vegetation is removed.
8. Possible subsidence or sinkhole development resulting from collapse of abandoned shafts and adits.
9. Potential for failure on slopes loaded by mine dumps and of the dumps themselves, or on slopes undercut by mining activities.
10. Sedimentation due to erosion of mill tailings and mine waste piles.
11. Possible health hazards from contamination of ground water and soil by toxic elements in mill tailings.

The following recommendations are made based on the results of this study:

1. Ground-water levels, including seasonal variations, should be determined prior to construction in areas of shallow ground water.
2. Development in flood prone areas should be avoided or measures taken to mitigate the hazard.
3. Installation of surface drainage systems in developed areas and as new development proceeds to accomodate runoff and help mitigate soil creep.
4. Construction should not be allowed on prehistoric slope failures until it is demonstrated that development will not cause renewed movement.
5. Slope stability analyses should be required for all construction sites and rights-of-way on slopes steeper than 15 percent.
6. Foundation investigations should be performed on a site-specific basis for all proposed construction.
7. An erosion control report should be prepared and reviewed by the City before building permits are issued for new construction.
8. Removal of vegetation, especially trees, from steep slopes should be avoided to limit avalanche hazard.
9. Negotiations should be entered into with United Park City Mines and other relevent parties to obtain all existing data on underground workings in Park City.
10. Erosion control measures should be initiated to protect the city's storm drain system from sedimentation resulting from the erosion of mine waste piles and mill tailings.

11. Development on mill tailings and mine dumps should be prohibited until a determination is made regarding the content and possible health effects of toxic substances contained in them.
12. All construction should conform to specifications listed in the Uniform Building Code for structures in seismic zone 3.

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SELECTED REFERENCES

Anderson, L. W., and Miller, D. G., 1979, Quaternary fault map of Utah: Long Beach, California, Fugro, Inc., 13p, 1:500,000.

Arabasz, W. J., Smith, R. B., and Richins, W. D., eds., 1979, Earthquake studies in Utah, 1850 to 1978: University of Utah Seismograph Stations, Department of Geology and Geophysics, 548 p.

Arabasz, W. J., Jahns, R. H., and Peck, R. B., 1983, Review and analysis of geologic, seismotectonic, and design data for the proposed Jordanelle Dam, Bonneville Unit, Central Utah Project, Utah: consultant review to U.S. Bureau of Reclamation, Denver, Colorado, 93 p.

Atwood, W. W., 1909, Glaciation of the Uintah and Wasatch Mountains: U.S. Geological Survey Professional Paper 61, 96 p.

Bailey, R. G., 1974, Land-capability classification of the Lake Tahoe Basin California-Nevada a guide for planning: Forest Service, U.S. Department of Agriculture in cooperation with the Tahoe Regional Planning Agency, 32 p.

Baker, C. H., Jr., 1970, Water resources of the Heber-Kamas-Park City area north-central Utah: Utah Department of Natural Resources Technical Publication No. 27, 79 p.

Boutwell, J. M., 1912, Geology and ore deposits of the Park City district, Utah: U.S. Geological Survey Professional Paper 77, 231 P.

Boysen, S. M., 1977, Erosion and sediment control in urbanizing areas: National Symposium on Soil Erosion and Sedimentation by Water, Chicago, Illinois, December 12-13, 1977: St. Joseph, Michigan, American Society of Agricultural Engineers, ASAE Publication 4-77, p. 125-136.

Bromfield, C. S., 1968, General geology of the Park City region, Utah: Utah Geological Society Guidebook to the Geology of Utah No. 22, p. 10-29.

Bromfield, C. S., Baker, A. A., and Crittenden, M. D., Jr., 1970, Geologic map of the Heber Quadrangle, Wasatch and Summit Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-864, scale 1:24,000.

Bromfield, C. S., and Crittenden, M. D., Jr., 1971, Geologic map of the Park City East Quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, scale 1:24,000.

Butler, E., and Marsell, R. E., 1972, Developing a state water plan, cloudburst floods in Utah, 1939-1969: U.S. Geological Survey in cooperation with Utah Department of Natural Resources Division of Water Resources, Cooperative Investigations Report No. 2, 103 p.

Costa, J. E., and Baker, V. R., 1981, Surficial geology building with the earth: New York, John Wiley and Sons, 498 p.

Christenson, G. E., 1983, Engineering geology for land-use planning Smithfield, Utah: Utah Geological and Mineral Survey Report of Investigation No. 181, 37 p.

Christenson, G. E., and Deen, R. D., 1983, Engineering geology of the St. George area, Washington County, Utah: Utah Geological and Mineral Survey Special Studies 58, 32 p.

Crittenden, M. D., Jr., 1976, Stratigraphic and structural setting of the Cottonwood area, Utah, in Hill, J. G., ed., Symposium on Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists, p. 363-379.

