COLLAPSIBLE SOIL HAZARD MAP FOR THE SOUTHERN WASATCH FRONT, UTAH

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ACKNOWLEDGEMENTS

This project was sponsored by the Utah Geological and Mineral Survey and appreciation is expressed for their financial support. Special thanks is given to Robert M. Robison, Utah County Geologist, for the use of his maps and timely advice. Rollins, Brown, and Gunnell Inc. provided much of the preliminary data and their support is greatly appreciated. Dr. Loren R. Anderson, Professor of Engineering at Utah State University and Dr. James L. Baer, Professor of Geology at Brigham Young University reviewed the report and provided valuable insights and suggestions.

INTRODUCTION

GENERAL

Collapsible soils are relatively dry, low density soils which undergo a decrease in volume when they become wet for the first time since deposition. This decrease in volume normally occurs without any increase in applied pressure. Collapsible soils are found throughout the world, particularly in semi-arid and arid environments. They are generally associated with dry loess or eolian deposits, alluvial fan deposits including mudflows and debris flows, or with unconsolidated, colluvium deposits. Collapsible soils in Utah are generally associated with alluvial fan deposits.

PURPOSE AND SCOPE OF STUDY

Soil collapse is usually associated with human activities such as irrigation, construction of canals, or disposal of waste water that introduce water into a relatively dry environment. Although soil collapse is generally not life threatening, it can cause severe damage to canals, dams, pipelines, roads, buildings, fields, etc. (Prokopovich, 1984).

Collapsible soils have been studied in several places in Utah including Cedar City by Kaliser (1977) and in Nephi by Christenson (1982). Pleasant Grove, Lindon, and Provo have all experienced problems due to collapsible soils as evidenced by numerous studies conducted by local geotechnical firms (Photos 1-2, Figure 1). Generally, these problem areas have been associated with alluvial fan deposits.

Alluvial fan deposits are formed where streams emerge from adjacent highlands and deposit their sediment load at the mouth of stream channels. Deposition is the result of a decrease in gradient and a decrease in the water depth (Bull, 1964). Thick alluvial fan deposits are often associated with normal faulting where highlands are created providing a consistent source of material that is deposited in the foothills below. The Wasatch Front is such a region, consequently there are numerous alluvial fan deposits.

The purpose of this study is to provide a collapsible soil hazard map along the southern Wasatch Front from the "Point of the Mountain" on the north to the city of Nephi on the south (see Figure 2). This map delinates the alluvial fans along the "Front" and ranks them according to their potential of containing collapsible soil. Additional areas found to contain collapsible soil, that are not associated with alluvial fans, are also included.

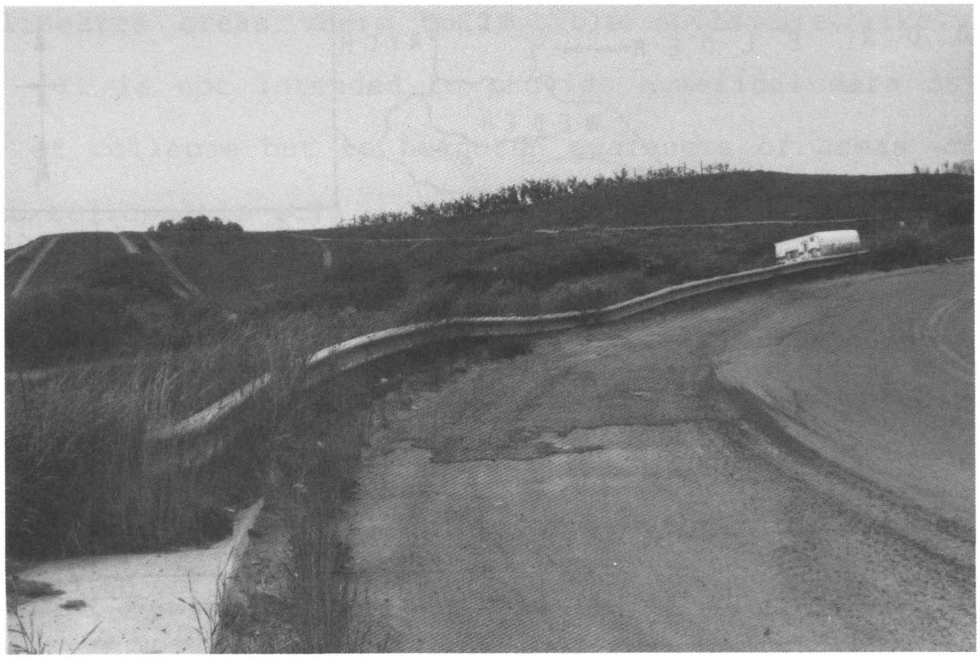


Photo 1, Bent guard-rail due to soil collapse.

Photo 2, Road damage due to collapsible soil.

FIGURE 1

(RLO & KMR-4)

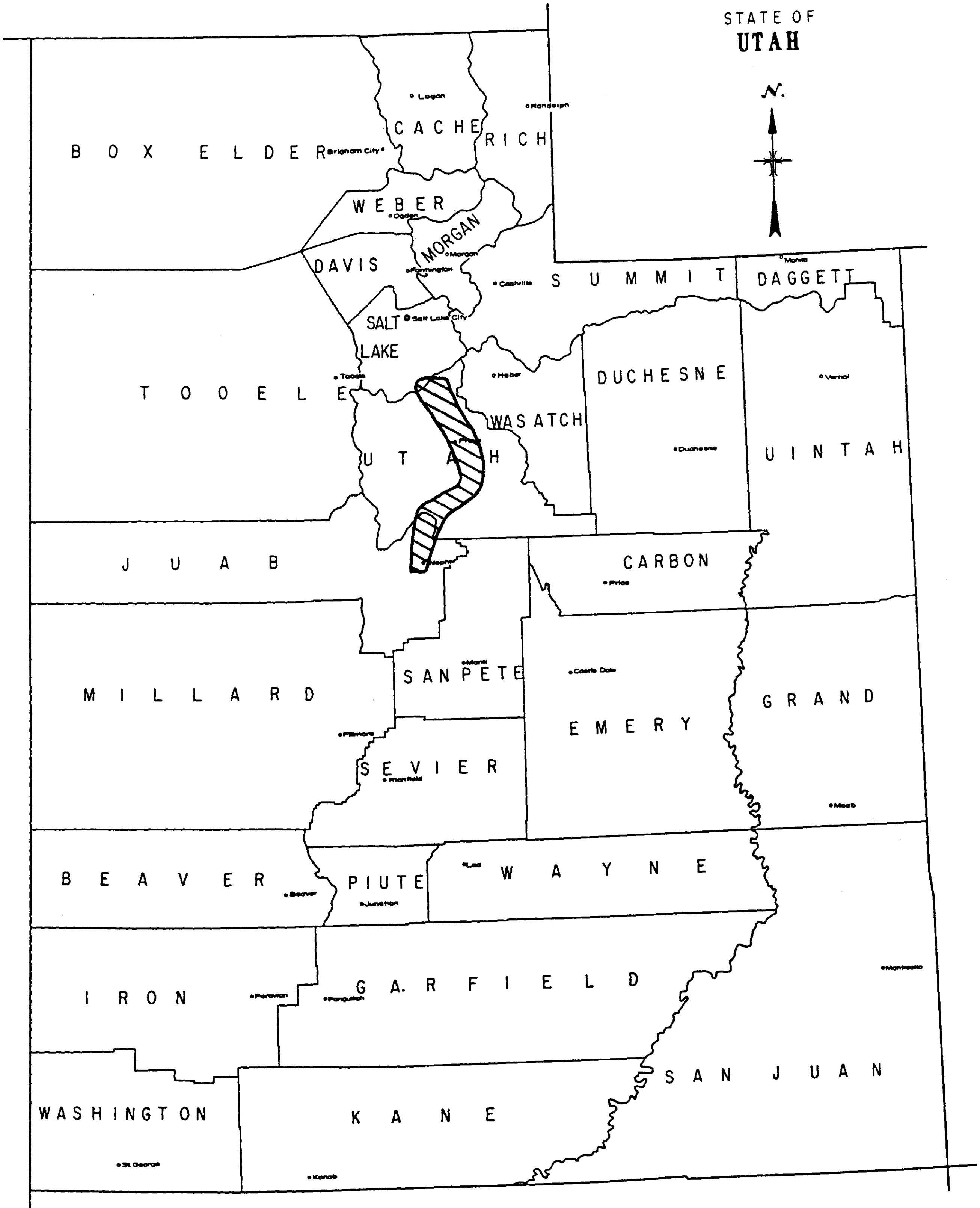


FIGURE 2 - AREA OF STUDY

A collapsible soil hazard map is beneficial to the state in that it delineates areas where collapsible soils are likely to be found. It is not intended to provide numerical data as to the degree of collapse but to heighten awareness of areas which may contain collapsible soil. This is of benefit to city and county planners, developers, and individual land owners in that it delineates potential problem areas. Site-specific investigations can then be initiated if deemed appropriate. Thus problem areas could be avoided or the hazard diminished, thereby reducing potential damage and eliminating costly repairs.

