GROUND SURFACE SUBSIDENCE IN CEDAR CITY, UTAH

by
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INTRODUCTION

The Utah Geological and Mineral Survey has undertaken this geotechnical study at the request of the city of Cedar City. Funding was provided by the Four Corners Regional Commission. Exploration tools and laboratory testing services were obtained from the State Department of Transportation, Loren Rausher being that agency's liaison on the project. In addition, Mr. William Gordon, geotechnical engineer with the firm of Dames & Moore, was retained for consultation on the project. Full cooperation was experienced from the branches of city government within Cedar City as well as from the citizens of the community (Appendix I).

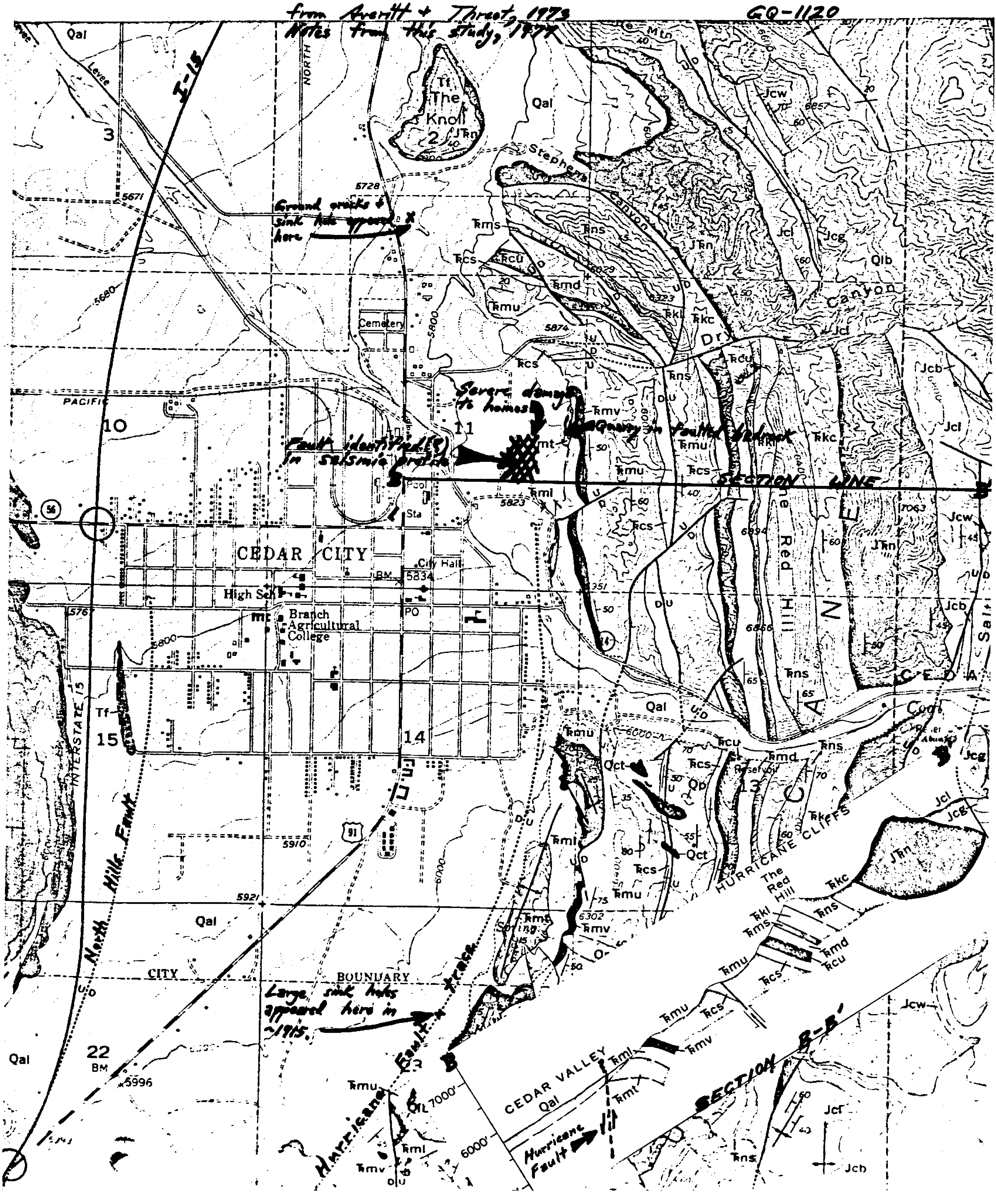
This study was initiated primarily as the result of the extremely detrimental ground surface subsidence which occurred within the Highland Park subdivision in Cedar City (Appendix I, Figure 1). Subsidence had recently become aggravated to the point that homeowners were having to face decisions with respect to relocating themselves. Particulars with respect to types of damage, dates, etc., are contained in Appendix I. Also in Appendix I is a compilation of tax assessment data showing losses in the subdivision to be in the $ 2/3 million range through August of 1977.

