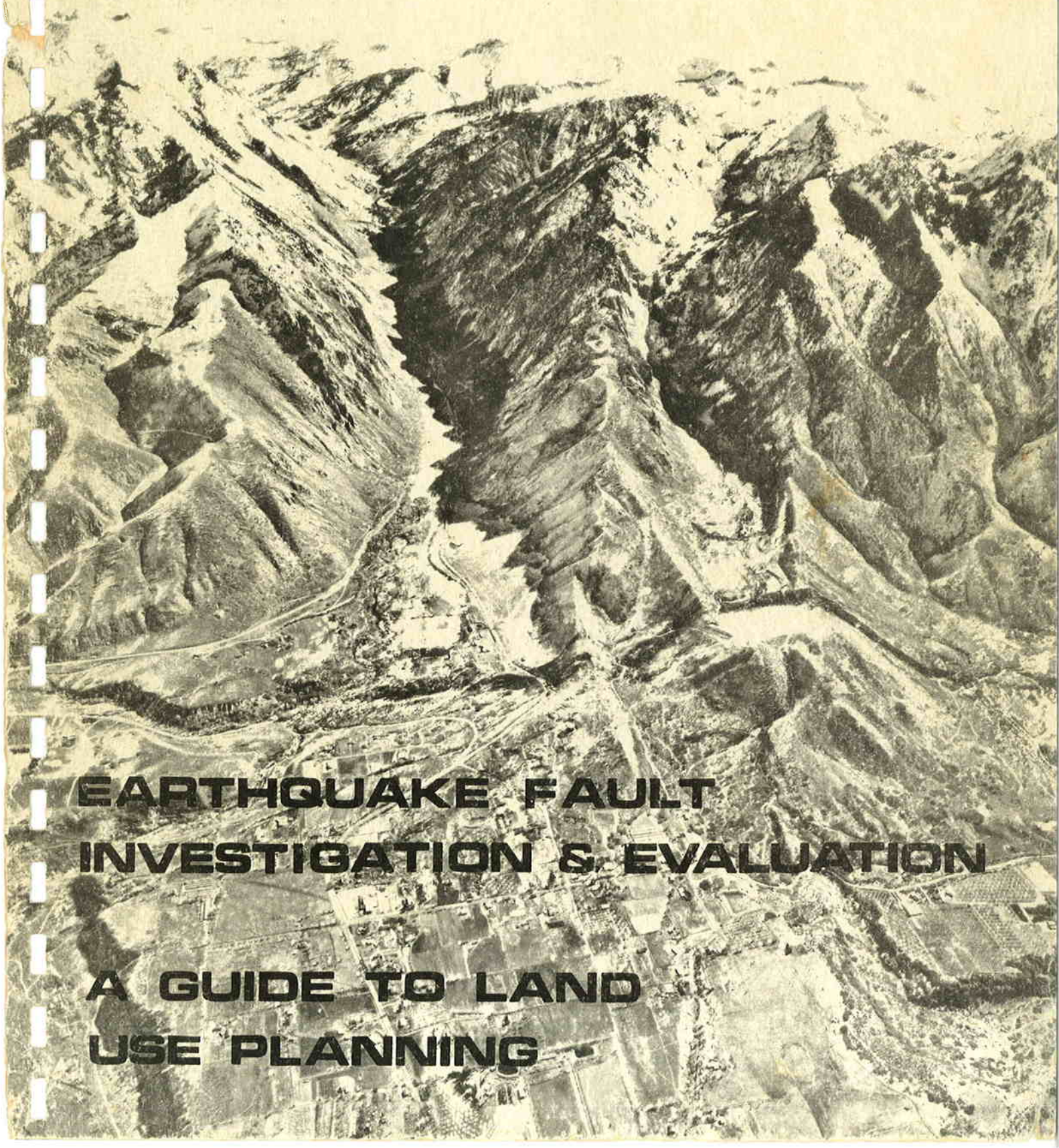
WASATCH FAULT

NORTHERN PORTION



EARTHQUAKE FAULT INVESTIGATION & EVALUATION

A GUIDE TO LAND USE PLANNING

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Project G-12069

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Attention: Dr. William P. Hewitt
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Gentlemen:

WASATCH FAULT - NORTHERN PORTION
EARTHQUAKE FAULT INVESTIGATION AND EVALUATION

The enclosed report and maps presents the results of our investigation and evaluation of the Wasatch fault from near Draper to Brigham City, Utah.

The completion of this work marks another important step in Utah's forward-looking approach to minimizing the effects of earthquake and geologic hazards.

We are proud to have been associated with the Utah Geological and Mineralogical Survey in completing this study, and we appreciate the opportunity of assisting you with such an interesting and challenging problem. If we can be of further assistance, please do not hesitate to contact us.

Very truly yours,

Lloyd S. Cluff

Lloyd S. Cluff
Vice President and
Chief Engineering Geologist

LSC:jh

Enclosure

WASATCH FAULT

NORTHERN PORTION

EARTHQUAKE FAULT INVESTIGATION & EVALUATION

BY

LLOYD S. CLUFF, GEORGE E. BROGAN & CARL E. GLASS

PROPERTY OF
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

A GUIDE TO LAND USE PLANNING

FOR

UTAH GEOLOGICAL & MINERALOGICAL SURVEY

WOODWARD·CLYDE & ASSOCIATES
CONSULTING ENGINEERS AND GEOLOGISTS
OAKLAND, CALIFORNIA

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ACKNOWLEDGEMENTS

We would like to acknowledge the assistance of the following individuals:

Dr. Ray E. Marsell, Consulting Geologist, who has studied and mapped the Wasatch fault throughout most of his professional career. His assistance and guidance were invaluable.

Mr. Bruce N. Kaliser, Engineering Geologist, Utah Geological Survey, who gathered pertinent information and assisted in our field studies, for which we are grateful.

Dr. David B. Slemmons, Professor of Geology, University of Nevada, who served as a Consultant during this investigation. His guidance and suggestions throughout the entire study were of utmost assistance.

Messrs. George E. Brogan and Carl E. Glass were our Staff Geologists assigned to this project.

INTRODUCTION

Utah is traversed by several active earthquake faults as shown on Figure 1. The Wasatch fault is the most important single active fault because of its proximity to the major areas of population and the industrial development located along the Wasatch front. This leads one to ask the following questions: What are the consequences of future fault displacements? Does living near and along an active earthquake fault pose serious problems in regard to potential hazards to life and property? If so, what are and where are these hazards and can they be evaluated in terms of taking positive action to minimize the hazards to an acceptable level? There are no simple answers to these questions.

Many variables influence the degree of risk that may be associated with urban development near and across an active fault. These variables include geologic factors such as: the exact location of the fault, type of fault, direction of displacement (horizontal or vertical), amount of displacement, magnitude and location of the resultant earthquake, and the near surface geologic and soil conditions. Land-use factors such as building occupancy, building height, structural system, and design and quality of construction also influence the degree of risk.

The purpose of this report is three-fold; first, to briefly explain the various hazards that are related to active faults and earthquakes; second, to more precisely delineate the location

of the Wasatch fault and indicate the potential hazards that exist along it; and third, to recommend specific steps that can be taken to minimize these potential hazards.

In order to accomplish these objectives this report has been organized and prepared as follows: The first portion briefly comments on potential hazards related to the Wasatch fault, more or less from a philosophical point of view. The next section explains the purpose, scope and methods of this investigation and evaluation. The following section presents the results of the study including (1) a series of maps showing the location of the Wasatch fault from near Draper north to Brigham City, (2) conclusions and recommendations, and (3) examples of ordinances from other areas located near earthquake fault zones.

A section entitled, "General Discussion of Faulting and Earthquakes," is presented as Appendix A of this report. Persons not familiar with active faults, associated earthquake problems, and related land-use planning problems should read Appendix A to ensure a common understanding.

Sudden displacement of the ground surface by fault movement represents a hazard of considerable engineering significance. Rapid fault displacements in historic time on active faults during a single event have reached amounts as great as 35 feet vertically and 25 feet horizontally. It is significant that almost all such displacements have occurred as discrete breaks

along faults that had been or could have been recognized had sufficient studies been conducted to locate them. Many displacements have occurred along faults that had clearly recognizable evidences of earlier historic or prehistoric breaks along the same line. Also, in recent years there has been increasing awareness of the problem of slow fault slippage. A number of faults in California as well as other parts of the world have been studied in detail from this point of view. It is evident that a considerable amount of nonseismic fault creep motion is occurring in many regions traversed by active faults. These slow fault motions have, in some cases, been the cause of considerable damage to structures built astride the fault zone.

During a quiescent period of an active fault, when there has been no significant fault movement, there is, unfortunately, a tendency for a complacent "it can't happen here" attitude to develop along with the feeling that active faults and earthquake hazards have been overrated and that they do not really pose an important problem. The risk from fault displacement depends not only on the location of the fault and seismic activity of the region, but also on the population density and economic development along the fault. If the fault displaces the ground through an unpopulated area, it does not constitute a hazard; if an earthquake strikes in an undeveloped area, it cannot cause an economic disaster. These hazards are potential hazards to areas where development is contemplated

along and across an active fault. In these respects, the active fault problem in Utah is becoming more serious because a major portion of the population of Utah is located along and across the active Wasatch fault. Therefore, future planning can avoid or reduce the risk that is associated with future fault movements along the Wasatch fault.

As population increases, there is a tendency to build on marginal land or to use less desirable sites. These land-use problems are becoming increasingly serious along the Wasatch fault, however, it is not clear precisely how they should be treated. It would seem unwise to make large development and construction investments on sites that will almost certainly be destroyed during the next major fault movement. But neither would it be prudent to prohibit use of all land within and immediately adjacent to the fault zone. At present, these hazards and risks are not defined to the extent that value judgments can be made concerning practical solutions to the fault risk problem. Knowing that future fault displacements are likely to occur along the Wasatch fault, precautions must be taken to minimize the loss of property and life from the effects of fault movement. Public welfare along the Wasatch fault depends upon answers to the following questions: Where is the Wasatch fault? What will happen as the result of future fault displacements? What will be the location and extent of surface ground rupture from fault movement? How frequently will fault displacements occur? How much displacement is

reasonable to expect in a single fault movement? How can planning, zoning, development, and construction be controlled to minimize and reduce the hazards? The answers to questions such as these are required if rational decisions are to be made to reduce the risk to an acceptable level.

The fault risk problem is not a simple question of either planning or designing for complete protection or ignoring the fault altogether. From the point of view of society, neither of these alternatives is acceptable. To establish an acceptable, efficient, and practical solution will require a greater knowledge of the Wasatch fault and its potential effects on works of man. The most recently active portion of the Wasatch fault, along its entire length, has never been sufficiently mapped nor its exact location and extent known. Accurate determination of the Wasatch fault and full evaluation of its significance can only be accomplished by extensive geologic investigations followed by interdisciplinary evaluations involving the disciplines of geology, engineering, and planning. The geologic investigations must utilize various new techniques that have been developed within the last few years. These methods include: special low sun-angle aerial photography, field mapping, and subsurface investigation.

A comprehensive investigation and evaluation to fully determine the exact location and significance of all active fault features and related hazards would entail the following steps:

A. Preliminary Regional Geologic Investigation and Evaluation

1. Special low sun-angle aerial photography.

2. Preliminary aerial photo interpretation.

3. Preliminary field reconnaissance.

4. Preparation of maps showing approximate location and extent of active fault zone and related hazards.

5. Preliminary regional evaluation of risk from faulting.

Upon completion of the above, sufficient preliminary information exists to establish general regional land-use planning guides. This will allow urban development to proceed on a regional basis while indicating where potential hazards exist so that more detailed investigations can be undertaken to more fully evaluate their magnitude, extent and significance.

B. Detailed Investigations and Evaluation

1. Detailed aerial photo interpretation.

2. Detailed field mapping.

3. Preliminary subsurface investigations including

geophysical methods (refraction seismic, magnetic and resistivity); and selected trenching and drilling.

4. Evaluation of fault related features in conjunction with structural engineering considerations.

5. Preparation of fault risk zone maps and a corresponding guide to land-use planning taking into consideration (a) type of occupancy or land use; (b) type of construction; (c) structural systems and height which will house the occupancy.

Upon completion of Step B, sufficient information will exist to determine the feasibility of certain types of land use and building occupancy. The next step may warrant even more detailed investigations and evaluations of sites for specific land use or building occupancy.

C. Detailed Site Investigation and Evaluation

1. Detailed extensive subsurface investigations utilizing mainly trenching and drilling.

2. Detailed structural engineering evaluation.

Upon completion of Step C, a specific site or proposed land use could be fully evaluated from all aspects of active faulting and related hazards.

Ideally, the above investigation and evaluation (Steps A through C) is what should be completed along the entire length of the Wasatch fault if high density urban development is desired. However, because of the time and costs involved our present study was limited to Part A "Preliminary Regional Investigation and Evaluation" of the northern portion of the Wasatch fault.

AREA OF INVESTIGATION

The present investigation emcompasses the "northern portion" of the Wasatch fault extending from just south of Draper to Brigham City as shown on Figures 1 and 2. Two areas were chosen for more detailed study; 1) Corner Creek to Little Cottonwood Canyon, and 2) North Ogden. These areas were chosen for two reasons; 1) the lack of high density development makes identification of fault features easier, and 2) both areas are potential areas for future expansion of urban development. It is reasonable to assume that the other areas that have not received as detailed a study would show similar degrees of faulting and related ground disturbance. It is also important to point out that because of extensive grading, construction, and development along certain portions of the Wasatch fault, the geomorphic and topographic features diagnostic of recent fault activity have been obliterated and destroyed.

The results of our investigation are presented on a series of maps as follows: (1) there are 16 separate 7½ minute Quad maps; (2) these 7½ minute maps have been systematically segmented into 21 separate 11 by 17 map sheets that are bound within this report. These 21 sheets cover the overall segment of the fault under study at a scale of 1:24,000. The two areas chosen for more detailed analysis are shown on two enlarged map sheets as well as 8 segmented map sheets A through G. Sheets A-G are also bound in this report.

METHOD OF INVESTIGATION

Our method of investigation entailed the following steps: (1) review of existing published and unpublished information, (2) special low-sun angle aerial photography, (3) photo interpretation, (4) reconnaissance field study, and (5) preparation of maps and report.

Review of Existing Data

We reviewed all existing available published and unpublished information pertaining to the northern portion of the Wasatch fault. The main purpose of this review was to establish the width of the area to be photographed. Information pertaining to the location of the Wasatch fault shown by previous workers was not utilized in the final preparation of the maps accompanying this report. The main sources of information included published and unpublished work by Dr. Ray Marsell, previous unpublished mapping by L. S. Cluff for Woodward-Clyde & Associates, Utah Geological and Mineralogical Survey published and unpublished work, and published information by the U.S. Geological Survey.

Special Low Sun Angle Aerial Photography

Over the past few years we have developed a new technique of aerial photography that enables one to see fault features and patterns of faulting unrecognizable on conventional aerial photographs. This new technique was developed in 1967-1968 by Cluff and Slemmons (Amer. Geoph. Union, Transactions, V50, May 1969)

and uses low angle sun illumination to accentuate fault features. The object is to use shadowing and lighting effects produced by optimal sun illumination conditions. This is done by photographing at the ideal time of day and year to enhance characteristic features which are difficult or impossible to see on conventional aerial photos.

The results of this new photography along the Wasatch fault are illustrated in Figures 3 through 18. Figure 3 is a reproduction of a conventional vertical aerial photograph taken along the Wasatch fault just south of Bells Canyon. Figure 4 is a vertical aerial photograph utilizing the low sun-angle technique of the same area as Figure 3.

Photographs for the present project were flown in both winter and spring, and in the morning and evening at 1:12,000 to assure maximum coverage. In addition, photos are special scales (1:6,000; 1:5,000) were flown of specific areas chosen for more detailed study.

Aerial Photo Interpretation

The aerial photographs were studied in stereo pairs and faults and related features were mapped on clear plastic overlays. The most significant of these fault-related features were then optically plotted on the 7½ minute Quad Sheets.

Field Reconnaissance

A brief field reconnaissance was conducted to field check the photo interpreted features. It is important to emphasize that because of time limitations, the scope of this investigation did not permit comprehensive field verification of all photo-interpreted features. However, we have plotted only those features that we feel confident may possibly be fault-related in context with the defined map symbols.

RESULTS OF INVESTIGATION AND EVALUATION

Upon completion of all aerial photo interpretation and field checking, a series of maps and a report were prepared as discussed earlier. The map legend discussion is reproduced here for continuity.

All lineaments were mapped using special low sun-angle illumination aerial photographs taken especially for this project. The basic scale of the photographs is 1:12,000 (1 inch = 1,000 feet) although scales of 1:5,000 and 1:6,000 were flown for detailed investigation of specific areas. Fault related features were optically transferred from photographs to 7½ minute topographic base maps using a vertical sketchmaster and were checked by inspection and scale dividers.

Accuracy

Fault related features plotted on the map generally have a lateral accuracy of ±100 feet. In areas of high relief or where cultural development such as roads, fence lines, and other similar features are lacking, the accuracy may be no better than ±200 feet. In urbanized areas the fault features have been modified and obscured by city development. In these areas only the most obvious scarps are plotted and more detailed studies are needed to locate the less prominent secondary faults.

Purpose of Maps

These maps are intended as an aid for general regional land-use

planning. The information presented is intended to provide a framework for more detailed investigations and evaluations. We are confident that the features plotted as Class I faults are the locations of the most recent surface fault ruptures. The Class I features have significant vertical relief or extend from surface ruptures having significant vertical relief.

It is our belief that all the Class I lineaments are well-defined topographic features that mark the most recent surface fault ruptures. They are believed to have been mostly produced by rapid fault displacements associated with strong earthquakes. Most Class I ruptures are undoubtedly the result of repeated fault displacements that are concentrated along previously established planes of weakness. Therefore, the Class I faults are the most likely candidates for significant future movements. Some fault movement along the Wasatch fault may be by slow tectonic creep as has been documented along other active faults.

The Class II features are probable surface faults. They have little vertical relief and may be secondary fault-related features associated with ground failure or graben development.

The Class III features are possible surface faults. They have little or no vertical relief. Most of them appear to be related to the Class I and II fault features; however, some Class III features may represent erosional fault line features or

shoreline features and this should be taken into consideration in more detailed investigations. The Class III features are shown because we feel they are possibly fault related and are important enough to be considered for further investigation and evaluation. Our confidence level decreases from Class I to III.

It is important to understand that some minor fault breaks may not have been identified or recognized or they may be confused with shoreline features, again emphasizing the need for more detailed surface mapping and subsurface investigations.

The most recent movements on the Wasatch fault are predominantly vertical, with the mountain block being displaced relatively upward in respect to the valley block. Because of the vertical movement and the geometry of the fault plane, past movements along the Wasatch fault have produced grabens, and tilted blocks adjacent to the main fault break. Future movements are expected to also produce tilted blocks and this should be given serious consideration in locating high-rise buildings or other structures that cannot tolerate tilting or changes in lines of level. Tilting should be of prime concern in more detailed investigations and evaluations.

Landslides are common along portions of the Wasatch fault. Many of them are outlined on the prepared maps. Some are presently active and some appear to be in a state of equilibrium.

The landslide debris deposits are important because, even though some appear not to be presently moving, they are potentially unstable, especially if they are altered or disturbed. Disturbances by earthquakes, fault movements, man-made cuts or heavy rainfall could re-activate the slide mass. Therefore, detailed investigations must be carried out before development is allowed near these landslides.

DESCRIPTION OF FAULTING BY AREA

Jordan Narrows to Corner Canyon

From Jordan Narrows to Corner Canyon the faulting appears subdued exhibiting dips or slopes of less than 20 degrees. All fault features have been modified by post-faulting Lake Bonneville erosion, and consist of vegetation lineaments, tonal changes, fault-controlled drainage and anomalous breaks in slope. The most obvious escarpments in this area are three arcuate escarpments trending from Corner Canyon to approximately the State Prison. Erosional differences between the top or upper feature and the lower feature suggests that the faulting has been modified by lake erosion. They appear to transect contour lines when plotted on topographic maps. The subtle nature of the scarps in this area dictated the Class III classification and suggests that the area has been active less recently than areas to the north. The major faulting directly related to the Wasatch fault appears to cross the hills near Corner Canyon. Many of the Class III features may be the result of ground failure caused by strong shaking.

Corner Canyon to Big Cottonwood Canyon

The faulting between Corner Canyon and Big Cottonwood Canyon is characterized by high, steep scarps (generally greater than 35 degrees); intense shattering; tilting and graben development; and spring activity along some of the major scarps. This area was chosen for detailed study because of its complexity and

extremely fresh nature of faulting. Mud flows and landslides which could have resulted from earthquakes have been subsequently faulted and displaced. In places, relatively large areas have been faulted and tilted eastward toward the Wasatch Range, in one case forming an area of internal drainage which is now being utilized as a pasture area and turkey ranch.

Several periods or episodes of faulting are represented in this area, particularly at Bells Canyon where the younger, steeper scarps are found progressively outward from the range. The total accumulated vertical displacement measured along one of the moraines was 110 feet. This is thought to be the result of more than one displacement (probably several).

Big Cottonwood Canyon to Fort Douglas

Faulting in this area has been largely modified by construction and urban development and appears as a large escarpment trending from approximately Tolcats Canyon through the Cottonwood Mall Shopping Center, up to and around the brick kilns and ending just northwest of the University of Utah. This fault is represented on our map by a single Class I line placed at the base of the slope. During future fault rupture, faulting may occur in a wide zone along the fault not unlike the faulting observed to the south near Bells Canyon Reservoir.

Fort Douglas to Centerville

Faulting between Fort Douglas and Centerville exhibits characteristics similar to the faulting between Jordan Narrows and Corner Canyon. The fault scarps have been modified by lake erosion and appear to be older than the two areas immediately south.

Several linear features indistinguishable from beach or bar deposits were noted on our photographs west of the Union Pacific Railroad tracks extending from Beck's Hot Springs to Centerville. These features were not topographically prominent enough to place undue importance on them by plotting them on the map. However, they do coincide with the projected continuation of the Wasatch fault through Beck's Hot Springs, and the possibility that they are fault related should not be completely overlooked with respect to future development in that area.

Centerville to North Ogden

The faulting between Centerville and North Ogden exhibits many of the same characteristics as those between Corner Canyon and Big Cottonwood Canyon, without the intensity of shattering. Several large landslides also exist with spectacular examples in Ogden at the mouth of Ogden Canyon and northeat of North Ogden near Rice Creek Spring. Ancient landslides may also exist and may explain the nonlinear nature of the faulting in many places. In some instances, the fault scarps diverge westward,

out from the range for several hundred feet then move back to rejoin the base of the range. These features may have been landslides of a fluid nature and the possibility that the faulting actually trends linearly across instead of around the toe should not be overlooked.

The feature cutting diagonally through Ogden is a break in slope which was given a classification of III and has heavy cultural development along it. This break joins the main fault near Waterfall Canyon and warrants careful investigation as we believe it is fault related.

North Ogden to Nerva

Faulting in the area between North Ogden and Nerva appears more subdued and less recently active than the area south, with the exception of a complex zone of faulting in the pole patch area. The patterns and complexity in this area suggest that secondary effects (ground failure) such as landslides and/or liquefaction may have played important roles in the present geomorphic features. This possibility dictated the Class II lines on the map.

Nerva to Brigham City

This area is similar to the area between Corner Creek and Big Cottonwood Canyon, but not as intensely faulted. Tilted blocks, en echelon fault scarps, graben development and large fresh scarps are evident. The Class I faulting starts east of Nerva and continues almost continuously to Willard. From Willard to

Brigham City, the faulting develops more en echelon features and becomes less continuous.

CONCLUSIONS

1. The Wasatch fault is part of a zone of active faults extending from southern Utah into Idaho and Montana. This zone has been associated with strong earthquake activity in the past and major earthquakes are expected in the future. Significant fault displacements are anticipated along the presently known active faults.

2. The Wasatch fault is considered active on the basis of geologic and seismologic evidence. The faulting along the length of the Wasatch fault exhibits fault features typical of recently active faults.

3. It is probable that future fault displacements will follow the most recently developed planes of weakness. The most likely locations for future major surface fault ruptures will be along lines marked on the accompanying maps as Class I. Minor displacements due to branch or splinter faulting or ground failure will most likely occur along Class II and Class III lines.

4. Vertical deformation may take place as a result of displacement during fault movement. Such deformation may uplift, depress or tilt the land surface for considerable distances (as much as several hundred feet) on either side of the causative fault. Several instances of tilted ground were found along the study area near the fault and in planning stages this should be considered as a definite hazard to multi-story or high-rise construction.

5. Aside from surface fault rupture, the area may be subjected to other earthquake effects such as strong shaking and ground failure. These effects are directly related to the intensity of shaking and the response of the foundation soils to the earthquake vibrations. The proximity of a particular site to an active fault is not as important as the ground conditions beneath the site. Therefore, it is possible to have a site located near an active fault that may be comparatively safer than a site having poor soil conditions located several miles from the fault.

6. Several landslides exist along the Wasatch Range front coincident with the Wasatch fault. An earthquake of the size which is capable of occurring there could cause slides and rock falls of large proportions, primarily affecting the areas adjacent to the range front.

7. The opinions and conclusions set forth in this report and the resulting recommendations attempt to set guidelines for general regional land-use planning near the Wasatch fault in order to avoid the most dangerous areas, and to minimize potential damage during a major earthquake.

RECOMMENDATIONS

Before development is allowed along the Wasatch fault, comprehensive geological and engineering investigations and evaluations should be required. These investigations should define the locations of surface fault ruptures and other geologic hazards on or near the proposed development Once these features have been accurately defined, an estimate should be made, with appropriate supporting data, as to the extent and magnitude of movement which should be anticipated for design purposes and the estimated probability of occurrence.

Attention should be given to evaluate the overall site stability to assure that the site can be expected to remain substantially intact during and subsequent to the maximum credible earthquake or fault displacement. Although some cracking of the ground and cracking of pavements might occur, it should be expected that there would be no large fissures, offsets, lateral movements or vertical slide movements of more than a few inches.

In evaluating landslide potentials, as well as locations of soil strata which might be subject to reduction of strength or liquefaction potential, it is recognized that complete certainty in the locations of such strata and in the evaluation of behavior during an earthquake is not practically feasible. Therefore, the studies should be carried to a degree of thoroughness which would indicate a high order of dependability of the overall conclusions. The recommendations

reached should include an appropriate evaluation of the limits of confidence which might be expected based on the extent of studies made.

Schools, hospitals, fire houses, and other buildings of high socio-economic importance should not be built over earthquake faults. High-pressure transmission lines such as water, gas, petroleum, chemical, and other volatile products should avoid crossing the Wasatch fault if possible. Where these transmission lines must cross the fault, they should do so near the surface and at right angles to the strike of the fault. They should encorporate such safety features as flexible joints and automatic shutoff valves to be activated immediately if the lines are damaged by fault movement or earthquakes.

In view of the many different uses which may be planned for land areas along the Wasatch fault and the variations in the geologic, soil, and foundation problems which require consideration, it is not feasible at this time to prescribe specific investigations, tests, or analyses which would be appropriate for all of these varied requirements. The object of the foregoing discussion, therefore, has been directed toward outlining the nature of the problems which might require consideration in any specific land use. It is believed that the implementation of policies required to answer these problems will require the formulation of a highly competent Review Board which will be charged with the responsibility of evaluating

the appropriateness of the specific investigations and analyses which may be required for any particular land use or project. The appropriate scope and extent of such investigations and studies should be sufficient to enable the knowledgeable professional geologists, engineers, and other specialists on the Board of Review to ascertain that the severity of each particular type of problem has been reasonably evaluated, and the margins of safety provided are appropriate in relation to the consequence of occurrence of the particular problem under consideration. It is expected that, as work is carried on under this program, there will develop a sound body of information concerning investigative and design and construction procedures. This will enable desirable projects to be carried out with an optimum balance between the factors of cost, risk, and function; this can be accomplished while encouraging a continued improvement in the "state of the art" regarding application of technical knowledge to advantageous use of the properties concerned.