COLLAPSIBLE SOIL CHARACTERISTICS

DESCRIPTION OF COLLAPSIBLE SOILS

Collapsible soils are low density, relatively dry soils with considerable dry strength that undergo a reduction in volume when they become wet. They have a high void ratio and an open structure composed of bulky shaped grains. Internal support is supplied by some material or force. The material or force is derived from a combination of factors including capillary tension, cementing agents such as iron oxide, calcium carbonate or clay binding, and other agents including silt bonds, clay bonds, and clay bridges. When water is added to the soil, the material or force is removed, or reduced, allowing the grains to slide past one another into vacant spaces. This causes a reduction in volume and the soil collapses (Dudley, 1970). The vacant spaces (voids) may be the result of intergranular voids, interlaminar voids, bubble cavities, dessication cracks, or voids left by buried vegetation (Bull 1964).

Collapsible soils are generally fine grained soils such as sandy silts, silty sands, and clayey sands although appreciable amounts of gravel may be found in collapsible soils.

FACTORS NECESSARY FOR COLLAPSE

Three factors are necessary for a soil to collapse. First, it must be in an open, potentially unstable condition. Second, it must have a high enough applied stress to develop an unstable condition. Third, it must have a strong bonding force or material which loses strength upon wetting producing collapse (Clemence, 1981). Thus for a soil to be susceptible to collapse it would need to have a low density, a high dry strength, and a relatively low moisture content to prevent spontaneous collapse. This means that collapsibility would generally be restricted to dry regions, that the collapsible soil would be well above the water table, and that the soil would not be exposed to previous flooding or prolonged wetting (Prokopovich, 1984).

RELATED GEOLOGY

Collapsible soils are found in a variety of geological environments. Loess, eolian deposits, colluvium, mud flows, alluvial fans, residual soil, and man-made fills have all produced collapsible soils. They are generally deposited in an open, unconsolidated state which allows them to dry out after original deposition. Because they typically have a fairly steep surface gradient, the soils are not subjected to subsequent saturation. They may then be covered by later deposits and left in a condition susceptible to collapse. Therefore, deposits continually subjected to saturation or flooding such as deltaic, lake, or flood plain deposits are not likely to contain collapsible soil.

In the area studied for the collapsible soil hazard map emphasis was placed on alluvial fans, but other areas known to contain collapsible soils were also investigated. These areas included weathered shale bedrock, alluvium and colluvium, and landslide deposits.

The fact that collapsible soils are associated with certain geologic environments does not mean that the existence of a particular environment insures the presence of collapsible soil. Testing for this study showed that parts of alluvial fans may contain collapsible soil while other parts of the same fan do not. However, once collapsible soils are found, regional correlations may be made to similar environments and the presence of a particular geologic environment may alert developers or planners to the necessity of more detailed investigations.

DEVELOPMENT OF A COLLAPSIBLE SOIL HAZARD MAP

PREVIOUS STUDIES

Previous studies of collapsible soils along the southern Wasatch Front have generally been performed by local geotechnical firms with site specific studies of building foundations. Christenson (1982) performed an investigation on ground cracking and subsidence in the Nephi area which he attributed to collapsible soil. Studies specifically addressing the problem of collapsible soils are few and generally site specific.

CURRENT STUDIES

Excellent studies of collapsible soils associated with alluvial fans have been completed by Bull (1964) covering western Fresno County in California. Because of similar geologic settings, the thrust of this study is to delineate alluvial fans and rank them as to the probability of containing collapsible soil. To avoid unnecessary overlap of geologic mapping, alluvial fan and debris flow maps of Utah and Juab Counties developed by Robert M.

Robison as part of the County Hazard Geologist program were initially used.

Robison's maps were developed from an extensive research of previously mapped areas combined with recent aerial photo mapping. The aerial photo mapping was carried out on 1:20,000 and 1:40,000 vertical aerial photos dated 1984 and 1980 respectively. The data from the aerial photos was transferred to overlays on 1:24,000 scale orthophoto maps. The orthophoto overlays were then used in transferring the data to 7 1/2 minute topographic quadrangle maps. The alluvial fans mapped were mostly Late Pleistocene or Holocene in age, and generally were mapped on the basis of recent activity.

Bull (1964) noted a correlation between certain lithologies in the drainage basin and the likelihood of the presence of collapsible soils in the associated alluvial fan. His studies showed that alluvial fans associated with shale dominated drainage basins were more likely to contain collapsible soil. Limited studies along the southern Wasatch Front, particularly in the Nephi area, showed similar correlations. The lithologies of the drainage basins associated with fans in the study area were determined from geologic quadrangle maps or other geologic maps. Emphasis was placed on maps with scales of 1:48,000 or less to obtain sufficient detail of the drainage basin lithologies.

(RLO & KMR-10)

A data search of local geotechnical firms and state agencies was undertaken to determine where consolidation tests had already been performed and areas of known collapse were delineated. Testing of alluvial fans, which included a variety of fan sizes and differing drainage basin lithologies, was then initiated. The previous mapping by Robison was revised to reflect the results of field studies and testing. Several older fans were added to the maps and some of the existing fans were extended to include parts of the fans that did not reflect recent activity. County soil maps were then used to locate areas of similar soil types and a ranking system was devised to delineate areas according to their potential to contain collapsible soil. Because of the size of the study area, the 7 1/2 minute quadrangle maps at a scale of 1:24,000 were reduced to a scale of 1:48,000. At this scale, three maps were necessary to cover the study area. The maps are labeled as northern, central, and southern sections and are attached with this report.

POTENTIAL COLLAPSIBLE SOIL AREAS

ALLUVIAL FANS

Extensive block faulting along the Wasatch Front has resulted in the formation of numerous alluvial fans at the abrupt change in slope caused by the faulting. Faulting and the associated uplift of adjacent highlands controls the site, rate, and the magnitude of deposition in the fans. Material from the highlands is transported by three intergradational mechanisms: (1) stream flow, (2) debris flow, and (3) mud flow. Stratification ranges from good in stream flow deposits to poor in debris flow deposits to non-existent in most mud flow deposits.

Stream flow deposits form when sediment-laden waters surge from the end of the stream channel and spread out over the fan. These surges deposit sheets of silt, sand, and gravel with little visible clay.

Deposits of debris flows are poorly sorted or nonsorted and are generally coarse grained. They often include cobbles and boulders in a fine-grained matrix of mud. A debris flow in which the material is mostly sand sized and finer, and in which mud is dominant is known as a mud flow (Friedman and Sanders, 1978).

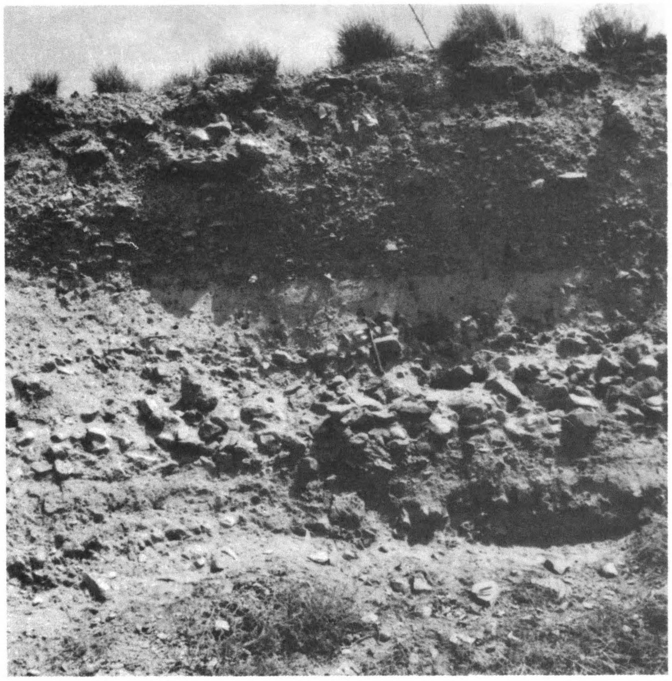


Photo 1, Collapsible soil between coarser material.

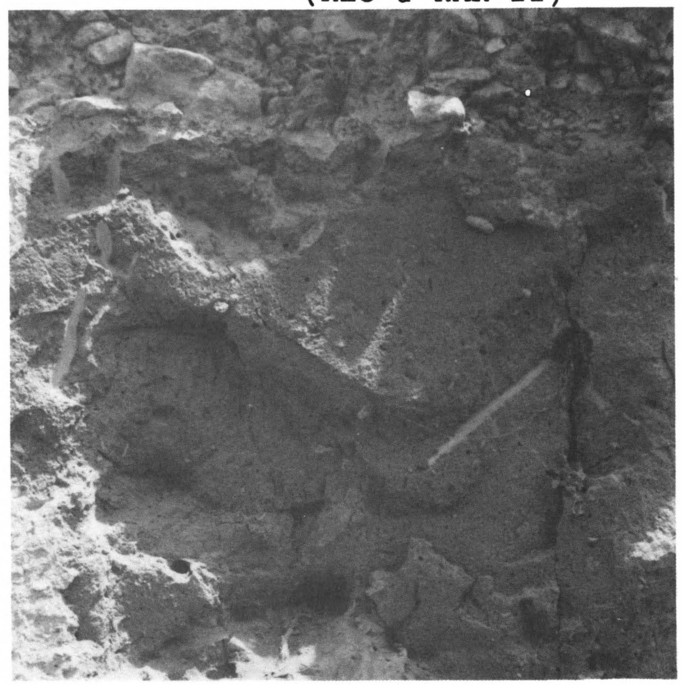


Photo 2, Voids in collapsible soil.