Although, to date, subsidence has been most severe in the Highland Park subdivision, this study has turned up evidence of significant damage to other structures elsewhere in town, and the phenomenon appears to be nearly regional in extent. Evidence from a knowledge of the distribution of geologic materials (Figure 1) and ground surface anomalies also points to a more widespread occurrence of the phenomenon. The Highland Park subdivision and much of Cedar City and areas to the north and south are underlain by alluvial fan deposits. An alluvial fan is a geologic environment at the base of hills or mountains, especially in arid regions, with the form of a low cone. Sediment carried by flowing water or in mudflows is dropped upon the cone, thus creating a continuously changing land form as long as these depositional processes remain active. Streams that contribute sediment to fans are intermittent, normally flowing only during rainstorms. There is little question but that the fans along the Hurricane Cliffs are still active environments today. Some data on historic flood events in the area is provided in Appendix II, Table 1.

Up to several feet of sediment may be deposited in any single event upon a portion of the fan, and so it is evident that alluvial fan deposits extend in depth to well over 100 feet. Right at the mountain front at the north end of Highland Drive (drill hole No. 1) the fan thickness is about 80 feet.

Underlying the sequence of alluvial soils is found bedrock of the Moenkopi Formation in the vicinity closely studied (Figure 1). This formation consists of beds (layers) of red shale, red-brown siltstone and mudstone, gray-white gypsiferous strata, fine-grained limestone, and yellowish gray and shaly limestone. When weathered, eroded, and later deposited, these sedimentary rocks yield mostly fine soils, mostly of silt size.

Fig. 1 Geologic Map[3] of Cedar City area
1" = 2,000'



AREAL RECONNAISSANCE

Because of suspicions aroused early in the project by the principal investigator, a reconnaissance was made and people interviewed over the entire city and beyond to the north and south. The writer believed it to be highly likely that the subsidence problem was not confined to the Highland Park subdivision.

Two avenues were pursued simultaneously to learn of other evidence that might be brought to bear on the problem. One avenue was to research historical data from sources such as photograph files in libraries and archives and from older Iron County residents. Secondly, a surface reconnaissance was done by vehicle, foot, and horseback in areas believed to be potentially susceptible to the problem.

HISTORICAL DATA ON GROUND SURFACE DISTRIBUTION AND DAMAGE

The writer, in the belief that the phenomena being studied should not have occurred over a short interval of time only, sought to interview older residents of Cedar City and those who with time have proven to be keen observers of the landscape.

The earliest record of ground surface disturbance that the writer could learn of was of two large, circular, vertical-walled subsidence features about 2.5 and 5.0 acres in area that were fresh appearing in about the year 1915. The vertical drop was on the order of 6 feet. These occurred just south of the Cedar City limits on the alluvial fan of an unnamed drainage (figure 1). Subsequent alluviation has removed all trace of the features as the same process has also removed traces of clay pits nearby that were used to a later date for brick manufacture.

Numbers of buildings in Cedar City have been damaged because of settlement. Some particular structures are the old city library, the old rock LDS church, Escalante Hotel, post office, Stevens Store, and the old junior high school. The portion of the Escalante Hotel without the basement settled. The rock church has cracks through its 21-inch thick walls, believed to have been caused by a leaking roof. The old library was a brick and concrete "Carnegie" design building which settled to the point of being unsafe; the new State Bank of Southern Utah sits on the site. In addition, the writer has seen damage to very many dozens of older structures in town.

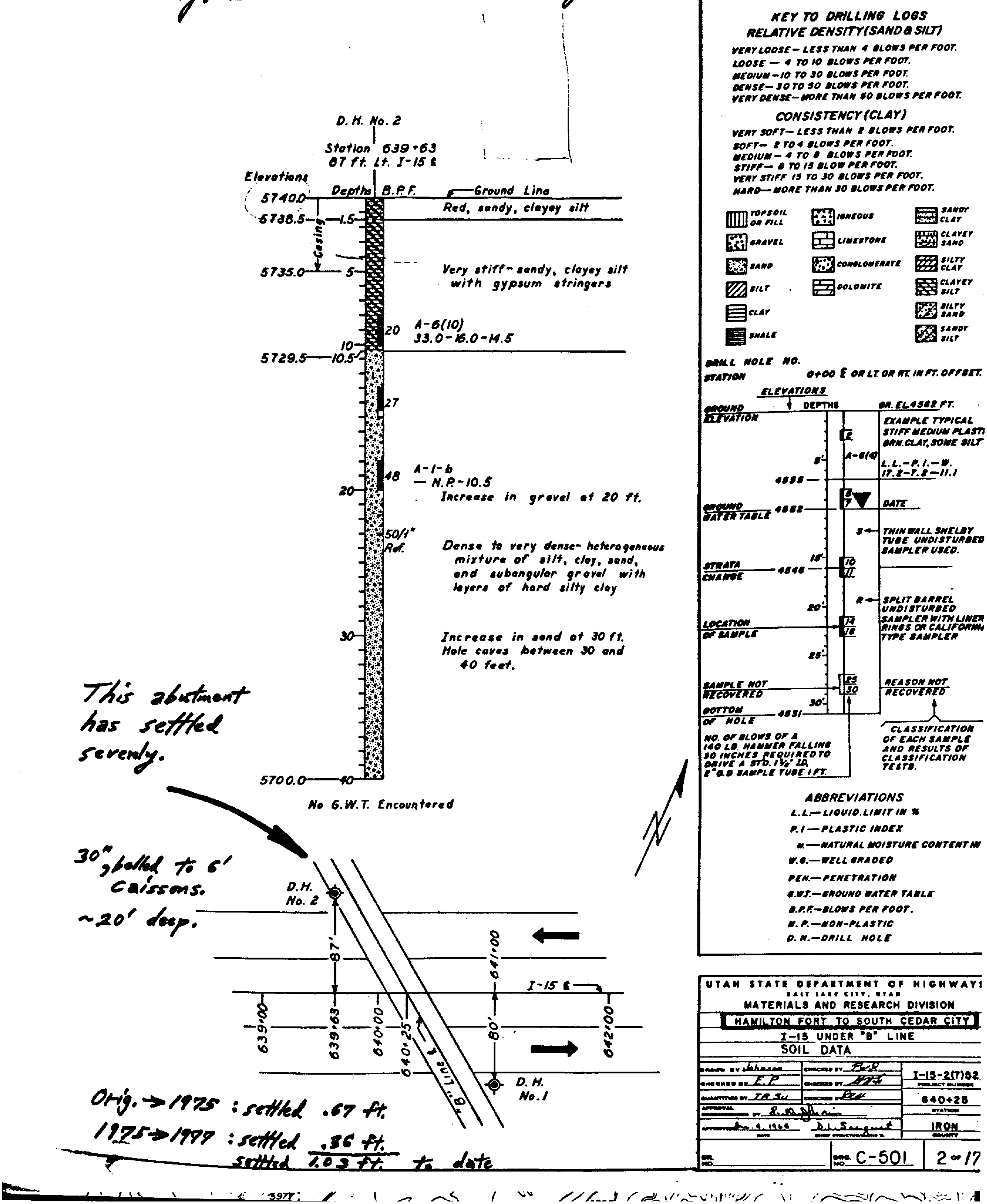
Figure 3 shows the locations of a number of structures in town that have been so seriously affected by ground movement as to require jacking.

