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CONTENTS

Petrographic Analysis of the Sunniland Formation, an Oil-producing Formation in South Florida .... Helen C. Klopp 3

Elaeocarpus Chitaleyi, sp. nov., from the Deccan Intertrappen Beds of India .... E. M. V. Nambudiri and William D. Tidwell 29

Environmental Geology of the Provo-Orem Area .... Robert M. Armstrong 39

Geology of the Fish Springs Mining District, Fish Springs Range, Utah .... Michael E. Oliveira 69

Recent Sedimentation Trends in Utah Lake .... Clair C. Bingham 105

Paleoecology of the Guilmette Formation in Eastern Nevada and Western Utah .... Roger D. Hoggan 141

Publications and Maps of the Geology Department 199

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Environmental Geology of the Provo-Orem Area*

ROBERT M. ARMSTRONG

Department of Geological Sciences, University of Texas, Austin, Texas 78712

ABSTRACT.—An environmental geology study of the Provo-Orem area discovers many serious geologic hazards. The most serious is building on known active fault scarps and in areas subject to frequent flash flooding. Misuse of landslides, talus slopes, and wetlands near Utah Lake is also found to be a serious geologic hazard. Hazards caused by misuse can be decreased by instituting zoning restrictions based on the results of the study and by planning land use in the community to decrease these dangers. Recommendations for solutions to these problems include zoning to prevent additional building on active fault scarps and in areas subject to flash flooding and restricting the land use near Utah Lake to agriculture.

Surficial geology, water systems, flood danger, landslides, the location of branches of the Wasatch fault system, and slope of the land are the most important parameters of the environmental geology of the area. The derivative maps show parameters for individual areas; a study of the maps could help individual landowners or prospective landowners to avoid problems. Examples of California court cases where landowners have successfully won compensation for damage caused by geologic hazards similar to those in this study area are in an appendix. These decisions have held developers and public officials liable for damage caused by geologic hazards ignored during planning and development of the land.

CONTENTS

Text	page
Summary and conclusions	40
Introduction	41
Previous work	42
Derivative maps	42
Acknowledgments	43
Environmental geology of the Utah Lake plain	43
General	43
Conclusions	45
Slope and surficial geology	45
Water systems and man-made features	46
Earthquake danger	48
Environmental geology of the Provo River floodplain and downtown Provo	48
Conclusions	48
Slope and surficial geology	50
Water systems and man-made features	50
Earthquake danger and active processes	52
Pleasant Grove	52
Conclusions	52
Slope and surficial geology	52
Water systems and man-made features	53
Earthquake danger and active processes	54
Orem City and neighboring areas	54
Conclusions	54
Slope and surficial geology	55
Water systems and man-made features	55
Earthquake danger and active processes	56
The Provo and Alpine benches south of the Provo River	56
Conclusions	56
General	57
Slope and surficial geology	57
Water systems and man-made features	58
Earthquake danger and active processes	60
Appendix	66
References cited	67

Text-figures	page
1. Index map	41
2. Index map of discussion areas	44

Plates	page
1. Surficial geology map	in pocket
2. Active processes and fault location map	in pocket

*A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, August 1974. James L. Baer, thesis chairman.

3. Water systems map ......in pocket
4. Slope map ....in pocket
5. Geologic hazards 49
6. Geologic hazards 61
7. Flood hazards 63
8. Flood and fault movement hazards 65
9. Fault movement hazard 66

Table page
1. Relative seriousness of important environmental geologic parameters by discussion area 45

SUMMARY AND CONCLUSIONS

This study shows the need for people in the Provo-Orem area to become more aware of the geologic aspects of their environment. These hazards and their solutions closely resemble those of California. Earthquake danger, primarily from shaking but with a considerable amount of danger from building near faults, is the greatest danger. Flash flooding is also a considerable danger, with liquefaction due to earthquake shaking in the saturated soil near Utah Lake composing the third greatest danger in terms of importance to the area as a whole. Landsliding and slump movement are also important geologic hazards in the area.

Earthquake shaking is a danger for the entire Wasatch Front. California's Uniform Building Code and the Los Angeles city building code are excellent examples of the type of building code that governments in the study area should adopt. There are no sites that are excellent for minimizing damage due to earthquakes; however, some building sites are far better than others. The best building sites are on the Provo level benches, especially the Orem bench. Areas near Utah Lake are water-saturated soils and are in great danger of undergoing liquefaction during an earthquake. The Alpine bench is a less desirable building site because it is on faults which, when they move, will cause a great amount of damage. The least desirable building sites are astride branches of the Wasatch fault system. Many of these branches need to be more precisely located (Pl. 2). Building must be prohibited within twenty feet of any active fault to lessen the danger of damage from possible movement along that fault (Alfors, 1973, p. 38).

Flash floods are the second greatest danger in the study area. Flash flood danger is limited to areas in the bottoms and at the mouths of canyons. Every canyon has some flash flood danger; the larger canyons have the greater danger. Building in these canyons is very dangerous. Zoning boards and land-use planning boards must recognize this danger when deciding whether construction should be authorized in those areas (Pl. 3). They should also remember they are liable for damage caused by inadequate awareness of problems incurred from development of such building sites (Alfors, 1973, p. 106).

Liquefaction is a problem in water-saturated soils such as those that exist near Utah Lake. It prevents large buildings from being placed on clay and silt soils (Pl. 1) where the water table is within 10 feet of the surface at all times (Pl. 3). It is recommended that building of structures larger than frame houses and agricultural buildings be prohibited in this area.

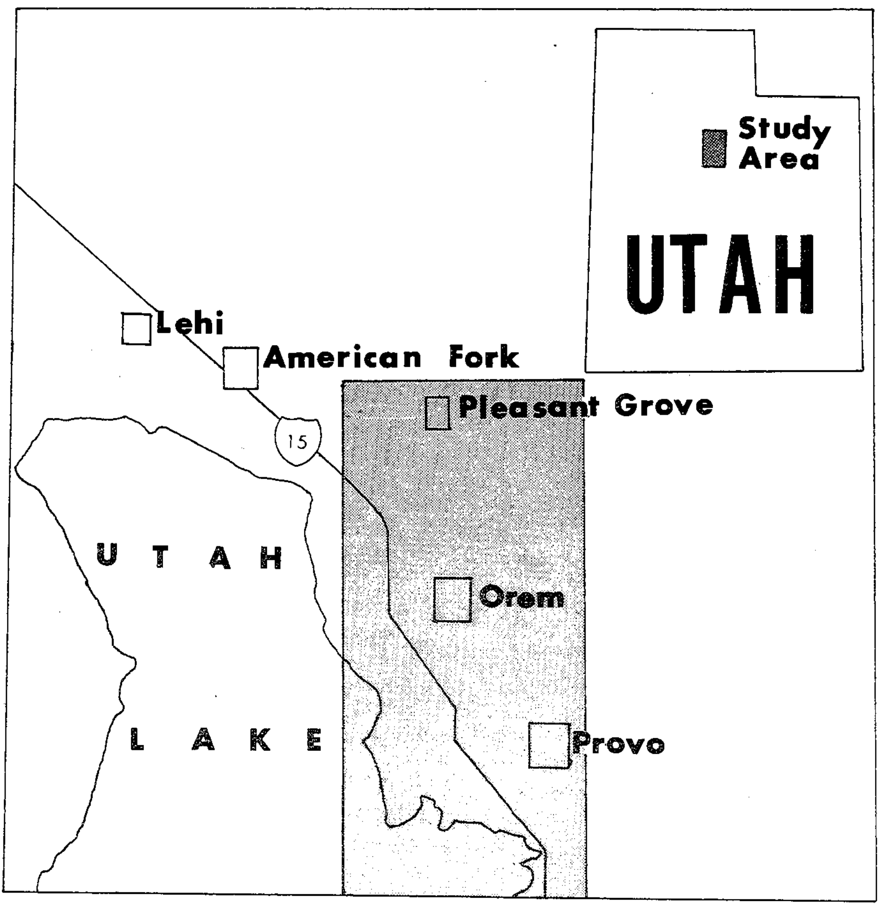
Landsliding is an important geologic hazard (Pl. 2). Building on landslides may reactivate the slides, but with proper engineering practice and grading it is possible to build on them (Alfors, 1973, p. 8).

As water is removed from the water table, subsidence may occur. This is most likely to be a problem in the Utah Lake area, where it may occur as the Provo Bay drains.

INTRODUCTION

This study partially fulfills the need for a study of the environmental geology of the Provo-Orem area and serves as a basis for more detailed studies. The area of the present study includes the Orem Quadrangle and the northern half of the Provo Quadrangle (Text-fig. 1). These quadrangles are located in Utah County, the southernmost county of the Wasatch Front metropolitan area. Utah County is considered a Standard Metropolitan Statistical Area. Provo, the largest city, is approximately 40 miles south of Salt Lake City. The combined population of the Provo-Orem area is over 85,000. The smaller cities of Lindon and Pleasant Grove are also included in the study area.