Photo 3, Voids in collapsible soil.

Photo 4, Field sample in consolidation ring.

FIGURE 3

The proportion of stream flow, debris flow, and mud flow in an alluvial fan deposit varies according to the frequency and intensity of the precipitation in the highlands. In general, fans of more arid regions are dominated by debris and mudflow sediments.

In cross section, fans show layers of coarse debris flow sediments, nonsorted mud flows, and well bedded stream flow deposits (Photo 1, Figure 3). This makes predictions of soil collapse based only on surface exposures inadequate, because collapsible soil in a previous mud flow may be buried by non-collapsible stream or debris flow deposits. The deposits are also quite variable in the lateral direction because channels are continually cut and filled and the flow is then diverted into a new channel (Friedman and Sanders, 1978). The particle size decreases from the head to the toe of the fan and collapsible soil tends to occur more on the fringe of the alluvial fan.

Fans tend to contain collapsible soil because the material is "dumped" on the fans, particularly by mud and debris flows. The material represents the load of the flow which simply came to rest. The internal water drains away or evaporates and the material is never reworked. As a result, the clay-size particles are not washed out. The material may be covered later by another flow but because of the relatively steep gradient of the fan, the material is never again saturated and does not fully consolidate under the increasing overburden pressure (Clemence, 1981). The soil is fully capable of supporting the pressure while in a dry, stiff condition but it will settle dramatically as it approaches saturation.

Deep percolation of precipitation into the fan is uncommon after deposition. Precipitation amounts in the region are generally low and saturation by precipitation is prevented by the steep gradient of the fan surface. The surfaces of the fans are concave upward and may slope as much as 25 degrees at the head. Most fan surfaces slope from 5 to 10 degrees.

The rate of deposition partly determines how much a fan will collapse. Rapid burial can help preserve the amount of clay, voids, and textural features that would otherwise be destroyed if the deposit were subject to surface weathering (Bull 1964). Voids created by bubble cavities, desiccation cracks, buried vegetation, or silt and clay bridges are responsible for the collapse (Photos 2 and 3, Figure 3).

The amount of clay in a deposit largely controls the tendency for collapse. Clay has a high dry strength and acts as a binder and bridge between the particles. It helps the deposits to withstand overburden pressures until water percolates into the deposit and is adsorbed by the clay. The clay then loses its strength allowing the deposit to collapse (Bull, 1964).

Alluvial fan deposits along the Wasatch Front that contain collapsible soils are usually associated with ephemeral streams that flow only as a result of direct precipitation. The channels of the ephemeral streams are always above the water table and the amount of flow is controlled by the intensity of precipitation, the vegetation cover, lithology, and the slope of the drainage basin. Alluvial fans with constant flowing streams tend to have a high water table and are subject to more frequent flooding, thus reducing the likelihood of containing collapsible soil.

COLLUVIUM/ALLUVIUM

During the preliminary data search of local geotechnical firms, it was noted that several areas contained collapsible soils which were not associated with alluvial fans. Further field investigations and testing indicated that several of the reworked Lake Bonneville deposits displayed collapse characteristics.

These deposits consisted primarily of silt and clay that had been eroded and transported downslope as colluvium or alluvium. This material tended to be deposited at the base of steeper slopes and collapsed when wetted. These areas are designated as undivided alluvium and colluvium (ac) on the collapsible soil hazard maps.

Some in-place Lake Bonneville deposits also display collapse tendencies. These deposits are poorly cemented with calcium carbonate derived from the limestone bedrock in the above highlands. This results in a high void ratio and an unstable structure which is susceptible to collapse. The deposits most likely to contain collapsible soil are the Silt and Clay Member of the Alpine Formation near Alpine, Cedar Hills, Pleasant Grove, Lindon, and Orem; the Sand Member of the Provo and Alpine Formations near Provo; the Silt Member of the Alpine Formation between Mapleton and the mouth of Spanish Fork Canyon; and the Silt and Sand Member of the Alpine Formation near Elk Ridge.

BEDROCK

As previously indicated, Bull (1964) recognized that the majority of the fans in California with collapsible soils had drainage basins underlain by clay rich bedrock such as shale or mudstone. These basins tended to have a sparse ground cover and were easily eroded, thereby producing a greater amount of material to be deposited in the alluvial fans below. It was noted in the preliminary search of data along the southern Wasatch Front that there were several predominantly shale bedrock formations. However, only the Manning Canyon Shale above Cedar Hills, Pleasant Grove, and Provo, and the Arapien Shale above Nephi were of sufficient extent to produce much erodible material. Investigations showed that residual weathering of these formations produced some collapsible soil and the formations were included as areas of potential collapse. The colluvial deposits below these bedrock formations were also included since they contain abundant clay and bulky material from the formations above.

LANDSLIDES

Geotechnical investigations above Provo indicated that the landslide deposits and the colluvium derived from these deposits also contained soils with collapse tendencies. These deposits are essentially equivalent to large scale debris and mud flows and were delineated as being potential problem areas. Three larger landslides between Santaquin and Nephi were also included in this category.

USE OF COLLAPSIBLE SOIL HAZARD MAPS

COLLAPSE POTENTIAL DESIGNATION CRITERIA

Based on the preliminary data search, field investigations, and subsequent laboratory testing, a ranking system was devised to indicate the likelihood of an area containing collapsible soil. This ranking is not intended to provide specific data on the amount of collapse but only to alert the user to areas where collapsible soils are more likely to be found.

The ranking provides a numerical designation as follow:

1. indicates areas of very low collapse potential
2. indicates areas of low collapse potential
3. indicates areas of moderate collapse potential
4. indicates areas of high collapse potential
5. indicates areas of very high collapse potential

The collapse potential designations are based on the following parameters:

very low (1)
- contains areas with a high water table
- includes the majority of Lake Bonneville deposits that are not susceptible to collapse
- areas with very low gradients (0-5%) and subject to previous flooding
- bedrock formations other than the Manning Canyon and Arapien Shale

low (2)
- predominantly very coarse fans (majority composed of cobbles and boulders)
- perennial stream drainage
- low gradient (5-10%)
- previously irrigated

moderate (3)
- fans with mixed deposits of fine and coarse material
- intermittent or ephemeral stream drainage
- moderate gradient (5-15%)
- low water table (deeper than 10 feet)
- correlated with similar areas of known collapse

high (4)
- predominantly fine grained fans
- colluvium/alluvium from Manning Canyon Shale or Arapien Shale or reworked Silt, Sand, and Clay Members of Lake Bonneville Group
- ephemeral stream drainage
- low water table (deeper than 10-15 feet)
- high gradient (10-30%)
- known areas of collapse

very high (5)
- predominantly fine grained fans derived from the Manning Canyon or Arapien Shale
- ephemeral stream drainage
- low to very low water table (deeper than 15-20 feet)
- known problem areas

TEST DATA

Sites from which samples were obtained for testing are indicated on the collapsible soil hazard maps as circled numbers. The numbers run in succession from north to south in the study area, and corresponding numbers with a summary of the test data are located in Tables 1-3. Tests performed specifically for this study include consolidation tests to determine the collapse potential, mechanical analyses to define the percentage of gravel, sand, and fines in each sample, Atterberg limits, in-place density and moisture determinations, and a Unified Soil Classification of each sample. Sampling data obtained from other sources may or may not give gradations or Atterberg limits depending on the purpose of sampling. All samples contain consolidation test data.