The earth flood control dikes built by the federal government at the south end of town have seen very extensive ground cracking. In 1976 a circular subsidence feature about 200 feet in diameter had to be graded.

Prior to construction of the Parkway Ford showroom in the 1000 North block of Main Street there also appeared a circular sink hole like feature with vertical walls.

Interstate Highway I-15 has also experienced problems including repeated patches on a section south of the south Cedar City interchange; the bridge, even farther south, over the interstate to Hamilton Fort (figure 2); and the stretch north of the north Cedar City interchange. The west abutment of the bridge settled 18 inches during the first year it was constructed and has subsequently settled farther, about 12 inches.

Fig. 2 - Hamilton Fort Bridge data



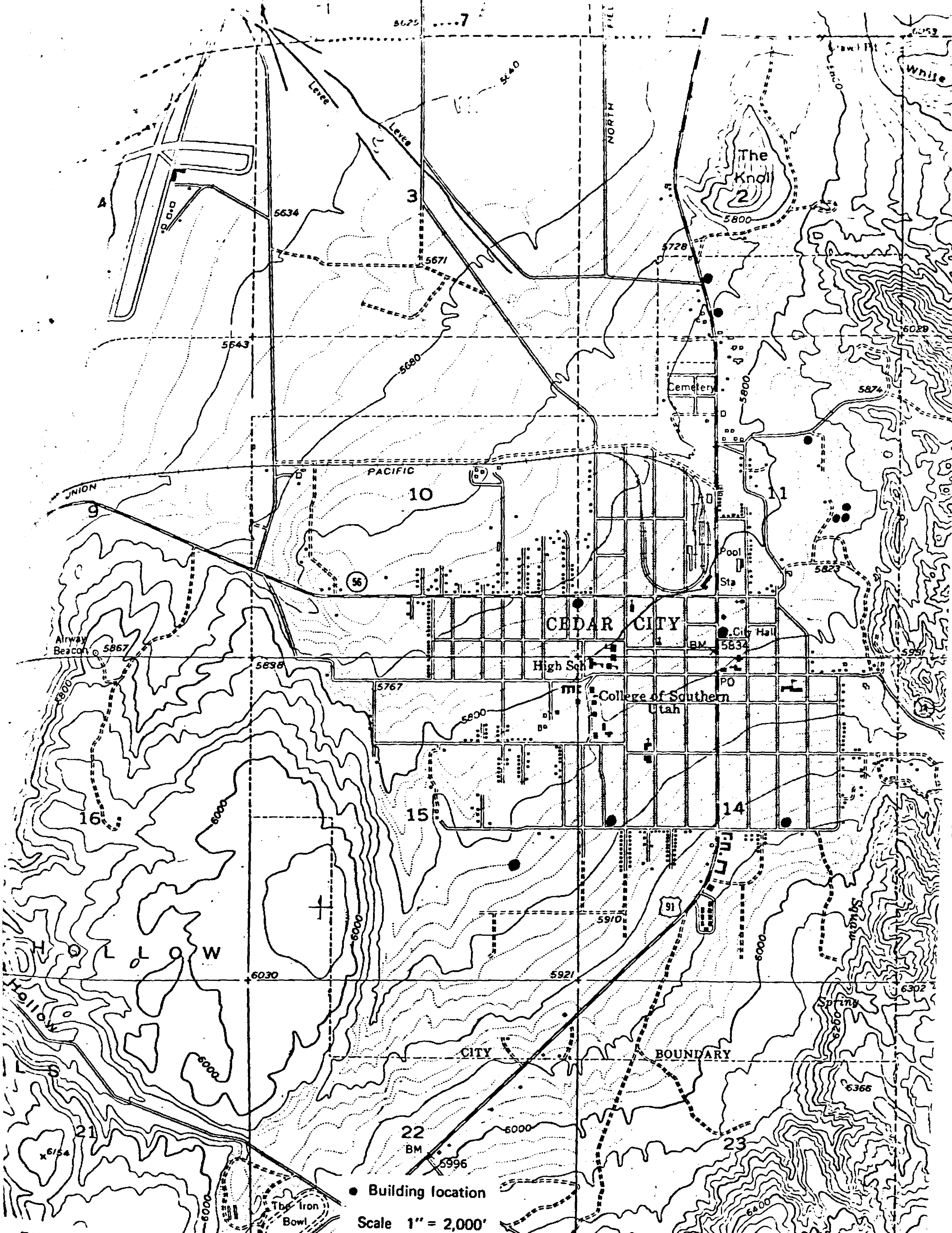


FIGURE 3. LOCATION OF BUILDINGS JACKED UP, FROM SINGLE CONTRACTOR'S RECORDS.

With respect to the Highland Park subdivision, it may be seen (Appendix I) that there is no time element that can be defined for the settling of the homes. Many residents of the Highland Park subdivision reported to the writer damage occurring in the winter of 1976-1977. It is obvious from the county assessor's inspections, however, that damage has been occurring subsequent to home construction, regardless of the date.

Most of the homes affected have basements, and the assessor's notes indicate that some homes had especially heavy reinforced foundations.

GROUND SURFACE STUDY

South of Cedar City it was soon found that the road paralleling the interstate on the east is now quite beset with an irregular grade. In places there are actual arcuate cracks in the asphalt pavement. Some of the cracks could be traced not only across the shoulder of the road, but across the terrain beyond the shoulder onto silty alluvial flats. Alongside the road on the east is a telephone conduit which also had ground cracks in proximity. No breaks have been reported from the telephone company, but their cable can enjoy a considerable degree of deformation before any damage could be done. Tracing ground cracks in the area is not easy because of the inherent nature of the soil. The soil materials consist mostly of very fine sand and silt. This type of material is equally highly susceptible to both wind and water erosion. Features such as ground cracks and holes are easily obscured by surface shifting of the soil.

Other geologic phenomena common in the area which must be considered are underground erosion (piping) and soluble salt in the soil profile. Animal burrowings and activity of man such as backfilling of excavations and waste disposal must also be given careful consideration.

Surface reconnaissance has shown earth movement to be still occurrii in the area of the flood retention dikes and the new subdivision area immediat to the north.