The responsibility of the Board should be as follows: 1) establish and revise safety criteria for the Wasatch fault and structures therein with respect to risk zoning; 2) review all proposed development projects for the adequacy of their specific safety criteria, and to make recommendations concerning these criteria; 3) gather and make available data developed from specific projects under their jurisdiction; and 4) to

complement the functions of local building departements and local city and county planning departments.

The organization of the Interdisciplinary Consulting Review Board should consist of an equal number of geologists, soil engineers, and structural engineers. An architect and a planner should also be on the Board. Of the total membership, no more than half of the members should have principal employment in one of the following fields: 1) private employment, 2) academic employment, and 3) governmental employment.

It is recommended that this same investigation and evaluation be completed for the southern portion of the Wasatch fault (Corner Canyon to Gunnison).

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Wasatch Fault Zone--Salt Lake City Aqueduct System, City Creek Canyon to Provo River, Salt Lake and Utah Counties, Utah, 1969, Utah Geological and Mineralogical Survey, Map No. 27.

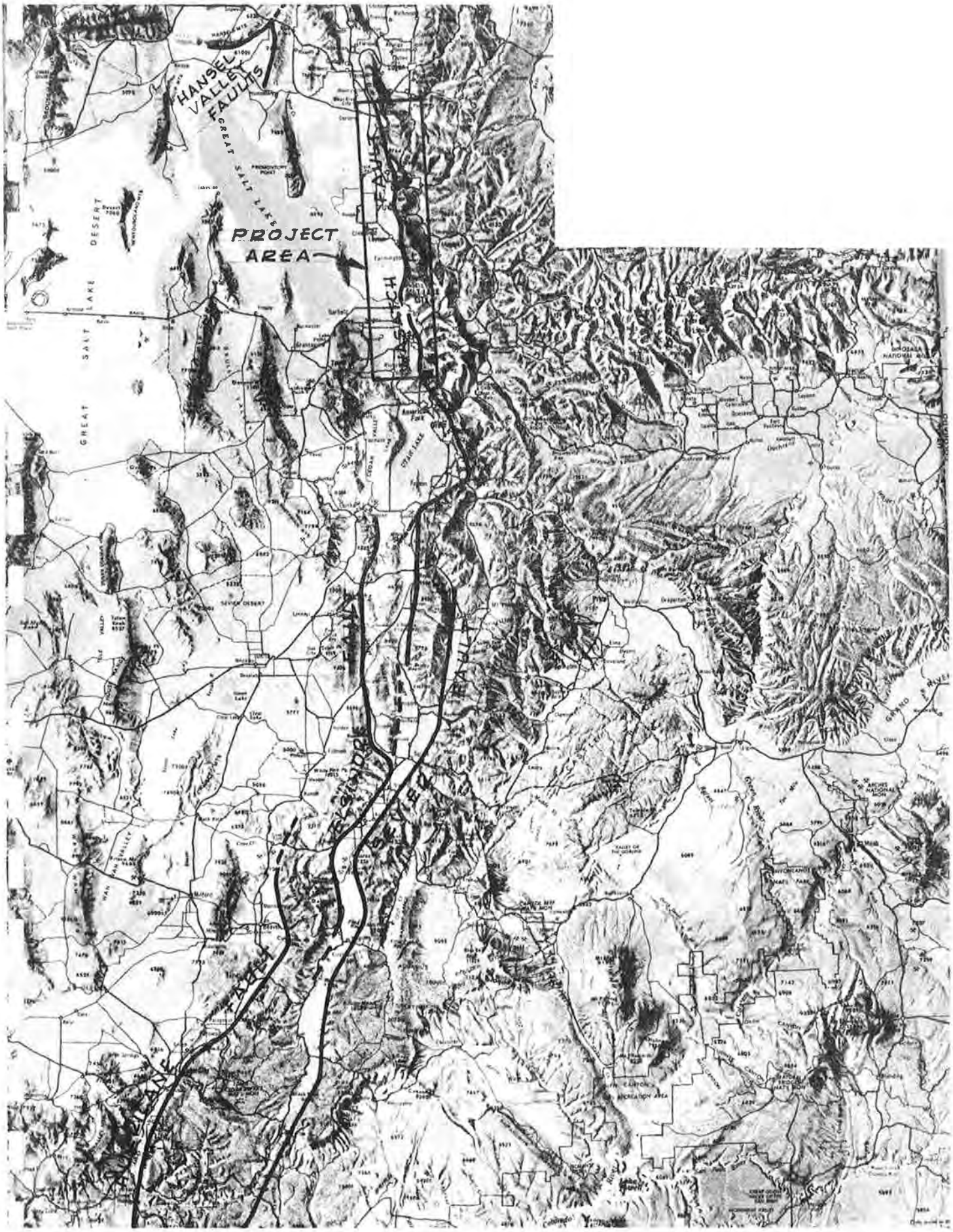


Figure 1 - Utah's active fault zones.

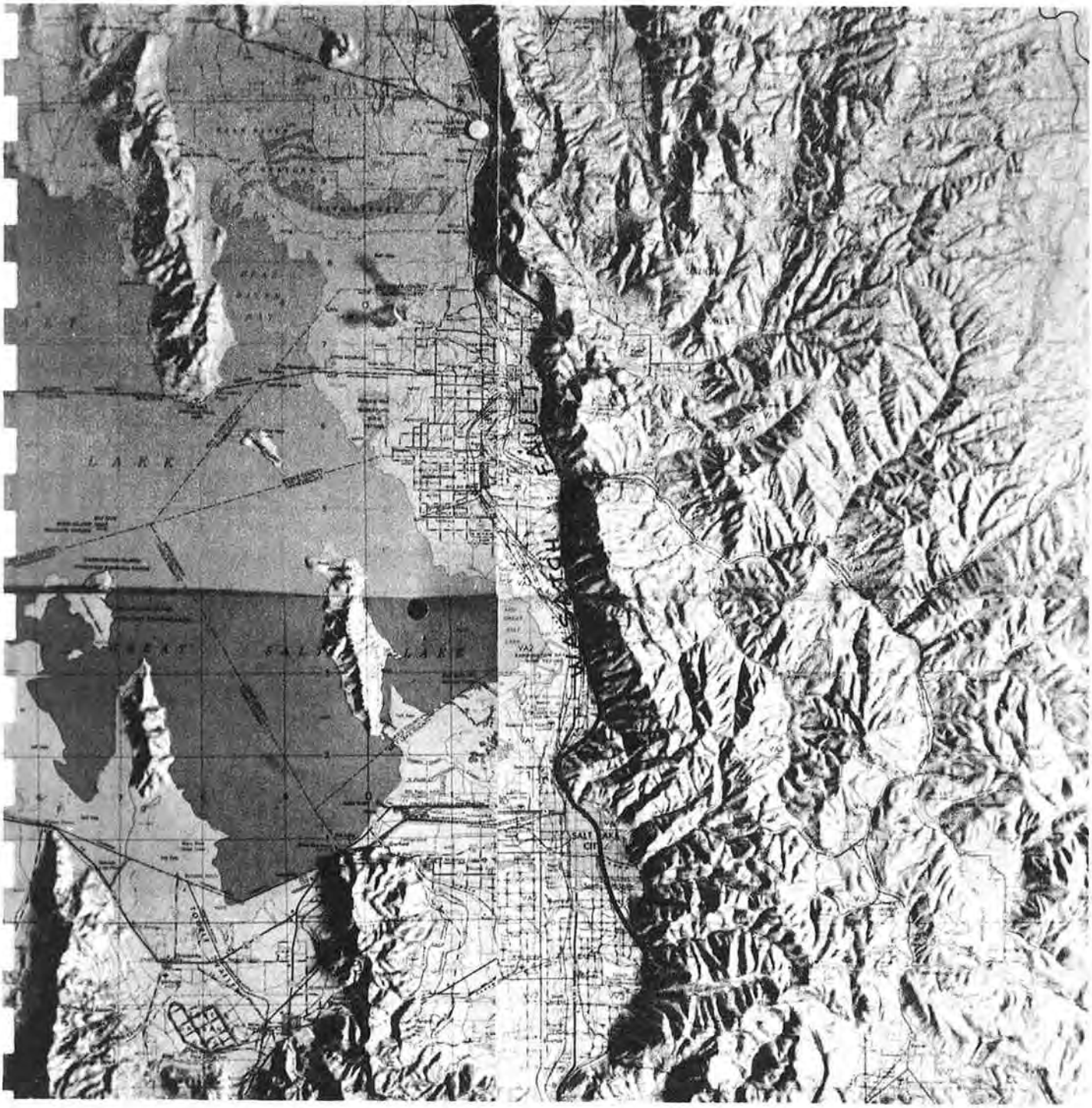


Figure 2 - Map showing limits of present study.

Figure 3 - Conventional vertical aerial photograph of the Wasatch fault south of Bells Canyon. Approximate scale 1:10,000.

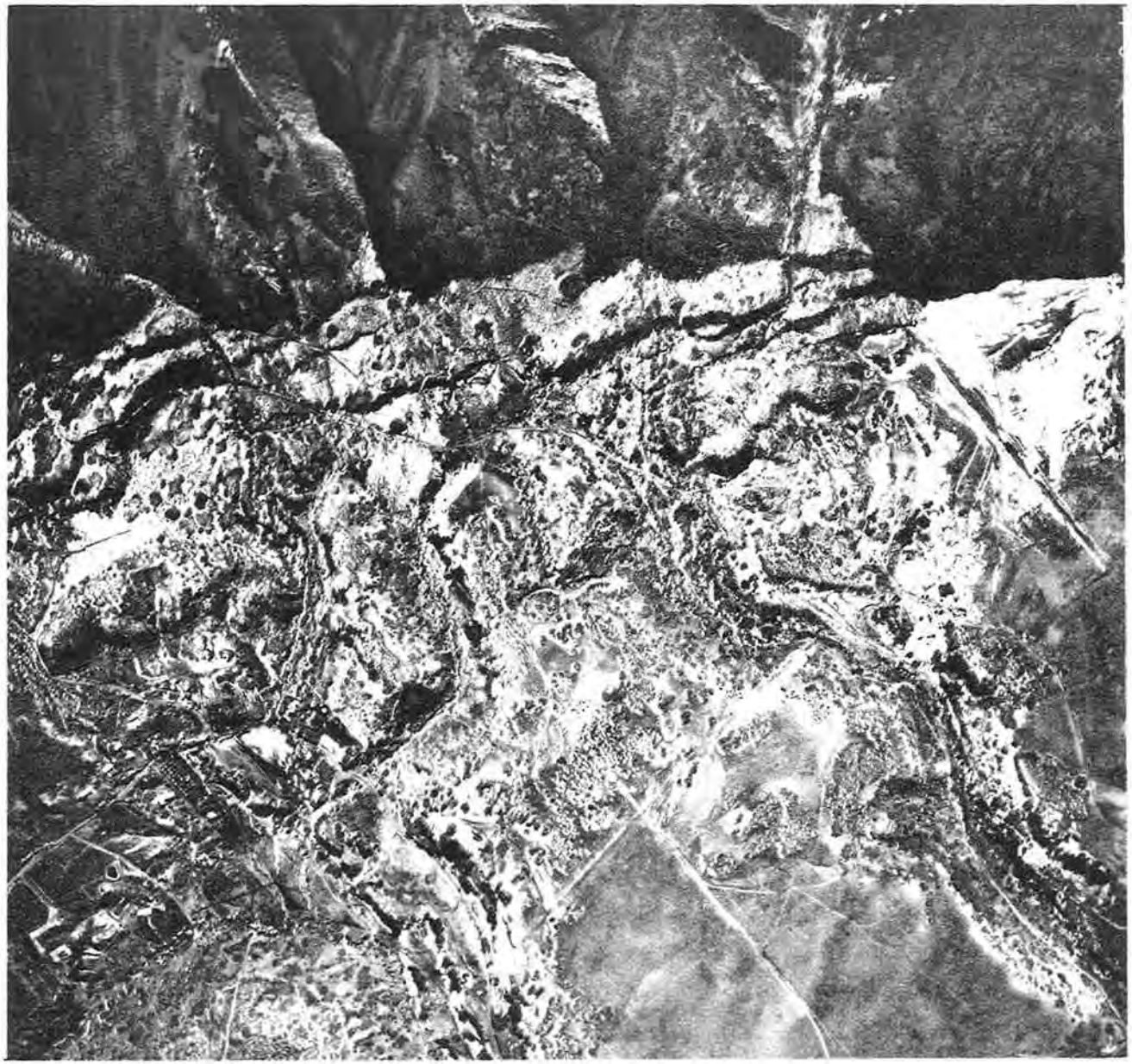


Figure 4 - Low sun-angle vertical aerial photograph of same area as Figure 3. Approximate scale 1:12,000.

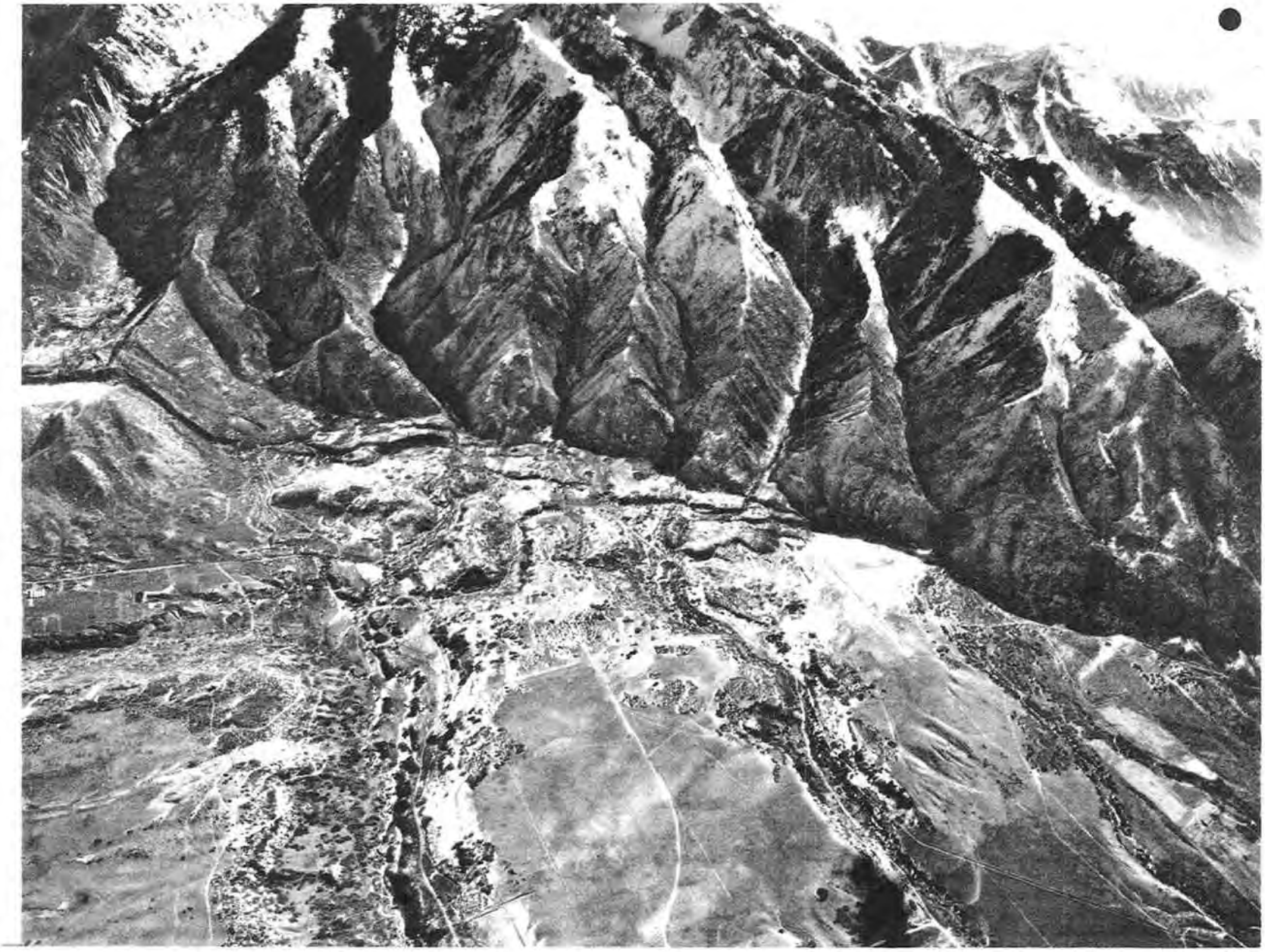


Figure 5 - Aerial oblique of area shown in Figures 3 and 4.

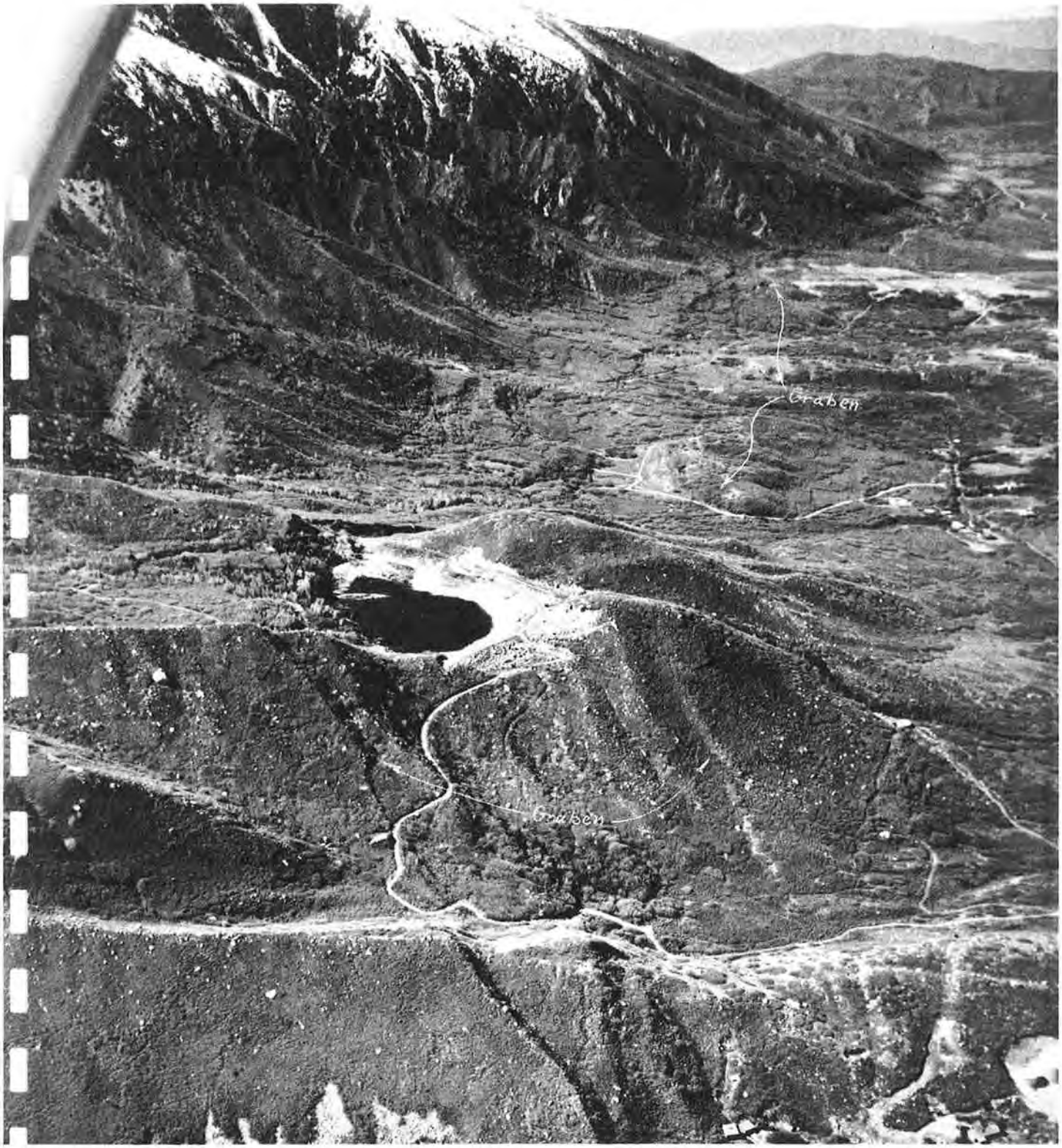


Figure 6 - View looking south along strike of fault from Lower Bells Canyon Reservoir to Corner Canyon.

Figure 7 - Vertical aerial photograph of Lower Bells Canyon Reservoir. Approximate scale 1:12,000. Early morning photograph.

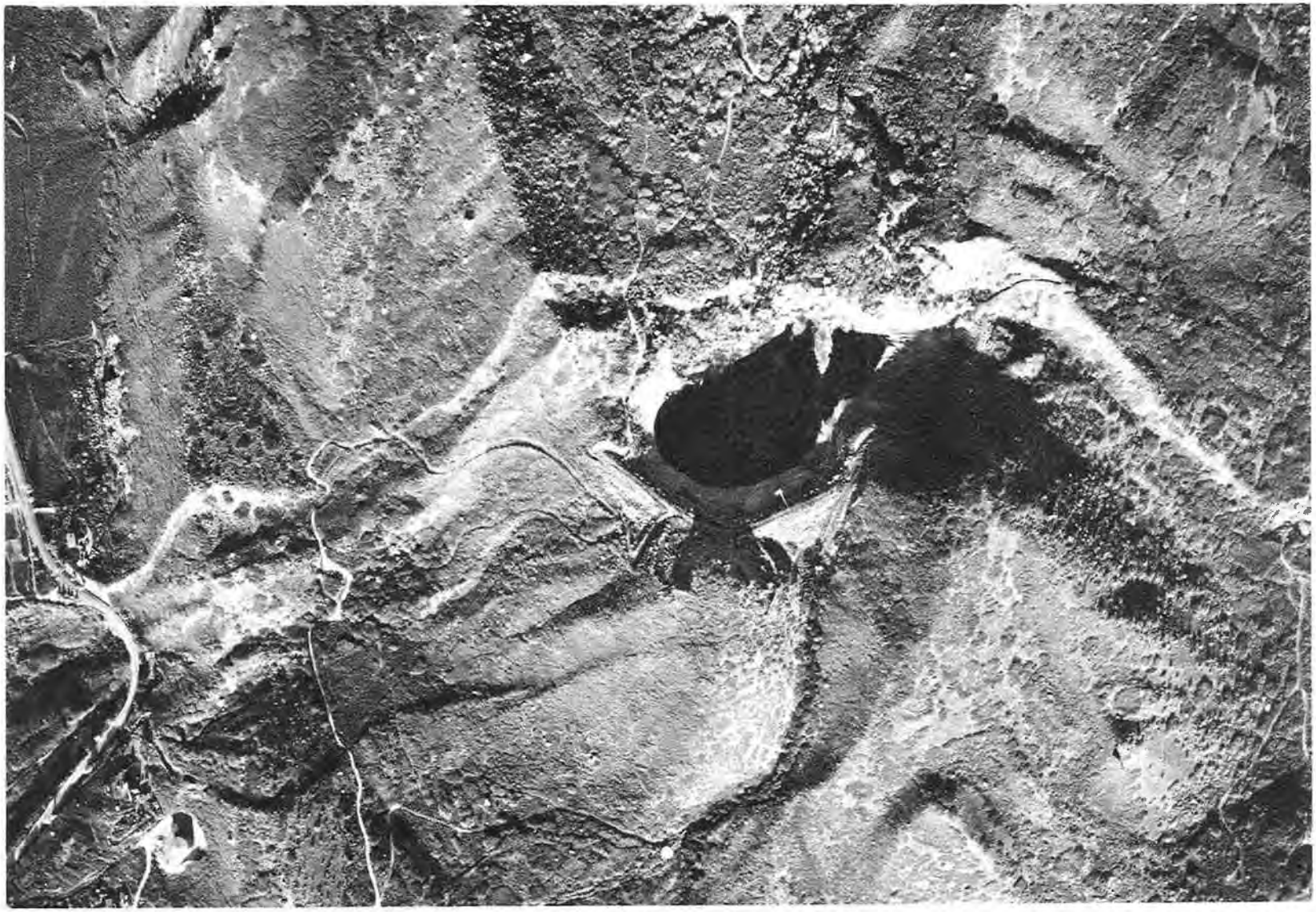


Figure 8 - Vertical aerial photograph of Lower Bells Canyon Reservoir. Approximate scale 1:6,000. Late afternoon photograph.

Figure 9 - Aerial view looking east at faulting between Big Cottonwood Canyon and Little Cottonwood Canyon.

Figure 10 - Aerial view looking northeast showing fault near Highland Drive.

Figure 11 - Aerial view of East Bench fault in Salt Lake City. Looking northwest.

Figure 12 - Vertical aerial photograph of East Bench fault in the vicinity of 2nd South 11th east.

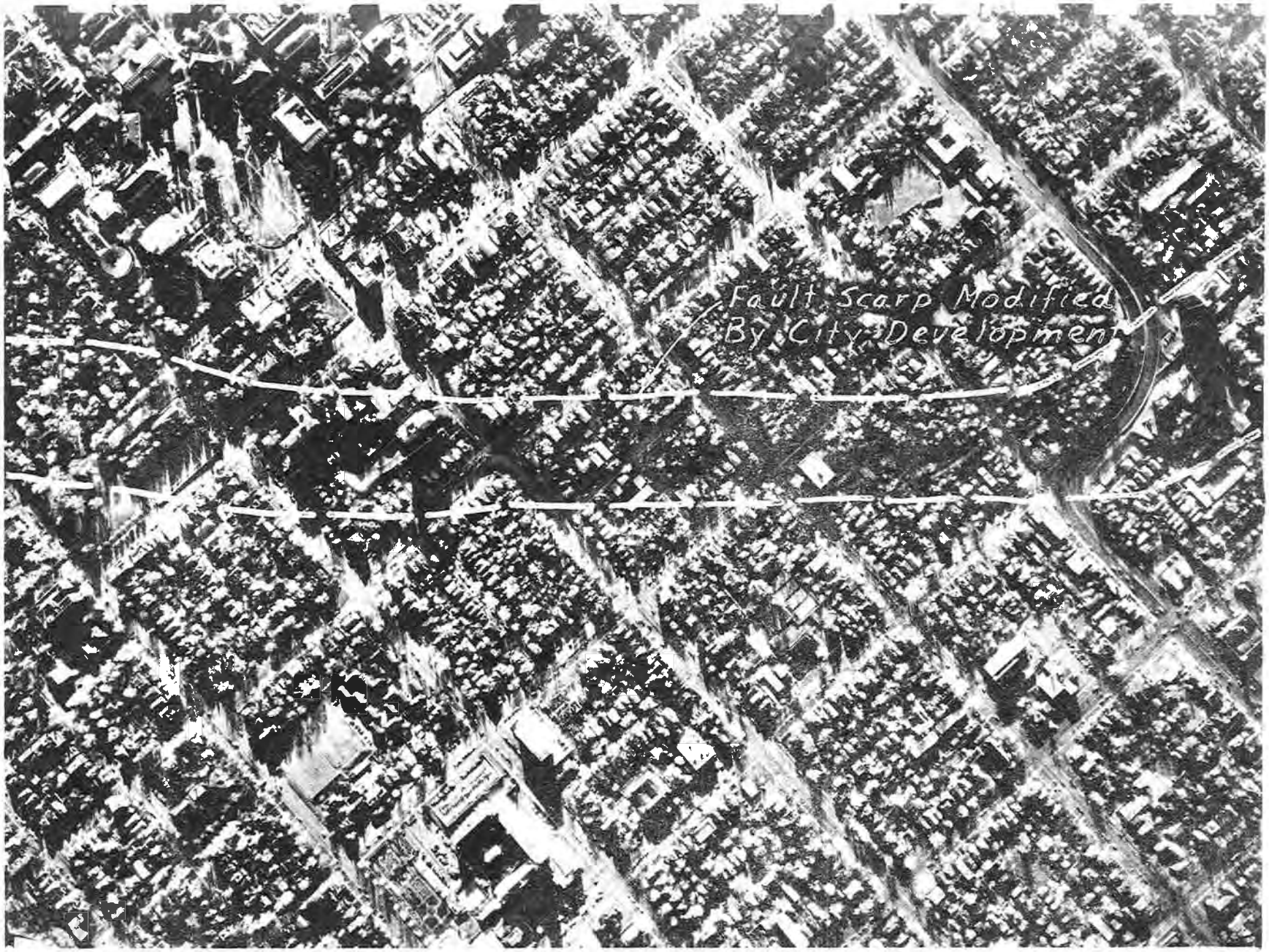


Figure 13 - Vertical aerial photograph of approximately the same area as Figure 12. Approximate scale 1:5,000.