Crittenden, M. D., Jr., Calkins, F. C., and Sharp, B. J., 1966, Geologic map of the Park City West Quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-535, scale 1:24,000.

Eardley, A. J., 1968, Regional geologic relations of the Park City District: Utah Geological Society Guidebook to the Geology of Utah No. 22, p. 3-9.

Economics Research Associates, 1981, The outlook for growth Park City/Snyderville Basin a market perspective: San Francisco, 57 p.

Erickson, A. J., 1973, Aids for estimating soil properties significant to engineering interpretations, Utah: Salt Lake City, U. S. Department of Agriculture Soil Conservation Service, 23 p.

———1973 (revised 1977), Aids for estimating soil erodibility-"K"value class and soil loss tolerance: Salt Lake City, U. S. Department of Agriculture Soil Conservation Service, 20 p.

Foster, G. R., and Meyer, L. D., 1977, Soil erosion and sedimentation by water - an overview: National Symposium on Soil Erosion and Sedimentation by Water, Chicago, Illinois, December 12-13, 1977: St. Joseph, Michigan, American Society of Agricultural Engineers, ASAE Publication 4-77, p. 1-13.

Gill, H. E., 1982, Geologic and hydrologic evaluation of Mt. Pleasant watershed Sanpete County, Utah: Utah Geological and Mineral Survey Report of Investigaion No. 169, 18 p.

Gough, L. P., and others, 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Griggs, G. B., and Gilchrist, J. A., 1983, Geologic hazards, resources, and environmental planning (2d ed.): Belmont, California, Wadsworth Publishing Company, 502 p.

Hawkes, H. E., and Webb, J.S., 1962, Geochemistry in mineral exploration: New York, Harper and Row, 415 p.

Hunt, C. B., 1972, Geology of soils: San Francisco, W. H. Freeman and Company, 344 p.

Israelson, G. E., and others, 1980, Erosion control during highway construction, manual on principles and practices: Washington D. C., National Research Council, National Cooperative Highway Research Program Report 221, 103 p.

Langer, C. J. and others, 1979, A study of the aftershocks of the October 1, 1972 $M_B = 4.7$, Heber City, Utah, earthquake, in Arabasz, W. J. and others, 1979, Earthquake studies in Utah, 1850 to 1978: University of Utah Seismograph Stations, Department of Geology and Geophysics, 548 p.

Lund, W. R., 1979, Preliminary engineering geologic report to Park City on the proposed Quittin Time development: Utah Geological and Mineral Survey unpublished data, 24 p.

———1981, Engineering geology for land-use planning Perry, Utah: Utah Geological and Mineral Survey Report of Investigation No. 165, 12 p.

Madsen, D. B., and Currey, D. R., 1979, Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah: Quaternary Research, v. 12, p. 254-259.

Mathewson, C. C., 1981, Engineering geology: Columbus, Ohio, Charles E. Merrill Publishing Company, 410 p.

Mears, A. I., 1976, Guidelines and methods for detailed snow avalanche hazard investigations in Colorado: Colorado Geological Survey Bulletin 38, 126 p.

———1979, Colorado snow-avalanche area studies and guidelines for avalanche-hazard planning: Colorado Geological Survey Special Publication 7, 123 p.

National Science Foundation, 1980, A report on flood hazard mitigation: Washington, D. C., 253 p.

O'Leary, D. W., and others, 1976, Lineament, linear, lineation: some proposed new standards for old terms: Geological Society of America Bulletin, v. 87, p. 1463-1469.

Sbar, M., and others, 1972, Tectonics of the intermountain seismic belt, western United States: microearthquakes seismicity and composite fault plane solutions: Geological Society of America Bulletin, v. 83, p. 13-28.

Robinson, G. D., and Spieker, A. M., editors, 1978, "Nature to be commanded..." earth-science maps applied to land and water management: U.S. Geological Survey Professional Paper 950, 95 p.

Roth, R. A., 1983, Factors affecting landslide - susceptibility in San Mateo County, California: Bulletin of the Association of Engineering Geologists, v. 10, no. 4, p. 353-372.

Schroder, J. F., 1971, Landslides of Utah: Utah Geological and Mineral Survey Bulletin 90, 51 p.

Schuster, R. L., and Krizek, R. J., editors, 1978, Landslides analysis and control: National Academy of Sciences Transportation Research Board Special Publication 176, 234 p.

Shelton, D. C., and Prouty, D., 1979, Nature's building codes - geology and construction in Colorado: Colorado Geological Survey Special Publication 12, 72 p.

Stokes, W. L., 1977, Subdivisions of the major physiographic provinces in Utah: Utah Geology, v. 41, no. 3, p. 441-465.

USDA Soil Conservation Service, 1970, Controlling erosion on construction sites: Agriculture Information Bulletin 347, 31 p.

———1976, Universal soil loss equation: Salt Lake City, 29 p.