North of Highland Drive is the city golf course with its surface morph undergoing almost continual change. Examination of the course does reveal that the changes are where the geologic materials are in place rather than where the landfilling has occurred (Appendix VII).

It is interesting to note that though landfills are not normally regarded as stable ground, in the vicinity of Highland Drive the two extensive landfill areas are perhaps the most stable. The second filled area is southwest of the Highland Park subdivision at the baseball diamonds. According to Alvin Matheson this location was earlier the site of extensive deep excavation for earth material. None of the asphalt-surfaced parking lots or streets are distressed, and the previous excavation probably explains its stability.

Farther north ground cracks were observed in the immediate vicinity of the State Highway Division district office and north. Landfill had occurred over many years in this vicinity, particularly to the east. Ground cracks had been observed by the city Water Superintendent just west of the drive-in theater to the north, but no trace other than some weed alignment could be found. Garrett Freightlines, immediately to the west, has suffered considerable damage to its facility. On the west side of Main Street subsidence and cracks are seen in the city cemetery, particularly at the north end. Finally, ground cracks and surface subsidence was clearly seen at about 1600 North Main on the east side of the road.

Considerable damage has been seen to buildings all along Main Street, including the State Department of Transportation, State Division of Wildlife Resources, and the Livestock Auction Building. Just to the east the new Federal Building is already showing signs of distress, and a hole in the lawn of a residence at 25 North 300 East was observed.

Surface investigation has clearly demonstrated that a broad zone along the mountain front is susceptible to earth movement.

FAULTING

One of the major active fault systems in the state is the Hurricane Fault. Cedar City is situated astride this fault zone near its northern terminus (Figure 1). The fault is a normal-slip fault with the downthrown block to the west (section B-B', Figure 1). In the vicinity of the Hurricane Cliffs at Kanarraville, southwest of Cedar City, the fault is believed to have a throw of about 8,000 feet (Threet, 1963).

Across Cedar City the position of the fault has not been precisely defined, but is believed highly likely to occur immediately west of the bedrock outcrop comprising Red Hill. Close inspection of the Timpoweap Member (a yellowish gray, resistant limestone) of the Moenkopi Formation, where it is exposed at the site of the pioneer lime kilns east of the Cedar City golf course (east-central part of section 11), reveals evidence for faulting (Figure 1). Fault surfaces are exposed here, and generally the rock is so highly fractured at this location along the front that the rock readily yielded to excavation for use in the adjoining kilns.