Figure 14 - Aerial view of Salt Lake City looking southeast, showing the approximate location of the Wasatch fault.

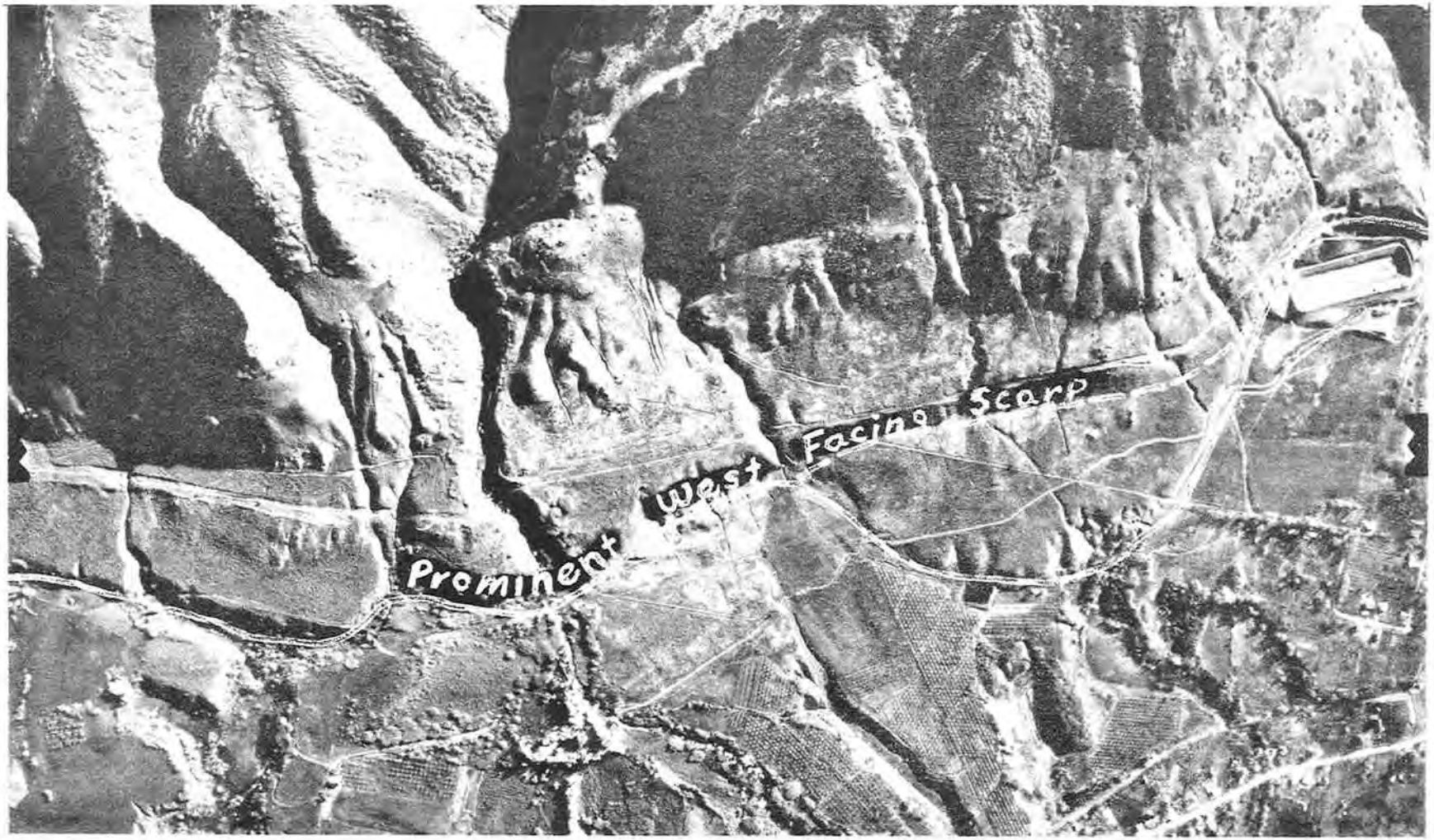


Figure 15 - Vertical aerial photograph of faulting south of Kaysville. Approximate scale 1:12,000.

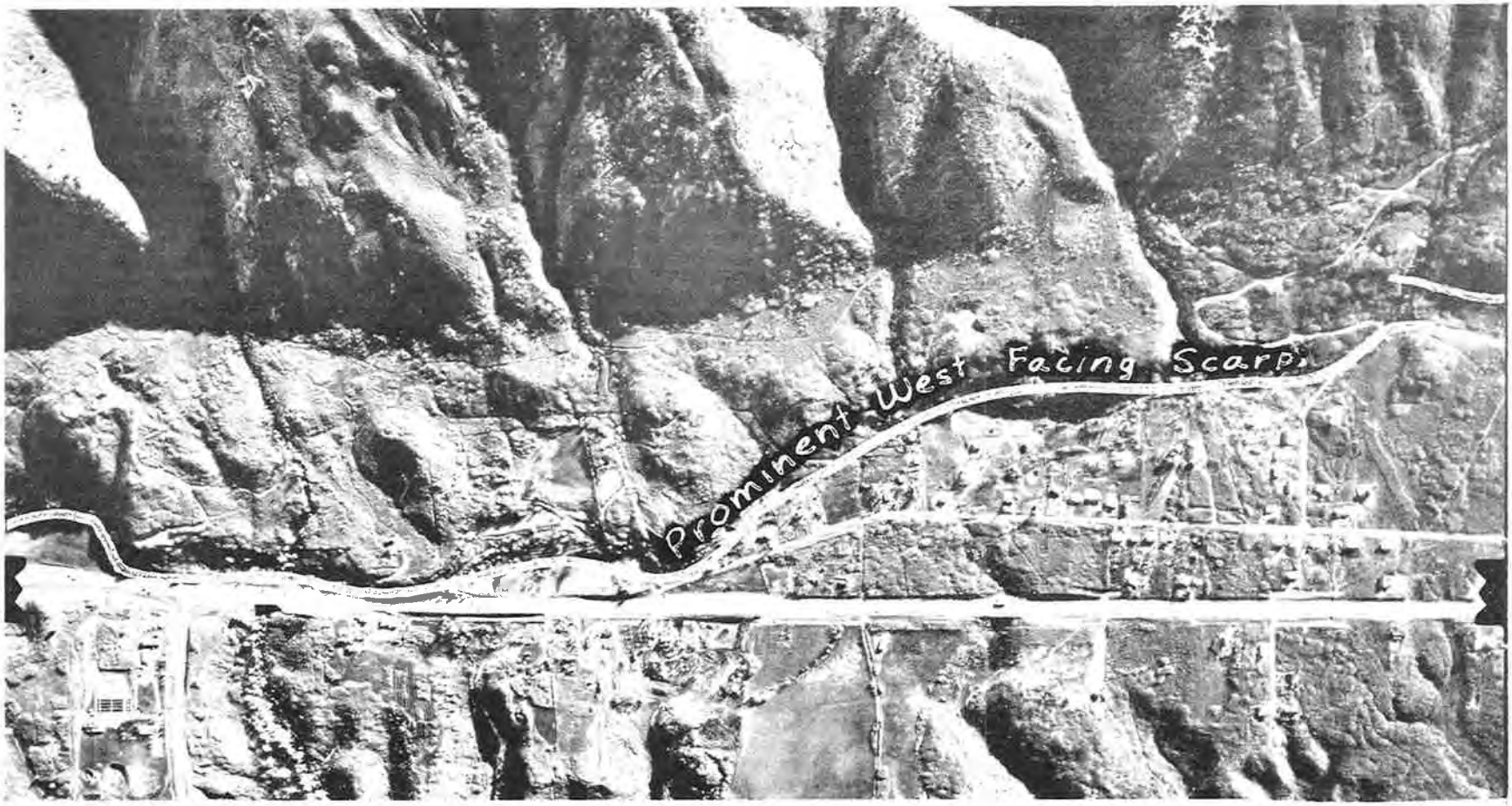


Figure 16 - Vertical aerial photograph of faulting near Hobbs Reservoir just south of Weber Canyon. Approximate scale 1:12,000.

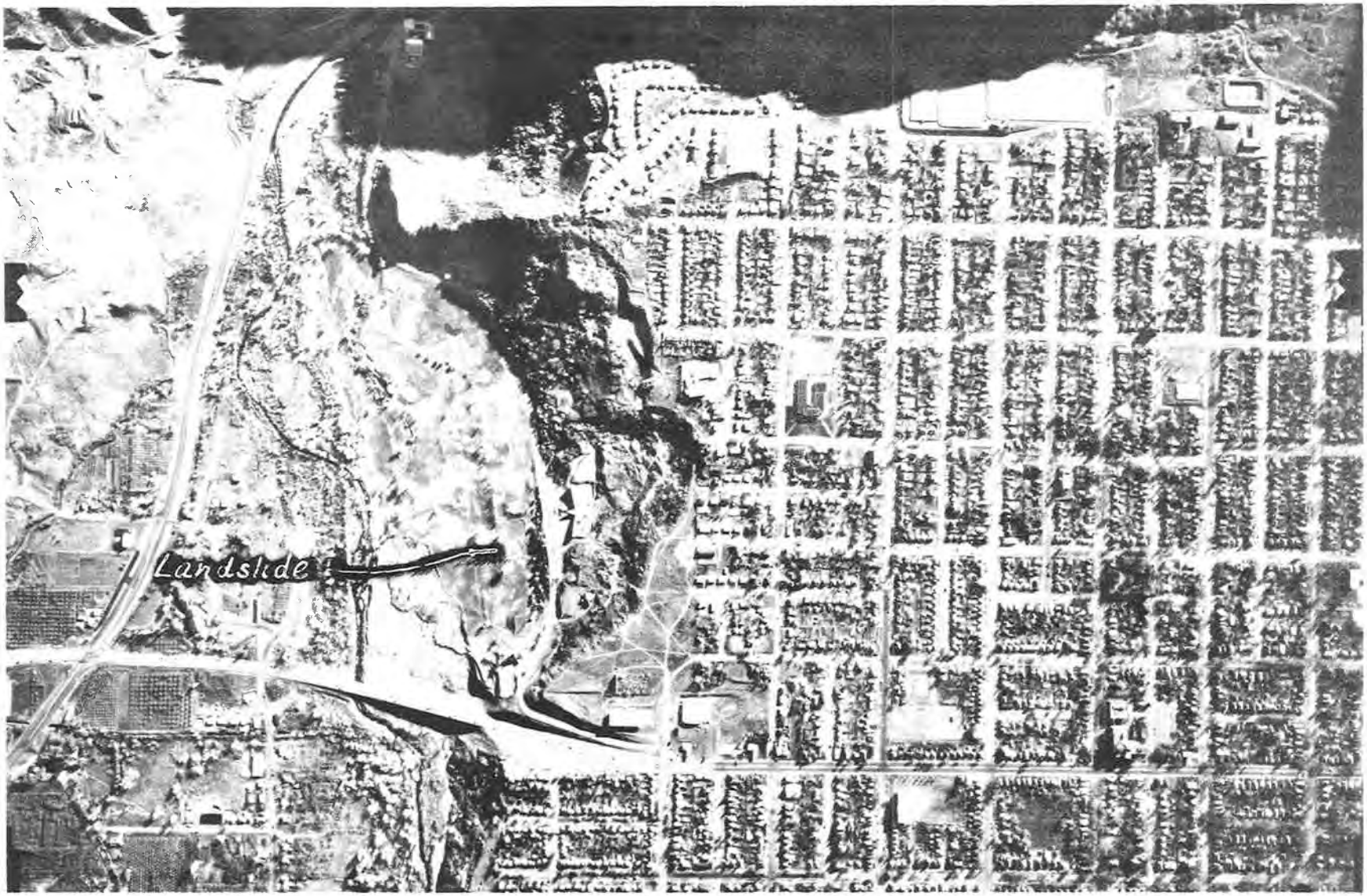


Figure 17 - Vertical aerial photograph of landslides at mouth of Ogden Canyon. Approximate scale 1:12,000.

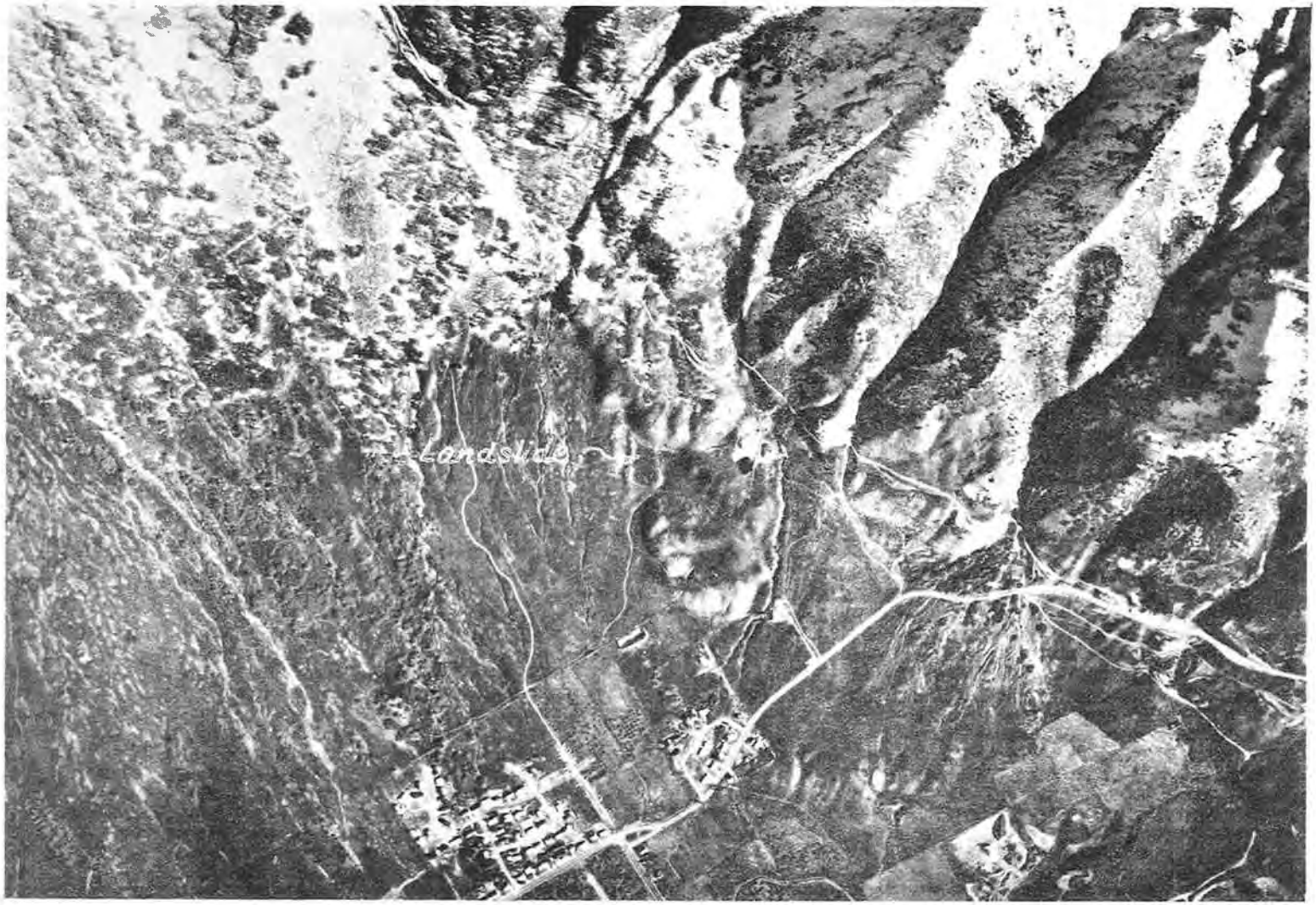


Figure 18 - Vertical aerial photograph of landslide northeast of North Ogden. Approximate scale 1:12,000.

APPENDIX A

GENERAL DISCUSSION OF EARTHQUAKES AND FAULTING

GENERAL STATEMENT

The following discussion is given primarily for persons not familiar with active faults and earthquake related problems. We encourage such individuals to read and study this discussion to ensure a common understanding.

WORLD-WIDE SEISMICITY AND CAUSES OF EARTHQUAKES

While small earthquakes occur widely over the surface of the Earth there are certain regions where large to moderate earthquakes occur frequently. The greater part of the ocean basins are devoid of earthquakes as are Antarctica and the relatively stable Pre-Cambrian shields of Africa, India, Siberia, Australia, Canada, and Brazil. Earthquakes marginal to these shield areas do occur however; for example, the 1663 St. Lawrence Valley earthquake and the 1968 Western Australia earthquake (magnitude 6.9) which partly wrecked the town of Mekering.

The most dense occurrence of earthquakes is found in the Circum-Pacific belt around the margins of the Pacific Ocean, and the Alpide belt, that traverses a comparatively broad area including the East Indies, the Himalayas, Iran, Turkey, and the Balkans. Highly localized concentrations of earthquake *foci* as shown in Figure A-1 also occur along the world-encircling system of mid-oceanic rises such as the Mid-Atlantic ridge and the East Pacific ridge. Wherever there are ocean trenches such as off the Aleutians, Japan, Chile, and Tonga-Kermadecs, and the eastern Carribean, there are earthquakes. The location of these zones of high seismic activity is shown in Figure A-1. This seismic map indicates those places where tectonic forces are now actively deforming the crust of the Earth. It should be noted that, on a global scale, California seismicity along the San Andreas fault system is an extension of the activity on the East Pacific Rise extending northward from the Gulf of California. The strong concentration of seismic activity trending from Southern Utah, bisecting Utah, and into Idaho and Montana is known as the Western Rocky Mountain Seismic Belt. This belt of seismic activity trends along the north-south boundary between the Rocky Mountain-Great Basin-Colorado Plateau physiographic provinces.

When the mechanical properties of the sources of world-wide earthquakes are studied in detail a great deal of variation is found. Not only does the size of earthquakes (in terms of energy released into seismic waves) vary enormously as shown in Figure A-2, but also the depth of the source of the waves ranges from

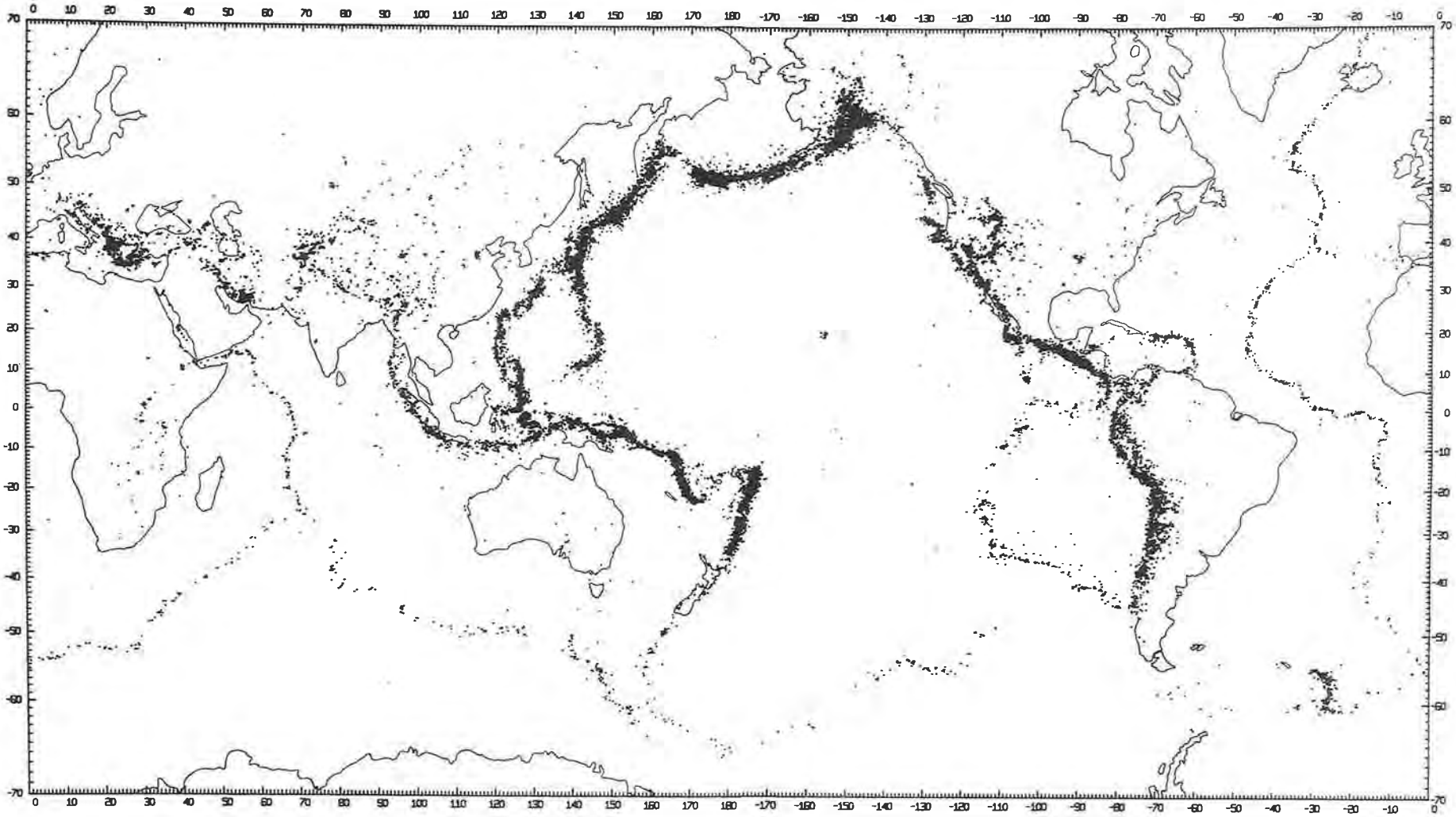


FIGURE A-1. Earthquake zones of the world. World-wide distribution of all earthquake epicenters (1961 through 1967).

near the Earth's surface (less than 10 miles) to depths of 450 miles or so. Earthquakes are often classified as *shallow*, *intermediate*, and *deep*. From the standpoint of earthquake risk, shallow earthquakes can be taken as those originating at a depth of less than about 40 miles. Deep shocks are those below about 200 miles. Deep-focus shocks are almost entirely restricted to a few regions such as Indonesia, Tonga, Japan Sea, and South America. Frequency of occurrence, as a world average, decreases rapidly with depth; over three-quarters of the average seismic energy released is due to shallow-focus earthquakes. Even when geographically near to developed areas, deep shocks are rarely destructive, one reason being that the source of the seismic waves is over 40 miles from the ground surface so that the wave amplitude is greatly attenuated. Another reason is that deep sources are not efficient generators of the seismic waves which travel only through the uppermost rocks of the Earth ("surface waves") and cause most of the sustained ground motion; nor do they generate *tsunamis* ("seismic sea waves").

Recent precise work in California and other parts of the western United States has indicated that earthquake foci along the coastal regions are not generally deeper than 9 miles in the crust and most are no more than 5 miles deep. The 1906 California earthquake was probably associated with a rupture no deeper than 10 miles over most of the ruptured-fault length. The 1811-1812 New Madrid Missouri earthquakes also probably originated in the crust and there is no evidence that the great 1964 Alaskan earthquake was associated with a rupture deeper than 40 miles. It should be noted, however, than even in the class of shallow-focus earthquakes, variations in focal depth are often sufficient to produce rather different surface effects. For example, the focus of the 1965 Seattle earthquake of April 29 (Richter magnitude 6-3/4), like many earthquakes in the region of the Puget Sound, had a depth of about 30 to 40 miles. As a consequence of the depth, the earthquake was felt widely but damage was only moderate with only a few deaths and about $12,000,000 damages estimated by the Washington State Civil Defense Department. This magnitude exceeds that of the 1933 Long Beach earthquake (magnitude 6.3) whose focus was probably at less than 10 miles in depth; it caused 120 deaths and over $40,000,000 damage. Because damaging earthquakes are shallow, the remainder of this paper will be restricted primarily to discussion of shallow-focus earthquakes.

It cannot yet be claimed that there is only one cause of all earthquakes. A minor cause of earthquakes is volcanic activity. Some deeper earthquakes may perhaps be related to sudden changes in rock properties due to motion deep within the Earth's mantle. However, most destructive, shallow-focus earthquakes appear to

be associated with a sudden rupturing (faulting) of the Earth's crust. (The crust is a rock layer of varying thickness, ranging from 30 miles under continents to 3 miles under oceans, which is found world-wide and is composed of mainly basaltic and granitic rocks.) The resulting earthquakes are caused by the sudden release of accumulative strain energy. The rupture, or break, is called a fault and is generally accompanied by displacement of blocks either vertically or horizontally or both, on opposite sides of the fracture.

This mechanical explanation of the creation of strong ground shaking, or an earthquake, only became widely accepted after the 1906 California earthquake. It is based on the "elastic rebound theory" of Professor H. F. Reid. Before Reid's time a common explanation was in terms of explosion-like phenomena at depth, often associated with the movement of hot magma (molten rock). In the 1906 earthquake, large-scale and continuous fault rupture was evident in the field. Of great importance, geodetic surveys of the region existed before and after the earthquake. The U. S. Coast and Geodetic Survey had made triangulation measurements across the San Francisco Bay region in 1851-65, 1874-92, and 1906-07. Reid interpreted these surveys as showing between the first and third surveys (a) little change in elevation, (b) significant horizontal right-lateral displacements of the crust parallel to the San Andreas fault, and (c) relative displacement of distant points on opposite sides of the fault of about 11 feet.

Reid stated, "It is impossible for rock to rupture without first being subjected to elastic strains greater than it can endure. We conclude that the crust in many parts of the Earth is being *slowly* displaced and the difference between displacements in neighboring regions sets up elastic strains, which may become larger than the rock can endure. A rupture then takes place and the then strained rock rebounds under its own elastic stresses, until the strain is largely or wholly relieved. In the majority of cases, the elastic rebounds on opposite sides of the fault are in opposite directions."

The seismic waves which are generated when the fault ruptures arise from the movement of the rocks in the vicinity of the fault.

At any point on the Earth's surface near to the fault, the wave motion will be complex. The *duration* of shaking at the point will depend roughly on the amount of displacement and largest linear extent of fault rupture. The variation of *intensity* of shaking with time will depend on the smoothness or otherwise, of the rupture and also on the position of the observer or building on the surface relative to the fault break;

if the fault ruptures toward the point the intensity may grow and then decline in some uneven way as the rupture moves away from the point. The ground motion will contain waves of many periods (or wave lengths). The higher frequency waves will be damped out by the rocks more quickly than the longer-period as the distance increases from the rupturing fault. In the epicentral area, the energy present in waves shorter than one second period may be quite high; at considerable distance from the epicenter, seismographs may detect mainly only waves with a period of over 5 seconds. The energy in such long waves is an indication of the extent of the source, but, of course, does not lead to response by either humans or most structures.