The towering Wasatch Mountains and the faults along which they moved are the most prominent aspects of the area's geology. Numerous dry washes extend from these mountains into the populated areas at their base. The



TEXT-FIGURE 1.—Index map.

Provo River has cut completely through the mountains. Large areas at the base of the mountains are covered by material deposited along the shores of Lake Bonneville, an ice-age lake which formerly filled most of the valleys of northern Utah. Utah Lake, a remnant of Lake Bonneville, poses water problems for those who live close to it.

Previous Work

While much work has been done on the geology of the area, little has been done on environmental aspects. The Utah Geological Association published the first important work on environmental geology in Utah, *Environmental Geology of the Wasatch Front, 1971*. Articles in this book discuss some regional environmental problems; however, there is still a need to discuss these problems over a smaller geographic area. Flood danger along the Provo River and at the mouths of Slate and Rock canyons was studied by the Army Corps of Engineers (1971, 1972). At the present time Provo City is studying flood hazard identification and zoning. Cluff (1973) used aerial photographs taken in the late afternoon, when sunlight strikes the earth at a low angle, to determine the probable location of branches of the Wasatch fault. Studies concerned with the geology of the Provo-Orem area include Thomas, Hunt, and Varnes (1953); Bissell (1962); and Baker (1964).

Derivative Maps

The basis of the present study is a series of maps which show important features of the geologic environment. They are called derivative maps because the data on them is derived from various sources and put on a map designed to show particular aspects of the environment.

Four such maps are used to show various aspects of the environment in the Provo-Orem area. The first shows surficial geology, the type of material found at the surface of the ground in the study area (Pl. 1). It was created by combining the maps of Lake Bonneville material in Utah Valley (Hunt, 1953; Bissell, 1963) and the Geologic Map of the Orem Quadrangle (Baker, 1964) and removing contacts caused by features other than changes in type of material. Because of the complexity of Lake Bonneville sediments, contacts are not as abrupt as shown on the map. Engineering studies of individual building sites need to be used in addition to the information provided by these maps and the accompanying report.

A map has been made showing active processes and newly discovered branches of the Wasatch fault system in this area (Pl. 2). The primary active processes are landsliding and flooding. Landsliding occurs near the mountains and in the canyons, and flooding occurs along the banks of permanent streams and on deposits of alluvium at the mountain base. The landslides and alluvial deposits are from Baker's (1964) map, while the faults are from a recent study of the Wasatch fault prepared from aerial photographs taken in the late afternoon, when sunlight strikes the earth at a low angle (Cluff, 1973). One measure of an area's flood danger is the Standard Project flood as calculated by the U.S. Army Corps of Engineers (1971, 1972). The area which would be covered by such a flood has been included on the active processes map for the streams for which such information is available.

A map showing water systems and man-made features (Pl. 3) has proven very useful in studying the Provo-Orem area's environmental geology. Water systems are means of removing water from large areas of land and moving it to the sea. In the study area all water systems drain into Utah Lake, which drains into the Great Salt Lake. The major portion of the water system consists of dry washes, which go unnoticed except during spring runoff and after summer rains. Buildings in dry washes are damaged at these times. Because storm sewer systems become overloaded during periods of high runoff, streets in certain sections of Provo City must be considered a man-made component of the water system (Pl. 3). In the lowland area compaction caused by roads has a significant effect on the water table. Roads in this area are shown on the map (Pl. 3). This lowland area is considered to be any place below the 4,500 foot contour, which has been shown on the map (Pl. 3). Levees in the study area are also shown.

Finally a slope map has been made (Pl. 4). This map shows the slope of the land in the study area. Slope has been divided into three categories—less than 5 percent, between 5 and 20 percent, and greater than 20 percent. Land with a slope of less than 5 percent is considered flat, while land with a slope of between 5 and 20 percent is considered to have a gentle slope. Both of these slope types are suitable for building. A slope of greater than 20 percent (Pl. 4) makes building difficult. The land is best kept in its natural state.

A table has been constructed showing the relative danger from important geologic hazards for each discussion area (Table 1). This table can be used as a summary of the geologic hazards in this study area.

It is hoped this study will lead to greater concern for the geologic difficulties encountered when modifying the natural environment for the use of man. The information contained in this study must be used to guide future planning in the Provo-Orem area if this planning is to be an accurate guide to a pleasant future for the residents of Utah Valley.

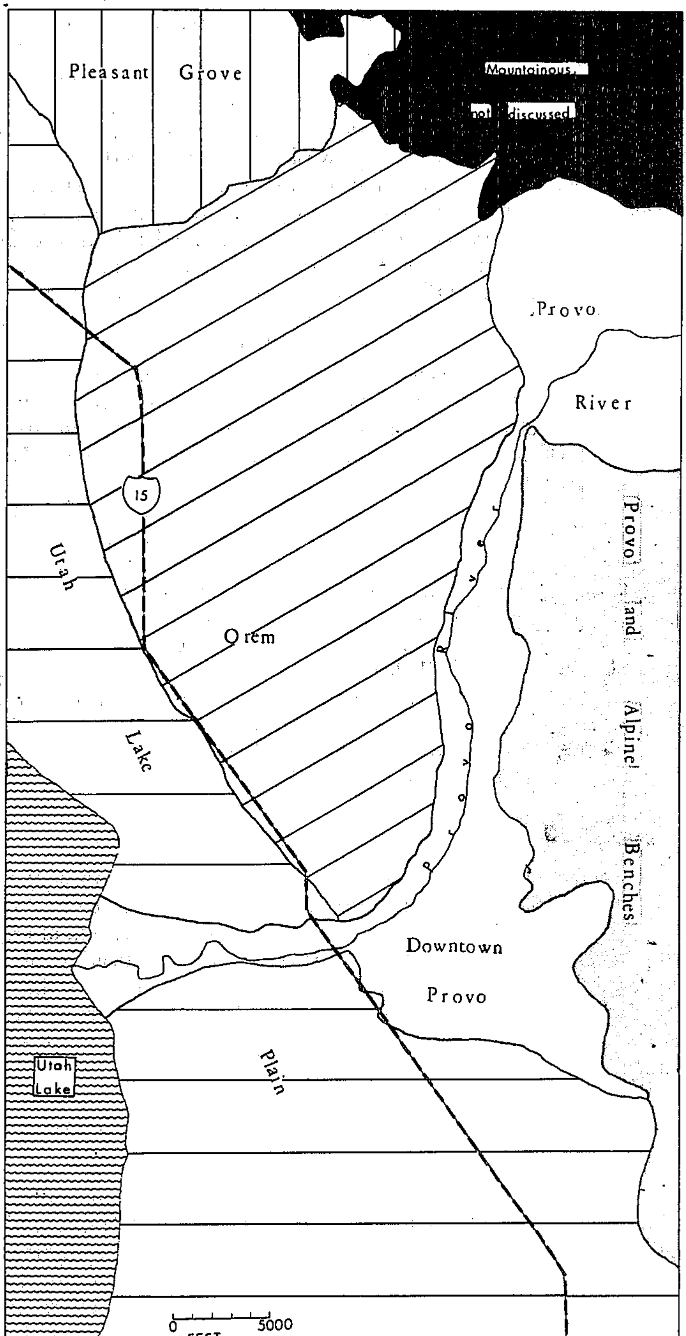
Acknowledgments

The writer wishes to express thanks to Dr. J. L. Baer who suggested the problem, contributed numerous suggestions, and critically reviewed the manuscript; to Dr. L. F. Hintze who also critically reviewed the manuscript; and to Dr. J. K. Rigby who contributed suggestions to the publication preparation of the study. The Orem City Planning Commission must be thanked for contributing a series of air photos of that part of the study area. Also to be thanked is Ren Olsen who did much of the final drafting work on the derivative maps.

ENVIRONMENTAL GEOLOGY OF THE UTAH LAKE PLAIN

General

For purposes of detailed study the study area has been divided into sections exhibiting the same type of environmental features (Text-fig. 2). Such an area is roughly delineated by the 4,550 foot contour on the topographic maps of the area and corresponds fairly well to the area underlain by post-Lake Bonneville Utah Lake clay (Bissell, 1963, p. 122). The western boundary is the shore of Utah Lake. The line separating clay from gravel (Pl. 1) also separates this area from its neighbors.



TEXT-FIGURE 2.—Index map of discussion areas

TABLE 1

RELATIVE SERIOUSNESS OF IMPORTANT ENVIRONMENTAL GEOLOGIC PARAMETERS BY DISCUSSION AREA

Definition of terms

Unimportant—the parameter is not a significant hazard to the area as a whole. Development in this area is not affected by the parameter.