An active fault is a fault still capable of generating earthquakes and demonstrating rejuvenation of movement. In historic time there is no record of movement along any portion of the Hurricane Fault system. Nevertheless, the possibility remains that the fault system is relieving the build up of strain by continual slow slippage, termed "tectonic creep." Because the fault zone across Cedar City occurs under alluvial soil material, creep would manifest itself by ground cracks in the soil. The Highland Drive area is in the zone where one might expect to see cracks if tectonic creep were occurring.

Results of this study do not indicate that tectonic creep is a process presently active, but the possibility cannot be 100 percent dismissed.

Faulting may be playing a role in another manner, however. The fault zone is a zone of fractured bedrock which is relatively close to the ground surface in the vicinity of Cedar City. Voids may still exist in the bedrock, either never having been fully healed with mineral matter or resolution of soluble minerals may keep the voids open. Soil material mantling bedrock in the fault zone may be settling into the bedrock voids with the aid of water, gravity, and seismic disturbances. In pursuit of the last potential causative factor, the writer attempted to research some of the seismic history of the area. This was done enlisting the aid of the Southern Utah State College seismograph station director, Harl Judd. A compilation of seismic events was made by going back to the records of the station since its inception in 1969. Appendix III contains the data that was prepared for this study. It should be noted that seismic events in the range of Richter magnitude 1.6 to 3.5 occurred in or extremely close to

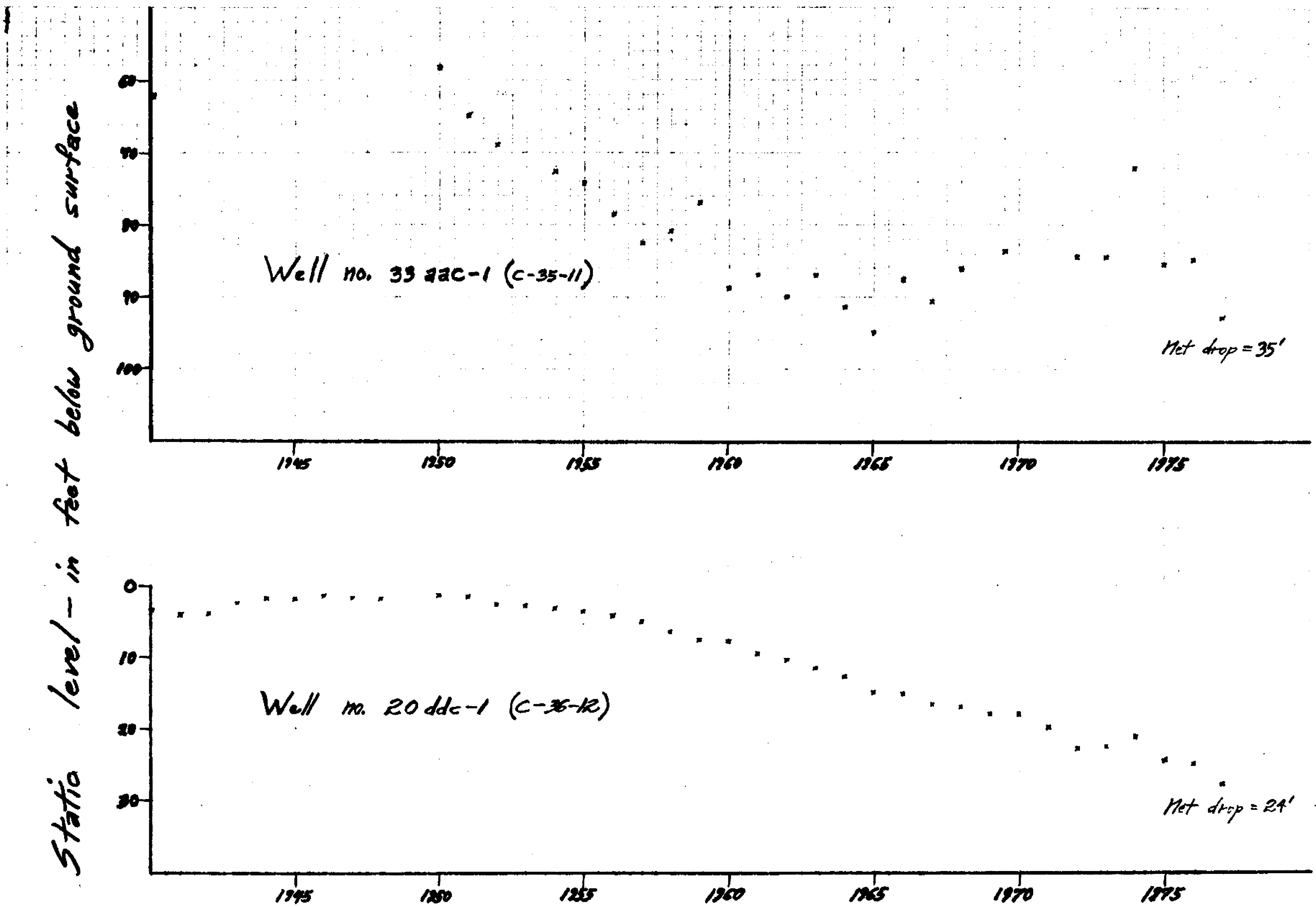
Cedar City in the 91-month period of record. Within 10 kilometers of the station in Cedar City, some 45 events of magnitude range 1.6 to 5.0 occurred during that period of record. It does not seem, therefore, unreasonable to hypothesize that these events are sufficient to be contributory to the displacement of soil particles into voids, thus accelerating the ground surface subsidence. Furthermore, the geometry of the soil-bedrock configuration along the fault zone in the subsurface, together with the topographic relief in juxtaposition to the fault zone, would appear to aggravate horizontal ground motion locally and thereby add to the region's seismic intensity.