SIZE OF EARTHQUAKES

Two measures of earthquake size have been found to be useful, *intensity* and *magnitude*. Unfortunately, these terms are often confused and sometimes even used synonymously. Magnitude attaches a single number to an earthquake which is independent of the distance from the earthquake center and independent of geological and soil conditions. For a measure of the *variation of ground motion* from point to point, an intensity scale is used. The intensity value is assigned by an experienced observer using a descriptive scale. Both measures are too simple to describe the full complexity of an earthquake and should be used judiciously. Numerical relations between the two measures have been considered but, as the seismological literature shows, these must be taken only to establish an order of magnitude.

In discussions of earthquake hazard, the term *seismic risk* has been introduced. In its correct usage, *seismic risk* is the likelihood of damage from an earthquake. Quantitative studies of seismic risk are few and, like the other two measures of earthquake size, the word risk is often used loosely in this context.

Intensity Scales

Intensity is a rating of the severity of the ground motion at a specific location. The scale of measurement is based upon the sensations of persons, the behavior of natural objects, and upon physical damage to natural and man-made objects. Intensity scales came into being long before magnitude scales because intensity does not require instrumental observation. Over the years, different intensity scales have been devised. The scale must reflect the type of structure which is common to a particular region. The most widely accepted intensity scale in the United States is the Modified Mercalli Intensity Scale. This scale is given on the following page. It goes from I to XII on a twelve-point scale, usually denoted by Roman numerals.

A-6

MODIFIED – MERCALLI INTENSITY SCALE OF 1931

I **Not felt by people, except under especially favorable circumstances. However, dizziness or nausea may be experienced.**
Sometimes birds and animals are uneasy or disturbed. Trees, structures, liquids, bodies of water may sway gently, and doors may swing very slowly.

II **Felt indoors by a few people, especially on upper floors of multi-story buildings, and by sensitive or nervous persons.**
As in Grade I, birds and animals are disturbed, and trees, structures, liquids and bodies of water may sway. Hanging objects swing, especially if they are delicately suspended.

III **Felt indoors by several people, usually as a rapid vibration that may not be recognized as an earthquake at first. Vibration is similar to that of a light, or lightly loaded trucks, or heavy trucks some distance away. Duration may be estimated in some cases.**
Movements may be appreciable on upper levels of tall structures. Standing motor cars may rock slightly.

IV **Felt indoors by many, outdoors by few. Awakens a few individuals, particularly light sleepers, but frightens no one except those apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like a heavy body striking building, or the falling of heavy objects inside.**
Dishes, windows and doors rattle; glassware and crockery clink and clash. Walls and house frames creak, especially if intensity is in the upper range of this grade. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeable.

V **Felt indoors by practically everyone, outdoors by most people. Direction can often be estimated by those outdoors. Awakens many, or most sleepers. Frightens a few people, with slight excitement; some persons run outdoors.**
Buildings tremble throughout, Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances, and a few fall. Hanging objects and doors swing generally or considerable. Pictures knock against walls, or swing out of place. Doors and shutters open or close abruptly. Pendulum clocks stop, or run fast or slow. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled open containers. Trees and bushes shake slightly.

VI **Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; general excitement, and some persons run outdoors.**
Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Small bells in churches and schools ring. Poorly built buildings may be damaged. Plaster falls in small amounts. Other plaster cracks somewhat. Many dishes and glasses, and a few windows, break. Knick-knacks, books and pictures fall. Furniture overturns in many instances. Heavy furnishings move.

VII **Frightens everyone. General alarm, and everyone runs outdoors.**
People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes and streams. Water is muddied. Gravel or sand stream banks cave in. Large church bells ring. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings adobe houses, old walls (especially where laid up without mortar), spires, etc. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns. Concrete irrigation ditches are considerably damaged.

VIII **General fright, and alarm approaches panic.**
Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off (especially palm trees). Sand and mud erupts in small amounts. Flow of springs and wells is temporarily and sometimes permanently changed. Dry wells renew flow. Temperatures of spring and well waters varies. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Panel walls break away in frame structures. Decayed pilings break off. Walls fall. Solid stone walls crack and break seriously. Wet grounds and steep slopes crack to some extent. Chimneys, columns, monuments and factory stacks and towers twist and fall. Very heavy furniture moves conspicuously or overturns.

IX **Panic is general.**
Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings - - some collapse in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged and underground pipes sometimes break.

X **Panic is general.**
Ground, especially when loose and wet, cracks up to widths of several inches; fissures up to a yard in width run parallel to canal and stream banks. Landsliding is considerable from river banks and steep coasts. Sand and mud shifts horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Dangerous cracks develop in excellent brick walls. Most masonry and frame structures, and their foundations, are destroyed. Railroad rails bend slightly. Pipe lines buried in earth tear apart or are crushed endwise. Open cracks and broad wavy folds open in cement pavements and asphalt road surfaces.

XI **Panic is general.**
Disturbances in ground are many and widespread, varying with the ground material. Broad fissures, earth slumps, and land slips develop in soft, wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes and embankments, even at long distances. Few if any masonry structures remain standing. Supporting piers or pillars of large, well-built bridges are wrecked. Wooden bridges that "give" are less affected. Railroad rails bend greatly and some thrust endwise. Pipe lines buried in earth are put completely out of service.

XII **Panic is general.**
Damage is total, and practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rock falls, and slumps in river banks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

Intensity ratings are bound to be subjective, as reported intensities may take on several meanings, depending on who reports them and the type of construction in an area. The reported intensity may be the maximum intensity at the built-up area nearest the epicenter, or it may be what the intensity should have been, at the epicenter based on observations at a center of population some distance away. Many circumstances arise making it difficult to assign intensities. The lack of precision in the intensity index should be recognized. Basically, intensity refers to the measure of earthquake effects of all types at a specified place. It is not based on the true measurement, but is a rating assigned by an experienced observer using a descriptive scale, with grades indicated by Roman numerals.

Because intensity is defined by the observed effects on the Earth's surface, such as landslides or underground pipes broken, the intensity of an earthquake on a mid-oceanic ridge might be taken as zero. On the other hand, a smaller shock centered near weak man-make structures on poor ground might yield a high intensity. For a given earthquake, intensity differs between localities depending upon the distance from the source, the duration of shaking, the geologic foundation and the quality of design and construction.

The subjective nature of intensity ratings makes it important that the observer report in detail the evidence upon which the rating was estimated. Engineers and others can then draw their own conclusions at a later time. In the United States, ratings are routinely gathered by the U. S. Coast and Geodetic Survey and the data are reported in "United States Earthquakes" which began in 1928.

In order to remove some of the subjectivity in assigning intensity, a dense network of strong-motion seismoscopes and seismographs would give quantitatively the distribution of ground motion. Only in the Los Angeles area is this now partly feasible. There are more than 130 strong motion seismographs and 75 seismoscopes located in the Los Angeles area. In the entire San Francisco Bay Area, there are only 34 strong motion seismographs and 48 seismoscopes.

Magnitude Scales

Magnitude is based on ground motion as recorded by distant seismographs. The most commonly used method of calculating magnitude in the United States for large earthquakes is that of C. F. Richter. (Other magnitude scales are, however, widely used by seismologists, both in the United States and in other countries, sometimes leading to what appears to be conflicting

magnitudes.) In order to use this scale, suppose that there is a particular kind of seismograph (called a Wood-Anderson instrument) at a distance of 60 miles from the epicenter. The instrument will produce a seismogram. A ruler with a centimeter scale is taken and the half-width ("amplitude") of the largest wave is measured and converted to microns (10^4 microns = 1 cm.). The logarithm (to base 10) of this number is the *Richter magnitude of the earthquake*. For example, if the maximum amplitude measured is 1 cm, the Richter magnitude is 4.0. Numerical tables provide the necessary adjustment when the seismograph is not at 60 miles epicentral distance or when other types of seismographs are used.

From the definition, the magnitude scale, unlike the intensity scale, has no greatest and smallest limit. Currently, more sensitive seismographs are available than when Richter defined magnitude in 1935; such instruments can record tiny earthquakes with minus or negative magnitudes, say -1.0. Large magnitudes have been recorded from the greatest earthquakes of the century. The 1964 Alaskan earthquake had a magnitude of about 8.6. Some of the early seismographs in Europe recorded the 1907 California earthquake and gave its magnitude to be near 8-1/4.

There is reason to believe that the largest earthquake which is mechanically possible under present geological conditions would have a magnitude less than about 9.0. The largest earthquakes recorded since the scale was devised are the Sauriku earthquake in Japan on March 2, 1933 with an estimated magnitude of about 8.9, and the earthquake centered off the west coast of South America, near Colombia in 1906, with perhaps a magnitude of 8.9.

Because the earthquake energy comes from elastic strain energy stored in the rocks, the total seismic energy released will be proportional in some way to the area of fault which ruptures. For great shallow-focus earthquakes, the depth of dislocation (say less than 30 miles) is small compared with the observed rupture length (of the order of hundreds of miles). Since the finite strength of crustal rocks limits the strain energy which they can store, the total energy release would thus appear to be bounded by the length of fault available to rupture. The geography of seismically active regions shows that there is a limit on this. Among the largest fault ruptures ever observed or estimated was 270 miles (California, 1906) and perhaps over 500 miles for the 1960 Chilean and 1964 Alaskan earthquakes.

While magnitude is a simple measure for ordering of earthquakes roughly according to size or total energy released, there is evidence that magnitude alone is often given too much weight in

urban planning and engineering design. This misuse comes from a failure to take into account the way that the partition of wave energy into various frequencies changes with the earthquake size and the great variation in rock and soil properties from place to place.

As an example, in Anchorage, after the 1964 earthquake, it has been pointed out that vibrational damage alone mainly affected only the tall high-rise buildings that respond to the longer frequency waves. An even more striking example is the Caracas, Venezuela earthquake, of 1967, where more than 200 lives were lost because of the collapse of five high-rise apartment buildings that were designed to be earthquake resistant. The Caracas earthquake was only a moderate-magnitude shock (Richter magnitude 6.5) and located approximately 30 miles from Caracas.

Consider, for example, structures which respond mainly to vibrations with periods of about 1/2 to 3/4 of a second; they will be most affected by that part of the earthquake which has similar periods. Due to relative attenuation in the rocks, however, the proportion of energy in waves with such periods falls with increased length of path so that waves coming from distant parts of the rupture will be mainly rich in longer periods. In simple terms, damage to small structures in a city from a large-magnitude earthquake nearby (long fault rupture) might be expected in general to be mainly a result of waves generated by the closest segment of the rupturing fault. Much the same wave energy might in the high frequency waves arise locally if *only* this local section of the fault ruptured (i.e., a smaller-magnitude earthquake occurred).

A number of empirical formulae linking magnitude and energy release have been worked out. For practical purposes, and particularly for the shallow earthquakes in California, the formula $\log_{10} E = 11.4 + 1.5 M$ is recommended, where E is the energy in ergs, and M is the Richter magnitude.

Because of the factor 1.5, the increase of a unit in magnitude indicates an increase in energy of 32 times so that there is an enormous range of energy between the smallest and largest size earthquake. An attempt to indicate the great spread is shown in Figure A-2 where the energy in an earthquake is plotted as a multiple of that in the 1933 Long Beach earthquake.

Seismic Risk Scales

Risk may be thought of in context with its everyday meaning which is similar to hazard. Unlike hazard, however, risk has the connotation of probability or chance of loss (e.g., as used in the insurance industry). This meaning is valuable for

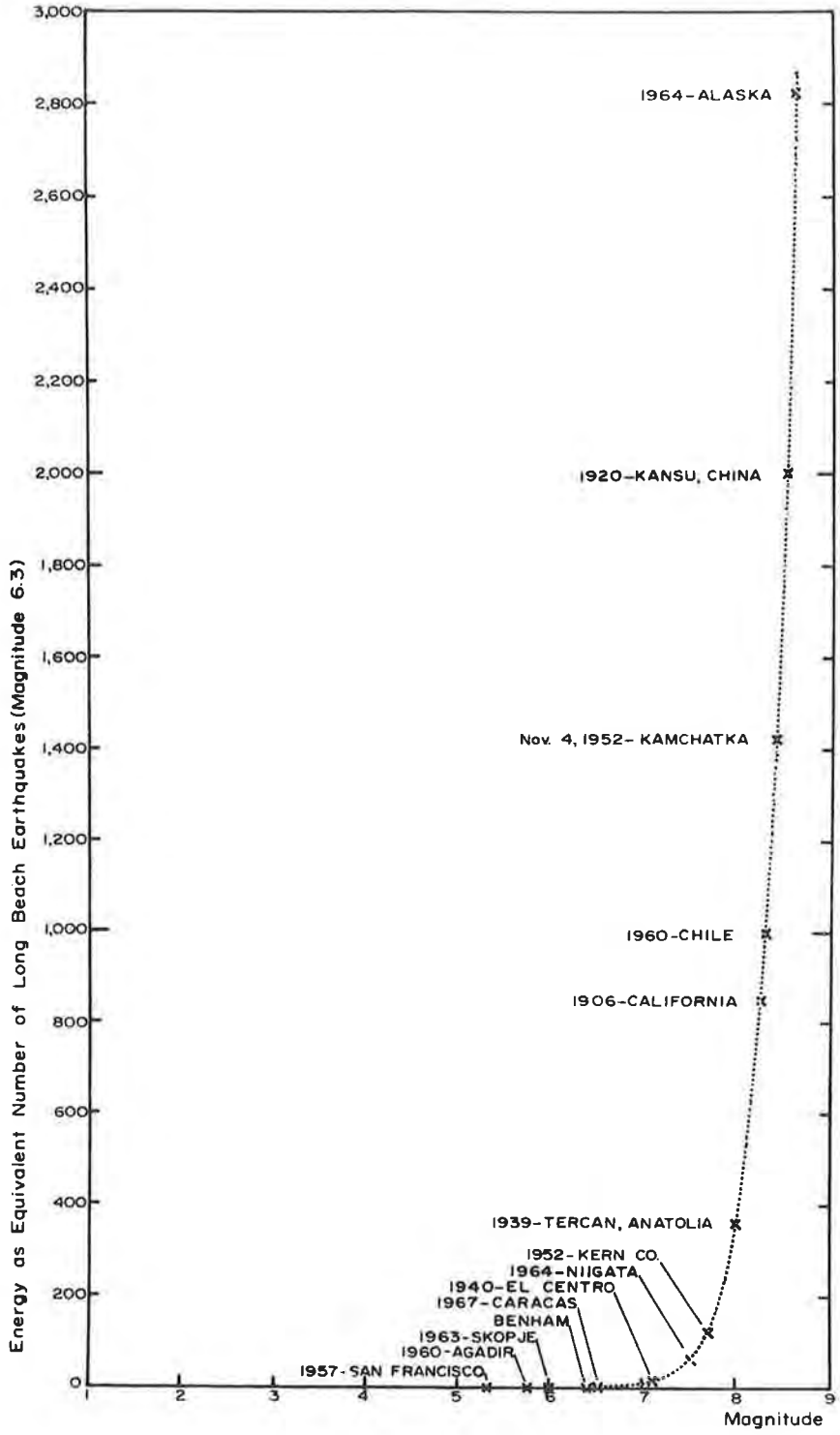


FIGURE A-2. Magnitude of an earthquake plotted against earthquake energy. In order to compress the energy scale, the energy values are equivalent numbers of 1933 Long Beach earthquakes.

setting a degree of likelihood of future earthquake damage and should be most carefully preserved.

Seismic (or Earthquake) Risk (SR) may be defined as the likelihood of damage or injury from an earthquake within a given time interval (design period). SR is normally given as a statement of probability. Like magnitude, there are different seismic risk scales. For example, statistical work on risk has been done in Mexico by Esteva and Rosenblueth and in Chile by C. Lomnitz and his coworkers. In a study for Santiago, Chile by F. Guzman, it was estimated that, in any 10-year period, the probability that the design acceleration of 10 percent of gravity will be reached or exceeded is about 60 percent.

A related measure of earthquake susceptibility is *Relative Seismic Risk* (RSR). The RSR scale replaces the probabilities of the SR scale by relative weighting factors. The scale usually ranges from 0 (no probability of damage) through 1, 2, 3, etc., with the highest number designating the region where risk is greatest. RSR weights or "seismic zone numbers" have been much used to modify requirements for lateral earthquake forces on structures as established by the California Earthquake Building Code. Relative seismic risk does not, however, show the statistical nature of risk as a function of time.

EARTHQUAKE ASSOCIATED DAMAGE

It is a commonly held misconception that distance from the surface trace of an active fault is the best assurance against earthquake damage. Experience has shown that the intensity of an earthquake is not necessarily highest at the surface trace of the earthquake-generating fault. If the structure is not astride an active fault, it matters little whether it is alongside the fault trace or several miles away, because energy reaching the surface will be almost the same at the two points, everything else being equal.

Earthquake damage depends on many variables: earthquake magnitude, epicentral location, depth of focus, duration of shaking, intensity of shaking, near-surface soil and geologic conditions, structural type, and design. Damage related to foundation conditions depends upon material density, shear strength, thickness, and water level. Thus, proximity to an active fault should not be given undue weight when deciding where to build; more consideration should be given to ground conditions and structural design.

Earthquake associated damage is usually manifest in four separate forms: (1) fault displacement; (2) strong ground motion (shaking); (3) ground failure; and (4) tsunamis (seismic sea waves).

Faulting

Faulting, as the movement or fracturing along faults is called, may have horizontal and vertical components of displacement and may vary from a fraction of an inch to many feet. In the California earthquake of April 18, 1906, horizontal offsets along the San Andreas fault averaged from 8 to 15 feet and occurred from just north of San Juan Batista to north of Point Arena, a distance of more than 200 miles.

Fracturing and shearing associated with faulting is often observed in the field to be of a multiple and en echelon character, with several planes of displacement being formed through geologic time (millions of years); thus the term fault zone is a more realistic designation. The exact location and characteristics of a fault zone are of vital concern in estimating the hazard from faulting. Once a fault is formed, it constitutes a plane of weakness that localizes further adjustments. Active faults usually are associated with one or more of the following: an historic record of faulting, the occurrence of earthquakes along their courses, evidence of geologically recent movement (the last few thousand years), and slow fault slippage. A fault should be considered active if it has displaced recent alluvium or other recently formed deposits, whose surface effects have not been modified to an appreciable extent by erosion, which has earthquakes located in the near vicinity, and whose recurrence of movement is expected.

Some fault zones, such as the San Andreas, are more than a mile wide in places, containing many "fault traces" within the broad zone. One might ask, "What is the relative risk of developing or locating structures within such wide active fault zones?" Assigned risk (SR or RSR) need not always be extreme. It depends upon factors such as type of development, intended land use, type of structure, and site location with respect to the *active* fault traces. The broad fault zones have been formed over long periods of geologic time and in some future geologic time (millions of years) not only may the present fault traces be reactivated, but new traces may be formed. However, if we consider this problem from the standpoint of "engineering design time," (of the order of 100 years say) the probability of fault movement is much higher along the most recent fault traces that lie within the broad fault zone. In such risk assessments perhaps weak soil conditions which may arise from crushed rock or gouge in a fault zone would turn out to be more crucial factors than concern over the exact positions of future faulting.

It is often believed that assurance against earthquake damage is directly proportional to the distance from the surface trace of a known active fault or fault zone. There is much evidence

that the intensity of an earthquake is not necessarily highest at the surface trace of the earthquake-generating fault. If the structure is not astride an active fault trace, so that displacement may shear it in two, it may not be decisive as a damage factor whether it is alongside the fault trace or several miles away; wave energy reaching the two sites may be comparable. Damage resulting from faulting occurs only where works of man are located astride the fault traces that move. Figure A-3 shows damage to a fence that was across the 1906 fault trace. Note the undamaged buildings of wood-frame, low-story construction located near the fault. They are also located on stable ground. By contrast, buildings located 10 to 20 miles from the fault, such as in Santa Rosa and San Jose, on relatively less stable ground were almost completely destroyed in the 1906 shock.

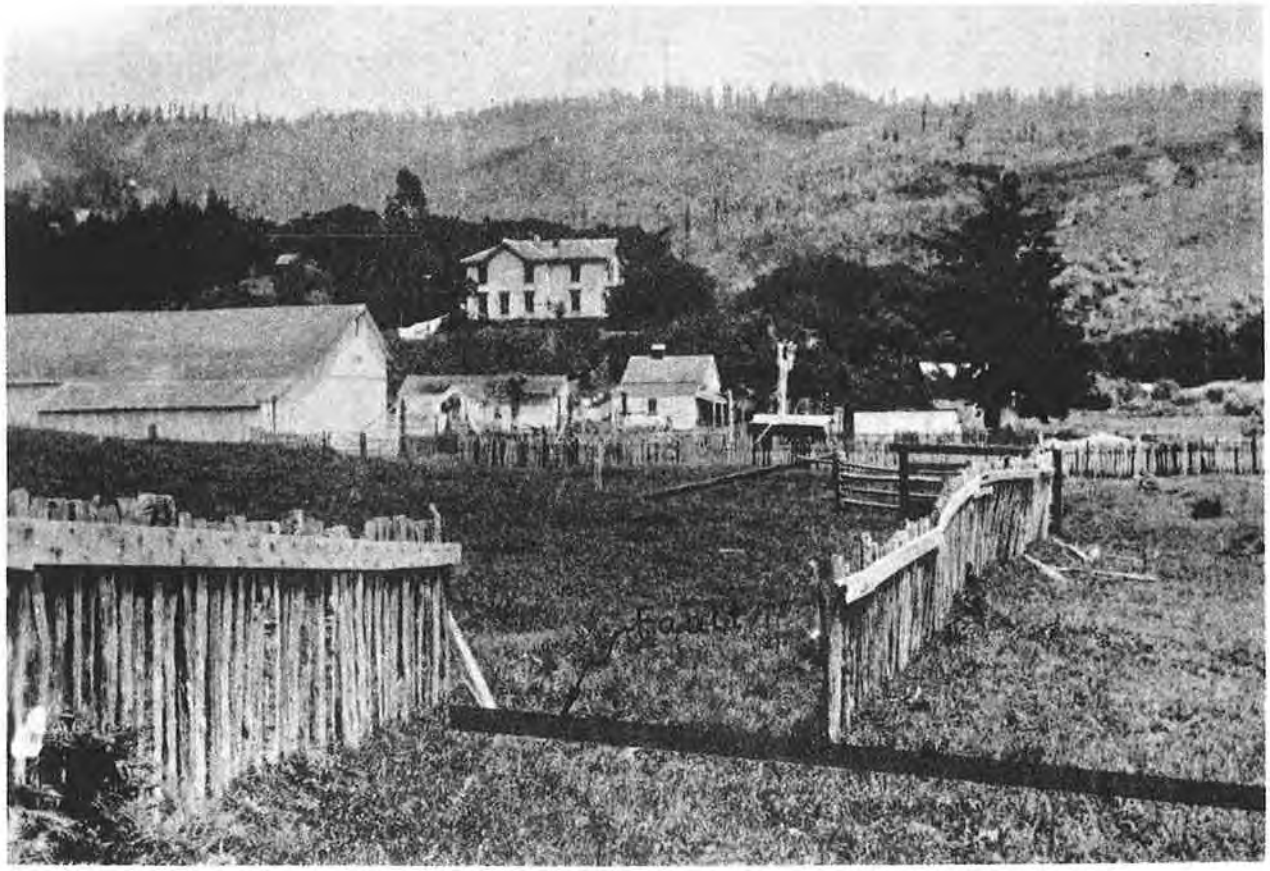


FIGURE A-3. Fence separated by displacement along the San Andreas Fault, April 18, 1906.

Avoidance of damage from fault dislocation can be achieved by recognizing the most active fault traces and either locating structures elsewhere, or allowing for fault movement in the design. This is a significant hazard only in a few localities.

Strong Ground Motion (Shaking)

Damage from strong ground motion (shaking) is caused by the transmission of earthquake vibrations from the ground into the structure. Figure A-4 shows damage to the Mijagual apartment building in Caracas, Venezuela from the 1967 earthquake. The main variable factors that determine the extent of vibrational damage are: type of ground, earthquake-resistant design, quality of materials and construction, and intensity and duration of shaking.

FIGURE A-4. Mijagual high-rise apartment building in Caracas, Venezuela, showing total pancake collapse.

Different kinds of ground respond differently to seismic loading. The relation between soil and basement rock conditions and earthquake shaking is not clearly known. Estimates can be calculated if soil and basement rock properties are known but should be used with caution for risk estimation until more testing under actual earthquake conditions is done. The ground motion associated with a great earthquake (similar to the 1906 California shock) has never been recorded instrumentally.

Many urban areas are presently located along and near active faults. For example, along the San Andreas fault, throughout its length from Northern to Southern California, along the Calaveras fault near Pleasanton, along the Hayward fault in the East Bay Cities, along the San Jacinto and Inglewood faults in Los Angeles and southern California, and the Wasatch fault near Salt Lake City, Utah. Continuing urban growth is bringing about a constant increase in the use of land near active faults that will most likely be associated with substantial earthquakes. Outside the city areas, industrial and utilities development is frequently considered for sites close to active faults. A case which gave rise to strong public controversy is the Bodega Head site north of San Francisco considered a few years ago for a nuclear power reactor.

In these circumstances the following question is becoming increasingly frequent: "In what ways, if any, does the strong ground motion differ near the fault from the ground motion some distance away?" No strong motion records were obtained of the large 1960 Chilean earthquake nor in Alaska from the 1964 shock. A widely used strong-motion record in engineering design is the El Centro record. It, however, was obtained about 6 miles from the Imperial Valley fault along which displacements were observed in the 1940 earthquake, magnitude 6.9. In 1966, an array of strong-motion instruments was operational across the San Andreas fault near Cholame. These instruments recorded the earth movements at the time of the June 27, 1966 Parkfield earthquakes. A record of ground acceleration was obtained within the fault zone about 200 feet from a fault trace that contained a slippage crack that appeared across Highway 46 where it intersects the San Andreas fault zone. These records are the closest to an earthquake source (active fault) yet obtained. (The records showed that the vertical and horizontal motions of the ground differed considerably in their frequency content and structure.) There was a large ground motion (which amounted to a displacement of 10 inches) perpendicular to the fault trace. The maximum horizontal ground acceleration was one-half the acceleration of gravity (0.5g), i.e., about 16 feet/sec^2. The duration of the strong ground motion was extremely short, lasting only about 1 second.

Although the record gives valuable information it is unclear whether the effects mentioned above could be scaled upwards for a large earthquake. The Parkfield main shock had a magnitude of 5.6 and the length of fault rupture observed was somewhat less than 20 miles. Very little damage was reported along the fault zone even though the short duration peak acceleration was surprisingly quite high. It is not clear whether a much larger magnitude earthquake might produce significantly greater accelerations near the fault; a longer interval of ground shaking (duration) is, however, quite likely.

FIGURE A-5. Earthquake damage resulting from ground failure. Turnagain Heights landslide, Anchorage, Alaska, March 27, 1964.

Because we lack direct observations, forecasts of ground motion must be largely based on extrapolation from experiments in the laboratory, from visual observations of past earthquakes, and upon suggestions from theoretical models. Certain likely properties of the ground motion near a fault can be stated for risk estimation, subject to the necessary caution implied by the above statement of our lack of current observational information.

Damage from Ground Failure

Damage from ground failure may occur in several different forms; landsliding, liquefaction, and settlement. Figures A-5 and A-6 illustrate damage from landsliding and liquefaction.

FIGURE A-6. Earthquake damage resulting from ground failure: Liquefaction. Niigata, Japan, 1964.

If the proper geological conditions exist on the ocean floor, subaqueous landslides or turbidity currents may be generated of sufficient force to affect offshore and onshore structures. In 1929, an earthquake in the North Atlantic triggered a high-velocity, high-density turbidity current that is believed to have led to the shearing of 11 Trans-Atlantic communication cables. The sea floor over which this flow occurred had no more than a 2% to 5% slope. Numerous subaqueous landslides occurred during the 1964 Alaska earthquake causing extensive damage to nearby areas especially from large water waves that were generated by the landsliding. Saturated granular layers located at shallow depth below the surface may be susceptible to liquefaction during an earthquake. This phenomenon has frequently been observed in the past, notably in Niigata, Japan, in 1964 and Chile in 1960 as shown in the photograph, Figure A-6. In general, the greater the depth and the relative density of a submerged sand layer, the less is the danger of liquefaction. Shallow loose saturated sands appear to be most liquefiable, deep dense sands least liquefiable.