Moderate importance—the parameter is a significant feature of the area's environmental geology and should be considered when developing an area. Development is not totally eliminated by the presence of this hazard.

Great importance—the parameter is a very significant feature of the area's environmental geology and will prohibit development of the area unless that development is undertaken in such a way as to lessen the parameter's impact.

Discussion Area	Flooding	Ground-water Table	Landsliding	Earthquake Danger
Utah Lake Plain	Great Importance	Great Importance	Unimportant	Great Importance
Provo River and Downtown Provo	Moderate Importance	Moderate Importance	Unimportant	Moderate Importance
Pleasant Grove	Moderate Importance	Moderate Importance	Great Importance	Great Importance
Orem Bench	Unimportant	Unimportant	Unimportant	Moderate Importance
Squaw Peak and "Y" Mountain	Great Importance	Unimportant	Great Importance	Great Importance

Conclusions

A high groundwater table is the greatest problem facing the lowlands near Utah Lake. Areas more than 20 feet higher in elevation than Utah Lake face few geologic hazards and from a geologic standpoint are suitable for nearly any use. Areas less than 20 feet higher than Utah Lake level, especially those within 10 feet of being at the same level as the lake, should not be put to uses which would be adversely affected by a high groundwater table. These uses include residential housing and industrial and commercial development. Agriculture is the best use for this land.

Slope and Surficial Geology

All the land in this area has a slope of less than 5 percent (Pl. 4). Clay is the major component of the surficial geology, but the Geneva Steel plant is built on a large deposit of sand. A linear sand feature also runs along state highway 114 to the Provo River (Pl. 1). Small deposits of sand and silt are found north and east of Provo Bay. Silt is found along the channels of

Spring, Hobble, and Big Dry creeks. The Provo River has deposited gravel along its floodplain all the way to Utah Lake (Pl. 1).

Water Systems and Man-made Features

Utah Lake is the dominating aspect of the water system in this area, and man-made features are designed to control it. Few dry washes are noticed, although all permanent streams cross it. The water table is within 10 feet of the surface over much of the Utah Lake plain.

Utah Lake is a remnant of Lake Bonneville. At the present time lake level, although fluctuating, maintains an average elevation of 4,487 feet. It is dammed at the north and at its entrance into the Jordan River. A spillway on the dam is at 4,488 feet. During years of less than normal rainfall, lake level may drop several feet below the official level of 4,488 feet. The basin that contains the lake is fairly shallow. If the lake level drops as much as a foot, hundreds of acres are uncovered. During years of greater than normal rainfall, lake level may increase by several feet, flooding several hundred acres. Plate 2 shows the land that would be covered by Utah Lake if its level were 4,490 feet, an increase of just two feet above the "compromise level."

Several systems of dikes have been built. The most important is the one guarding the Provo City airport. Another runs north from the airport to the mouth of the Provo River and from there some distance further north. A third protects farmland at the southeast corner of the bay. The dikes were built to protect lowland from fluctuations in the water level of Utah Lake and adjoining Provo Bay.

The groundwater table is a very important aspect of the Utah Lake plain's environmental geology. Because all water in the groundwater table in the Utah Lake plain travels towards Utah Lake (Thomas, 1953, p. 80), the height of the groundwater table is dependent upon the height of Utah Lake. This may surprise some people, since in arid regions such as Utah the level of lakes and rivers often has little relationship to the groundwater table. On the east side of Utah Lake precipitation increases toward the Wasatch Mountains. On the west side of the mountains water flows toward Utah Lake. The levels of Utah Lake and the permanent streams in the study area are in part controlled by the height of the groundwater table. The surface of the Provo River intersects the surface of the groundwater table at every point along that portion of the Provo River within the study area. The surface of Utah Lake roughly corresponds to the surface of the groundwater table at the shoreline of the lake.

Since the level of Utah Lake is approximately 4,487 feet above sea level, the depth to the groundwater table for those areas within the 4,490 foot contour line must be less than 3 feet, and for those within the 4,500 foot contour line it must be less than 13 feet. The predominate soil type is a clay, a soil type usually considered relatively impervious. Water drains slowly through such an impervious soil, and the low slope of this area also slows the rate of draining. The combination of low permeability in the soil, low slope, and nearness to a large body of water causes the groundwater table to remain within 10 feet of the surface over a large part of the area.

A permanently high water table restricts land use to buildings which require little or no basement and can tolerate a foundation in permanently saturated soil. The factors mentioned above that cause the water table to remain within 10 feet of the surface have other effects. When extra weight, such as a man-made structure, is placed on a clay soil, compaction occurs. The soil becomes even less permeable than it was before. This aggravates water problems because draining progresses even more slowly than it did previously. For a house or similar structure this problem has minimal effect. However, the problem is greater with roads, dikes, and other long, narrow structures. They all act as dikes, forcing water to drain through different, longer routes. The extent of the problem depends on the amount of compaction, which is dependent on the size of the structure. Minor roads and trails have a minimal effect, while large roads such as Interstate 15 maximize this effect. For instance, the high water table in the area south of Provo City and east of I-15 has created many problems (Pl. 5, fig. 1). The Interstate has caused the groundwater table to increase. In places where it was usually several feet below the surface for most of the year it is now at the surface, causing swamps to form. Much of the land is rendered useless and a loss to investors who purchased the land before the Interstate was built and the water table rose. It may be possible to drain the land by putting conduits under the Interstate at proper intervals.

Other man-made features include the drainage canals that cover the area near Provo Bay. These canals increase the rate at which water drains out of this area and thus make the land useful for agriculture. With the water table decreased, it becomes possible to build homes, barns, and related structures on the lowlands near Provo Bay and to use the land for agriculture, the best use.

All permanent streams must cross the present discussion area on the way to Utah Lake. The Provo River has carried gravel to its mouth. (The entire length of the Provo River through the study area will be discussed in a following section.) Spring Creek, Dry Creek, and Hobble Creek are other permanent streams in the study area, and they will empty into Provo Bay. A distributary of the Spanish Fork River also flows into Provo Bay, though not in the present study area. Spring Creek drains a series of springs occurring along a branch of the Wasatch fault near Springville. Dry Creek drains several springs near the north shore of Provo Bay. Hobble Creek is the fairly large creek whose canyon separates Maple Mountain from Power House Mountain. As they flow over the clay of the Provo Bay lowland all of these streams deposit a layer of silt (Pl. 1). They also bring a large amount of water to Provo Bay, but in the study area they pose no flood danger. To facilitate the use of the Provo Bay lowland, the mouths of these streams have been channelized.

Because the water table is often within 10 feet of the surface, there are many swamps in the lowlands close to Utah Lake. Swamps are places where the groundwater table is so close to the surface that normal plants cannot grow. The water table is often several inches above the land surface. Almost all the swamps are at an elevation that is less than 40 feet higher than that of Utah Lake. The greatest number of swamps and the largest swamps are found within 13 feet of the lake's elevation, that is, within the area between Utah and the 4,500 foot contour line (Pl. 3).

Provo Bay is the largest of these swamps. The bay is connected to Utah Lake, and when lake level is high, the bay tends to take on more of the characteristics of an arm of the lake. A series of sand bars has formed across the mouth of the bay, restricting circulation in and out of it. As mentioned before, three streams flow into the bay. The factors described under the section on the groundwater table in the Utah Lake area and also possible seepage from deeper aquifers (Thomas, 1953) are problems that must be considered in any plan to drain the bay. Draining the bay would increase the amount of useable agricultural land in Utah Valley and decrease the surface area of Utah Lake, according to the directors of the Central Utah Project.

Earthquake Danger

There are no proven faults in this discussion area, although the springs at the head of Dry Creek may be fault controlled. The Geologic Map of Utah (Stokes, 1962) shows faults running through the center of Utah Lake and southwest of Provo Bay. These faults are inferred primarily from geophysical evidence. Earthquake danger due to movement along faults located in the area is slight. There is little danger of an earthquake epicenter being located in this area.

The soil near Utah Lake is subject to liquefaction during a large earthquake. Vibrations created by an earthquake cause the water-saturated, loose material to act as a liquid. The clay cannot support large weights after this occurs. Buildings that are affected by liquefaction include shopping centers, factories, warehouses, and large apartment buildings. Since they would lose much of their support, these buildings would sink. Larger buildings are in greater danger than smaller ones. The danger is greatest on the shores of the lake and decreases inland, with increasing depth to the groundwater table.