———1977, Guidelines for soil and water conservation in urbanizing areas on Massachusetts: Amherst, Massachusetts, 292 p.

USDA Soil Conservation Service and others, 1977, Soil survey and interpretations Parleys Park portion of soil survey of Summit Valley Summit County, Utah: Utah Agricultural Experiment Station Bulletin 495, 317 p.

U.S. Department of Housing and Urban Development Federal Insurance Administration, 1976, Flood hazard boundary map, City of Park City, Utah: map no. H-01 and H-03.

U.S. Department of Interior Bureau of Reclamation, 1974, Earth manual (2nd ed.): Washington D. C., U.S. Government Printing Office, 810 p.

University of Utah Seismograph Stations, 1983, Unpublished earthquake epicenter data, 1850 - September 1983: Department of Geology and Geophysics, Salt Lake City, Utah.

Utah Division of Comprehensive Emergency Management, 1981, History of Utah floods, 1847 to 1981: Floodplain Management Status Report.

Wilson, C. L., 1959, Park City mining district: Intermountain Association of Petroleum Geologists Guidebook to the Geology of the Wasatch and Uinta Mountains, Tenth Annual Field Conference, p. 182-188.

Varnes, D. J., 1974, The logic of geological maps, with reference to their interpretation and use for engineering purposes: U.S. Geological Survey Professional Paper 837, 48 p.

———1978, Slope movement types and processes, in Schuster, R. L., and Krizek, R. J., eds., 1978, Landslides analysis and control: National Academy of Sciences Transportation Research Board Special Publication 176, 234 p.

Vermont Geological Survey, 1982, Erosion control-Vermont handbook for soil erosion and sediment control on construction sites: Special Publication No. 3, 115 p.

Wooley, R. R., 1946, Cloudburst floods in Utah, 1850-1938: U.S. Geological Survey Water-Supply Paper 994, 128 p.

APPENDIX

GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	Age estimate of beginning (millions of years ago)
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	1.6
	Tertiary	Pliocene	5.0
		Miocene	22.5
		Oligocene	37.5
		Eocene	53.5
		Paleocene	65
Mesozoic	Cretaceous		135
	Jurassic		190-195
	Triassic		225
Paleozoic	Permian		280
	Pennsylvanian		320
	Mississippian		345
	Devonian		395
	Silurian		430-440
	Ordovician		500
	Cambrian		570
Precambrian			4500

GLOSSARY

Adit: Horizontal or nearly horizontal passage from the surface from which a mine is entered.

Alluvial fan: A cone-shaped deposit of alluvium deposited by a stream where it runs out onto a level plain or meets a slower stream.

Alluvium: A general term for clay, silt, sand, gravel or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water.

Anticline: A fold in rock strata that is convex upward.

Aquifer: Stratum or zone below the surface of the earth capable of producing water as from a well.

Colluvium: Loose, heterogeneous, incoherent mass of soil material and/or rock fragments deposited chiefly by mass-wasting.

Compaction: Instantaneous reduction in pore space by mechanical means.

Compressibility: Time-dependent reduction in pore space as a result of loading.

Dike: Tabular igneous intrusion that cuts across planar bedding or foliation of the surrounding rock.

Eolian: Resulting from the action of wind.

Moraine: Mound, ridge, or other distinct accumulation of unsorted, unstratified glacial material, deposited chiefly by direct action of glacier ice.

Normal fault: A fault, with an angle usually between 45-90 degrees, at which the hanging wall (upper block) has moved downward relative to the footwall (lower block).

Permeability: Capacity of a rock or soil material to transmit a fluid.

Regressive sea: Retreat of the sea from land areas.

Residual soil: Unconsolidated or partly weathered material, presumed to have developed in place (by weathering) from the consolidated rock on which it lies.

Reverse fault: Fault with a dip greater than 45 degrees at which the hanging wall (upper block) appears to have moved upward relative to the footwall (lower block).

Shear strength: The internal resistance of a material to shear stress (movement of one part of the body relative to another part).

Shrink-swell: The capacity of a soil material to increase or decrease in volume with changes in moisture content, generally a function of type and percentage of clay.

Surcharge: Vertical pressure caused by the weight of overlying material, as a result of gravity alone.

Thrust fault: Fault with a dip of 45 degrees or less in which the hanging wall (upper block) appears to have moved upward relative to the footwall (lower block).

Transgressive sea: Spread or encroachment of the sea over land areas.

Tuff: Consolidated pyroclastic (volcanic material explosively ejected from a volcanic vent) deposit of volcanic ash and dust.

Unconformity: Surface of erosion or nondeposition that separates younger from older rocks.

Volcanic breccia: Pyroclastic rock that consists of angular volcanic fragments that are larger than 64 mm in diameter and may or may not have a matrix.

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Information Bulletin; 6 (5), 1974, p. 28.

UTAH GEOLOGICAL AND MINERAL SURVEY

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Salt Lake City, Utah 84108-1280

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