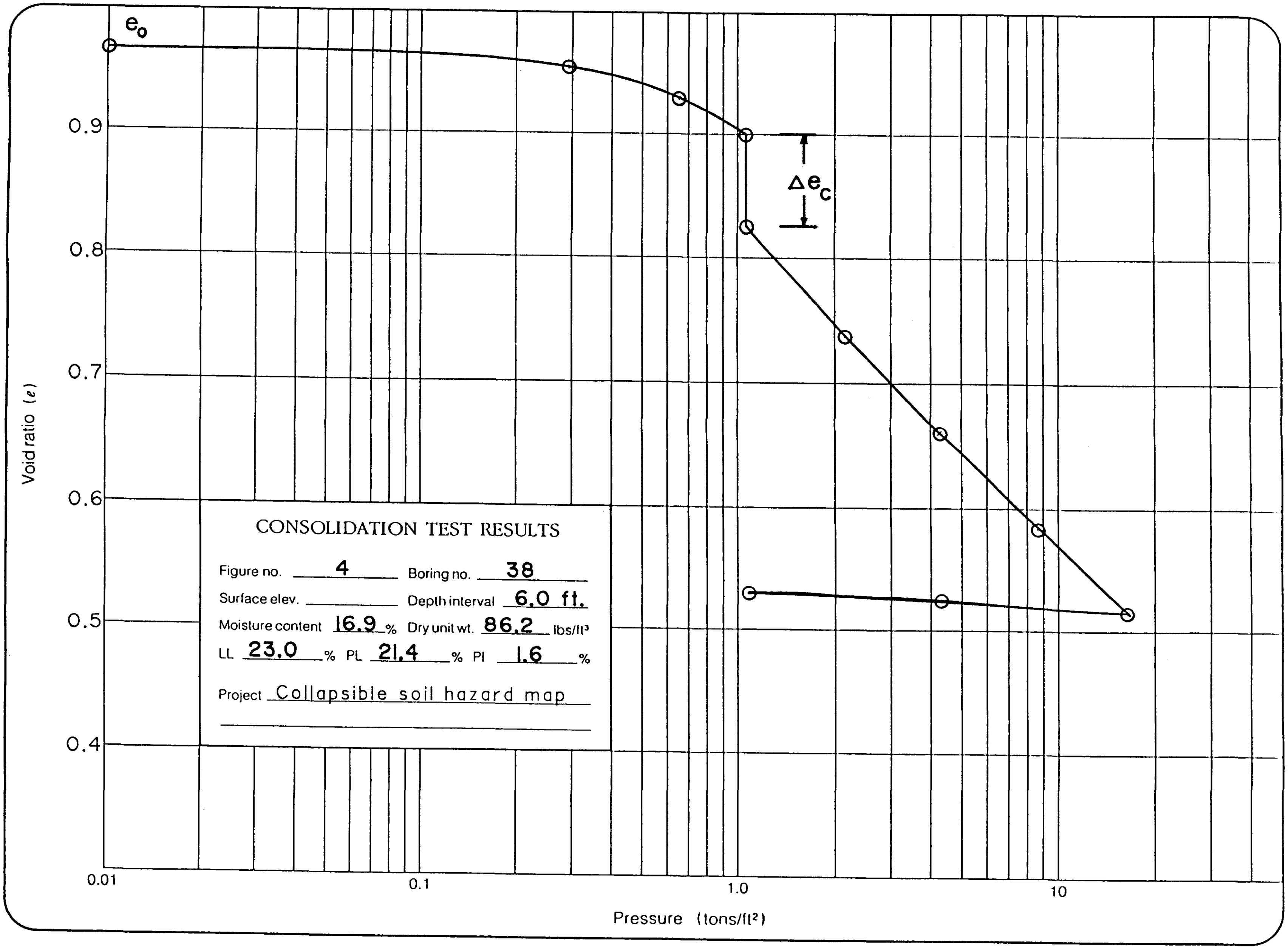
CORRELATION WITH COUNTY SOIL MAPS

Some general correlations can be made with existing county soil maps, however, the presence of a certain soil series does not necessarily mean that collapsible soil is present. Table No. 4 gives a brief summary of pertinent data obtained from the county soil maps. For detailed locations and descriptions of the soil series mentioned below, refer to Soil Survey Maps (USDA, 1972 and 1980).

In the south foothills of the Traverse Mountain area the Cleverly Series (CrD), is associated with alluvial fans. In the foothills east of Alpine, Pleasant Grove, and Orem, the Pleasant Grove Series (PmE2) is associated with alluvial fans. Colluvium/alluvium from the reworked Lake Bonneville Group are associated with the Pleasant Grove Series (PlC, PlD), Hillfield-Welby Series (HpF,HmE), and the Welby Series (WeC, WhD, WeD2, WhE). Weathered Manning Canyon Shale is associated with the Pleasant Grove Series (PNG2).

East of Provo and Springville, alluvial fans are associated with the Pleasant Grove Series (PmE2, PlD, PlC) and reworked colluvium/alluvium from the Lake Bonneville Group is associated with the Hillfield Series (HNG, HOF).

From Mapleton to the mouth of Spanish Fork Canyon, alluvial fans are associated with the Cleverly Series (CsC, CrD) and minor Layton Series (LfC). The reworked alluvium/colluvium is associated with the Hillfield Series (HpF), the Kilburn Series (KRE2), and the Sterling Series (SNG).



e_o
Δe_c
0.9
0.8
0.7
0.6
0.5
0.4
Void ratio (e)
0.01
0.1
1.0
10
Pressure (tons/ft²)
CONSOLIDATION TEST RESULTS
Figure no. 4 Boring no. 38
Surface elev. Depth interval 6.0 ft.
Moisture content 16.9 % Dry unit wt. 86.2 lbs/ft³
LL 23.0 % PL 21.4 % PI 1.6 %
Project Collapsible soil hazard map

(RLO 8 KMR-22)

From the mouth of Spanish Fork Canyon to Payson the alluvial fans are associated with a variety of soil series including the Cleverly Series (CsC, CrD), the Hillfield Series (HNG), the Pleasant Grove Series (PmE2, PlD, PlC), the Bingham Series (BmC, BmD), and the Manila Series (MAF). The alluvium/colluvium deposits are associated with the Sterling Series (SNG), and the Welby-Hillfield Series (WhE, WhD).

From Payson to the Utah-Juab County line the alluvial fans are associated with the Pleasant Grove Series (PmE2, PlD, PlC), the Kilburn Series (KOD), the Cleverly Series (CsD), the Rake Series (RAG2), and the Dry Creek Series (DCF).

From the Utah-Juab County line to Nephi the alluvial fans and landslides are associated with the Bezzant Series (BeD), the Borvant Series (BgD, BgC), the Donnardo Series (DdC, DdE), the Lizzant Series (LbE), the Juab Series (JbB, JcB), and the Rofiss Series (RpD). Weathered Arapien Shale is associated with the Lizzant Series (LcF).

SAMPLE TESTING

CONSOLIDATION TESTS AND COLLAPSE POTENTIAL

A laboratory test procedure to determine the collapse potential of a soil using a modified, one dimensional consolidation test is outlined by Jennings and Knight (1975). In this test the samples are cut to snuggly fit into a consolidation ring 1.0 inch high with a 2 3/8 inch diameter (Photo 4, Figure 3). Samples for this study were generally cut in the field to avoid altering the moisture content, but several samples were cut from undisturbed block samples in the laboratory. The samples were put into a loading device and loaded progressively to 1.15 tons per square foot (110 kPa). This pressure varies slightly from that of 2.1 tons per square foot (200 kPa) suggested by Jennings and Knight (1975) but it more closely matches the overburden pressure of the in-place samples and the load intensities most commonly induced by structures on these materials. At 1.15 tons per square foot, the sample is flooded with water and allowed to stand overnight. The change in sample height resulting from settlement under a constant load is measured and the consolidation test is then carried out to its normal maximum loading and then unloaded. From the consolidation test, the in-place natural density, the natural moisture content, and the initial void ratio can be determined. The reduction in void ratio is then plotted against the loading on semi-log paper. The resulting curve of a typical collapsible soil is given in Figure 4. Collapse is due to the addition of water alone and not due to any additional loading.

Jennings and Knight (1975) have also proposed a Collapse Potential (CP) to give the engineer a "ball park" figure of the collapse which may be encountered. The Collapse Potential (CP) is defined as

$$\frac{\Delta e_c}{e_o + 1} \times 100$$

where Δe_c is the change in void ratio upon wetting and e_o is the initial void ratio. The Collapse Potential (CP) can also be expressed in terms of strain as $\varepsilon = \frac{\Delta H}{H_o}$ where ΔH is the change in height of the sample upon wetting and H_o is the initial height of of the sample. An accompanying guide relating the Collapse Potential (CP) to the severity of the problem due to collapse is given as follows:

CP	Severity of problem
0 - 1%	No problem
1% - 5%	Moderate trouble
5% - 10%	Trouble
10% - 20%	Severe trouble
> 20%	Very severe trouble

The Collapse Potential for each sample is included in the Summary of Test Data Sheets (Tables 1-3). Some partly saturated soils show minor Collapse Potential due to the consequences of rebound on sampling, therefore, some leeway is given in the above guide. The Collapse Potential is not a design figure and does not tell how much a sample will collapse. It is merely an index to use so that the engineer knows whether further investigations are justified.

A method for predicting the amount of collapse of a soil for design purposes is explained by Jennings and Knight (1975) using a double consolidation test. No double consolidation tests were run on any of the samples for this study.

FIELD IDENTIFICATION

Besides general associations of collapsible soils with certain geologic environments, collapsible soils can often be identified by their structure alone. Typically, collapsible soils will have an open structure composed of bulky grains with numerous voids (Photos 2 and 3, Figure 3). Collapsible soils will have a low density and a relatively low natural moisture content. Of the

(RLO & KMR-27)