TSUNAMIS (SEISMIC SEA WAVES)

Tsunami (Seismic Sea Waves)--Water waves may be generated in the ocean by large submarine earthquakes. The mechanism is probably rapid vertical displacement of part of the ocean floor through faulting or, sometimes, by submarine landslides. Such waves are called *tsunamis* or *seismic sea waves*.

In the open ocean, tsunamis are characterized by long wave length (on order of hundreds of miles), long periods of oscillation (about an hour), high velocities (more than 600 miles per hour), and low wave heights (no more than a few feet). Shoaling begins as the ocean becomes shallower than one-half the wave length of the acting wave. Tsunamis, therefore, begin to react as they approach the shore by decreasing velocity and increasing wave height. Their approach is typically indicated by water withdrawal followed by a series of wave surges. Some surges have attained heights of 75-100 feet. Recorded surge heights of 50 feet are not uncommon along the Hawaiian shores. An earthquake in the Aleutian trench on April 1, 1946 generated a tsunami which impinged on the California coast and forced water to 11 feet at Half Moon Bay and 12 feet at Santa Cruz. The 1964 Alaskan earthquake generated a tsunami which resulted in damage in a number of places in the Pacific. The tsunami was disastrous at Crescent City, California, where it reached a height of 20.7 feet above mean sea level killing 11, injuring 35, and causing about $8,500,000 in property damage.

Mendocino County reported damage to fishing boats in Noyo Harbor, with 10 sunk. In Marin County, $1,000,000 damage occurred to small boats and berthing facilities. There was

damage to docking facilities in Los Angeles County and Long Beach Harbor. California had a longer time to prepare for the onslaught of the sea wave than other Pacific states. However, there was lack of sensible response among the public. Newspapers estimate 10,000 curious people waited on the San Francisco beaches to watch the tsunami arrive.

EARTHQUAKE RISK ESTIMATION AND DAMAGE CONTROL

There is no way known to predict exactly where, or when, the next sudden fault displacement will occur, or how strong the resulting earthquake will be. However, provided sufficient geological and seismological information is available, the prediction of the general level of earthquake activity for a given region may be attempted. This is the starting point for the estimation of the seismic risk (SR) or relative seismic risk (RSR) throughout the region. In seismic regions such as the San Francisco Bay Area, minor perceptible earthquakes of Richter magnitude less than 5.0 may be expected yearly. A large percentage of the earthquakes will fall within this harmless level, and will seldom result in substantial ground breakage along an active fault, or in damage to adequately designed structures. Every so often an earthquake of greater magnitude (from 5.0 to 6.0) may occur, causing some damage in localized areas, especially to structures not designed to resist shaking (or to structures located on poor ground), but will not adversely affect properly designed structures. Earthquakes having a Richter magnitude above 6.5 usually occur many years apart, and are usually associated with significant surface ground ruptures along the fault, destruction of inadequately designed and constructed structures, and damage to structures astride the displaced fault trace. It is largely a task for the future to prepare detailed SR and RSR maps of California, based on seismicity as well as geologic and soil conditions.

Although exact time and location of the next earthquake in a seismic region cannot now be predicted from past experience and recently acquired knowledge, the general *effects* can be reasonably predicted provided there is knowledge and understanding of the main variable factors that influence earthquake effects and damage. These factors include: (1) size (Richter magnitude), and depth of the earthquake, (2) epicentral distance or distance to the ruptured fault, (3) duration and frequency content of strong ground motion, and (4) underlying geological and soil conditions. A further factor is the extent to which precautions have been taken by industry, governmental agencies, school boards, planning commissions, and private individuals to reduce the damaging effects through proper planning, design, and construction. The last may be the most important because it is the one factor man can hope to control.

In conclusion, it is important to recognize the interdisciplinary nature of solving problems associated with earthquake hazards. The solution to many of these problems will be dependent upon the ability of the seismologist, geophysicist, geologist, and earthquake engineer to evaluate and delineate the basic causes and effects of earthquakes and communicate this information in practical terms. The result of such work can only be translated into effective action by the cooperation of planners, engineers, public officials and contractors, to reduce life loss and property damage in the next major earthquake. Broad public and governmental support must also exist.

APPENDIX B

CALIFORNIA CITY, COUNTY, AND STATE ORDINANCES RELATING TO ACTIVE FAULT AND GEOLOGIC HAZARDS

The following are excerpts from selected city, county, and state ordinances where active faults and other geologic hazards have been taken into consideration. These are presented as examples of how other cities, counties, and states are facing these problems.

LOS ANGELES COUNTY

Ordinance No. 10,037

"An ordinance adding Section 310 to Ordinance No. 2225, the Building Code, relating to building sites within potentially active earthquake fault zones.

"The Board of Supervisors of the County of Los Angeles do ordain as follows:

"Section 1. Section 310 is added to Ordinance No. 2225 entitled 'Building Code,' adopted March 20, 1933, to read:

"SEC. 310. EARTHQUAKE FAULTS.

"If a building site is within a potentially active fault zone, and the County Engineer so finds, geological or engineering records submitted in connection with the evaluation of each site shall contain information pertaining to the safety of such building site with respect to the probability of surface fractures occuring during an earthquake on the fault zone. Such reports also shall contain a recommendation as to the magnitude of ground shaking to be assumed in determining the aseisamic design of the building.

"For the purposes of this section, potentially active earthquake faults shall be those within the San Andreas Fault zone which enters the county at a point southeasterly from Big Pines and extends across the county in a northwesterly direction leaving the county near the intersection of the boundaries of the Counties of Kern, Los Angeles, and Ventura; and the Newport-Inglewood Fault zone which extends in a generally northwesterly direction through the cities of Long Beach and Signal Hill, and traversing the Baldwin Hills to the north.

"The County Engineer shall maintain maps showing the location of faults within potentially active fault zones

when such faults have been accurately located by geologic investigation, and such information has been filed with the County Engineer.

"Buildings shall not be constructed over a potentially active fault.

"Exception:

"Light-frame buildings not over one (1) story or twelve (12) feet in height, having an area of not more than one thousand (1000) square feet and not used for human occupancy, may be constructed over such a fault when an agreement has been recorded in the office of the County Recorder relieving the county, its officers and employees of liability for damage or loss which may result from the construction or use of such building. The agreement shall be binding on successors of interest in such property.

"Buildings within a potentially active fault zone shall be designed to resist the earthquake forces prescribed by this code or those recommended in the geological or engineering reports, whichever is greater.

"Section 2. This ordinance shall be published in the Journal of Commerce and Independent Review, a newspaper printed and published in the County of Los Angeles.

"(seal) ERNEST E. DEBS,
"ATTEST: Chairman.
"JAMES S. MIZE,
"Executive Officer - Clerk of the Board of Supervisors of the County of Los Angeles.

"I hereby certify that at its meeting of June 16, 1970, the foregoing ordinance was adopted by the Board of Supervisors of said County of Los Angeles by the following vote, to wit:

"Ayes: Supervisors Frank G. Bonelli, Kenneth Hahn and Burton W. Chace.

"Noes: None.

"(seal) JAMES S. MIZE,
"Executive Officer - Clerk of the Board of Supervisors of the County of Los Angeles.

"Effective Date July 17, 1970."

Ordinance No. 4478

"Sec. 94.

"(t) If the Advisory Agency finds that a geological report is necessary to determine whether the property to be divided is subject to an existing or potential geological hazard, a written report stating how the geological conditions will affect the proposed development may be required. The report shall be prepared by a geologist experienced in engineering matters and qualified by the County Geological Qualification Board."

"Sec. 158. (9071 4-22-66) LAND SUBJECT TO FLOOD HAZARD, INUNDATION, OR GEOLOGICAL HAZARD. If any portion of the land within the boundaries shown on a tentative map of a division of land is subject to flood hazard, inundation, or geological hazard and the probable use of the property will require structures thereon, the advisory agency may disapprove the map on that portion of the map so affected, and require protective improvements to be constructed as a condition precedent to approval of the map.

"If any portion of a lot or parcel of a division of land is subject to flood hazard, inundation, or geological hazard, such fact and portion shall be clearly shown on the final map or parcel map by a prominent note on each sheet of such map whereon any such portion is shown.

"Sec. 159. LAND SUBJECT TO OVERFLOW, PONDING OR HIGH GROUND WATER. If any portion of such land is subject to sheet overflow or ponding of local storm water or should the depth to ground water be less than ten feet from the ground surface the Regional Planning Commission shall so inform the State Real Estate Commissioner.

"Sec. 160. (9071 4-22-66) NATURAL WATER-COURSE DESIGNATION. In the event that a dedication of right of way for storm drainage purposes is not required, the Regional Planning Commission may require that the location of any water-course, channel, stream or creek, be shown on the final map or parcel map."

Los Angeles County Uniform Building Code, 1970

"SEC. 308 -- PROHIBITED USES OF BUILDING SITES

"(a) Flood Hazard. Buildings housing occupancies classified as A, B, C, D, H, or I are not permitted in an area determined by the County Engineer to be subject to flood hazard by reason of inundation, overflow or erosion. This prohibition shall not apply when provision is made to eliminate such hazard to the satisfaction of the County Engineer by providing adequate

drainage facilities, by protective walls, by suitable fill, by raising the floor level of the building, by a combination of these methods or by other means.

"(b) Unsafe Building Site. Work requiring a building or grading permit by this Code is not permitted in an area determined by the County Engineer to be subject to hazard from landslide, settlement or slippage. This prohibition shall not apply when the hazard has been eliminated to the satisfaction of the County Engineer as set forth in (1) of this Subsection, or the condition is not found to be unsafe for the proposed use by the County Engineer as set forth in (2) of this Subsection.

"1. By modification of topography, reduction of subsurface water, buttressing, a combination of these methods or by other means.

"2. The applicant has submitted a geological and/or engineering report or reports complying with the provisions of Section 309 which report or reports show that the proposed use of the site will not be unsafe. If a geological report indicates that the site appears to be safe for the proposed use but is located in an area subject to a hazard of geological nature, before a permit is issued the owner first shall record in the office of the County Recorder the finding of such report or reports, and an agreement relieving the County and all officers and employees thereof of any liability for any damage or loss which may result from the issuance of such a permit. This agreement shall provide that it is binding on all successors in interest of the owner and shall continue in effect until the County Engineer records in the office of the County Recorder a statement that he finds such hazard no longer exists.

"(c) Fills Containing Decomposable Material. Buildings or structures regulated by this Code shall not be constructed on fills containing rubbish or other decomposable material unless provision is made to prevent the accumulation of decomposition gases within or under enclosed portions of such buildings or structures and to prevent damage to structure, floors, underground piping and utilities due to uneven settlement of the fill. One-story light-frame accessory structures not exceeding 400 square feet in area nor 12 feet in height may be constructed without special provision for foundation stability.

"(d) Conditional Use. Work required by this Section as condition for the use of the site shall be performed prior to the connection of the utilities or occupancy of the building.

"SEC. 309 -- GEOLOGICAL ENGINEERING REPORTS

"The Building Official may require a geological or engineering report, or both, where in his opinion such reports are essential for the evaluation of the safety of the site. A geological report shall be prepared by an engineering geologist, qualified by the Los Angeles County Engineering Geologist Qualification Board. The report shall contain a finding regarding the safety of the building site for the proposed structure against hazard from landslide, settlement or slippage. An engineering report shall be prepared by an engineer experienced in soil mechanics. When both a geological and an engineering report are required for the evaluation of the safety of a building site, the two reports shall be coordinated before submission to the County Engineer."

ALAMEDA COUNTY

Hayward Municipal Code

"SECTION 3-6.03 DEFINITIONS"

* * *

"10. ENGINEERING GEOLOGIST shall mean a geologist licensed by the State of California to engage in the practice of engineering geology.

"11. ENGINEERING GEOLOGY shall mean the application of geologic knowledge and principles in the investigation and evaluation of naturally occurring rock and soil for use in the design of civil works."

* * *

"15. GEOLOGICAL REPORT shall mean a report prepared by an engineering geologist, based on a study and investigation of the site by an engineering geologist, including such geological structures and characteristics as fault line, fault creep, and land slide, and shall include recommendations for the execution, testing, and control of all grading operations proposed."

* * *

"18. HAYWARD FAULT ZONE is defined as being that area over or adjacent to the recently active breaks along the Hayward Fault as shown on the most current geological map prepared

by the United States Geological Survey. A copy of such map and amendments and successors thereto shall be kept on file in the office of the City Engineer."

* * *

"24. SOIL ENGINEER shall mean a civil engineer licensed by the State of California to engage in the practice of civil engineering who is experienced in and is engaged in professional practice in the field of soil mechanics.

"25. SOIL ENGINEERING shall mean the application of the principles of soil mechanics in the investigation, evaluation, and design of civil works involving the use of earth materials and the inspection and testing of the construction thereof.

"26. SOIL REPORT

"a. Preliminary Soil Report. 'Preliminary Soil Report' shall mean a report prepared by a soil engineer prior to any construction and for the purpose of providing information for preparation of plans and specifications. It shall be based on an examination of the site by the soil engineer and shall be a detailed engineering report describing the complete soil investigation by the soil engineer. It shall include but not be limited to a description of the surface and subsurface soil and groundwater characteristics, laboratory tests, and engineering analysis. The report shall include recommendations for site preparation, excavation, subsurface drainage, if necessary, grading, filling, and the necessary testing and control by the soil engineer to insure proper construction.

"b. Final Soil Report. 'Final Soil Report' shall mean a report prepared by a soil engineer describing in detail all work performed under his observation. It shall contain the results of tests and express an opinion as to the adequacy of the work completed and the conformance with plans and specifications."

* * *

"SEC. 3-6.10 GRADING PERMIT REQUIRED. It shall be unlawful for any person to commence or perform any grading in the City without first having obtained a grading permit from the City Engineer. A separate permit shall be required for each site, but, however, one permit may be used to cover both the excavation and fill made from the excavated material."

* * *

"SEC. 3-6.13 HAZARDOUS CONDITIONS. Whenever the City Engineer determines that any existing excavation or embankment or fill has become a hazard to life and limb, or endangers property, or adversely affects the safety, use, or stability of a public way or drainage channel, the owner of the property upon which the excavation or fill is located, or other person or agent in control of said property, upon receipt of notice in writing from the City Engineer shall within the period specified therein repair or eliminate such excavation or embankment so as to eliminate the hazard and be in conformance with the requirements of this Article."

* * *

"SEC. 3-6.20 APPLICATION FOR PERMIT. An application for a grading permit shall be in writing and filed with the City Engineer on forms provided for said purpose. Said application shall be accompanied by triplicate copies of the following information, unless otherwise provided by the City Engineer."

* * *

"14. Geological Report. Prior to issuance of a grading permit, the City Engineer may require an engineering geological investigation, based on the most recent grading plans, and a geological report thereof. The geological report shall include an adequate description of the geology of the site and conclusions and recommendations regarding the effect of geologic conditions on the proposed development. Where the site of the proposed grading is located in the Hayward Fault Zone, such geological report shall be mandatory.

"15. Soil Report. The City Engineer may require a soil engineering investigation, based on the most recent grading plan, and a soil report thereof. Such report shall include data regarding the nature, distribution, and strength of existing soils, conclusions and recommendations for grading procedures, and design criteria for corrective measures.

"16. All reports shall be subject to approval by the City Engineer and be referred to Planning Director for review and comment. Recommendations included in the report and approved by City Engineer shall be incorporated in this plan."

* * *

"SEC. 3-6.23 ISSUANCE OR DENIAL OF PERMIT"

* * *

"3. DENIAL FOR GEOLOGICAL OR FLOOD HAZARD. If, in the opinion of the City Engineer, the land area for which grading is proposed is subject to geological or flood hazard to the extent that no reasonable amount of corrective work can eliminate or sufficiently reduce the hazard to human life or property, the grading permit shall be denied."

* * *

"SEC. 3-6.38 DESIGN STANDARDS

"1. GENERAL INTENT. It is the general intent of the regulations of this Section that site development design shall preserve to the extent that is reasonable and feasible the existing natural scenic value of hills and valleys and contours of land.

"2. CRITERIA FOR DESIGN. All site development work, whether or not a permit is required under this Article, shall be designed to:"

* * *

"h. Take into consideration geologic hazards and adverse soil conditions and their effect on the future stability of the development."

* * *

"SEC. 3-6.40 GRADING INSPECTION AND SUPERVISION.

"1. GRADING INSPECTION, GENERAL. All grading operations for which a permit is required shall be subject to inspection by the City Engineer. When required by the City Engineer, special inspection of grading operations and special testing shall be performed in accordance with the provisions of paragraph 3 of this Section.

"2. GRADING DESIGNATION. All grading in excess of two thousand (2000) cubic yards shall be performed in accordance with the approved grading plan prepared by a civil engineer, and shall be designated as 'engineered grading.' Grading involving less than two thousand (2000) cubic yards shall be designated 'regular grading' unless the permittee, with the approval of the City Engineer, chooses to have the grading performed as 'engineered grading.'

"3. ENGINEERED GRADING REQUIREMENTS. For engineered grading it shall be the responsibility of the civil engineer who prepares the approved grading plan to incorporate all recommendations from the soil and geological reports into the grading plan. He shall also be responsible for the professional inspection of the work and expression of a professional opinion as to the adequacy of the grading within his area of technical specialty. This responsibility shall include, but need not be limited to, inspection and certification as to the establishment of line, grade, and drainage of the development area. The civil engineer shall act as the coordinating agent in the event the need arises for liaison between the other professionals, the contractor, and the City Engineer. The civil engineer shall also be responsible for the preparation of revised plans and the submission of as-graded grading plans upon completion of the work.

"Soil reports shall be required as specified in Section 3-6.20. During grading all necessary reports, compaction data, and soil engineering and engineering geology recommendations shall be submitted to the civil engineer and the City Engineer by the soil engineer and the engineering geologist.

"The soil engineer's area of responsibility shall include, but need not be limited to, the professional inspection and submission of a professional opinion concerning the preparation of ground to receive fills, testing for required compaction, stability of all finish slopes, and the design of buttress fills, where required, incorporating data supplied by the engineering geologist.

"The engineering geologist's area of responsibility shall include, but need not be limited to, professional inspection and submission of a professional opinion concerning the adequacy of natural ground for receiving fills and the stability of cut slopes with respect to geological matters, and the need for subdrains or other ground water drainage devices. He shall report his findings to the soil engineer and the civil engineer for engineering analysis.

"The City Engineer shall inspect the project at the various stages of the work requiring certification and at any more frequent intervals necessary to determine that adequate control is being exercised by the professional consultants."

* * *

"5. NOTIFICATION OF NONCOMPLIANCE. If, in the course of fulfilling his responsibility under this Article, the supervising civil engineer finds that the work is not being done

in conformance with this Article or the plans approved by the City Engineer, or in accordance with accepted practices, he shall immediately notify the person in charge of the grading work and the City Engineer in writing of the non-conformity and of the corrective measures to be taken."

* * *

"SEC. 3-6.43 COMPLETION OF WORK

"1. FINAL REPORTS. Upon completion of the rough grading work and at final completion of the work the City Engineer may require the following reports and drawings and supplements thereto:

"a. An as-graded grading plan prepared by the civil engineer including original ground surface patterns and locations and elevations of all surface and subsurface drainage facilities. He shall render a professional opinion as to whether the work was done in accordance with the final approved grading plan.

"b. A Soil Grading Report prepared by the soil engineer including locations and elevations of field density tests, summaries of field and laboratory tests, and other substantiating data and comments on any changes made during grading and their effect on the recommendations made in the soil engineering investigation report. He shall include a professional opinion as to the adequacy of the site for the intended use.

"c. A Geologic Grading Report prepared by the engineering geologist including a final description of the geology of the site including any new information disclosed during the grading and the effect of same on recommendations incorporated in the approved grading plan. He shall render a professional opinion as to the adequacy of the site for the intended use as affected by geologic factors."

STATE OF CALIFORNIA

Excerpt from State Planning Law relating to general plans.

"Article 5. Authority for and Scope of General Plans

"65300. Each planning agency shall prepare and the legislative body of each county and city shall adopt a comprehensive, long-term general plan for the physical development

of the county or city, and of any land outside its boundaries which in the planning agency's judgment bears relation to its planning.

"65301. The general plan shall be so prepared that all or individual elements of it may be adopted by the legislative body, and so that it may be adopted by the legislative body for all or part of the territory of the county or city and such other territory outside its boundaries which in its judgment bears relation to its planning.

"65302. The general plan shall consist of a statement of development policies and shall include a diagram or diagrams and text setting forth objectives, principles, standards, and plan proposals. The plan shall include the following elements:

"(a) A conservation element for the conservation, development, and utilization of natural resources including water and its hydraulic force, forests, soils, rivers and other waters, harbors, fisheries, wildlife, minerals, and other natural resources. The conservation element may also cover:

"(1) The reclamation of land and waters.

"(2) Flood control.

"(3) Prevention and control of the pollution of streams and other waters.

"(4) Regulation of the use of land in stream channels and other areas required for the accomplishment of the conservation plan.

"(5) Prevention, control, and correction of the erosion of soils, beaches, and shores.

"(6) Protection of watersheds.

"(7) The location, quantity and quality of the rock, sand, and gravel resources.

"(b) A recreation element showing a comprehensive system of areas and public sites for recreation, including the following and, when practicable, their locations and proposed development:

"(1) Natural reservations.

"(2) Parks."

* * *

"(k) A safety element for the protection of the community from fires and geologic hazards including features necessary for such protection as evacuation routes, peak load water supply requirements, minimum road widths, clearances around structures, and geologic hazard mapping in areas of known geologic hazards."

There is a pending amendment concerning the earthquake hazard element which defines the applicable hazards from earthquakes (susceptibility to surface rupture from faulting, to shaking, to ground failure, and to tsunamis) and shall set standards for land use and development in such areas.

California State Education Code, Chapter 434, Section 15002.1

"The governing board of a school district, prior to acquiring any site on which it proposes to construct any school building as defined in Section 15452, shall have the site, or sites, under consideration investigation by competent personnel to ensure that the final site selection is determined by an evaluation of all factors affecting the public interest and is not limited to selection on the basis of raw land costs only. *The investigation shall include such geological and engineering studies as will preclude siting of a school over or within a fault, on or below a slide area, or in any other location where the geological characteristics are such that the construction effort required to make the site safe for occupancy is economically unfeasible.* The evaluation shall also include location of the site with respect to population, transportation, water supply, waste disposal facilities, utilities, traffic hazards, surface drainage conditions, and other factors affecting the operating costs, as well as the initial costs, of the total project." (emphasis added)

MAP LEGEND

CLASS I - Prominent or Obvious Fault

CLASS II - Probable Fault or Rupture

CLASS III - Possible Fault or Rupture

LANDSLIDE - Arrow shows direction of movement

DASHED LINES are approximate

DOTTED LINES are concealed or inferred

All lineaments were mapped using special low sun-angle illumination aerial photographs taken especially for this project. The basic scale of the photographs is 1:12,000 (1 inch = 1,000 feet), although scales of 1:5,000 and 1:6,000 were flown for detailed investigation of specific areas. Fault-related features were optically transferred from photographs to 7-1/2 minute topographic base maps using a vertical sketchmaster and were checked by inspection and scale dividers.

ACCURACY

Fault-related features plotted on the map generally have a lateral accuracy of ± 100 feet. In areas of high relief or where cultural development such as roads, fence lines, and other similar features are lacking, the accuracy may be no better than ± 200 feet. In urbanized areas the fault features have been modified and obscured by city development. In these areas only the most obvious scarps are plotted and more detailed studies are needed to locate the less prominent secondary faults.

PURPOSE OF MAP

The purpose of these maps is an aid for general regional land-use planning. The information presented is intended to provide a framework for more detailed investigation and evaluations. We are confident that the features plotted as Class I faults are the locations of the most recent surface fault ruptures. The Class I features have significant vertical relief or extend from surface ruptures having significant vertical relief.

It is our belief that all the Class I lineaments are well defined topographic features that mark the most recent surface fault ruptures. They are believed to have been mostly produced by rapid fault displacements associated with strong earthquakes. Most Class I ruptures are undoubtedly the result of repeated fault displacements that are concentrated along previously established planes of weakness. Therefore, the Class I faults are the most likely candidates for significant future movements. Some fault movement along the Wasatch fault may be by slow tectonic creep as has been documented along other active faults.

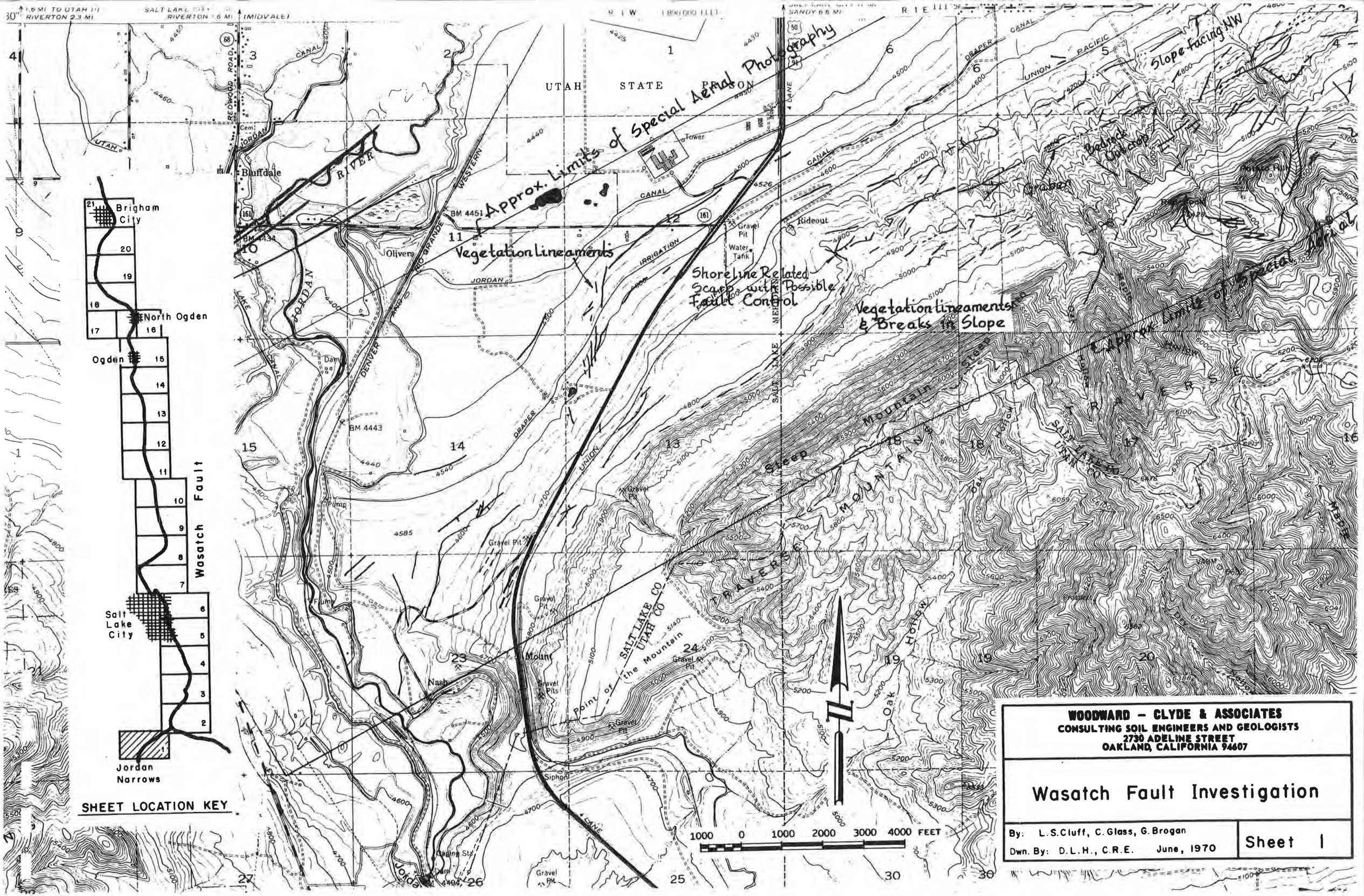
The Class II features are probably surface faults. They have little vertical relief and may be secondary fault-related features associated with ground failure or graben development.