ENVIRONMENTAL GEOLOGY OF THE PROVO RIVER FLOODPLAIN AND DOWNTOWN PROVO

Conclusions

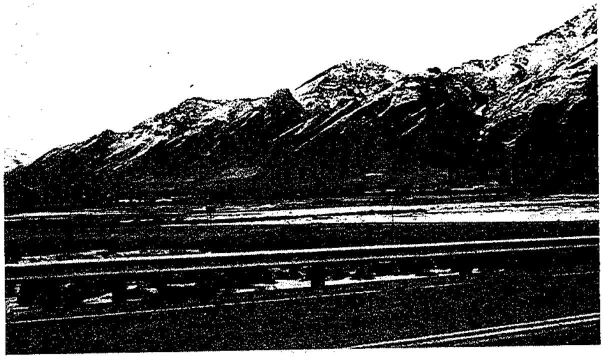
The Provo River floodplain discussion area is located between the Orem discussion area and the Provo and Alpine bench discussion area (Text-fig. 2). The major geologic hazard on the Provo River floodplain is flooding. Snowmelt floods could cause damage during years of especially heavy snowfall. During such years more water runs off the land than can be held by

EXPLANATION OF PLATE 5
GEOLOGIC HAZARDS

Fig. 1.—View looking east from north Springville exit of I-15. Pipe-making plant in the distance. Notice the large area covered by standing water.

Fig. 2.—Houses in a subdivision south of 1600 South in southwest Orem City. The house you see in the lower left has been built on a lot created by removing material from the hill. In case of a heavy rain this material may slump downhill into the house. The weight of the house on top of the hill aggravates the situation.

Fig. 3.—This reservoir along Main Street between 1200 and 1600 South in Orem is used to prevent flash floods which would go down the wash shown in Plate 5, figure 2. Notice conduit in rear used to bring water from a neighboring shopping center parking lot.



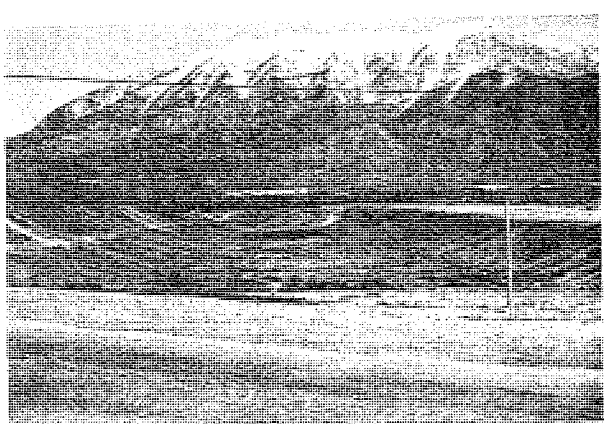


PLATE 5

the Deer Creek Reservoir, and the excess water is allowed to run off and flood the lower part of the Provo River. A greater source of flood water is from the breaking of Deer Creek Dam, which is most probable during an earthquake in the dam area. Damage from earthquake shaking is another danger in this discussion area.

The Deer Creek dam must be checked every year to insure that it is in excellent condition. Local government should also be aware of work being done in California as a result of damage to earth-filled dams during earthquakes in that state. To decrease damage due to earthquake shaking, buildings should be required to conform to the highest possible standards of earthquake-resistant construction, the same standards which are in effect for Los Angeles, California. The Wasatch Front area is located in a class three earthquake danger zone, the same class in which California's San Andreas fault region is located. The same size earthquakes can occur here as in California, and these damaging earthquakes can occur with the same frequency. Earthquake shaking is the greatest danger in downtown Provo.

In some areas groundwater problems may be critical. There may be some danger due to subsidence and differential settling because of the various soil types making up the surficial geology of this area.

Slope and Surficial Geology

The valley of the Provo River is flat with steep-sided walls. Slope, except in small areas, is under 5 percent, increasing to above 20 percent on the side walls (Pl. 4). The valley floor is underlain mostly by gravel.

According to Bissell (1963, p. 121) the gravel underlying downtown Provo was deposited as alluvial fan deposits shortly after Lake Bonneville receded from the area. A valley was eroded through the Provo delta, splitting it in half. Poorly sorted boulder, cobble, and pebble gravel was deposited. Some lenticular bedding exists. While particle size ranges from clay to medium-sized boulders, most are small cobbles. A sand matrix surrounds most of the cobbles. Differential settling problems, caused by building in an area where there is a change in the type and size of foundation materials over a small area, may occur.

Water Systems and Man-made Features

The Provo River is the major water system in this area. Water from the mountains east of the river eventually flows into it. Many small channels exist along the floodplain subparallel to the Provo River (Pl. 3). During heavy rainstorms they can help carry water to the river.

The river bottom gravels have high water tables (Varnes, 1953, p. 50), even though they are fairly permeable. This high water table is expected since the Provo River surface intersects the groundwater table at every point within the study area. Still, great variations occur in the groundwater table level because of the presence of underground channels. It is easier for water to travel through these channels, where effective porosity is higher and pores are interconnected to facilitate the movement of water down slope, than it is for water to travel through the material between the channels, where the pore spaces are not as well connected. These channels act as underground rivers and carry large amounts of water great distances. The water table is higher where they exist, since more water is carried in them than in other areas. Buildings in which the foundations intersect such a channel would find greater problems with water in the basement and would have increased dampness in their basements compared with buildings located outside such channels. These channels must be mapped and investigated.

Silt and clay lenses, both in downtown Provo City and along the Provo River, impede drainage over small areas. They increase in number downstream, another problem affecting future development. In places, some of which may exist in the southeastern section of this discussion area, it can be difficult for groundwater to flow from the area at a rapid rate. While the gravel is quite permeable, the clay on the downslope side is quite impermeable, and water would be backed up because of the slow speed at which it must move through the clay.

A study of the record of wells drilled by Provo City during the spring of 1972 shows a complicated groundwater table pattern. Data was collected by measuring the depth of each well that was above the groundwater table. The wells were only 10 feet deep. If the groundwater table were deeper than 10 feet, the depth to it could not be determined. The presence of mud was also recorded. The wells were read every two weeks for a year, and the above data was recorded. The information is held by the Provo City Engineering Department.

In analyzing this data, it was considered significant if the well had water at least six consecutive months. As expected, the wells near the Provo River had water for much, if not all, of the year. Scattered wells farther from the river had water for the entire year. This high water may be due to impeded drainage. The high water level in these wells is probably caused by buried channels from a dry wash. This data indicates that a more careful study of the water table in south Provo City needs to be made and published.

Irrigation increases the groundwater table in the lowlands. Most irrigation is undertaken on the Provo bench. However, construction on the Alpine bench has led to an increased use of water on this bench. Water used on the benches sinks until it reaches the groundwater table underneath, flowing to the Provo River or directly to Utah Lake. The groundwater table increases during the summer as extra water enters the system. Several wells in the Provo City study are excellent examples of the effect of irrigation on the groundwater table and show a large increase in water during the summer.

Much of the danger of major flooding on the Provo River is prevented by Deer Creek Dam, which is approximately 10 miles from the mouth of Provo Canyon. The maximum level of flooding that should occur has been calculated by the Army Corps of Engineers (1971, 1972). This flood zone has been reproduced on the active processes map with this study (Pl. 2). The greatest flood danger results from damage to the Deer Creek Dam during an earthquake. The Deer Creek Dam is an earth-filled dam resembling the earth-filled dam on the Van Norman Reservoir in California, which nearly failed during the 1971 San Fernando earthquake (Iacopi, 1971, p. 134-4). If an earthquake occurred while the Deer Creek Dam area was saturated with water and the reservoir was nearly full, landsliding into the reservoir could cause water to spill out over the dam, as occurred during the Vaiont landslide in Italy in 1960. Shaking could even cause the dam to fail. In either case a large amount of water would flow down Provo Canyon to its mouth, destroying everything in the canyon and, even after losing much effectiveness due to the width of the Provo River floodplain, destroying most things on the floodplain. The active process map shows the area which would be affected by such a flood (Pl. 2). This area corresponds to the entire floodplain.

The presence of Deer Creek Dam does not completely prevent snowmelt flooding from occurring along the lower reaches of the Provo River. The primary purpose of Deer Creek Reservoir is to provide water for Salt Lake and Utah valleys. The reservoir is allowed to fill during the runoff season to insure an adequate water supply for the populated areas of Utah. Once the reservoir is full, any additional water is allowed to run down the Provo River. An extremely large volume of runoff during a short runoff season would lead to flooding on the Provo River below Deer Creek Dam. This flooding is described by the Army Corps of Engineers (1971, 1972) and shown on the active processes map (Pl. 2) with this report.

Earthquake Danger and Active Processes

The Provo River crosses the Wasatch fault zone at the mouth of Provo Canyon. In the area where the river crosses the fault zone the fault branches are concealed by river gravel. The river gravel may conceal branches of the Wasatch fault which may be active. Since most of the discussion area is well drained, liquefaction is not a major problem.