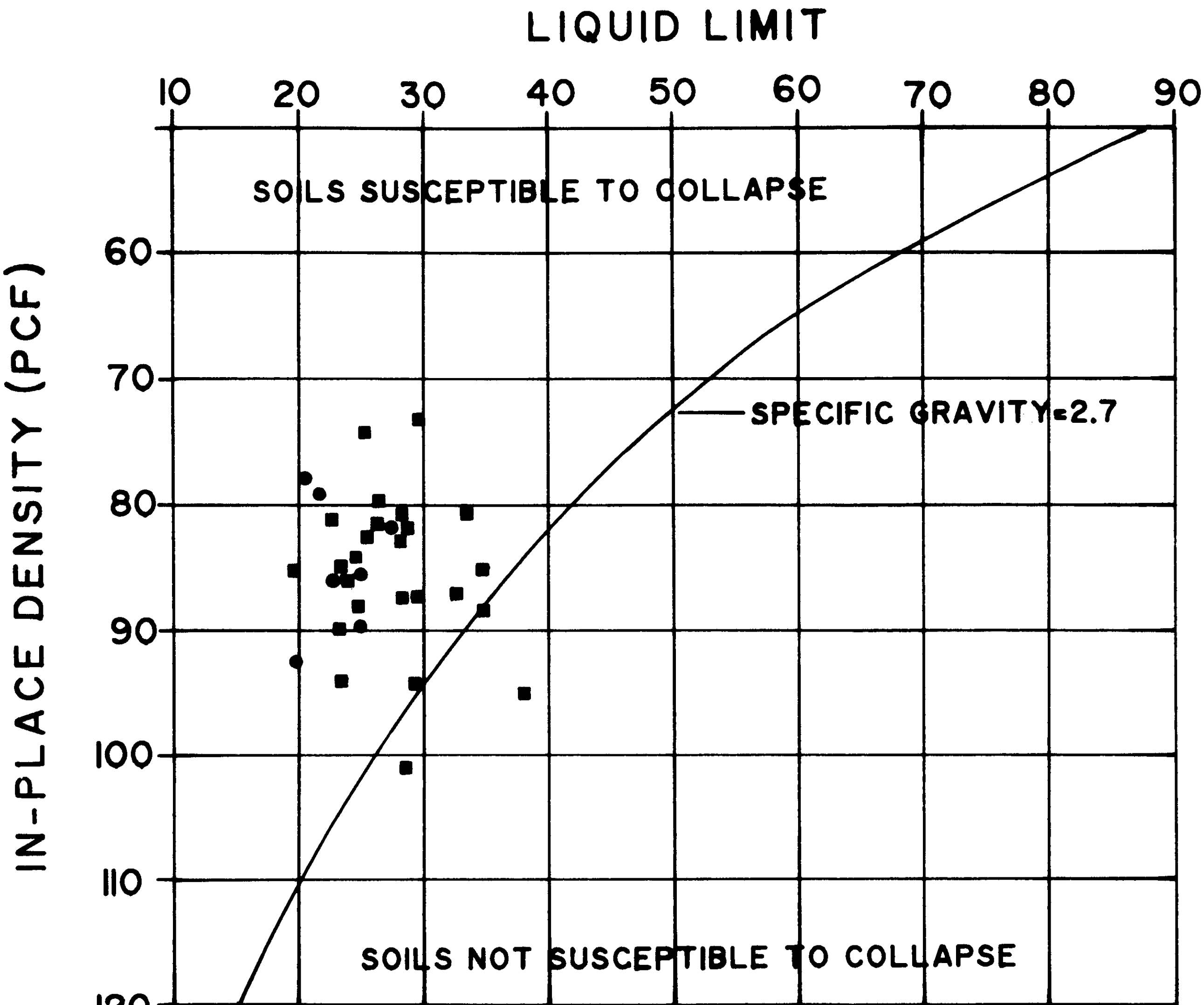


FIGURE 5 - SUSCEPTIBILITY TO COLLAPSE

(AFTER GIBBS AND BARA, 1962)

■ COLLAPSE POTENTIAL - 1-5%

● COLLAPSE POTENTIAL >5%

65 samples on which data was available, the in-place densities ranged as follows:

Collapse Potential	In-place Density (pcf)
0-1%	73.6-111.8
1-5%	73.6-100.7
>5%	77.7- 91.7

In-place moisture contents ranged as follows:

Collapse Potential	In-place Moisture Content
0-1%	3.5-36.3
1-5%	4.2-23.7
>5%	5.1-14.9

Unified Soil Classifications included SM, ML, SC, CL, SC-SM, SM-ML, and SP with ML, CL, and SM being the most common (see Summary of Test Data, Tables 1-3).

Clemence (1981) has used a simple field test in which a hand sized sample of soil is broken into two pieces and the pieces are trimmed to equal volumes. One of the pieces is wetted and molded to form a damp ball. The two pieces are then compared and if the wetted ball is significantly smaller, collapse may be suspected.

LIQUID LIMIT AND IN-PLACE DENSITY

Gibbs and Bara (1962) have used a plot of dry density and liquid limit as a criteria for predicting soil collapse (Figure 5). Their premise is that soil collapse is caused by a loss of dry strength in the soil. A complete loss of dry strength occurs when the soil is saturated to the liquid limit. If the volume of water corresponding to the liquid limit stage is larger than the natural porosity, the material, under normal conditions cannot be saturated to the liquid-limit. Therefore, it cannot completely lose its dry strength and is not considered collapsible. If the volume of the natural porosity exceeds the volume of water required to reach the liquid limit, the soil may be "liquified" and may be subject to collapse (Prokopovich, 1984). Soil densities that plot above the line shown in Figure 5 are in a loose condition and will have a moisture content greater than the liquid limit. Therefore they will be susceptible to collapse. Soils that plot below the line are presumably not susceptible to collapse.

Prokopovich (1984) argues that the above method is invalid because collapse can occur when the moisture content of the soil is well below the liquid limit, and that the relative strength and other properties vary between the undisturbed and remolded clays. Samples with a Collapse Potential greater than 1.0% were plotted on Figure 5. With Prokopovich's limitations in mind, it can be seen that there is generally a good correlation between the liquid-limit\dry density and the susceptibility to collapse for soils with a CP from 1-5%. Figure 5 is a very good indicator for soils with a CP greater than 5%. Such a plot may alert the user that a soil may be susceptible to collapse and further testing may be warranted.

CONCLUSIONS AND RECOMMENDATIONS

Collapsible soils along the southern Wasatch Front are generally associated with alluvial fans. Colluvium\alluvium derived from reworked Silt, Sand, and Clay Members associated with the Alpine and Provo Formations of the Lake Bonneville Group also contain collapsible soil. Other environments that contain collapsible soil include weathered bedrock of the Manning Canyon and Arapien Shale, colluvium derived from these bedrock units, and larger landslides above Provo and Mona.

A collapsible soil hazard map (see attached maps) was developed for the Southern Wasatch Front delineating areas likely to contain collapsible soil. A collapse potential designation was devised to alert users to areas where collapsible soils are more likely to be found. This numerical designation ranks areas according to the likelihood of containing collapsible soils but does not provide specific figures as to the degree of collapse.

Consolidation tests run on all samples indicate that the severity of collapse varies from "no problem to very severe trouble" depending on the location of the sample. Because alluvial fan deposits vary both in cross section and areally, a site specific investigation may be necessary if collapsible soils are suspected.

The utilization of the collapsible soil hazard maps can alert the public of areas most likely to contain collapsible soils. A plot of the liquid limit versus in-place density of soils from the area may be used to predict if a soil will collapse and whether additional tests are warranted. If collapsible soils are suspected in an area, consolidation tests should be run to positively identify the collapsible soils and to help determine the severity of the problem.

Collapsible soils can often be identified in the field by their bulky, open structure. Samples in this study have in-place densities ranging from 73.6-111.8 pcf and in-place moisture contents ranging from 3.5-36.3 percent.

It is recommended that the collapsible soil hazard maps be updated as more data is obtained. This update should include further refinement of areas known to contain collapsible soils, as well as modification of the collapse potential designations.

REFERENCES

Bull, W. B., 1964, Alluvial Fans and Near-Surface Subsidence in Western Fresno County, California, United States Geological Survey Pressional Paper 437-A: U.S. Government Printing Office, Washington, DC, 70 p.

Christenson, Gary E., 1982, Ground cracking and subsidence in the Nephi Area, Juab County, Utah: Memorandum dated 11/5/82, Utah Geological and Mineral Survey, 5 p.

Clemence, Samuel P. and Finbarr, Albert O., 1981, Design considerations for collapsible soil, in Journal of the Geotechnical Engineering Division: Proceedings of the American Society of Civil Engineers, Vol 107, No. GT3, pp. 305-317.

Dudley, J. H., 1970, Review of collapsing soils, in Journal of the Soil Mechanics and Foundations Division: Proceedings of the American Society of Civil Engineers, Vol. 96, No. SM-3, pp. 925-947.

Friedman, Gerald M., and Sanders, John E., Principles of Sedimentology (John Wiley and Sons, 1978), pp. 202-207.

Gibbs, H. J., and Bara, J. P., "Predicting Surface Subsidence from Basic Soil Tests", Soils Engineering Report No. EM658, U.S. Dept. of the Interior, Bureau of Reclamation, Denver, Colo., June, 25, 1962.

Jennings, J.E., and Knight, K., "A Guide to Construction on or with Materials Exhibiting Additional Settlement Due to 'Collapse' of Grain Structure," Sixth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Sept., 1975, pp. 99-105.

Kaliser, B. N., 1977, Ground subsidence in Cedar City, Utah: Utah Geological and Mineral Survey Report of Investigation RI-124, 130 p.

Prokopovich, Nikola P., 1984, Validity of Density-Liquid Limit Predictions Hydrocompaction: Bulletin of Association of Engineering Geologists, Vol. XXI, No.2, pp. 191-205.

Robison, Robert M., 1988, "Preliminary Alluvial Fan and Debris Flow Maps of Utah and Juab Counties", Utah County Planning Office, Utah County Geologist.

Soil Survey of Utah County, Utah, Central Part: U.S. Dept. Agriculture-Soil Conservation Service (Washington, D.C.: GPO, 1972), 161 p.

Soil Survey of Fairfield-Nephi Area, Utah: U.S. Dept. of Agriculture-Natural Cooperative Soil Survey (Washington, D.C.: GPO, 1980), 361 p.