The Class III features are possible surface faults. They have little or no vertical relief. Most of them appear to be related to the Class I and II fault features; however, some Class III features may represent erosional fault-line features or shore-line features and this should be taken into consideration in more detailed investigations. The Class III features are shown because we feel they are possibly fault related and are important enough to be considered for further investigation and evaluation. Our confidence level decreases from Class I to Class III.

It is important to understand that some minor fault breaks may not have been identified or recognized, or they may be confused with shore-line features again emphasizing the need for more detailed surface mapping and subsurface investigations.

The most recent movements on the Wasatch fault are predominantly vertical, with the mountain block being displaced relatively upward in respect to the valley block. Because of the vertical movement and the geometry of the fault plane, past movements along the Wasatch fault have produced grabens and tilted blocks adjacent to the main fault break. Future movements are expected to also produce tilted blocks and this should be given serious consideration in locating high-rise buildings or other structures that cannot tolerate tilting or changes in lines of level. Tilting should be of prime concern in more detailed investigation and evaluations.

Landslides are common along portions of the Wasatch fault. Many of them are outlined on the prepared maps. Some are presently active and some appear to be in a state of equilibrium. The landslide debris deposits are important because, even though some appear not to be presently moving, they are potentially unstable, especially if they are altered or disturbed. Disturbances by earthquakes, fault movements, man-made cuts or heavy rainfall could re-activate the slide mass. Therefore, detailed investigations must be carried out before development is allowed near these landslides.

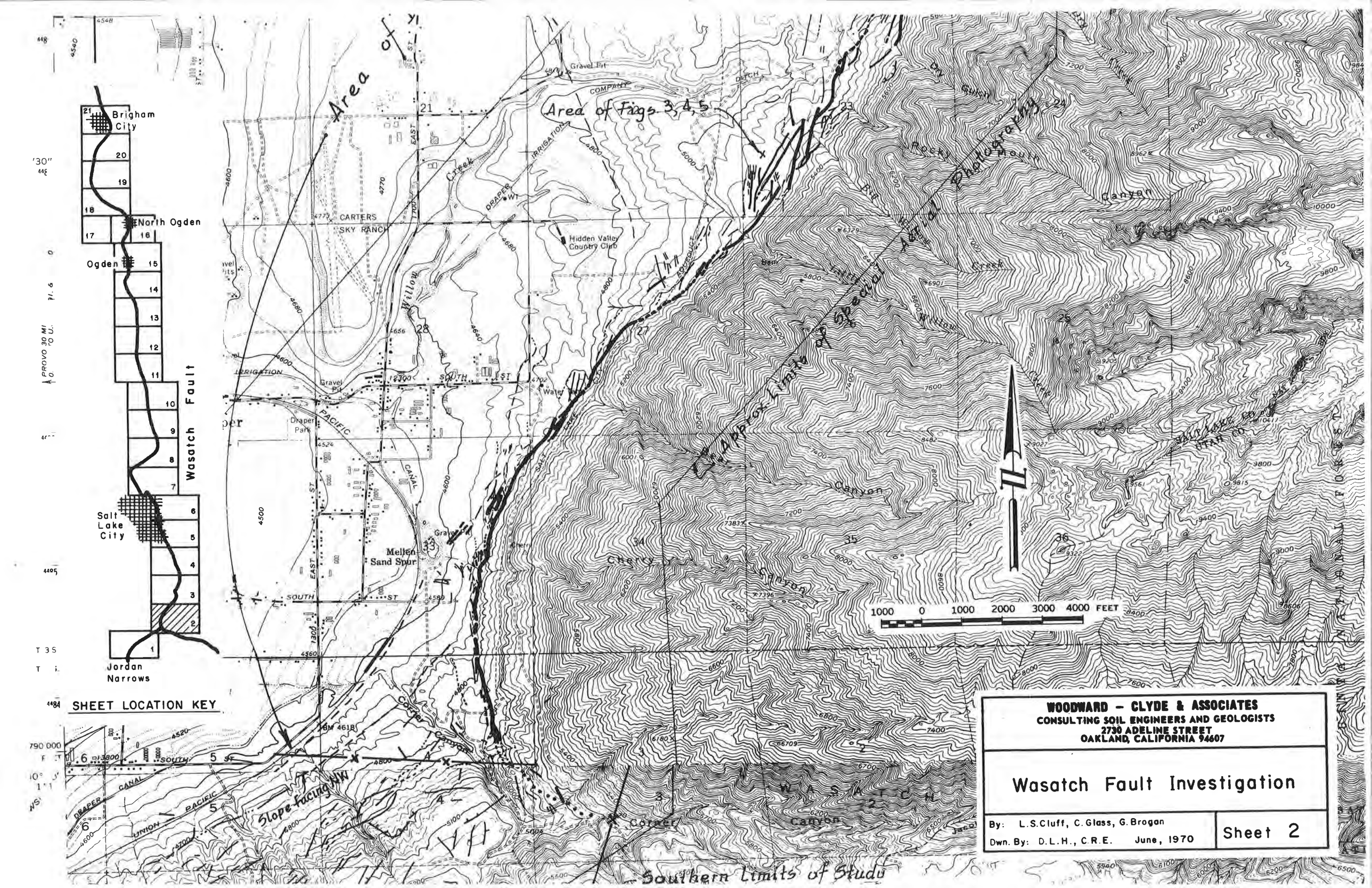


WOODWARD – CLYDE & ASSOCIATES
CONSULTING SOIL ENGINEERS AND GEOLOGISTS
2730 ADELINE STREET
OAKLAND, CALIFORNIA 94607

Wasatch Fault Investigation

By: L.S.Cluff, C.Glass, G.Brogan
Dwn. By: D.L.H., C.R.E. June, 1970

Sheet 1



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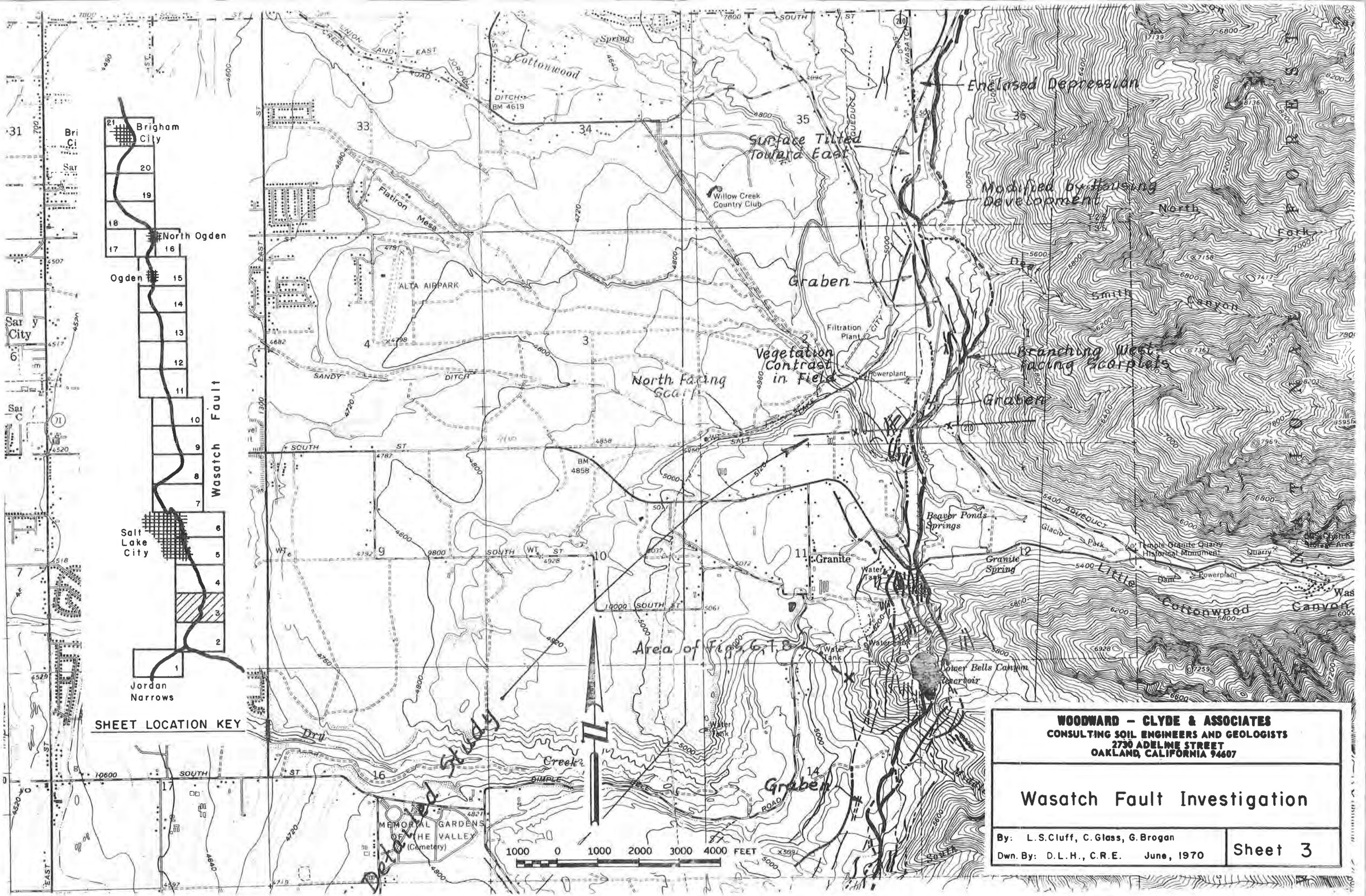
Sheet 2



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Sheet 3

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Wasatch Fault Investigation

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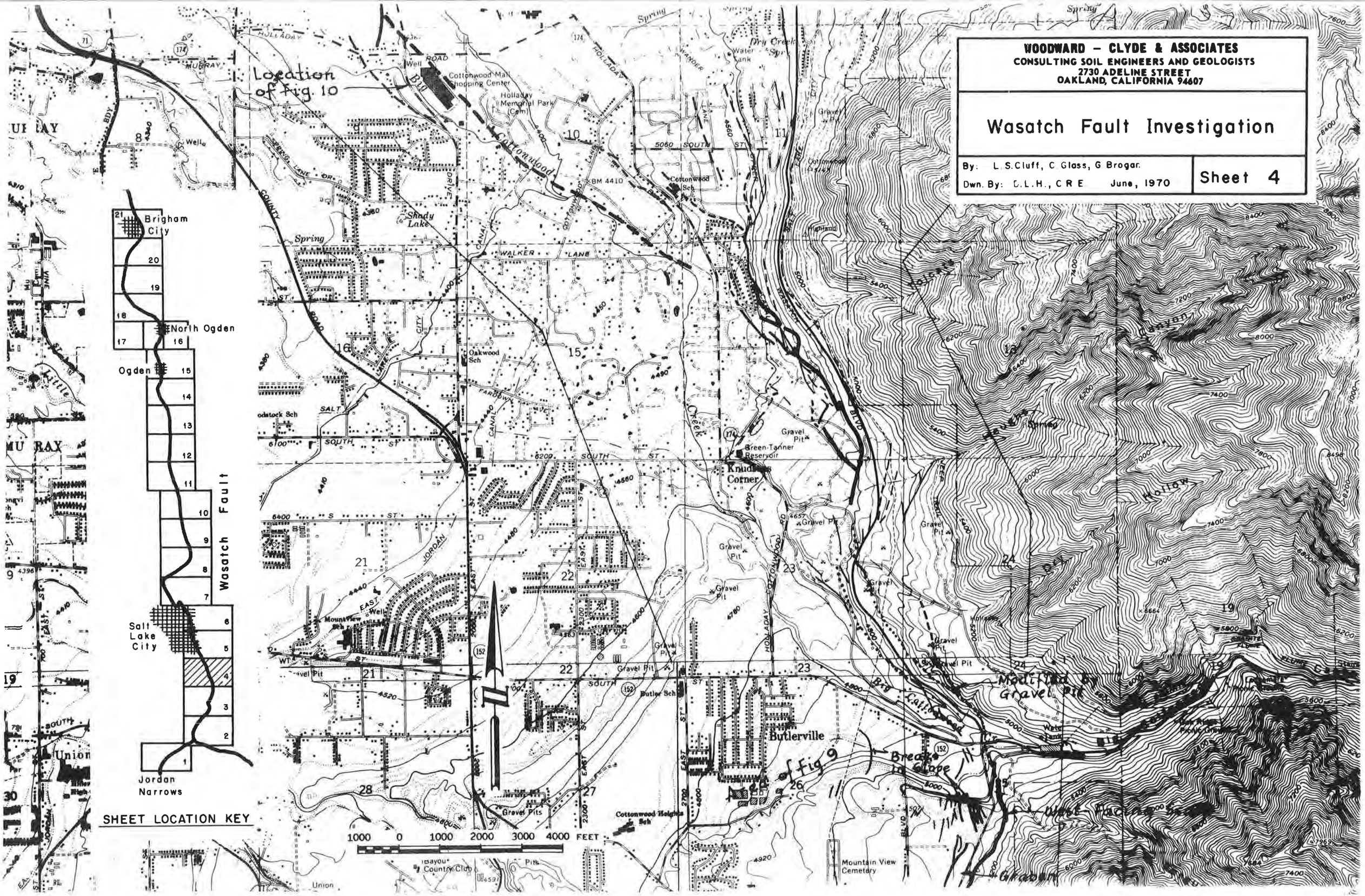
Dwn. By: D.L.H., C.R.E. June, 1970

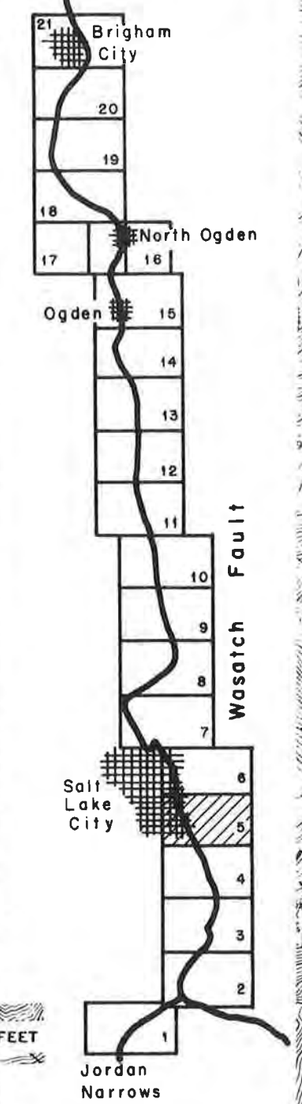
Sheet 4



Prominent West Facing Scarp Modified by City Development

Approx. Limits Special Aerial Photography

Sugar House
Forest Sch
Sugar House Mon
Highland High Sch
SUGAR HOUSE PARK
Fairmont Park
Rosslyn Heights Sch
FOREST DALE GOLF COURSE
Parleys Creek
Country Club
Highland Park Sch
Nibley Park Sch
SALT LAKE CITY
Grandview Sch
Rosecrest Sch
Canyon Rim Sch
Park Res
Terminal Res
Drive-in Theater
East Millcreek
Eastwood Sch
Brick Kilns
Lubbie Edward Sch
Roosevelt Sch
Library
Fish Hatchery
WASATCH LAWN MEMORIAL PARK
Sherman Sch
Evergreen Jr H S
Mill Creek
Flume
Victoria Park Shopping Center
Millcreek Sch
Drive-in Theater
William Penn Sch
Wasatch Jr H S
Skyline High Sch
Water Tank
Olympus High Sch
Mortimiside Sch
Creatview Sch
Hillview Sch
Elysian Burial Gardens
Holladay Sch
Olympus Jr H S
Holladay
Castle Spring



SHEET LOCATION KEY

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By: L. S. Cluff, C. Glass, G. Brogan
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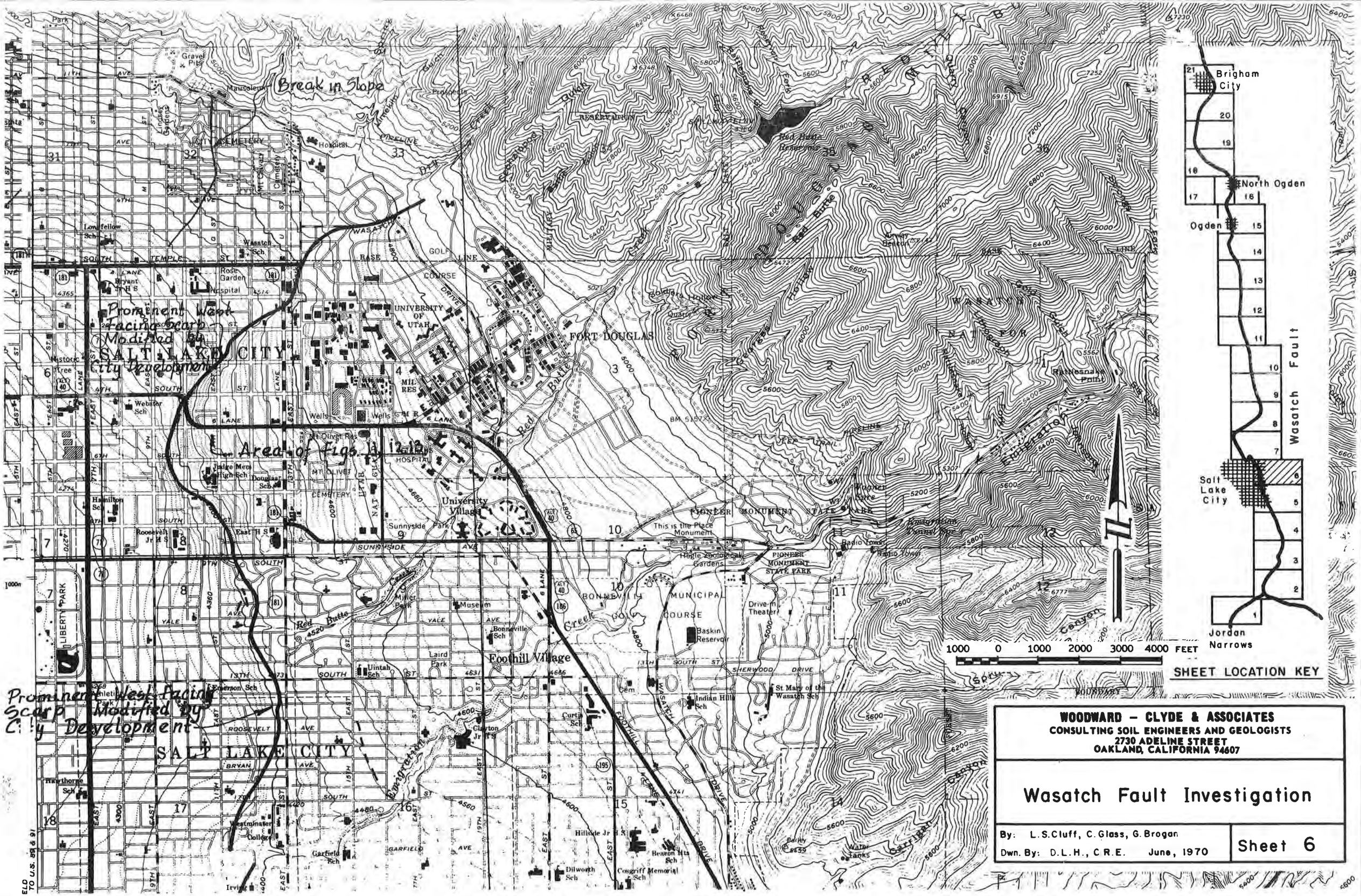
Sheet 5



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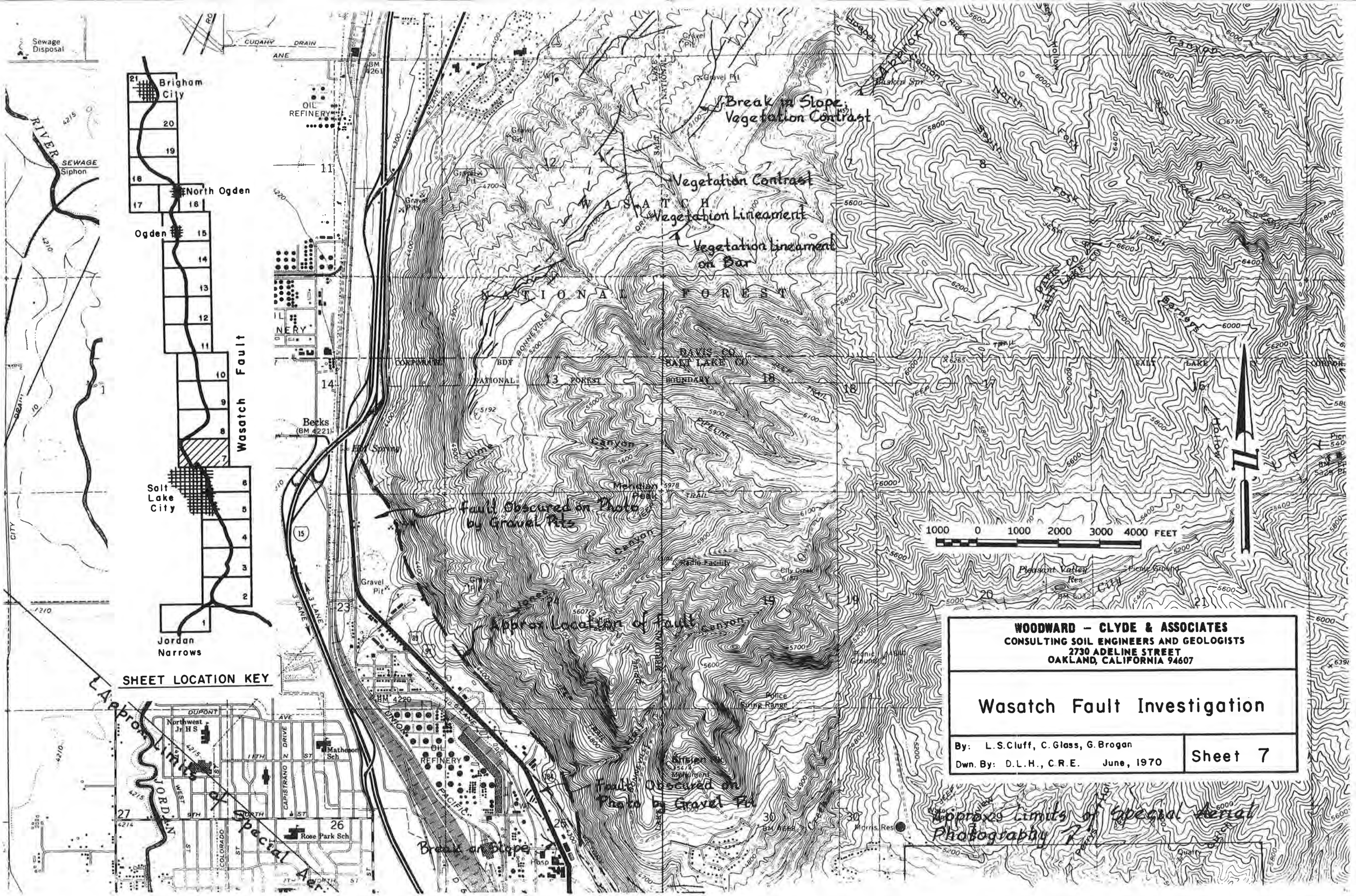
Sheet 6



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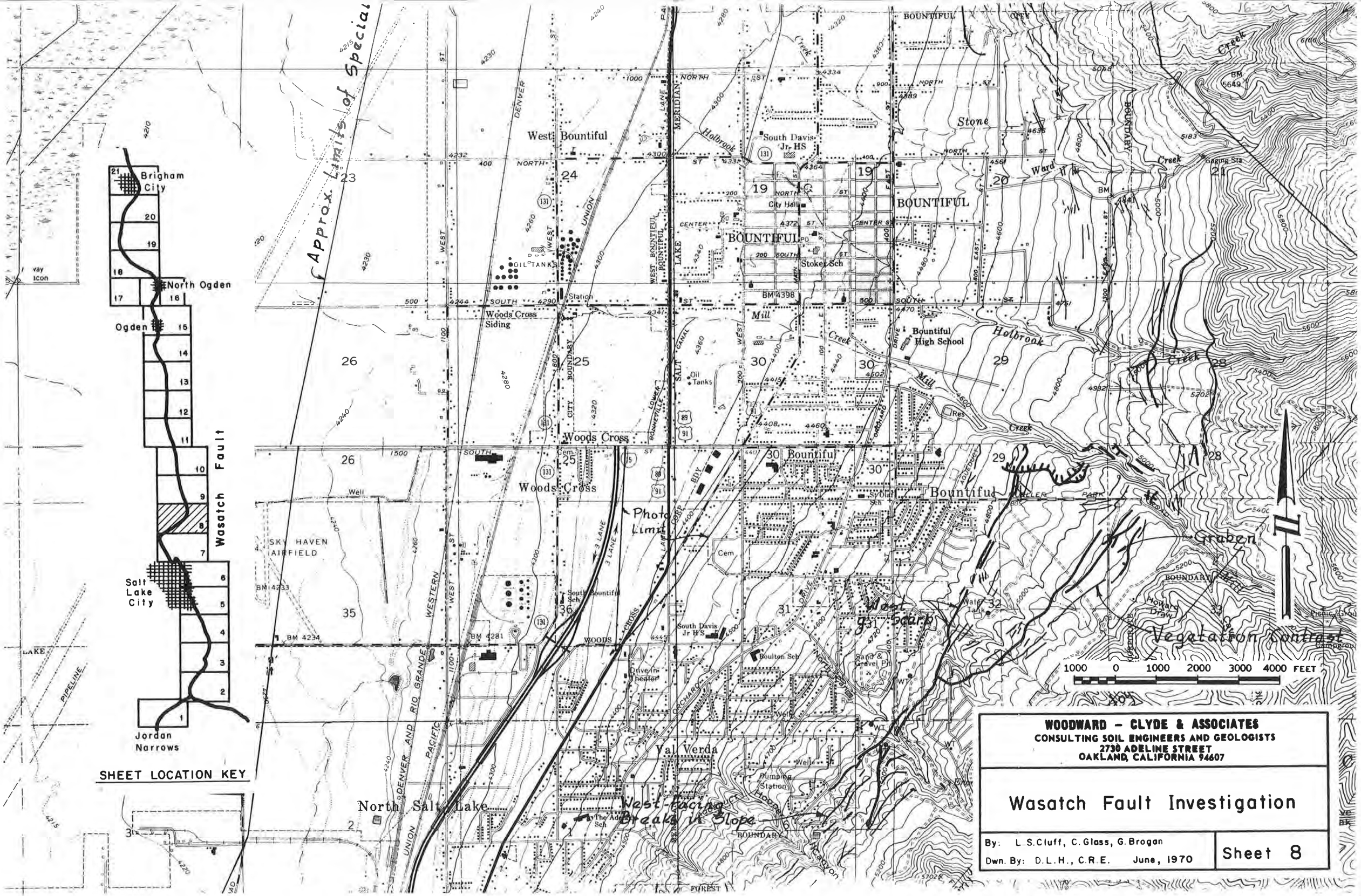
Sheet 7