Earthquake shaking is a major problem for every place in Utah Valley. Building codes must reflect this danger. The California Uniform Building Code and the Los Angeles city building code are examples of codes which do reflect this danger. Damage to Deer Creek Dam and landsliding into its reservoir are also great earthquake dangers in this area, as these could cause a massive flash flood capable of destroying everything on the floodplain.

PLEASANT GROVE

Conclusions

Pleasant Grove is in the northern part of the study area (Text-fig. 2). The greatest problem in this area is a lack of information concerning the precise location of many of the buried branches of the Wasatch fault. The lack of recent movement along these faults is disturbing. Further mapping by field and seismic methods is needed to determine the precise location of these faults. Buildings in Pleasant Grove should be capable of withstanding the largest possible earthquake. The California Uniform Building Code and the Los Angeles city building code are examples of the type of building codes needed in the Pleasant Grove area.

Landsliding, rockfalls, and flash floods along dry washes during heavy rainstorms are other important problems. The flash flood problem (Pl. 3) is the most immediate.

Slope and Surficial Geology

Slope percentage decreases from east to west across the field area (Pl. 4). Slope in the mountains is higher than 20 percent, making it difficult to use this land for any purpose besides recreation. All the consolidated rocks of this area are in that part of the area which has a slope of greater than 20 percent.

All the Alpine bench in the Pleasant Grove area is composed of clay (Pl. 1). This clay forms an area in which the average slope is between 5 and 20 percent, being steeper close to the mountains. Pleasant Grove City is built on Provo stage Lake Bonneville silt. In many places this silt is not present and pre-Lake Bonneville alluvial fan material is exposed. This material is poorly sorted angular boulders, cobbles, and gravel in a sand and silt matrix (Hunt, 1953, p. 14). In places this material has been cemented.

A silt lens exists in the extreme western part of the discussion area. This silt is of the Provo stage of Lake Bonneville and grades into clay-sized particles toward the west.

Water Systems and Man-made Features

Dry washes extending from the mountains are the major aspects of Pleasant Grove's water drainage system (Pl. 3). Those washes have their heads at varying elevations on the face of Mount Timpanogos. Some have cut a considerable distance into the mountain and are longer but have gentler gradient than most dry washes. They have formed large canyons. Small washes on the mountain slope concentrate rain runoff and snowmelt along them and rapidly fill during the spring and during and after heavy rainstorms.

Two major dry washes, Grove Creek and Battle Creek, are the most prominent washes in the Pleasant Grove area. They have cut deep canyons into Mount Timpanogos. During a heavy rainstorm or during the spring they would drain approximately a 10 square mile area. Battle Creek drains an area of approximately 4 square miles, while Grove Creek drains an area of approximately 6 square miles. During times of heavy rainfall there is danger of flash floods sweeping out of these canyons onto the flatland below. The alluvial fans at the canyon mouths stand as evidence of previous floods; there is flood danger for everything built on an alluvial fan. To decrease flood danger, dams have been built at the canyon mouths. Behind the dams depressions have been made to aid in collecting flood waters and prevent them from suddenly moving downstream. These dams must be studied by engineers every spring to make sure they are capable of stopping flood waters.

The smaller dry washes are not as apparent a problem as Battle Creek and Grove Creek, yet they pose a far greater danger since they might easily be ignored during the planning stages of land development. Builders fail to realize that these dry washes concentrate water from several hundred acres of mountainside into a small, but effective, stream. When this stream moves down its channel, it can damage anything in its path. The small series of streams between Battle Creek and Grove Creek and another series of streams in the southeast portion of the discussion area are excellent examples. Building contractors, land purchasers, and land owners should carefully study the stream drainage pattern (Pl. 3) in this area before building.

All these streams end before entering Pleasant Grove City. They always terminate on gravel, either outwash fan gravel from Grove Creek and Battle Creek or pre-Lake Bonneville fan gravel. When water flows down these washes, it sinks into the ground as it flows over the gravel. Soon all the water has entered the groundwater table. This indicates that the gravel is highly permeable. The gravel is subject to the same problems as the gravel underlying downtown Provo City. Buried stream channels give subsurface water favorable paths for movement to Utah Lake. Water flows through these channels, becoming concentrated in them. The groundwater table is higher in them, and the same subsurface water problems can occur in these channels that occur in the Provo River floodplain. In Pleasant Grove cementation of parts of the fan gravel can also affect the groundwater table by decreasing the porosity of the gravel in places where cementation is present. Information about the Provo River floodplain and the locations of buried stream channels and cemented areas needs to be developed.

Earthquake Danger and Active Processes

There is considerable earthquake danger in the eastern part of the discussion area. Several branches of the Wasatch fault system exist in the bedrock of the mountains in the extreme eastern part of the field area (Pl. 2). The contact between the Alpine bench and Paleozoic rock is not along the actual surface of a fault. The fault along which these rocks were uplifted is further to the west, though probably not a great distance. If the fault pattern of the Provo area is an indication of the general location of branches of the Wasatch fault in this part of Utah, there are probably faults to the west of the one previously discussed.

Faults buried by alluvium are particularly dangerous because they have not moved during a period long enough to allow them to be covered. People are unconcerned about movement along them since they cannot be seen. When active faults remain stationary for a long period of time, stress builds up along the faults, increasing the chances and size of the earthquake to be expected. Earthquakes are at least as probable in the Pleasant Grove area as in any other portion of the study area.

Earthquakes can activate new landslides and reactivate old ones, especially if the sliding material is water saturated. There are no known landslides in this area, but the Alpine bench clay could be considered possible landslide material. Building on this material can increase the weight on the head of a potential landslide. Builders often remove the toe of potential landslides in order to produce a large level land area for building foundations (Pl. 5, fig. 2). This could restart landslide movement that could endanger the structure. Development of an area leads to the establishment of lawns and gardens, which are maintained during the summer by watering. This additional water may promote landsliding. The best way to determine the landslide potential of the area is to study the effects of weight, slope, undercutting of the slope, and addition of water on the particular soil types represented in the area. This must be done by geological engineers on a site-by-site basis.

OREM CITY AND NEIGHBORING AREAS

Conclusions

At the present time the basic problem in the Orem City area (Text-fig. 2) is the large amount of construction that is not earthquake resistant, thus failing to meet the type of building code Utah County should adopt. The California State Uniform Building Code and the Los Angeles city building code are examples of the type of building code needed in the Orem City area. The gradual removal or upgrading of buildings failing to meet this building code is necessary to solve this problem.

There are few problems concerning building in dry washes at the present time since there are few buildings in dry washes. This type of development is not desirable. The one subdivision presently building in a dry wash should look elsewhere for new building sites. The city park in Lindon shows an excellent use for a dry wash. The park should be maintained in its present condition.

The Alpine bench area northeast of Orem City is agricultural land at the present time; this is an excellent use for this land because of the lack of precise locations for suspected faults and the presence of a number of small washes which pose a flash flood danger. Until these problems are solved, this land should remain agricultural.

Slope and Surficial Geology

All the land on the Orem bench has a slope of less than 5 percent (Pl. 4). At the edge of the bench the slope increases to between 5 and 10 percent but returns to less than 5 percent for most of the area between the Orem bench and the Utah Lake discussion area. There are few slopes between 5 and 10 percent in this area. Slope increases to between 5 and 10 percent on the Alpine bench and to over 20 percent in the mountains.

The Orem bench surficial geology is mostly gravel (Pl. 1). Thin layers of sand and silt cover the gravel on the east and south edges of the bench (Hunt, 1953, Pl. 1). To the west of the Provo bench the material is mostly sand with some silt lenses. There is a gravel deposit in the north central part of this area. The Alpine bench is covered with post-Lake Bonneville gravel and alluvial fans in many places, but the actual bench material is a clay (Hunt, 1953, Pl. 1). Near Provo Canyon the sand member of the Alpine replaces the clay member.

Water Systems and Man-made Features

Because of the excellent drainage of the bench gravels and the low slope of the bench, there are few dry washes on the Orem bench. There are many small dry washes at the edge of the bench, several of which have cut canyons into the bench. The largest is in the city park in Lindon. The next largest flows through a subdivision south of 1600 South in southwest Orem (Pl. 5, fig. 2). The head of this stream drains at least one shopping center parking lot. During large rainstorms parking lots provide water for flash floods. To decrease the danger for this particular dry wash, a water storage reservoir has been built near its head, the diversion dam being created by fill needed to carry Main Street across the wash (Pl. 5, fig. 3). This dry wash poses the most difficulties of any dry wash in Orem. Problems encountered by owners of property in dry washes are further discussed in the section on problems discovered in the Provo and Alpine bench areas east of Provo City. It is suggested that the reader turn to the water systems discussion for further information on dry washes. Several other dry washes cut the Orem bench, and contractors should not overlook the difficulties faced by the owner of a building located in a small dry wash.