MAP SOURCES OF DATA

Anderson, Loren R., Keaton, Jeffrey R., and Bischoff, Jon E., 1986, Liquifaction Potential Map for Utah County, Utah: under U.S. Geological Survey contract no. 14-08-0001-21359, 42 p.

Baker, A. A. and Crittenden, M. D., Jr., 1961, Geology of the Timpanogos Cave quadrangle, Utah: U. S. Geological Survey Map GQ-132.

Baker, A. A., 1964a, Geology of the Aspen Grove quadrangle, Utah: U. S. Geological Survey Map GQ-239.

Baker, A. A., 1964b, Geology of the Orem Quadrangle, Utah: U.S. Geological Survey Map GQ-241.

Baker, A. A., 1972a, Geologic map of the Bridal Veil Falls quadrangle, Utah: U.S. Geological Survey Map GQ-998.

Baker, A. A., 1972b, Geologic map of the N.E. part of Spanish Fork Peak Quadrangle, Utah: U.S. Geological Survey Open-File Map.

Baker, A. A., 1973, Geologic map of the Springville quadrangle, Utah: U.S. Geological Survey Map GQ-1103.

Bissell, H. J., 1963, Lake Bonneville: Geology of southern Utah Valley, Utah: U.S. Geological Survey Professional Paper 257-B.

Brown, R. S., Geology of the Payson Canyon-Picayune Canyon area, Southern Wasatch Mountains, Utah: Compass of Sigma Gamma Epsilon, v. 29, pp. 331-349.

Bullock, R.L., 1958, Geology of the Lehi quadrangle, Utah: Unpublished Brigham Young Univ. M.S. thesis.

Davis, F.D., 1983, Geologic Map of the Southern Wasatch Front, Utah: Utah Geological and Mineral Survey, Map 55-A.

Demars, L. C., 1956, Geology of the northern part of Dry Mountain, Southern Wasatch Mountains, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 3, no. 2.

Foutz, D.R., 1960, Geology of the Wash Canyon area, Southern Wasatch Mountains, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 7, no. 2.

Hintze, L.F., 1962, Geology of the southern Wasatch Mountains and vicinity, Utah: Brigham Young University Geology Studies, v.9, part 1.

Hintze, L.F., 1978, Geologic Map of the Y Mountain area, east Provo, Utah: Brigham Young University Geology Studies, Special Publication 5.

Hunt, C.B., 1953, Lake Bonneville: Geology of northern Utah Valley, Utah: U. S. Geological Survey Pressional Paper 257-A.

Johnson, K. D., 1959, Structure and stratigraphy of the Mount Nebo-Salt Creek area, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 6, no.6.

Machett, Michael, 1986, Preliminary Geologic Map of the southern 1/3 of the Spanish Fork quadrangle: U.S. Geological Survey.

Miller, R.D. 1982, Surficial geologic map along the southern part of the Wasatch Front, Great Salt Lake, and Utah Valley, Utah: U.S. Geological Survey Map MF-1477.

Peterson, D. J., 1956, Stratigraphy and structure of the west Loafer Mountain-upper Payson Canyon area, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 3, no. 4.

Pitcher, G. G.,1957, Geology of the Jordan Narrows quadrangle, Utah: Brigham Young University Geology Series, v. 4, no. 4.

Rawson, R. R., 1957, Geology of the southern part of Spanish Peak quadrangle, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 4, no. 2.

Reconnaissance Engineering Geologic Evaluation Traverse Ridge Project between Alpine and Draper, Utah and Salt Lake Counties, Utah: Dames and Moore, Job No. 13196-002-47, S.L.C., Utah.

Robison, Robert M., 1988, "Alluvial Fan and Debris Flow Maps of Utah and Juab Counties", preliminary version, Utah County Planning office, Utah County Geologist.

Smith, C. V., 1956, Geology of the North Canyon area, Southern Wasatch Mountains, Utah: Brigham Young Univ. Research Studies, Geol. Ser., v. 3, no. 7.

TABLE NO. 1 — SUMMARY OF TEST DATA

SAMPLE NUMBER AND AREA	DEPTH (FT)	UNIFIED SOIL CLASS.	GRADATIONS % GRAVEL	% SAND	% FINES	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	COLLAPSE POTENTIAL	IN-PLACE DENSITY (pcf)	IN-PLACE MOISTURE CONTENT	COMMENTS
1. Alpine	3.0	SL	5	78	17	29.8	21.6	8.2	0.2	94.3	15.7	irrigated
2. Alpine	3.0	SM	3	62	35	24.5	21.5	3.0	3.87	84.55	13.3	
*3. Alpine	3.0	SM	---	54.3	45.7	---	---	---	0.37	89.0	3.8	irrigated
	6.0	SM	0.5	71.1	28.4	---	---	---	0.27	90.1	3.5	irrigated
*4. Manila	3.0	ML	---	---	---	19.9	16.7	3.2	6.86	91.7	5.1	
5. Highland	1.0	CL-ML	---	49.2	50.8	27.4	21.5	5.9	.078	94.48	17.2	
6. Pl. Grove	5.0	SC	trace	52	48	38.9	23.6	15.3	2.1	94.94	13.9	
*7. Pl. Grove	1.0	CL-1	---	---	---	29.2	21.1	8.1	2.59	87.4	10.9	
	6.0	CL-1	---	---	---	28.7	18.8	9.9	1.7	87.4	11.4	
	3.0	CL-2	---	---	---	35.4	20.3	15.1	1.3	85.1	9.0	
8. Pl. Grove	1.0	CL	---	36	64	29.5	22.1	7.4	1.3	94.1	14.52	
9. Pl. Grove	2.0	SC	1	67	32	29.6	21.4	8.2	3.5	100.74	14.0	
*10. Pl. Grove	3.0	SM-ML	---	---	---	---	---	---	13.3	87.9	5.1	
	6.0	SM-ML	5.1	45.6	49.3	---	---	---	4.5	86.5	4.3	
	9.0	SM-ML	---	---	---	---	---	---	6.74	90.9	5.4	
11. Orem	2.0	SC	---	61	39	35.1	22.9	12.2	2.6	88.69	11.0	
12. Orem	1.5	SM	---	76	24	---	---	non-plastic	4.9	84.95	5.5	
13. Provo	1.5	SM	2	64	34	non-plastic	non-plastic	non-plastic	0.4	111.8	12.29	possibly irrigated
*14. Provo	3-4.5	SM	0	87.5	12.5	---	---	---	0.94	83.7	9.2	
	6-7.5	ML	0	42.8	57.2	---	---	---	0.36	87.1	8.3	
15. Provo	3.0	SM	---	53	47	19.3	---	non-plastic	2.6	85.4	11.4	irrigated
*16. Provo	2.0	CL-ML	---	---	---	22.6	18.4	4.2	1.79	94.4	8.5	
*17. Provo	6.0	GC,CL-1	53.8	28.6	17.6	28.5	17.2	11.3	1.45	81.8	14.6	

* Data obtained from Rollins, Brown, & Gunnell Inc.

CONTRACT NO. 5-22154 RLO & KMR

TABLE NO. 2 — SUMMARY OF TEST DATA

SAMPLE NUMBER AND AREA	DEPTH (FT)	UNIFIED SOIL CLASS.	GRADATIONS % GRAVEL	% SAND	% FINES	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	COLLAPSE POTENTIAL	IN-PLACE DENSITY (pcf)	IN-PLACE MOISTURE CONTENT	COMMENTS
*17. (cont.)	9.0	CL-1, GC	17.6	31.9	50.5	32.9	18.0	14.9	2.33	87.2	13.4	
*18. Provo	3-4	CL-1	---	---	---	35.7	22.4	13.3	0.91	81.0	21.7	
19. Provo	no data; known problem area											
*20. Provo	3.0	SM	2.6	48.3	49.1	non-plastic			2.29	88.8	7.4	
*21. Provo	10.0	ML	0	34.0	66.0	"	"	"	0.87	86.9	5.7	
*22. Provo	3-4	SM	17.9	39.6	42.5	---	---	---	3.1	93.5	9.1	
	6	SP	---	---	---	21.7	18.7	3.0	0.6	97.5	13.9	
	9-10	ML	---	---	---	23.3	23.0	0.3	0.5	94.4	24.8	
*23. Provo	3.0	---	---	---	---	24.9	23.2	1.7	13.7	85.6	5.6	
	3.0	ML	1.5	12.6	85.9	non-plastic			12.6	80.2	7.3	
	6.0	ML	0	18.8	81.2	"	"	"	19.7	78.7	9.1	
	9.0	ML	0	28.6	71.4	"	"	"	3.5	85.3	4.2	
24. Provo	3.4	ML	1	26	63	26.0	25.1	0.9	1.7	74.59	16.1	
*25. Provo	3.0	CL-1	---	---	---	28.7	17.7	11.0	8.13	81.3	9.1	
26. Provo	2.4	SC-SM	26	53	21	28.3	21.4	6.9	3.6	83.55	16.1	
27. Springville	4.5	CL	1	42	58	28.9	20.8	8.1	0.8	87.29	20.9	
28. Springville	1.5	SC-SM	---	70	30	24.6	19.3	5.3	5.0	88.47	15.4	
29. Springville	Gravelly; excavation displayed potential for collapse.											
30. Mapleton	4.5	SM	trace	72	28	non-plastic			0.7	93.07	9.5	
31. Mapleton	1.5	ML	---	39	61	26.6	24.7	1.9	1.1	82.44	23.7	irrigated
32. Mapleton	4.0	SM	---	63	37	22.7	20.7	2.0	6.9	86.78	14.9	
*33. Sp. Fork	6.0	SM	0	64.4	35.6	---	---	---	---	90.8	8.5	
34. Sp. Fork	4.0	SM	trace	88	22	23.3	non-plastic		1.5	90.12	13.8	

* Data obtained from Rollins, Brown, & Gunnell Inc.