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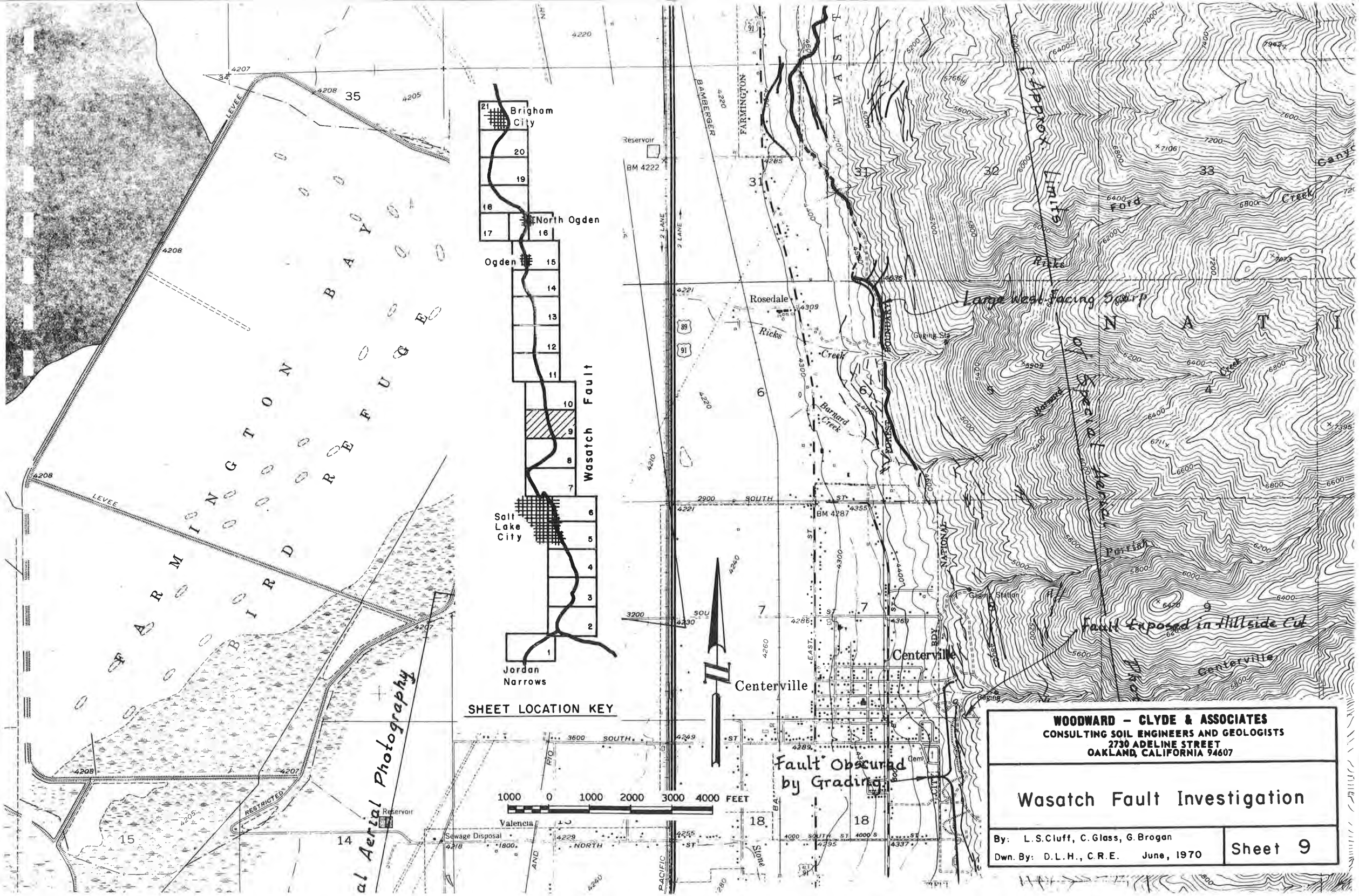
Sheet 8


Large West-Facing Scarp
Fault Exposed in Hillside Cut
Fault Obscured by Grading
Centerville
Rosedale
Farmington
Brigham City
North Ogden
Ogden
Salt Lake City
Jordan Narrows
Wasatch Fault
SHEET LOCATION KEY
1000 0 1000 2000 3000 4000 FEET
Reservoir
Sewage Disposal
Valencia
Gaging Sta
Gaging Station
Ricks Creek
Barnard Creek
Portlock Creek
Ford Canyon Creek
Levee
Restricted
Bamberger
Farmington Bay
Bird Refuge
Aerial Photography
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By: L.S.Cluff, C.Glass, G.Brogan
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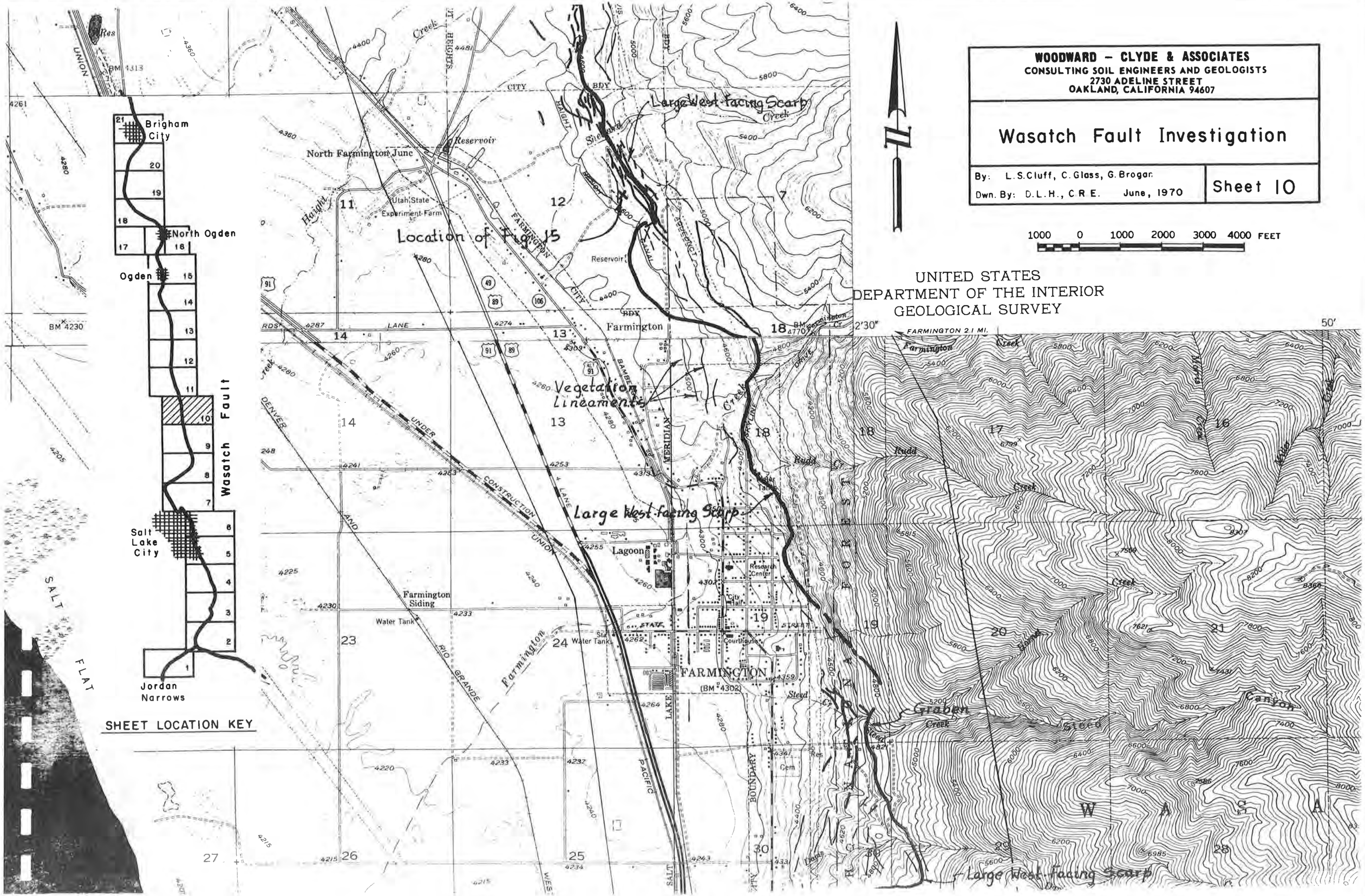
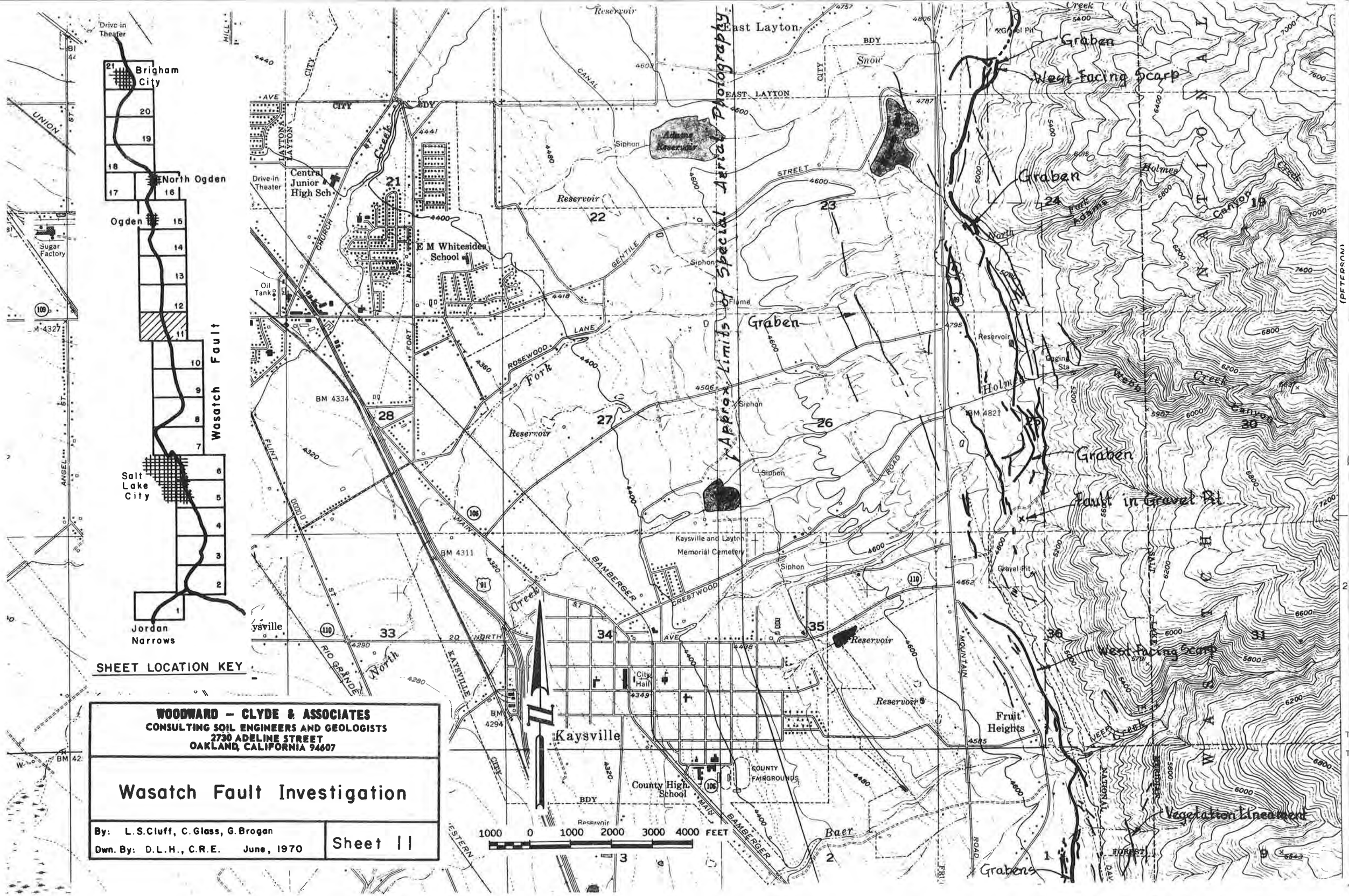
Sheet 10

1000 0 1000 2000 3000 4000 FEET

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY





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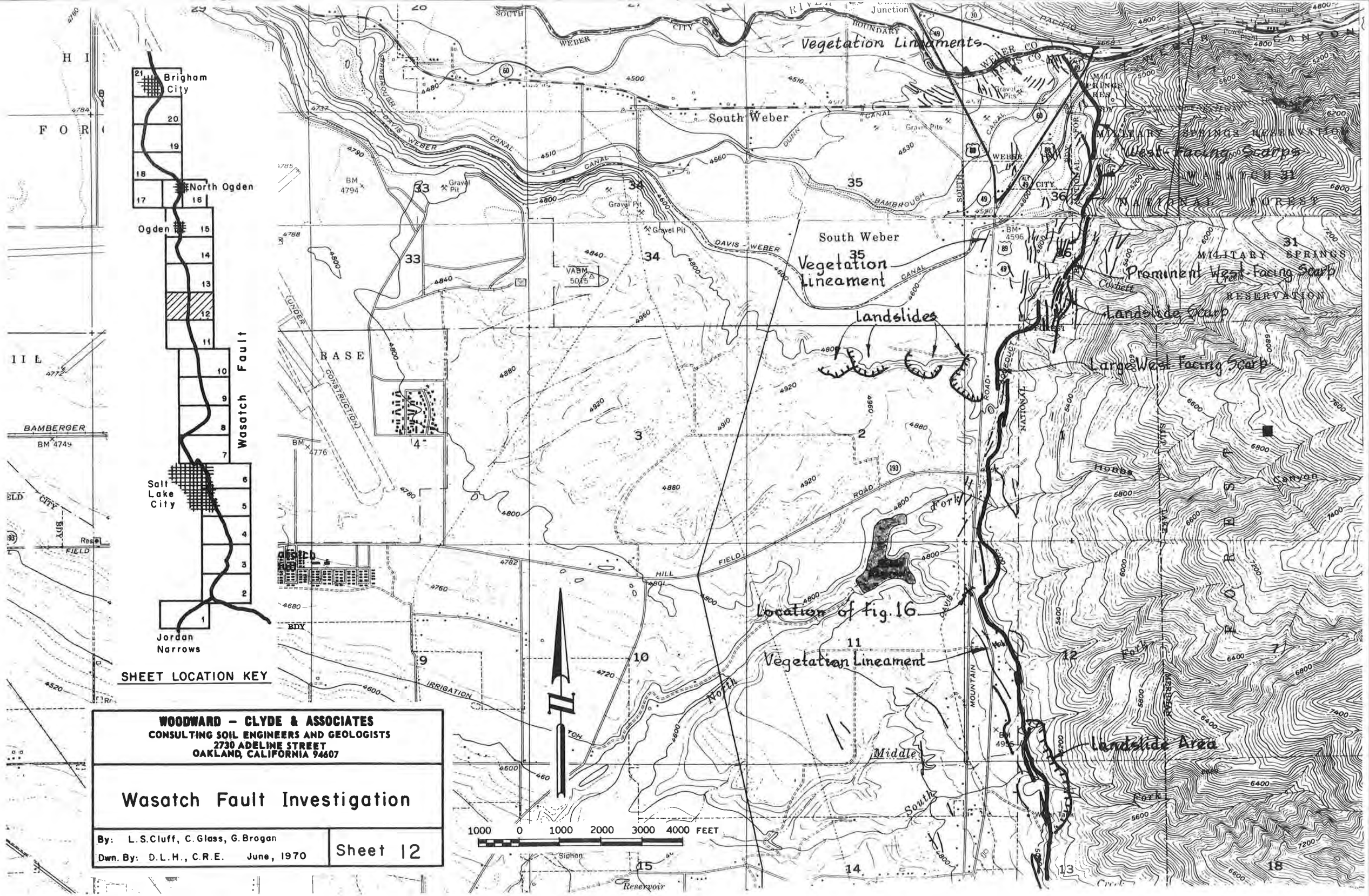
Sheet 11



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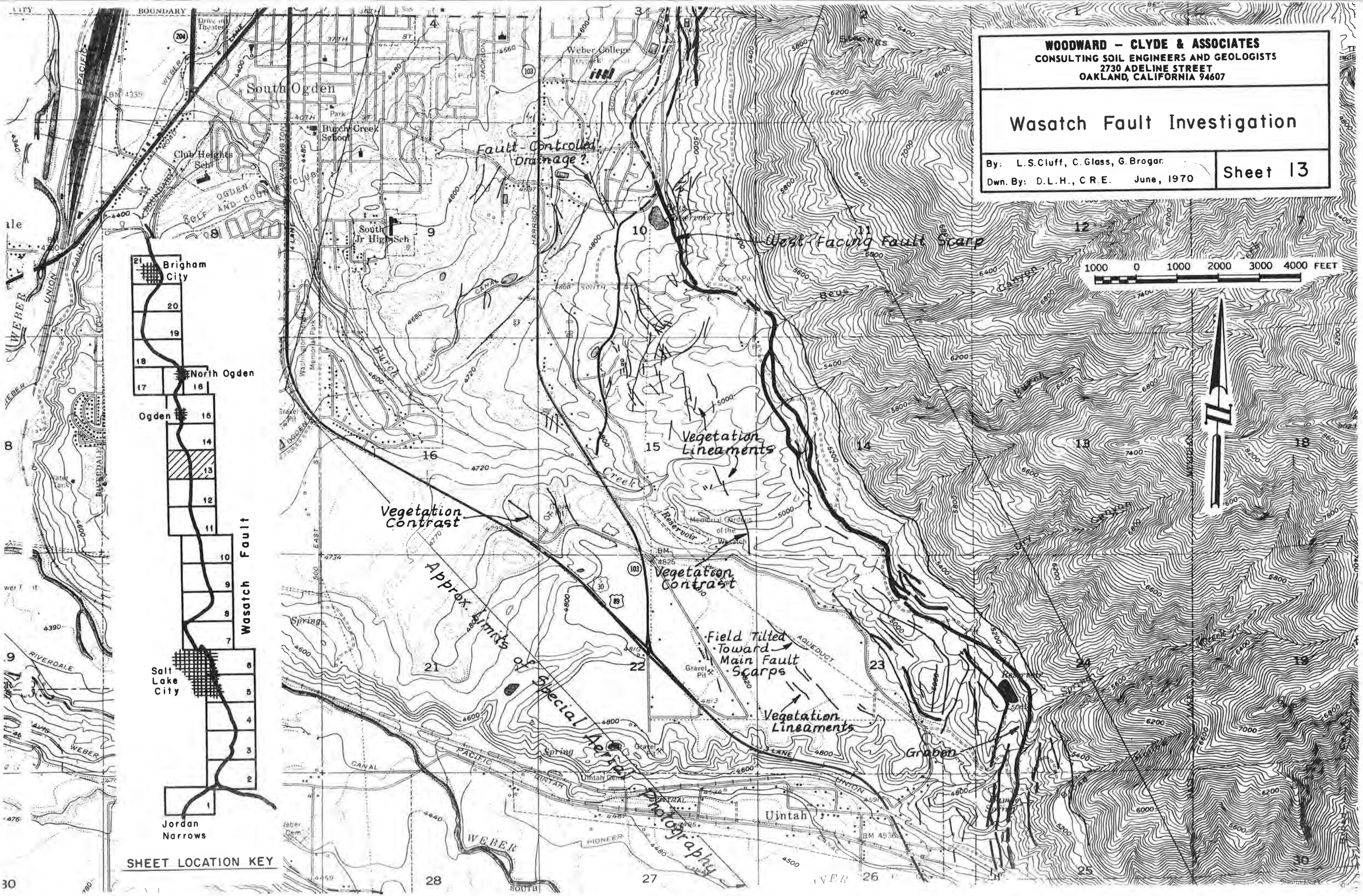
Sheet 12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Wasatch Fault Investigation
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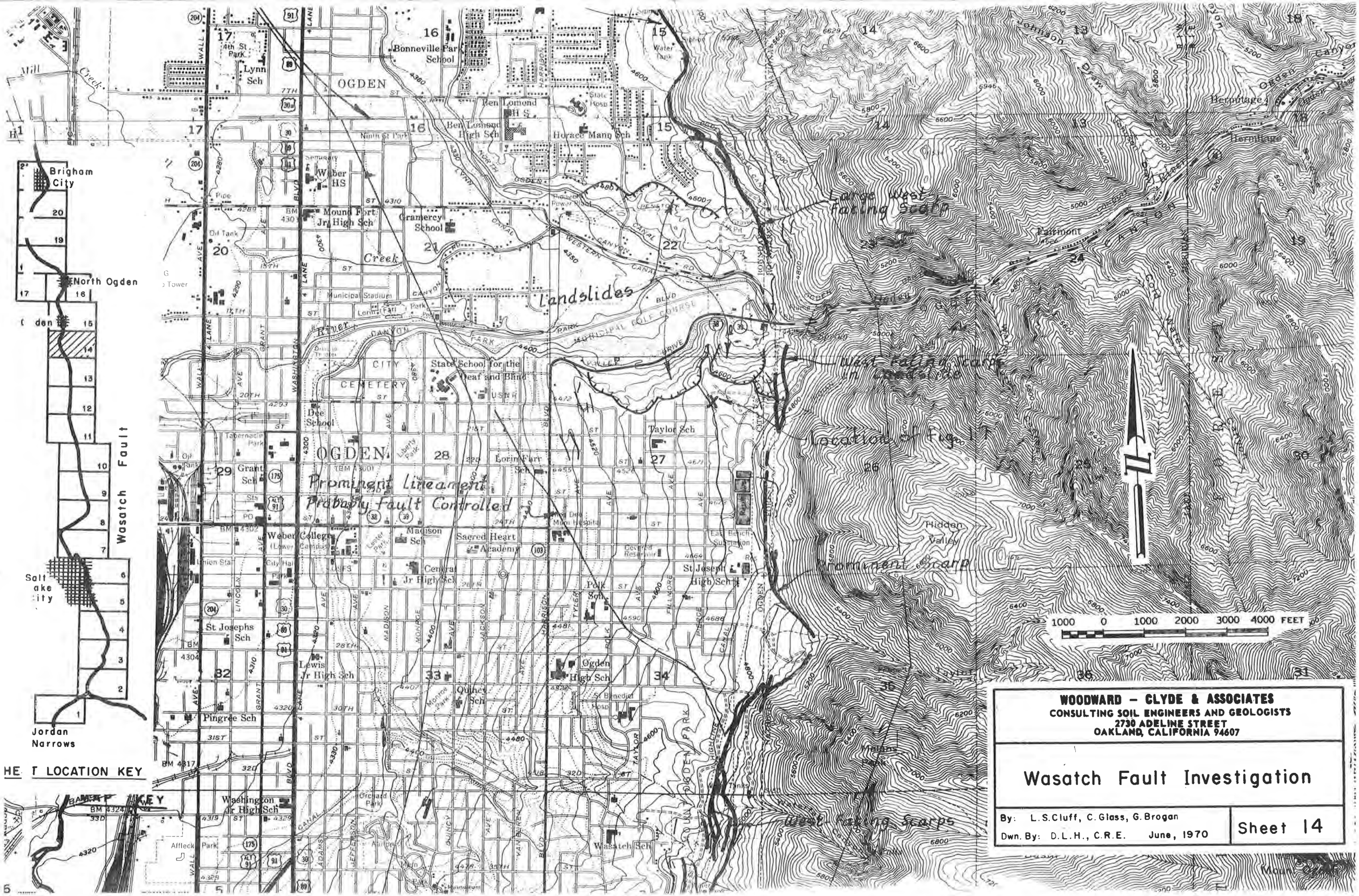
Sheet 13
1000 0 1000 2000 3000 4000 FEET
Fault-Controlled Drainage?
West-Facing Fault Scarp
Vegetation Lineaments
Vegetation Contrast
Vegetation Contrast
Approx. Limits of Special Aerial Photographs
Field Tilted Toward Main Fault Scarps
Vegetation Lineaments
Graben
South Ogden
Weber College
Brigham City
North Ogden
Ogden
Salt Lake City
Jordan Narrows
Wasatch Fault
SHEET LOCATION KEY



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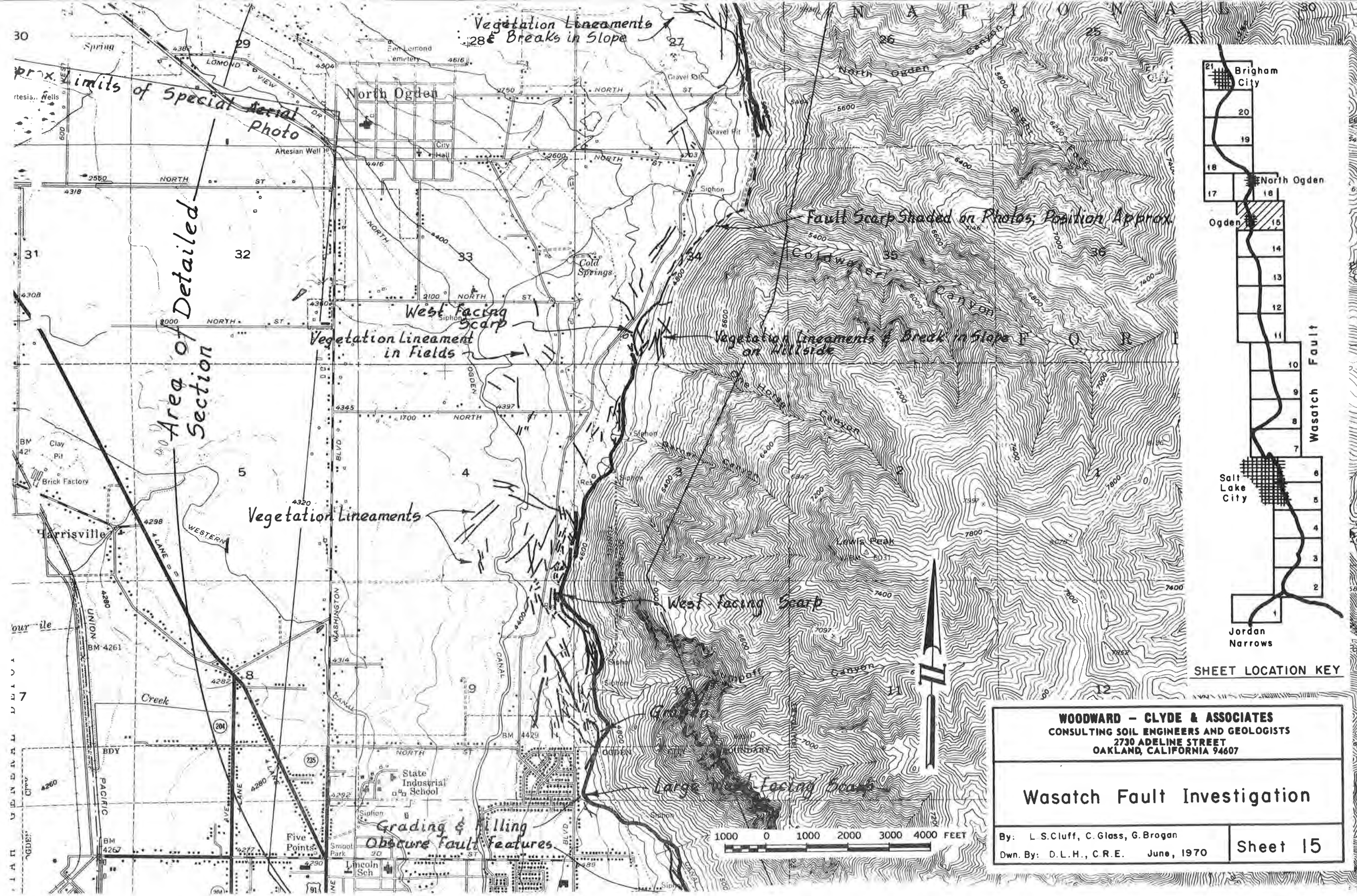
Sheet 14