Also, the configuration of several reported subsidence features which coincide very closely with the trace of the Hurricane Fault zone (Figure 1) are such as to lend support to this hypothesis. The circular-plan, vertical-walled "sink holes" are described under the "Areal Reconnaissance" portion of this report. Such features are quite likely the result of voids at depth.

Still another possible fault mechanism is that the fault zone, occurring as it does along the margin of the wedge of valley sediments, may be acting as a hinge for dropping the valley floor to the west. The valley floor could be settling due to tectonic processes of earth deformation that remain active or due to ground surface subsidence resulting from the withdrawals of groundwater at depth in the valley fill sediments (Figure 4).

This study has found no evidence in support of either of the latter hypotheses, but neither can be altogether dismissed at this time.

The writer believes it likely that the Hurricane Fault system is partially responsible for ground cracking seen on the surface at Highland Drive, using



See Appendix VII for supporting data available on these wells.

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Fig. 4 - Decline of ground water levels, Cedar City area

the mechanism described earlier with respect to seismic inducement of soil particle movement. It is interesting to note that two seismic events are documented in Cedar City in January 1977 (Appendix III, Table 3) at the time when individual homeowners indicated that there was acceleration of distress of their homes.

EXPLORATION TECHNIQUES

Exploration borings, seismic refraction profiling, and trenching was done to acquire subsurface data.

Seismic Profiles

Seven seismic refraction profiles were undertaken (Appendix IV, Figures 1-7). These varied in length from 350 feet to 1,300 feet. The purpose of using this geophysical technique was to determine the layering of subsurface soils, depth to bedrock, and seismic velocities of soil and rock materials. Soil materials yielded velocities in the range of 1,200 to 2,900 fps (feet per second). Rock velocities varied from 6,200 to 8,250, with weathered rock in the order of 4,400 fps.

Most of the profiling was done in the immediate area of the Highland Park subdivision, but an area to the north was also chosen because of the occurrence of ground cracks and similar geologic materials (Appendix IV, Figure 8).

Exploration Trenching

In order to explore the ground cracks, two test trenches were constructed.

The first trench was oriented in an east-west direction and was

Drill Holes

Five holes were drilled to depths of from 40 feet to 87.5 feet (Appendix V). Three of the five holes were drilled in the immediate vicinity of the Highland Park subdivision and two in the Country Aire Estate trailer park at the north end of town. The latter two holes were sited following a ground surface reconnaissance by the writer which turned up subsidence features in the trailer park. Being north of The Knoll, the soil materials were different at the latter location, particularly with respect to gypsum content.

Air was employed in the drilling process so that moisture content of the soils would remain unaltered and samples would, therefore, be more meaningful.

Samples

Augered holes were required for the seismic profiles in order to place explosives. During the augering operation bulk samples were acquired, logged, and some were later analyzed for soluble salt content.

Borings yielded undisturbed soil samples and some rock core. Testing of these samples was done sufficient to accurately identify the materials and to determine their characteristics with application of water.

The test data can be found in Appendix VI, Tables 1 and 2.

DISCUSSION

The boring logs indicate that the alluvial deposits are comprised largely of sandy silts and clayey silts with varying percentages of sand, gravel, and clay. Zones of silty sand, gravel, and cobbles do occur at various horizons within the alluvium. As was anticipated, most of the situated at the north end of Highland Drive, its western terminus bordering on the street. The trench extended to a depth of 10 feet. This trench intercepted a 100 foot long ground crack which has a strike (orientation) of N. 35° W. At the ground surface the crack is up to 4 inches wide. In this trench the crack was observed to a maximum depth of 6 feet. At the 4 foot depth a 1.5 inch wide opening was observed. The crack appeared to become lost in a 1.5 foot thick, fine sand layer. Dip of the fracture surface varied 5 degrees either side of vertical. This fracture when traced to the south intercepts and cracks a home foundation, but the fracture cannot be traced across the foundation though the home no longer is present on the site.

The second trench is 28 feet in length, 9 feet in depth, and north-south in orientation. Its location was immediately north of the Highland Park subdivision and immediately south of the earth dike that the city constructed on its property. The ground crack intercepted by this trench was traced for a distance of 200 feet along its general strike of N. 80° E. The fracture extended to a depth of 6 feet 8 inches. A one inch wide void was present at a depth of 5 feet 7 inches, and the crack had some slight degree of width to a depth of 6 feet 3 inches. The fracture surface dipped to the south at only a slight divergence from the vertical.