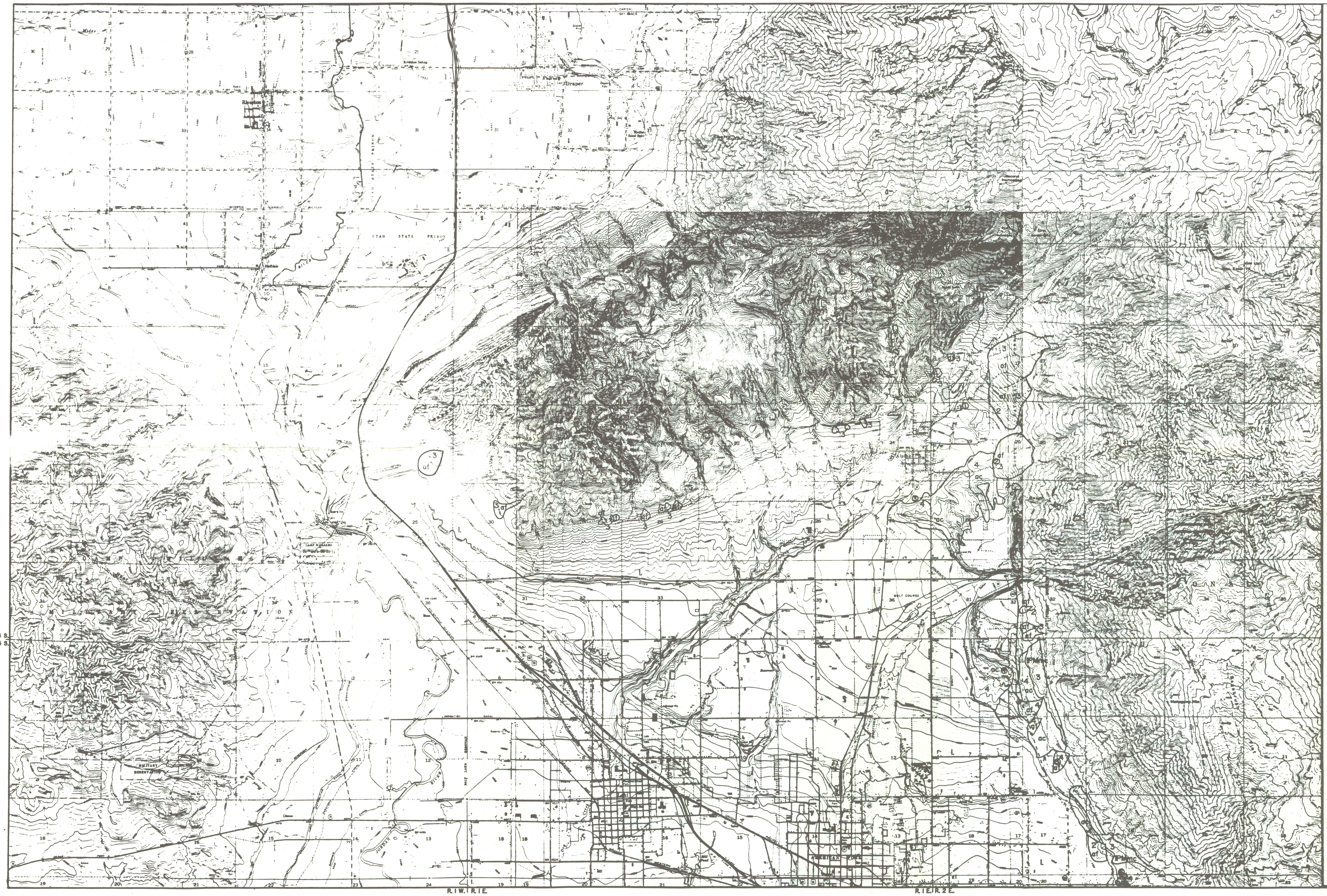
TABLE NO. 3 — SUMMARY OF TEST DATA

SAMPLE NUMBER AND AREA	DEPTH (FT)	UNIFIED SOIL CLASS.	GRADATIONS % GRAVEL	% SAND	% FINES	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	COLLAPSE POTENTIAL	IN-PLACE DENSITY (pcf)	IN-PLACE MOISTURE CONTENT	COMMENTS
35. Sp. Fork	3.0	SM	---	69	31	26.7	24.5	2.2	3.7	79.43	19.6	
36. Sp. Fork	1.5	SM	---	81	19	non-plastic			0.3	100.0	13.1	
*37. Salem	3.0	ML	---	---	---	28.1	24.4	3.7	1.53	80.8	8.9	
	6.0	SM	0	63.3	36.7	---	---	---	0.24	81.6	9.5	
	3.0	ML	---	---	---	29.7	27.3	2.4	4.63	73.6	9.9	
38. Salem	6.0	SM	---	51	49	23.0	21.4	1.6	3.6	86.21	16.9	
39. Elkridge	2.0	SC	7	62	31	30.5	17.5	13.0	0.9	97.99	20.3	
40. Payson	9.0	ML	---	---	---	25.8	23.5	2.3	0.72	81.3	18.7	
	12.0	ML	---	---	---	26.0	23.6	2.4	0.72	80.7	19.9	
41. Payson	2.0	SM	7	76	17	25.1	21.7	3.4	10.62	89.79	11.3	
42. Spring Lake	1.5	ML	3	35	62	non-plastic			0.8	73.66	36.25	
43. Santaquin	2.5	SC	trace	61.8	38.2	33.3	22.3	11.0	1.1	80.48	19.89	
44. Santaquin	2.0	SC	---	70.6	29.4	30.6	20.45	10.15	0.24	83.56	19.0	irrigated
45. Mona	1.5	SM	6	54.1	39.9	23.6	19.7	3.9	2.98	80.82	15.51	
46. Mona	1.5	SM	9	58.6	32.4	24.8	22.0	2.8	4.79	85.65	17.14	
47. Nephi	1.0	SM	---	57.1	42.9	non-plastic			4.94	86.77	21.8	irrigated
*48. Nephi	3.0	CL-ML	---	---	---	20.5	16.0	4.5	21.47	77.7	6.7	
	6.0	CL-ML	---	---	---	22.1	15.8	6.3	10.75	78.7	8.8	
49. Nephi	2.0	SP-SC	trace	61.9	38.1	26.64	19.95	6.69	2.38	82.86	22.19	irrigated

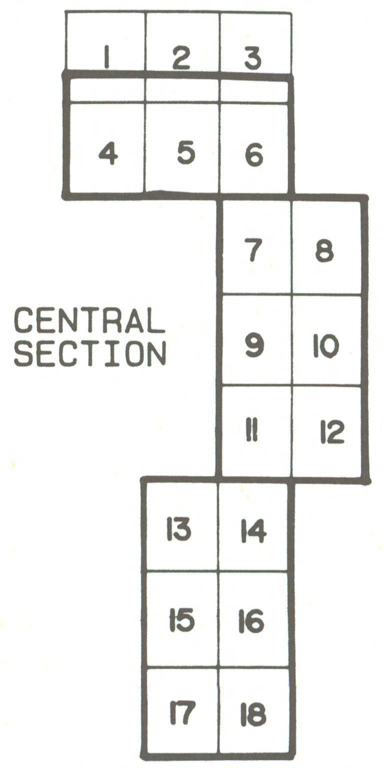
* Data obtained from Rollins, Brown, & Gunnell Inc.

TABLE NO. 4 SUMMARY OF COUNTY SOIL SURVEY MAPS

SOIL SERIES	GEOLOGIC SETTING	USCS CLASS.	SURFACE GRADIENT	PERCENT PASSING NO. 200 SIEVE
Bezzant (BeD)	alluvium colluvium	GM-GC SM-SC	6-30%	40-50 30-40
Bingham (BmC) (BmD)	alluvial fans	SC GM	3-10%	35-45 2-10
Borvant (Bgd)	alluvial fans	CL-ML GM-GC	2-25%	50-60 20-40
Cleverly (CrD) (CsC)	alluvium colluvium	SM	3-15%	25-35
Donnardo (DdC) (DdE)	alluvial fans	CL-ML GM-GC	2-25%	50-60
Dry Creek (DCF)	alluvial fans	CL or SC GC or SC	10-30%	35-65 10-30
Hillfield (HpF,HmE,HNG)	terrace	ML SM	6-60%	55-80 30-40
Juab (JcB,JbB)	fans terrace	CL-ML GM	0-8%	50-75 10-25
Kilburn (KRE2,KOD)	fans colluvium	SM SM or GM	3-30%	50-75 10-20
Layton (LfC)	terrace	SM SP-SM	1-6%	25-40 2-20
Lizzant (LbE)	alluvium colluvium	GM-GC SM-SC	8-30%	30-40 35-50
Manila (MAF)	alluvial fans	CL or ML CL or CH	10-30%	85-95 90-100
Pleasant Grove (PmE2, PlC PlD, PNG2)	fans terrace	SM GM or SC	3-10%	20-30 15-25
Rake (RAG2)	Colluvium alluvium	GM GP-GM	20-70%	15-30 5-15
Rofiss (RpD)	alluvium	GM-GC	4-15%	15-50
Sterling (SNG)	terrace	SM GP-GM	30-70%	5-20 5-15
Welby (WhE, WhD,WeC,WeD2)	terrace	ML or CL	6-10%	80-100



INDEX MAP



QUADRANGLE NAMES

1. MIDVALE
2. DRAPER
3. DROMEDARY PEAK
4. JORDAN NARROWS
5. LEHI
6. TIMPANOGOS CAVE
7. OREM
8. BRIDAL VEIL FALLS
9. PROVO
10. SPRINGVILLE
11. SPANISH FORK
12. SPANISH FORK PK
13. SANTAQUIN
14. PAYSON LAKES
15. MONA
16. NEBO BASIN
17. NEPHI
18. FOUNTAIN GREEN N.