The Orem area has excellent drainage because the sands and gravels are highly porous and permeable and silt layers are not thick enough to affect the height of the groundwater table or hinder the movement of water to it. A series of springs about 35 feet below the surface of the Orem bench indicates the water table is also that depth.

While no major dry washes extend from the mountains in this area, many minor ones create a hazard to construction. At the present time these washes pose no hazard, since no construction has occurred in the northeastern part of Orem (Text-fig. 2). During the spring runoff and after heavy rains, water runs down these canyons carrying clay, sand, and gravel which have been deposited to form a complex series of outwash fans. The shapes of these deposits show it is a fallacy to assume that the only flood danger is in the present stream channel (Pl. 3). Many of these washes currently flow only to one side of their outwash fan. As material is deposited in this channel, the stream will shift and flow across the outwash fan into a different channel. Movement of a stream across its outwash fan must be anticipated before construction. The stream can be channelized to decrease this danger; however, the channel should be sufficient to handle a Standard Project flood as defined by the Army Corps of Engineers (1971, p. 34).

The northeastern part of Orem is well drained. There are no swamps or areas where the groundwater table is within 10 feet of the surface for an extended period of time. On outwash fans stream channel gravels provide an excellent route for water flowing from the mountains. This problem is analogous to one mentioned under the drainage topic for the Provo River floodplain.

Earthquake Danger and Active Processes

Known branches of the Wasatch fault are restricted to the northeastern section of the discussion area (Pl. 2), though faults could occur anywhere in the discussion area. As in the Pleasant Grove area there is a high probability of faults covered with alluvium to the west of those presently known or suspected. Apparent inactivity along these faults is deceiving, the danger of a large, destructive earthquake along concealed faults being as great as along any other faults in this area. The Geologic Map of Utah (Stokes, 1962) shows a fault under Orem City, the presence of which is verified by seismic records. Whether or not this fault is active is unknown at this time.

Except for solid rock, well-drained gravel offers the best building sites to be found in Utah Valley from the standpoint of decreased danger of damage from earthquake shaking. The large expanse of the Orem bench offers a large number of building lots with as little danger of damage from earthquake shaking as can be found in Utah Valley. Construction must be carried out in accordance with the building standards for a class three earthquake risk zone to insure the least damage. The California State Uniform Building Code and the Los Angeles city building code are good examples of such standards. The greatest source of earthquake danger on the Orem bench is from large amplitude surface waves. An earthquake building code requiring buildings to be constructed to withstand the effects of such waves is a necessity for Utah County. Buildings over 20 floors in height should not be built in Utah County.

THE PROVO AND ALPINE BENCHES SOUTH OF THE PROVO RIVER

Conclusions

Most of the presently existing geologic hazards of the study area are discussed here. The area is overdeveloped; all adequate building sites have been used as well as many inadequate ones. Should a large earthquake occur along a fault in this area, damage would be in the millions of dollars, mostly due to fault movement and extreme shaking because of the close proximity to the epicenter. An extremely large cloudburst would give similar results—damage in the millions of dollars. Both in monetary terms and in terms of human needs society has the right to restrict and prohibit further building in many of these areas until studies of the flood and earthquake problems can be completed. Building, where allowed, should be in compliance with a building code at least as strict as the California State Uniform Building Code and the Los Angeles ctiy building code. It should include provisions for buildings to withstand accelerations of as much as the force of gravity (1g). Accelerations of this magnitude were measured during the 1971 San Fernando Valley earthquake. Building within 20 feet on either side of a known active fault must be prohibited to decrease damage due to fault movement. Building in the bottoms of canyons must be restricted to prevent damage caused by flash flooding.

As an investment, land in this part of the study area is presently very attractive. After an Intermediate Regional or Standard Project flood or a Richter magnitude 8 earthquake, however, land in many portions of this discussion area will be worth much less. A study of the features described in this discussion area should be made to prevent a repetition of these mistakes in other parts of Utah.

General

This area is at the base of Y Mountain and Squaw Peak Mountain (Text-fig. 2). Most of this land is on the Alpine bench, although some is on the Provo bench. The area is heavily developed, mainly by Brigham Young University campus, Provo LDS Temple, and several subdivisions which are located in it. Most of the geologic hazards in the study area are located in this discussion area.

Slope and Surficial Geology

That part of the Provo bench east of the Provo River floodplain is included in this discussion area. The western portion of the Provo bench in this area is gravel, while the eastern is sand (Hunt, 1953, Pl. 1). Slope along the bank separating the Provo bench from the Provo River valley is greater than 20 percent except where dry washes have cut through it (Pl. 4).

The Alpine bench has a complex slope pattern (Pl. 4). The foothills in this area are composed of sand and gravel, Alpine bench sand composing the major part of the Alpine bench geology. The Alpine bench is dissected by channels cut while Lake Bonneville was at the Provo level. The Alpine sand seems to be able to stand at a slope greater than 20 percent, but Varnes (1953, p. 50) indicates the sand has very little dry strength and is not stable in high angle cuts. Another area of fairly high slopes separates the Alpine level sand from the Bonneville level gravel. The top of these gravel layers is flat; however, it is necessary to travel up an extremely steep slope to get to them. To the east of these benches is the solid rock composing the mountains.

Building is now being undertaken on the Manning Canyon shale, a fine-grained clay found north of Little Rock Canyon (Pl. 1). It forms the canyon floors of most of the dry wash tributaries of the Provo River in Provo Canyon. Since much of the clay of the Utah Lake plain comes from the Manning Canyon shale, the physical properties of the shale are similar to those of Utah Lake clay. When exposed to water, the shale turns to a fine-grained clay which tends to slump downhill. The wide point in the Provo Canyon highway just below Deer Creek Dam has resulted from the clay's slumping downhill on the Manning Canyon shale. Slumping is an effect that must be carefully considered as weight is added to the shale, especially when the effects of the extra water used after development are considered. The effects of poor drainage of a clay soil also should be considered before building in this area.

Southeast of the main Brigham Young University campus there is a large deposit of outwash fan gravel. The area northeast of the State Mental Hospital is clay. Layers of gravel, sand, and landslide material are also found in this area. The area southeast of the University and west of the State Mental Hospital has a slope of less than 5 percent (Pl. 4). Most of the rest of this land has a slope greater than 20 percent.

Water Systems and Man-made Features

The dominating features of the water system in this discussion area are the numerous dry washes that extend from the mountains to the east (Pl. 3). Rock Canyon is the largest dry wash in this discussion area. A diversion dam has been built near the mouth of the canyon to prevent flooding of the subdivisions to the west by flash floods sweeping down the canyon. The Army Corps of Engineers report states, "The magnitude of floodflows would not be significantly reduced by the debris dam at the canyon mouth" (Army Corps of Engineers, 1971, p. 19). To retain flood waters on the higher slopes and to prevent the rapid runoff of rainwater, a series of retaining ditches has been built on the mountain slope at the source of the Rock Canyon stream. A small, man-made ditch runs west from the diversion dam for several thousand feet before entering an underground conduit. The ditch is designed to carry water from the dam at a fairly slow rate after a flood has reached the dam. Neither dam, ditch, nor retaining devices are adequate for a Standard Project flood. The Corps of Engineers report (1971) describes the area shown on the active processes map (Pl. 2), which would be affected by such a flood.

The dam is a considerable distance from the mouth of the canyon, so a relatively small change in stream direction at the mouth would allow flood waters to bypass the dam and flow into populated areas. Among the buildings facing a danger from a change in the direction of the Rock Canyon flood stream is the Provo LDS Temple. The probability of such an event is quite high, as several small channels already exist to take water out of Rock Canyon while missing the dam. The dam could be enlarged until it covers the entire group of discharge channels, a new dam could be built further up the canyon, or channeling could be undertaken to insure that any flood waters flow into the present dam areas. A large channeling project would probably be the best flood danger protection measure.

Slate Canyon is the southernmost canyon in the study area. It drains more than six square miles of mountainous terrain and has at its mouth a large alluvial fan. The debris basins and deflection dikes at the mouth of this canyon provide protection only against minor flooding (Army Corps of Engineers, 1972, p. 11). Flash flood waters pose a danger in this area because construction increases near the mouth of the canyon. Flood waters at the mouth have a velocity great enough to cause considerable damage to buildings. Debris, sometimes several feet in depth, is deposited over a large extent of the fan. The Army Corps of Engineers study (1972) and the active processes map (Pl. 2) show the areas that would be flooded by a Standard Project flood in the Slate Canyon area.