Neither crack had the appearance of being old features recently rejuvenated. Although gypsum was observed in both trenches, there did not appear to be any relationship of gypsum distribution with the fracture surface.

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The majority of the samples tested for consolidation-collapse exhibited moisture sensitivity characteristics. Moisture sensitivity is defined as the characteristic of the soil to collapse and become more highly compressible with the addition of water. Because of extreme variability in gradation, density, moisture content, soluble solids present, etc., a specific key indicator as to the degree of moisture sensitivity versus any one of the above parameters is almost impossible to define. In general, however, it can be stated that the sandy silt and silty clay soils with low to high percentages of soluble solids appear to be more collapsible than coarser grained soils containing low percentages of soluble salts.

Mechanism of Hydrocompaction

Hydrocompation is the term generally applied to this phenomenon of soil collapse. Its general mechanism has been relatively well documented. It occurs when the magnitude of shear stresses between bulky grains comprising the overvall soil material exceeds the shear strength of the bonding mechanism at a given moisture content and load condition. Typical bonding agents are silts, clays, and chemicals. Hydrocompactible soils generally occur when the sediments are deposited without sufficient water to cause normal consolidation. Alluvial fan environments in arid climates where deposition is from more or less viscous flows typically contain significant quantities of hydrocompactible soils. Silt and chemical bonding appears to be of primary importance in the soils in the Cedar City area. Clay bonding, although probably present to some minor extent, is not believed to be significant because of the relatively nonplastic characteristics exhibited by the fine grain portions of the samples tested (Appendix VI, Table 1). Gypsum and calcium carbonate appears to be the predominant chemical bonds.

Whatever the bonding agent it must be regarded as very delicate and easily reduced or completely destroyed with increase in moisture. For the most delicate of bonds, complete saturation of the soil is not required. Rather, moderate increases in the soil moisture are sufficient to initiate collapse. In the case of chemical bonds, the presence of moisture sufficient to cause any solutioning of soluble solids is adequate to break down the bonding. Geotechnical documentation exists also to confirm that the strength of clays and especially silts decreases with increased moisture content.

In addition to the collapse of the bonds, the solutioning out of chemicals from the soils also contributes to the total subsidence. It is likely, however, that this is of much less significance than the breaking down of the chemical bonding which was previously discussed.

It is estimated that over 90 percent of the subsidence which has occurred in any specific area and specifically in the Highland Park subdivision area is the result of relatively short term and immediate effects of chemical, silt, and/or clay breakdowns. It would appear that a large, continuous source of water which contains low percentages of soluble salts would be required before significant solutioning subsidence could result.

The Problem

Almost any known source of water, natural or manmade, under the right conditions can induce hydrocompaction. Normally, land developments do add moisture to the soil. Runoff is increased and frequently concentrated to certain localities. Sewer lines, water lines, storm drains, curb and gutter, landscape irrigation, and downspout discharge all contribute to the increase of moisture content in the subsurface hydrocompactible soils. Although infiltration can be reduced by requiring specific grading, irrigation restrictions, and other measures, it can never be altogether stopped. The potential for soil collapse is, therefore, always present. Once initiated, the problem becomes aggravated by utility line breaks and ground surface contour modification.

Efforts to Correct the Problem

When existing facilities begin to experience detrimental subsidence, it is necessary to terminate inflow of any and all waters into the subsurface environment. In the case where ground cracks already appear, they afford paths for the steady downward migration of water. They are also planes of weakness.

Success at any remedial action is doubtful. Relevelling of damaged homes where the subsurface sequence of collapsible soils is deep is at best an intermediate remedy. When it can be shown that nonmoisture sensitive, that is stable, soils are existent at a relatively shallow depth, underpinnings extending to the stable soils can be installed. Although this system can be quite positive in reducing subsequent movements, it is very expensive.

In undeveloped areas with proposals under consideration, precautions must be taken. There must be insistence upon a detailed subsurface investigation. Because of the variability of alluvial soils, a rather large number of exploratory borings and laboratory tests will be required for accurate definitions of subsurface conditions. If hydrocompactible soils are encountered, the actions that can be taken will be basically dependent upon the thickness of those deleterious soils.

Deeper foundations can be considered and/or support upon granular or replacement fill of some type extending down to sound geologic materials may be possible (costs, Appendix VII). Although quite expensive when compared to conventional foundation systems, especially for single family residential structures, it should be noted that these techniques have been utilized elsewhere. Note, however, that in the case of the Hamilton Fort Bridge, caissons did not prove to be successful. The problem soils obviously extended to a depth in excess of 20 feet at that location (Figure 3).

Method of another technique is appropriate here. Presaturation, with or without preloading, of moisture sensitive soils can be attempted. This technique is not regarded to be as positive a measure as deep foundations or replacement of materials. Accurate determination as to whether this technique would be applicable under the circumstances encountered in the Cedar City area would be dependent upon very sophisticated and long term, long scale tests.

With respect to the design of a home, there does not appear to be anything structural or architectural that can be done economically to eliminate the possibility of detrimental damage due to hydrocompactible soils. This conclusion has been reached after consultation with other experts on the subject.