EXPLANATION

af	alluvial fan
ac	undivided alluvium and colluvium
ls	landslide
IPMmc	Manning Canyon Shale
Ja	Arapien Shale
(9)	sample location

COLLAPSE POTENTIAL DESIGNATION

1. Very Low
2. Low
3. Moderate
4. High
5. Very High

0.5 0 1 Mile

6000 4000 2000 0 6000 Feet

Scale: 1:48000

N

BRIGHAM YOUNG UNIVERSITY

COLLAPSIBLE SOIL HAZARD MAP FOR THE SOUTHERN WASATCH FRONT

NORTHERN SECTION

UTAH GEOLOGICAL AND MINERAL SURVEY
CONTRACT NO. 5-22154

RUSSELL L. OWENS
JUNE 1988
KYLE M. ROLLINS


INDEX MAP
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CENTRAL SECTION
SOUTHERN SECTION
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
QUADRANGLE NAMES
1. MIDVALE
2. DRAPER
3. DROMEDARY PEAK
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5. LEHI
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ls landslide
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BRIGHAM YOUNG UNIVERSITY
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SOUTHERN SECTION
UTAH GEOLOGICAL AND MINERAL SURVEY CONTRACT NO. 5-22154
RUSSELL L. OWENS
JUNE 1988
KYLE M. ROLLINS
UINTA NATIONAL FOREST


INDEX MAP
NORTHERN SECTION
CENTRAL SECTION
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QUADRANGLE NAMES
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9 sample location
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6000 4000 2000 0 6000 Feet
Scale: 1:48000
BRIGHAM YOUNG UNIVERSITY
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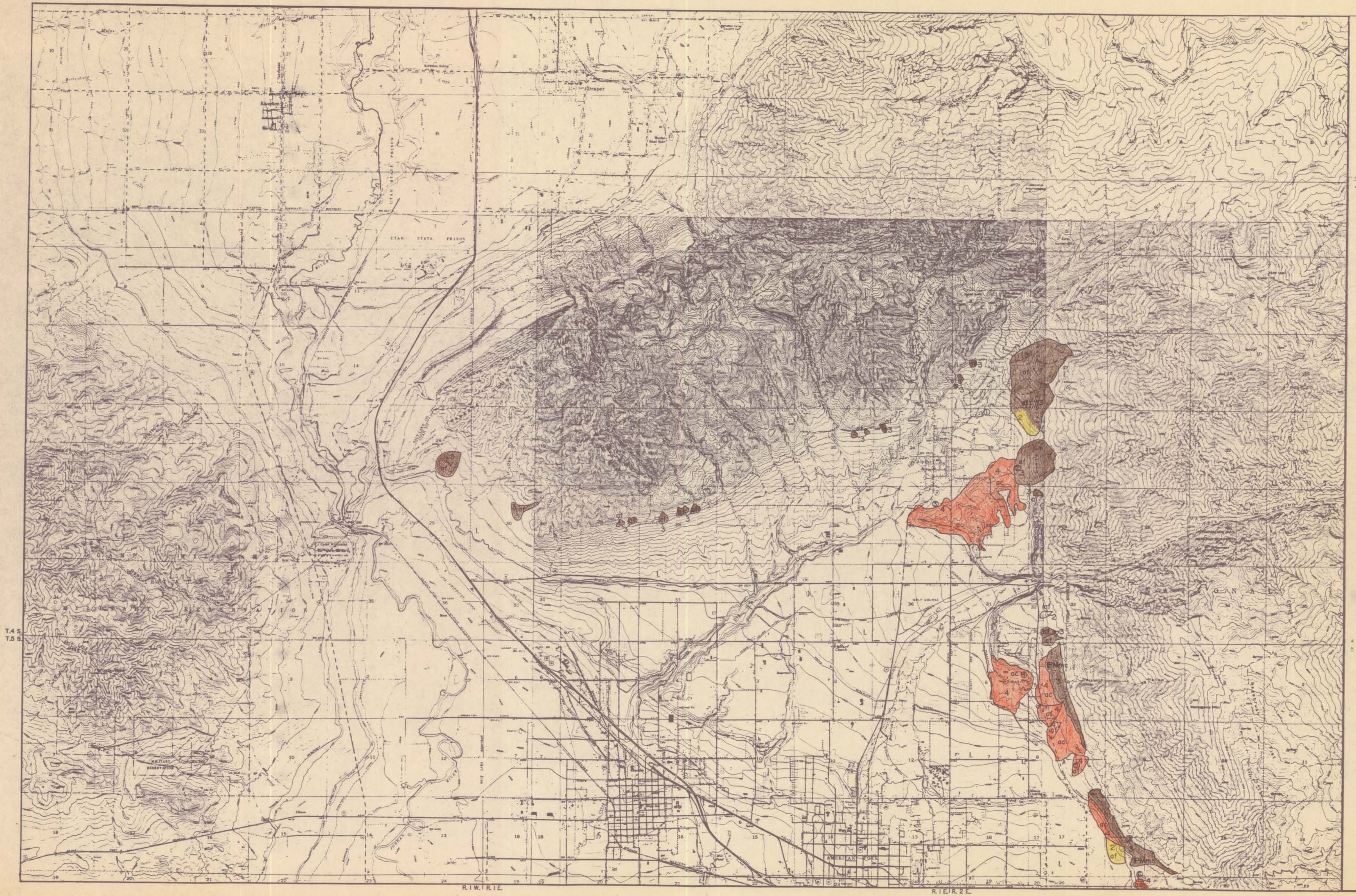
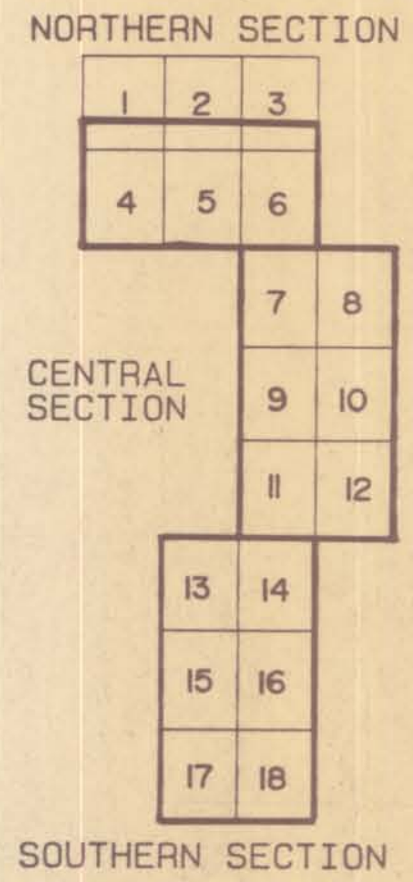
CENTRAL SECTION
UTAH GEOLOGICAL AND MINERAL SURVEY CONTRACT NO. 5-22154
RUSSELL L. OWENS
JUNE 1988
KYLE M. ROLLINS
UTAH LAKE
SPRINGVILLE
T.5S.
T.6S.
T.7S.
T.8S.
T.9S.
R.2 E. R.3 E.
R.3 E. R.4 E.



INDEX MAP



QUADRANGLE NAMES

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EXPLANATION

af	alluvial fan
ac	undivided alluvium and colluvium
ls	landslide
IPMmc	Manning Canyon Shale
Ja	Arapien Shale
(9)	sample location

COLLAPSE POTENTIAL DESIGNATION

1. Very Low
2. Low
3. Moderate
4. High
5. Very High

0.5 0 1 Mile
6000 4000 2000 0 6000 Feet
Scale: 1:48000

BRIGHAM YOUNG UNIVERSITY

COLLAPSIBLE SOIL HAZARD MAP FOR THE SOUTHERN WASATCH FRONT

NORTHERN SECTION

UTAH GEOLOGICAL AND MINERAL SURVEY
CONTRACT NO. 5-22154

RUSSELL L. OWENS
JUNE 1988
KYLE M. ROLLINS

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15. MONA
16. NEBO BASIN
17. NEPHI
18. FOUNTAIN GREEN N.

EXPLANATION

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UTAH LAKE
T.5S.
T.6S.
T.7S.
T.8S.
R.2E. R.3E.
R.3E. R.4E.