Little Rock Canyon is the largest canyon between Rock Canyon and Provo Canyon. The canyon has a drainage area of approximately one square mile in the mountains, but it drains a considerable part of the Alpine bench. Unless building occurs in the canyon bottom, there is no flood danger. Unfortunately such building is presently being undertaken. A road has been built across Little Rock Canyon and then along the creek bed to the sharp change in slope at the mountain base (Pl. 7, fig. 1). A storm drainage system placed under this highway is not adequate to remove more than a small amount of runoff in case of a Standard Project flood. Houses built along this road near the mouth of the canyon would be in great danger from a Standard Project flood because water coming from the canyon would be concentrated into a narrow stream as it hit them. This would severely damage or destroy the houses and possibly kill or injure the occupants. This stream could destroy the road and remove the fill put in the canyon, thus destroying homes built on the fill.

Building has occurred in a dry wash directly south of Little Rock Canyon (Pl. 7, fig. 2). A Standard Project flood in this canyon would have the same result as one in Little Rock Canyon. The area where the houses are located would be removed by the flood waters and the houses destroyed. Disrupting the drainage system has the additional effect of diverting large amounts of water beyond what would normally be received into streets and storm sewers in other areas of the city, overloading them and, in case of a heavy rainstorm, causing floods. This effect is more common than destruction due to major flooding since an extremely heavy rainstorm is not needed. New construction in a subdivision can affect the danger of minor flooding in older parts of a city.

Numerous dry washes of various sizes cross the study area (Pl. 3; Pl. 6, fig. 2). One of the largest is located in the south end of the subdivision just north of Rock Canyon (Pl. 3; Pl. 7, fig 3). In this area streets must be considered a part of the drainage system since during cloudbursts storm sewer systems become overloaded. Sometimes basements in the bottom of dry washes are flooded. Flooding is also a danger when water can run down a driveway into a garage. A study of the effects of an Intermediate Regional or Standard Project flood has not been made in this area. Floods of either type would probably damage or destroy the buildings in the bottom of the canyon. A debris dam may be built further up this dry wash to control such floods.

Another area of flood danger is a canyon in the Edgemont area (Pl. 3; Pl. 8, fig. 1). As in the Little Rock Canyon area, during an Intermediate Regional or Standard Project flood water would be concentrated into a narrow stream that would destroy the houses. The position of the houses in the canyon is serious: they are directly in the path that water must take when passing down the valley. Every cloudburst can result in water problems because the only way for water to flow through this canyon is to flow through basements and backyards. This is an excellent example of the worst way to develop a canyon.

There are several large dry washes and numerous small ones that are only potential geologic hazards. Construction has not yet taken place in them. After construction is undertaken, these washes will present hazards similar to those discussed above.

Earthquake Danger and Active Processes

Most active processes in this discussion area are affected by the presence of branches of the active Wasatch fault. The danger of an earthquake triggering old landslides and creating new ones must always be considered as must the possibility of material falling from the cliffs at the peak of Y Mountain (Pl. 2; Pl. 6, fig. 2). Earthquake shaking can loosen this material and cause a large amount to fall from the mountain tops in a short period of time. Much material rolls from the top of the mountain down small washes and can be seen as large blocks of rounded limestone. Buildings at the bottom of these washes face a danger of damage from material rolling down upon them. This material can roll down anywhere; thus a zone several hundred feet wide on the Alpine bench under Y Mountain should not be developed.

An apartment complex on the Alpine bench north of Slide Canyon is an example of a structure built among numerous geologic hazards (Pl. 6, fig. 2). The building is situated on top of a presently inactive landslide. Several house sites have been created by removing material from the bottom of the landslide. The combination of putting weight on the top of a landslide and removing material from the bottom of it can easily reactivate the landslide, causing considerable damage. This building is surrounded by branches of the Wasatch fault which have moved approximately 25 feet since the end of Lake Bonneville time, approximately eleven thousand years ago. Movement along these faults might result in reactivating the landslide. It is believed the lower fault may pass through the corner of the building. If there is an earthquake along the fault, considerable damage might be done by fault movement. There is a good chance that this particular landslide would be reactivated by any large earthquake in the valley. It might even become active without the occurrence of an earthquake.

EXPLANATION OF PLATE 6
GEOLOGIC HAZARDS

Fig. 1.—A canyon near Slide Canyon from the corner of 700 North and 1200 East. During an Intermediate Regional or Standard Project flood buildings in the mouth of the canyon would be destroyed or severely damaged.

Fig. 2.—Notice the dry washes in the middle portion of the picture. Material rolls down the washes and can destroy buildings at the bottom. During an Intermediate Regional or Standard Project flood these dry washes can create major flood problems. Notice the faults in the lower portion of the picture. They surround the large building in the lower center. This building is on a landslide.

Fig. 3.—House built astride the Wasatch fault in the subdivision directly south of Rock Canyon on the Alpine bench. Movement along this fault would split houses in this area apart.

Fig. 3

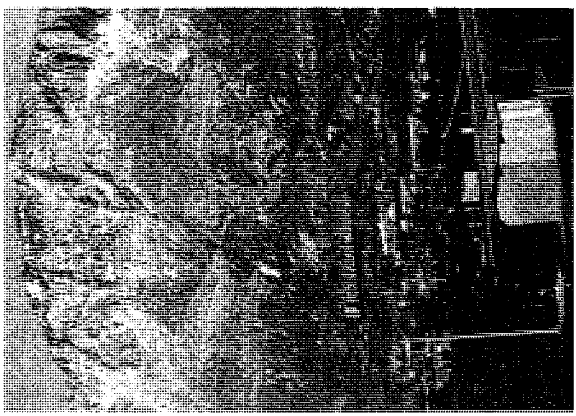


Fig. 2

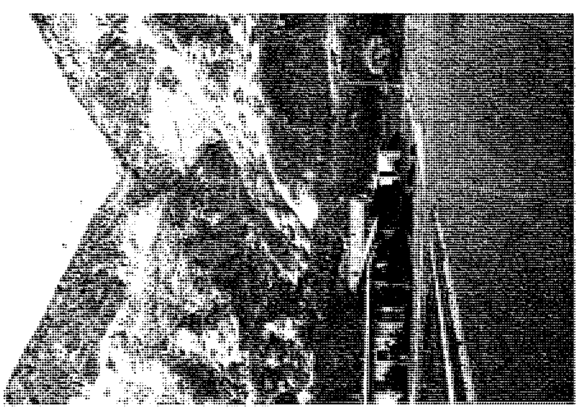


Fig. 1

PLATE 6

The entire area from the southernmost subdivision on the Alpine bench to Slide Canyon must be treated as landslide material or potential landslide material (Pl. 2). Much of the material is talus, loose material that has fallen from the peak of Y Mountain. More of this material will be derived from the same source, material that can damage structures built at the base of Y Mountain. A zone within 200 feet of the base of Y Mountain should be avoided when developing this area because of the danger posed by falling rocks. Builders should be very careful when building in this area to avoid starting new landslides or reactivating old ones.

Another area of potential landsliding is on the Manning Canyon shale north of Little Rock Canyon. This shale has been discussed previously. To prevent landsliding, it is necessary to prevent the shale from becoming permanently saturated. An excellent subsurface drainage system is necessary, in addition to natural drainage created by the shale's elevation in relation to the groundwater table. If only the natural drainage is used, water may not be able to drain away fast enough to prevent lubricating the clay. Movement would be a very slow creep instead of a landslide. Over a period of several years cracks in roads and buildings would become noticeable. If the clay contains the mineral montmorillonite in considerable quantity, it will expand when wet, creating additional problems.

Earthquake danger in this area is obvious yet still overlooked. Three faults run through the subdivision just south of Rock Canyon (Pl. 2), each with a scarp ranging from only a few feet to more than 30 feet (Pl. 8, figs. 2, 3). While there is an excellent view of Utah Valley from the top of these fault scarps, there is also considerable danger. If an earthquake occurs along a fault upon which construction has occurred, damage caused by acceleration of the ground will increase due to nearness to the fault. The weight of buildings on the top of these escarpments might cause landsliding along the fault during an earthquake. Foundations can be destroyed by fault movement. Some houses are built astride the fault (Pl. 6, fig. 3). Creep along these faults can tear these houses apart—an important consideration since a possible method of preventing a disastrous earthquake is to induce creep along a fault to dissipate the energy stored along it. The existence of these houses makes measuring strain and tilt easier, since it is necessary only to measure the strain and tilt of the structure. To prevent damage from fault movement in California it has

EXPLANATION OF PLATE 7
FLOOD HAZARDS

Fig. 1.—Road in bottom of Little Rock Canyon. An Intermediate Regional or Standard Project flood would damage or destroy buildings along this road. Such a flood might remove the road and reopen the canyon.

Fig. 2.—House in the first canyon south of Little Rock Canyon. During an Intermediate Regional or Standard Project flood this house would be damaged.

Fig. 3.—These houses are in the largest dry wash in the subdivision just north of Rock Canyon. They would be destroyed or damaged during an Intermediate Regional or Standard Project flood unless debris basins and deflection dams large enough to prevent the waters of these floods from moving down the canyon are built farther up the canyon.