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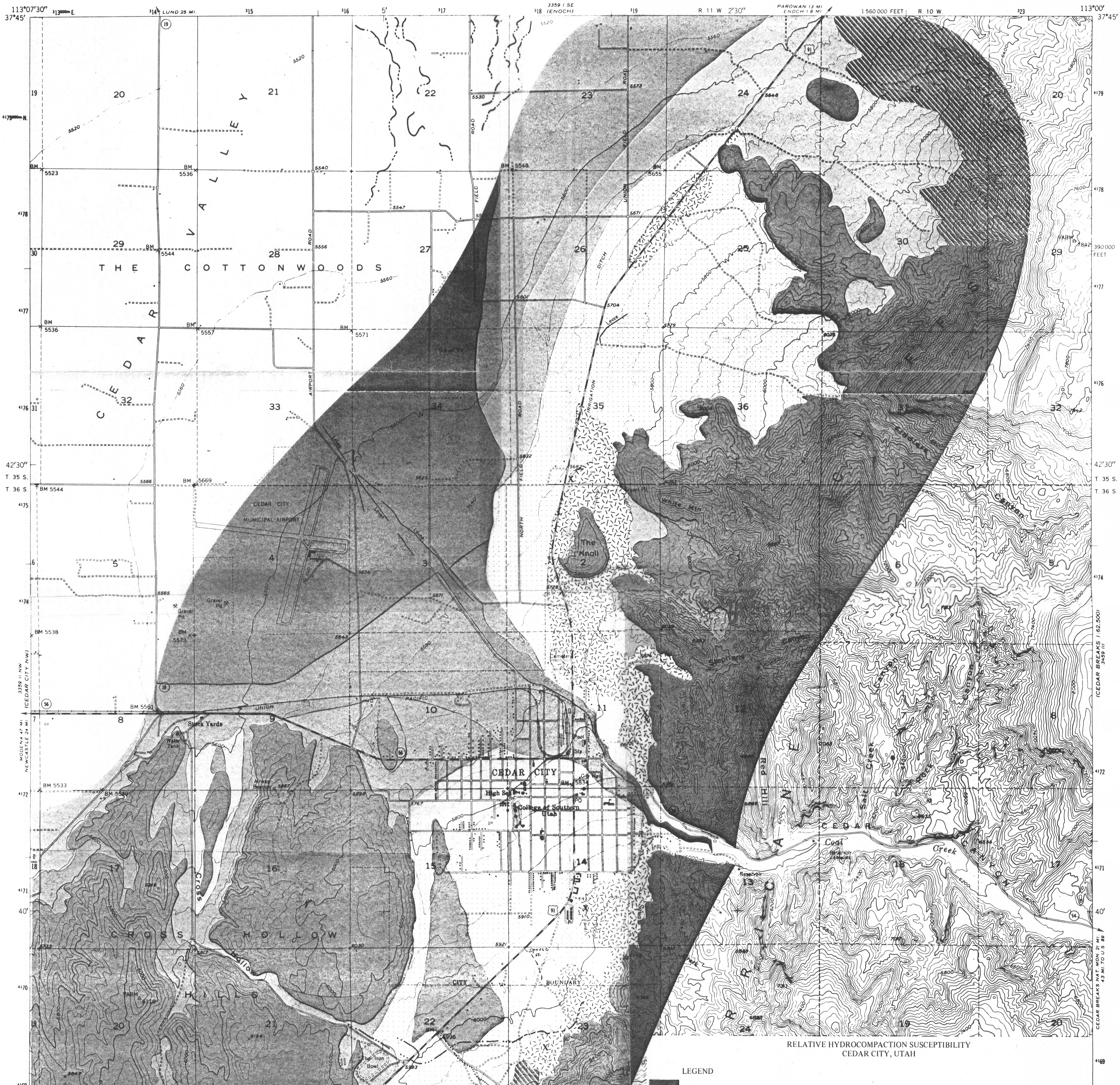
STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

Map 46

Plate to accompany UGMS Report of Investigation No. 124, "Ground Surface Subsidence in Cedar City Utah," by Bruce N. Kaliser, January 1978.



Relative degree of susceptibility to hydrocompaction is depicted on this map (see legend). Geomorphologic analysis, with aerial photographs at a scale of 1:20,000 as the primary tool, was principally employed in the preparation of this map. Only limited field checking has been done; no drilling, sampling or testing undertaken other than that shown in RI No. 124.

This map has been constructed utilizing all information available through March 1978, and is subject to revision as additional data from future drilling becomes available.

Purpose of this map is to inform all interested government agencies, private enterprises, and individuals planning to construct new buildings or to purchase existing buildings of a potential natural hazard from unstable ground, termed "hydrocompaction". This geologic phenomenon may be aggravated by activities of man.

Appropriations No. 01-61-03
Archives Approval 7800157

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Map prepared for City of Cedar City by State of Utah, Geological & Mineral Survey.

Since this is a natural hazard, no liability is implied or assumed by the State of Utah, Four Corners Regional Commission, the City of Cedar City, nor the county of Iron County.

April, 1978

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

CEDAR CITY, UTAH
U.S. Geological Survey 7½' Quadrangle