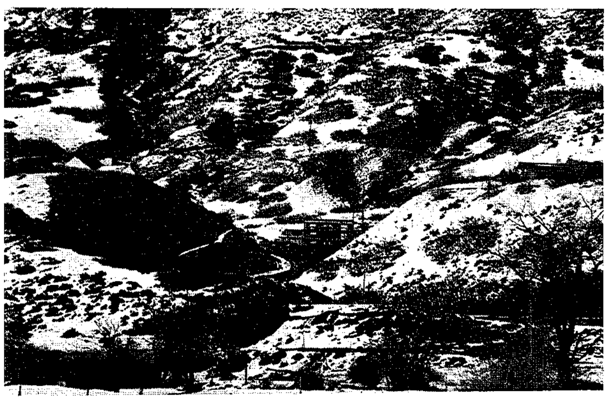


PLATE 7

been recommended that building should be prohibited in a zone within 20 feet of an active fault trace (Alfors, 1973, p. 38). In Los Angeles no building may be done on an active fault trace (Alfors, 1973, p. 38).

Fault scarps in the area south of Rock Canyon are excellent paths for roads, pipelines, and electric lines (Pl. 9, fig. 1). When natural gas, electric, and water lines are run across branches of the Wasatch fault, special care must be taken to prevent damage by fault movement. Flexible joints and pipe capable of withstanding up to 20 feet of displacement should be used on any pipe crossing a known fault trace and valves put on the pipeline to shut the flow of material if the pipeline is ruptured. Fault scarps make excellent road sites. When road construction takes place along a fault scarp, it becomes difficult to determine if it is a fault scarp since the process of creating a road cut can create a straight line resembling a fault scarp on aerial photographs. This increases the danger posed by a suspected fault since the fault may not be recognized until movement occurs along it.

This area contains concealed faults, faults along which movement has not taken place for a period of time long enough to allow erosion to remove or deposition to cover most of the evidence of movement. The dangers of concealed faults are discussed in the Pleasant Grove section of this paper. Many of these faults are mapped by Cluff (1973). An extremely long fault may extend from Caryhurst to Wymount Terrace, passing through several subdivisions. Since movement has not occurred along this fault for a long period of time, there is the chance of sudden movement, such as that which occurred during the San Fernando, California, earthquake of 9 February 1971. The length of this fault indicates it may be one of the more important faults in the Wasatch fault system, certainly worthy of further study with strain and tilt measuring equipment as well as seismic devices to verify its existence.

Many people believe there is little danger of an earthquake occurring in Utah Valley. Only two major earthquakes have occurred in Utah since the pioneers entered it, each with a magnitude of 4.3 on the Richter Scale (Cook, 1972, p. H23-26). No large, destructive earthquake has occurred in Utah Valley since its settlement by the white man. However there has been at least one large earthquake in the Provo area within the last several hundred years. Were an earthquake of the same magnitude to occur today, great damage would result and many lives would be lost. The lack of earthquakes of any measurable magnitude is not a sign of an end to movement along this part of the Wasatch fault system. The system is very active in places both north and

EXPLANATION OF PLATE 8
FLOOD AND FAULT MOVEMENT HAZARDS

Fig. 1.—A series of homes along a canyon bottom in a subdivision in Edgemont. These homes will be destroyed during an Intermediate Regional or Standard Project flood unless debris basins and deflection dams are built farther up the canyon.

Fig. 2.—Houses built along active fault traces in the subdivision directly south of Rock Canyon on the Alpine bench.

Fig. 3.—Houses built along an escarpment caused by movement along a fault in the subdivision directly south of Rock Canyon on the Alpine bench. Damage from earthquake shaking from an earthquake along this fault would be considerable.

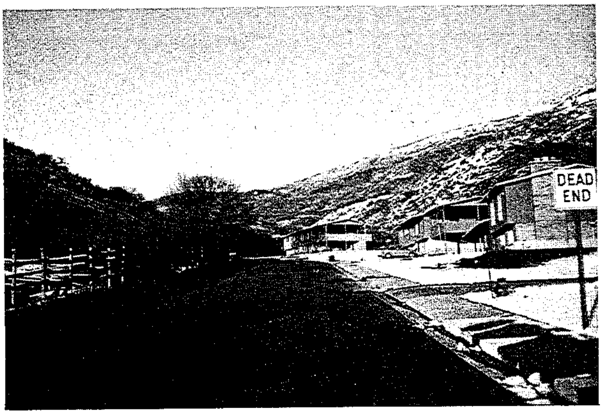


PLATE 8

EXPLANATION OF PLATE 9
FAULT MOVEMENT HAZARD

Fig. 1.—Natural gas transmission line along an active fault trace south of Rock Canyon. This is dangerous because it greatly increases the danger of pipeline damage during an earthquake caused by movement along this fault.

south of Utah County. It can be assumed stress is building in this sector. This stress will be released by a major earthquake, such as the one that occurred several hundred years ago. Because this earthquake can happen at any time, it is necessary to develop an earthquake prediction program for Utah County.

APPENDIX

Summary of Significant Court Decisions from Courts in the State of California Pertaining to Environmental Geology (Alfors, Burnett, and Gay, 1973, p. 106)

In recent years there have been many attempts by government to reduce losses from geologic hazards. The following summaries are some of the more important ones.

1. Sheffet decision (Los Angeles Superior Court Case No. 32487): Declared that a public entity is liable for damages to adjacent property resulting from improvements planned, specified, or authorized by the public entity in the exercise of its governmental power. (The State Supreme Court refused to rehear this decision, which establishes a judicial precedent.)
2. L. A. County Superior Court (Case No. 684595 and consolidated cases): This decision found the county liable for damages which may have resulted from roadwork and placement of fill by the county. This case concerned the Portuguese Bend Landslide, Palos Verdes Hills, Los Angeles County, California.
3. City of Bakersfield vs. Miller (48 Cal. Rptr. 889), heard in the State Supreme Court 1966: This decision affirms that the city may declare an older structure to be a public nuisance if it is not in compliance with the newly adopted Uniform Building Code. Further, the city may enforce

abatement of the nonconforming condition even though to do so may require the demolition of the building.

4. Burgess vs. Conejo Valley Development Co. (Connor vs. Great Western Savings and Loan Association) (73 Cal. Rptr. 369) heard in the State Supreme Court in 1968, concerning damage to tract homes from expansive soil in Thousand Oaks, Ventura County: This decision affirmed that the home buyer, both first buyer and all subsequent ones, has the right to protection from negligent construction practice leading to damage. In this case neither contractor, county inspectors, nor representatives of the major lending institution acted to ascertain expansive soil conditions or to prevent damage from them.
5. Oakes vs. the McCarthy Co. (California Appellate Reports, 2d Series, 267, 1968) the court held that in the Palos Verdes area, Los Angeles County, a developer and soils engineering company could be liable for negligence for damages to a home resulting from using improper (clay) fill material and improperly compacting that fill so that earth movement resulted. Also, the court awarded punitive damages against the developer for fraudulent concealment of material facts concerning the property, i.e., failure to volunteer to the prospective buyer that the house was built upon fill.

REFERENCES CITED

Alfors, J. T., Burnett, J. L., and Gay, T. E., 1973, Urban geology: master plan for California: Calif. Div. Mines and Geol., Sacramento, Calif., p. 112

Army Corps of Engineers, 1971, Flood plain information Provo River and Rock Canyon Creek, Provo-Orem, Utah: Dept. of the Army, Sacramento, Calif., p. 34.

———, 1972, Flood plain information, Provo River and Slate Canyon Creek, Provo, Utah: Dept. of the Army, Sacramento, Calif. p. 34.

Baker, A. A., 1964, Geology of the Orem quadrangle, Utah: U.S. Geol. Surv. Map G Q 241.

Bissell, H. J., 1963, Lake Bonneville: geology of southern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257-B, p. 101-30.

Cluff, L. S., Brogan, G. E., and Glass, C. E., 1973, Wasatch Front, southern portion earthquake fault investigation and evaluation, a guide to land-use planning: Woodward, Lundgren, and Associates, Oakland, Calif. p. 103.

Cook, K. L., 1972, Earthquakes along the Wasatch Front, Utah—the record and the outlook: *in* Environmental Geology of the Wasatch Front, 1971: Utah Geol. Assoc. Put. no. 1, p. H1-H29.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257-A, p. 1-99.

Iacopi, Robert, 1971, Earthquake country: how, why, and where earthquakes strike in California: Lane Books, Menlo Park, Calif. p. 160.

Stokes, W. L., 1962, Geologic Map of Utah, Northwest Quarter: Utah Geol. and Mineral Survey, Univ. Utah, Salt Lake City.