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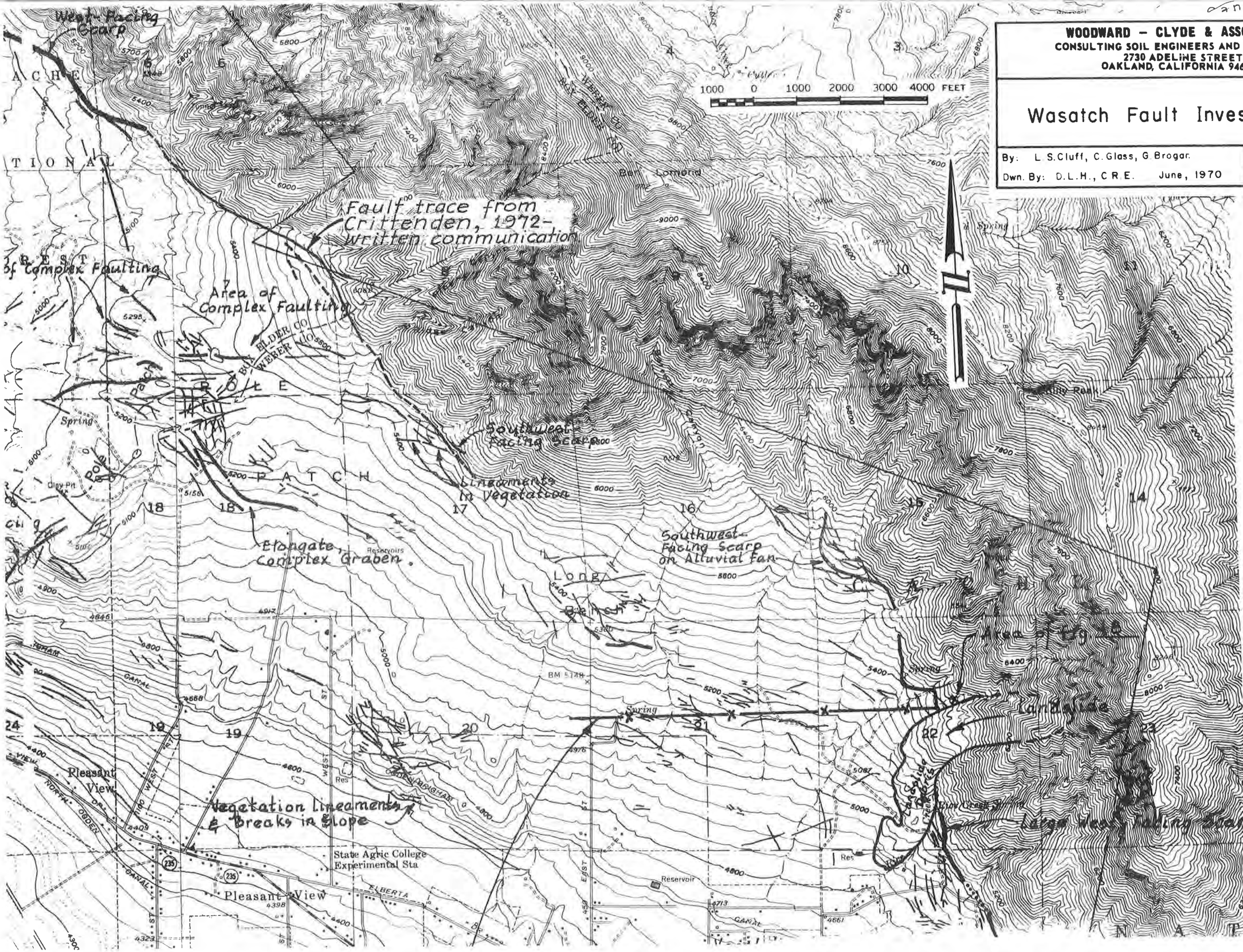
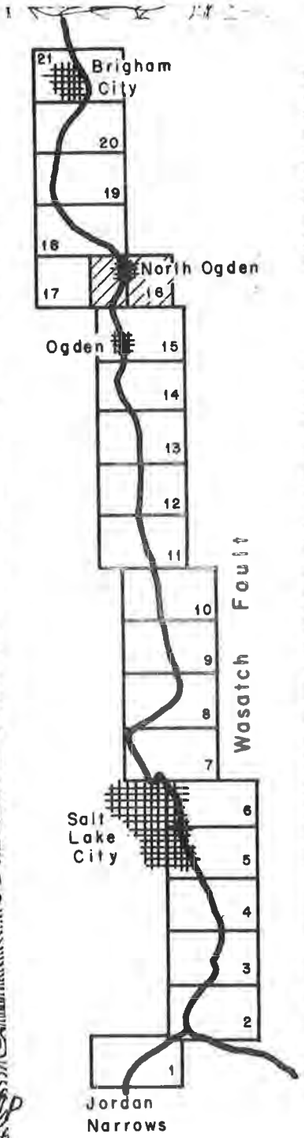
Sheet 16





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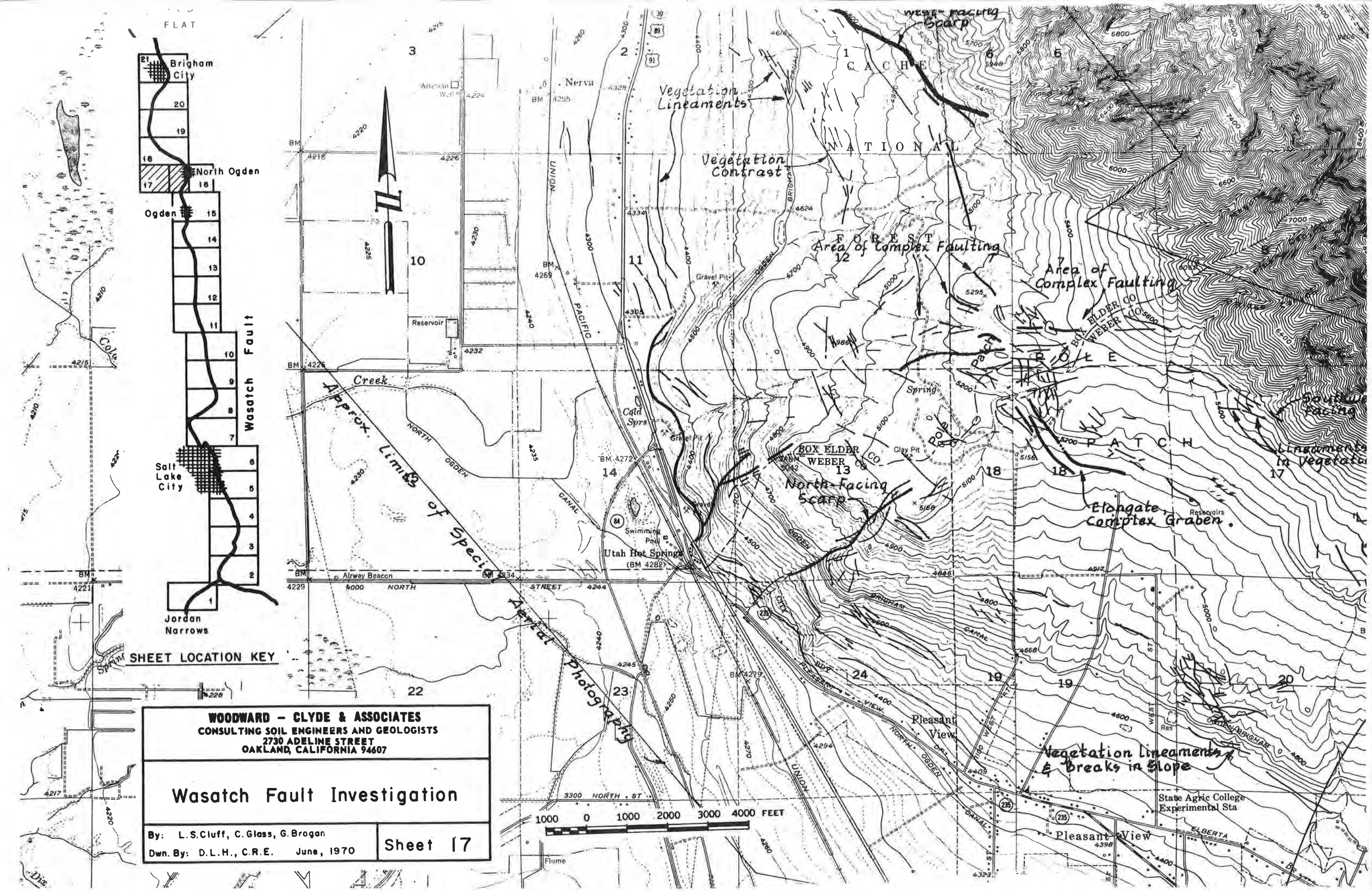

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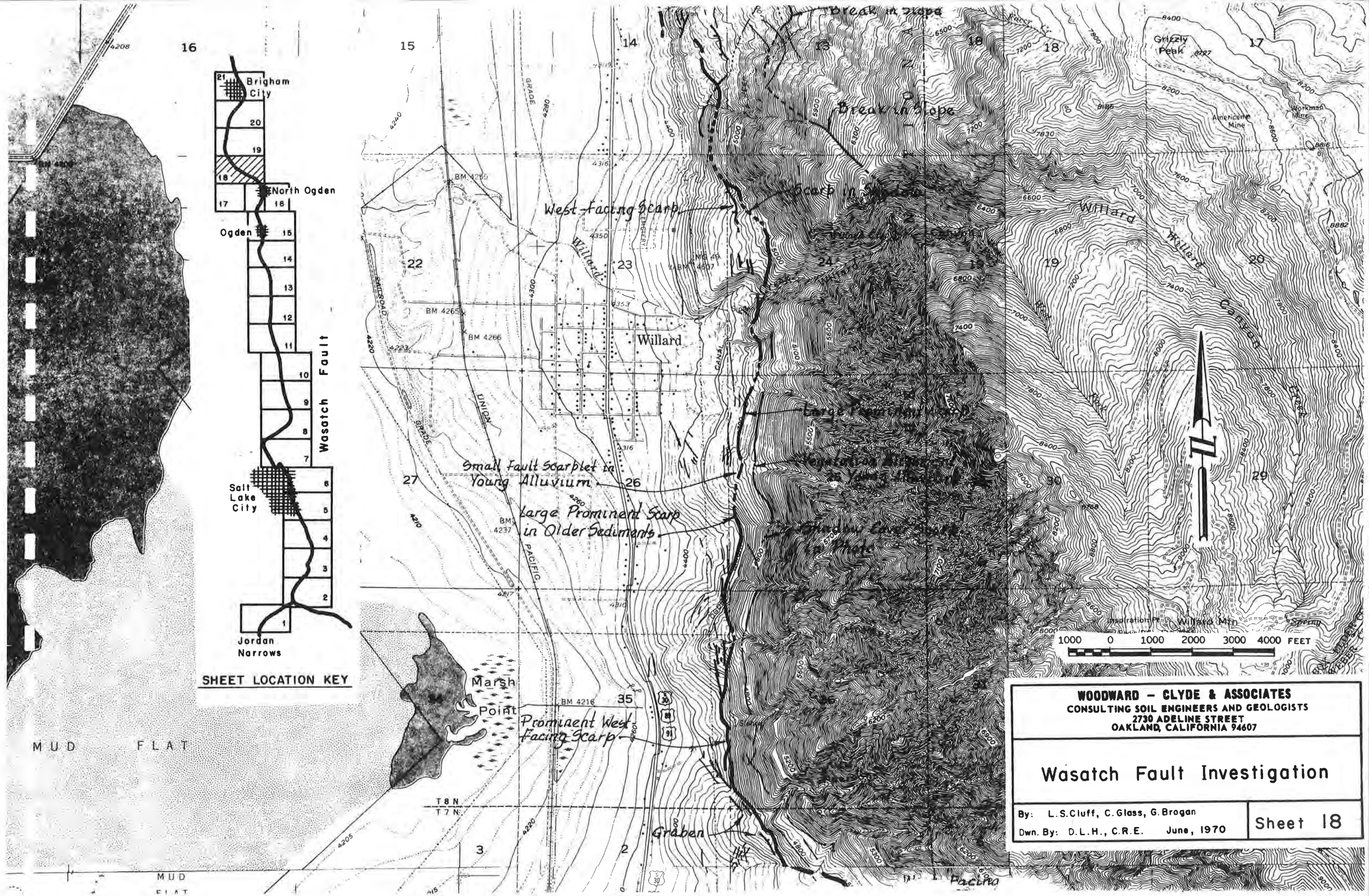
Sheet 17



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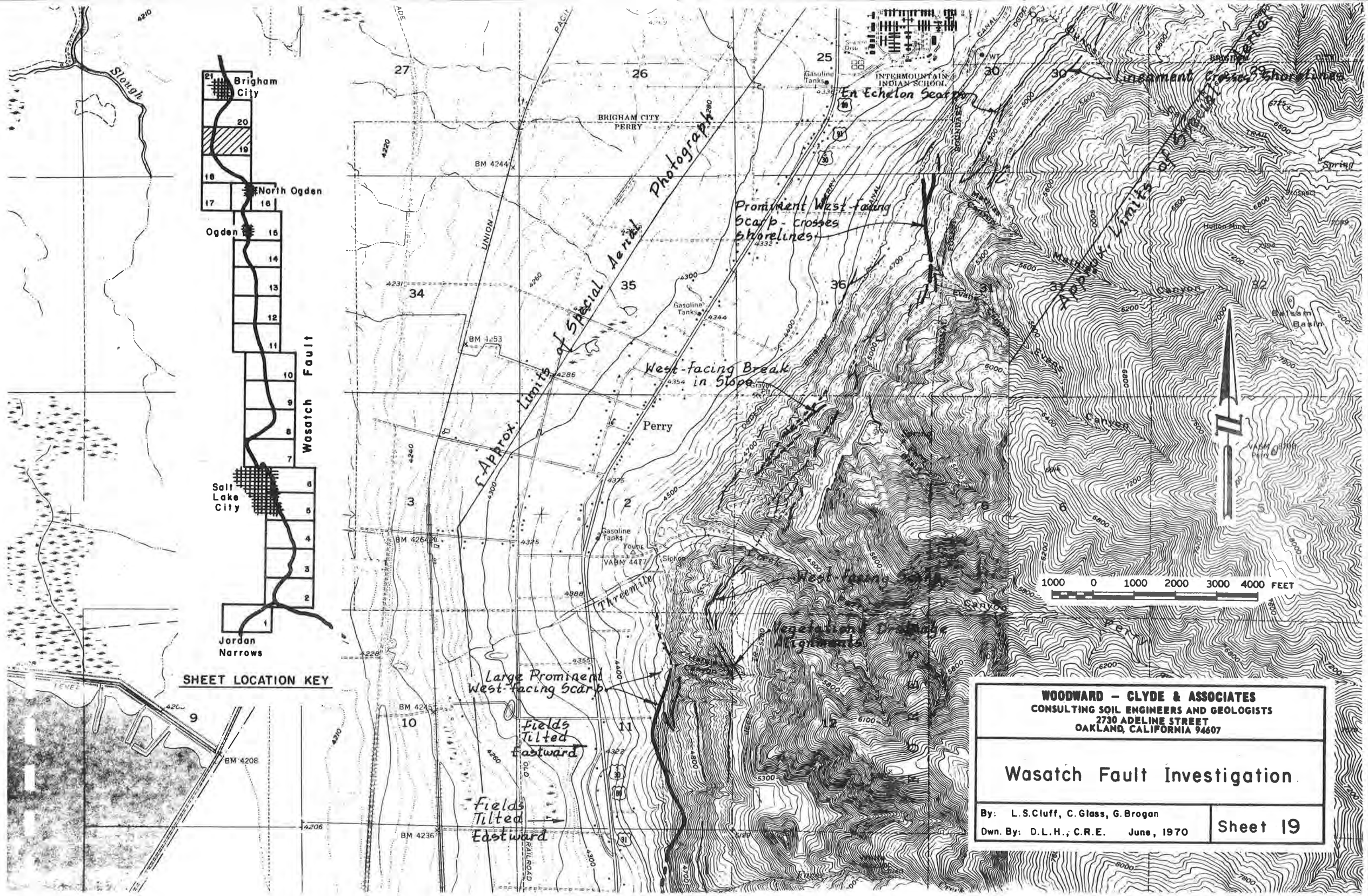
Sheet 18



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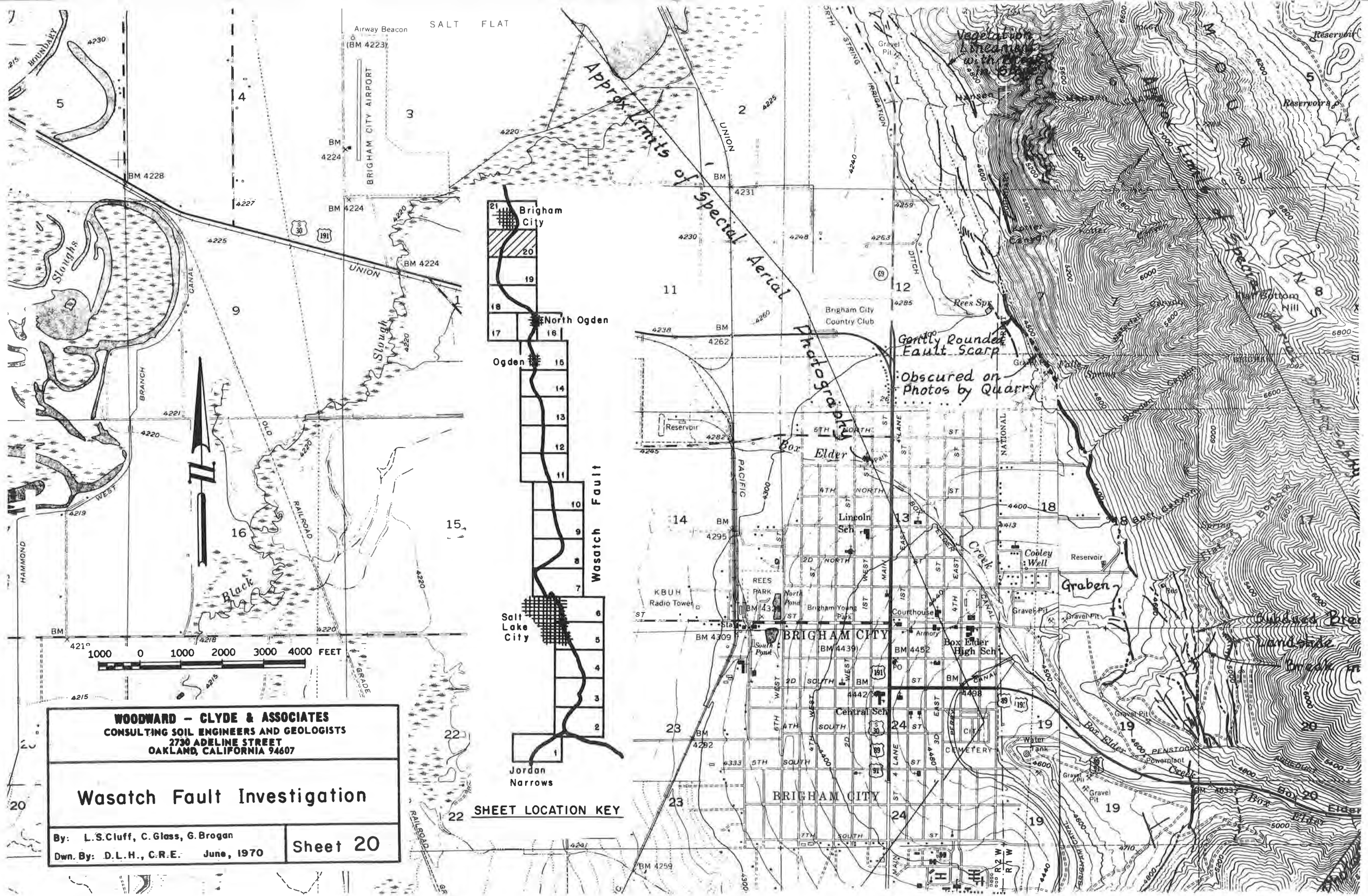
Sheet 19



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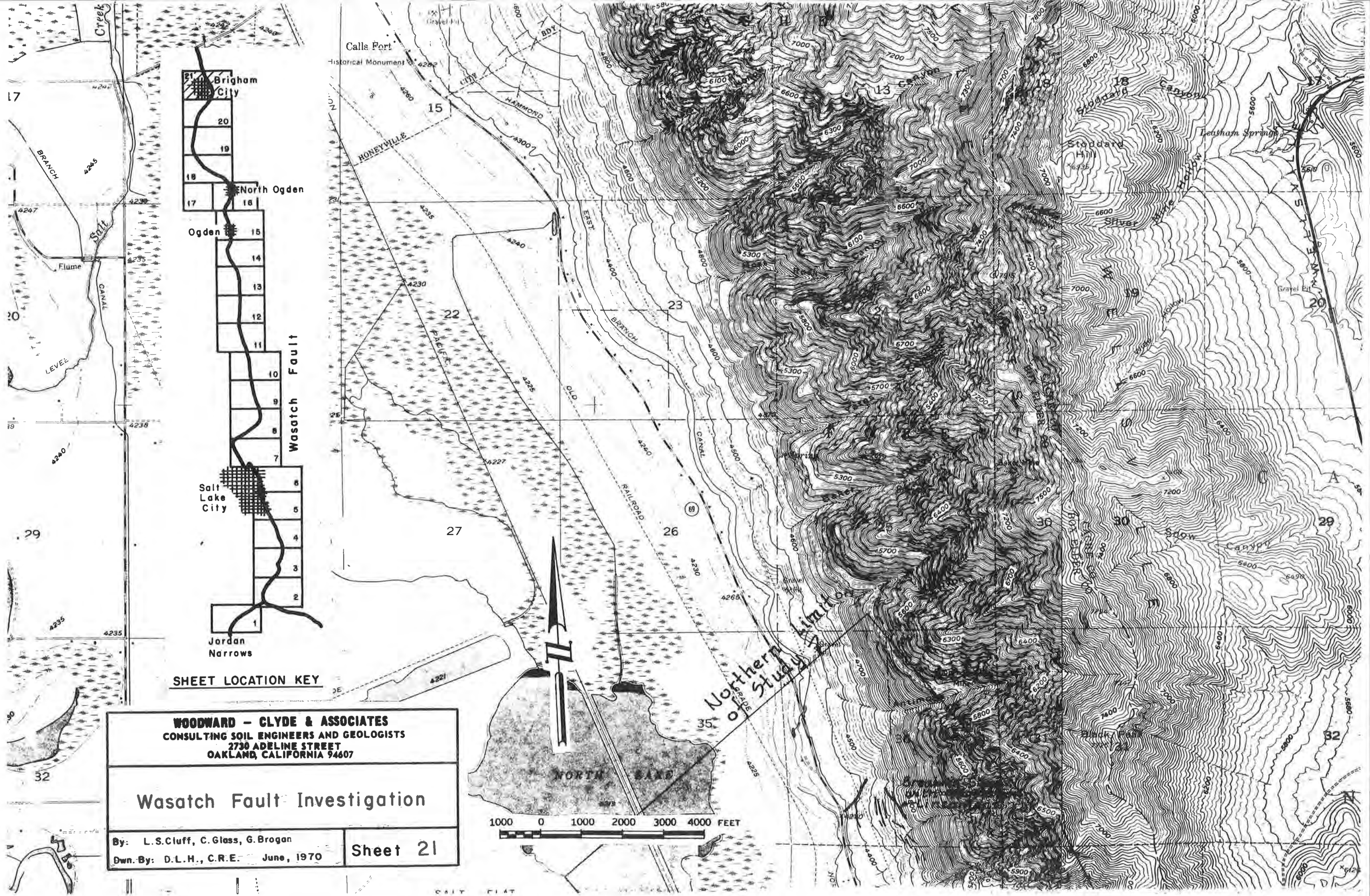
Sheet 20



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Dwn. By: D.L.H., C.R.E. June, 1970

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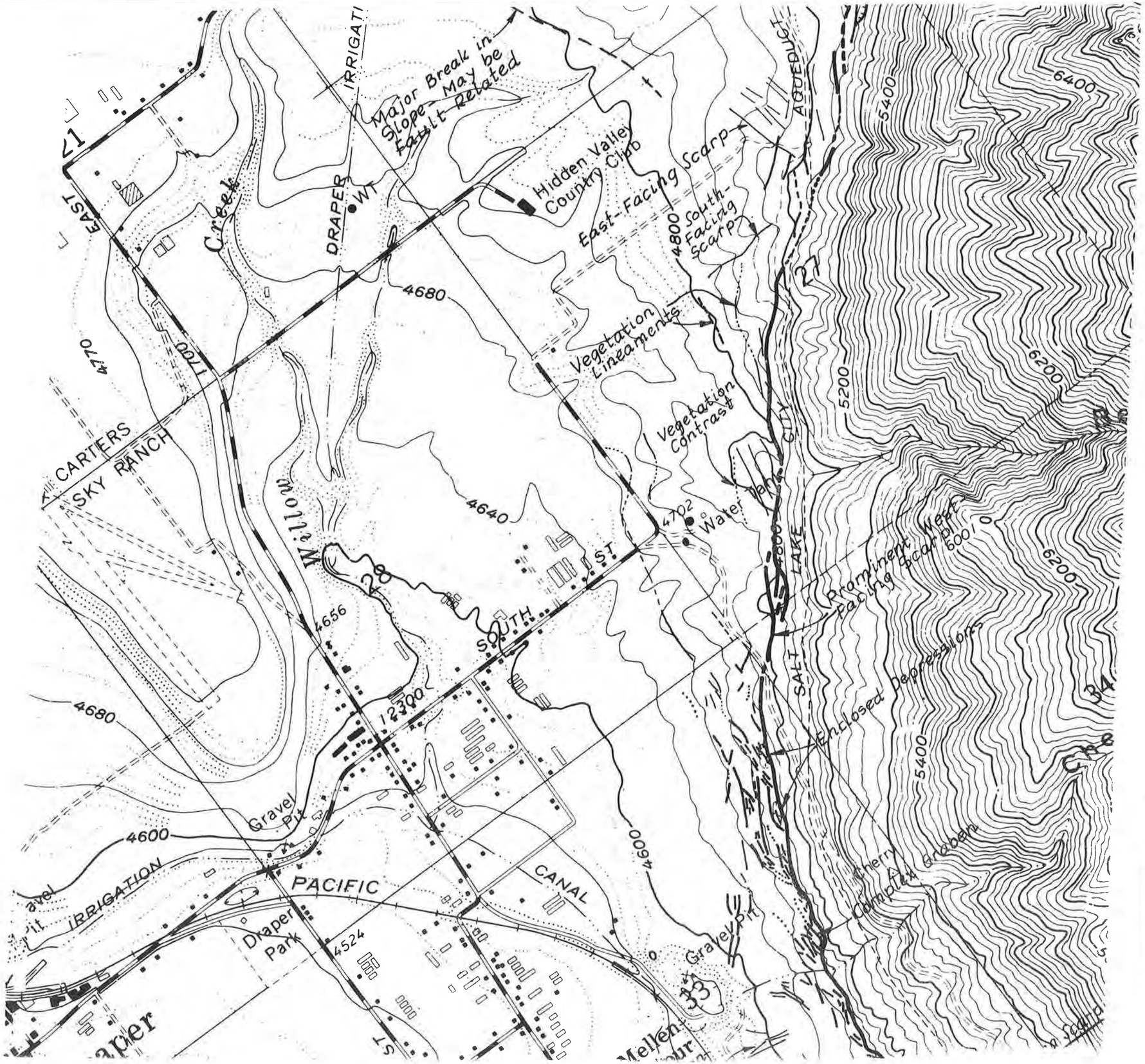
OAKLAND, CALIFORNIA 94607

Wasatch Fault Investigation
DETAILED STUDY

By: L.S.Cluff, C.Glass, G.Brogan
Dwn. By: D.L.H., C.R.E. June, 1970

Sheet A

DETAILED SECTION - CORNER CANYON to BELLS CANYON



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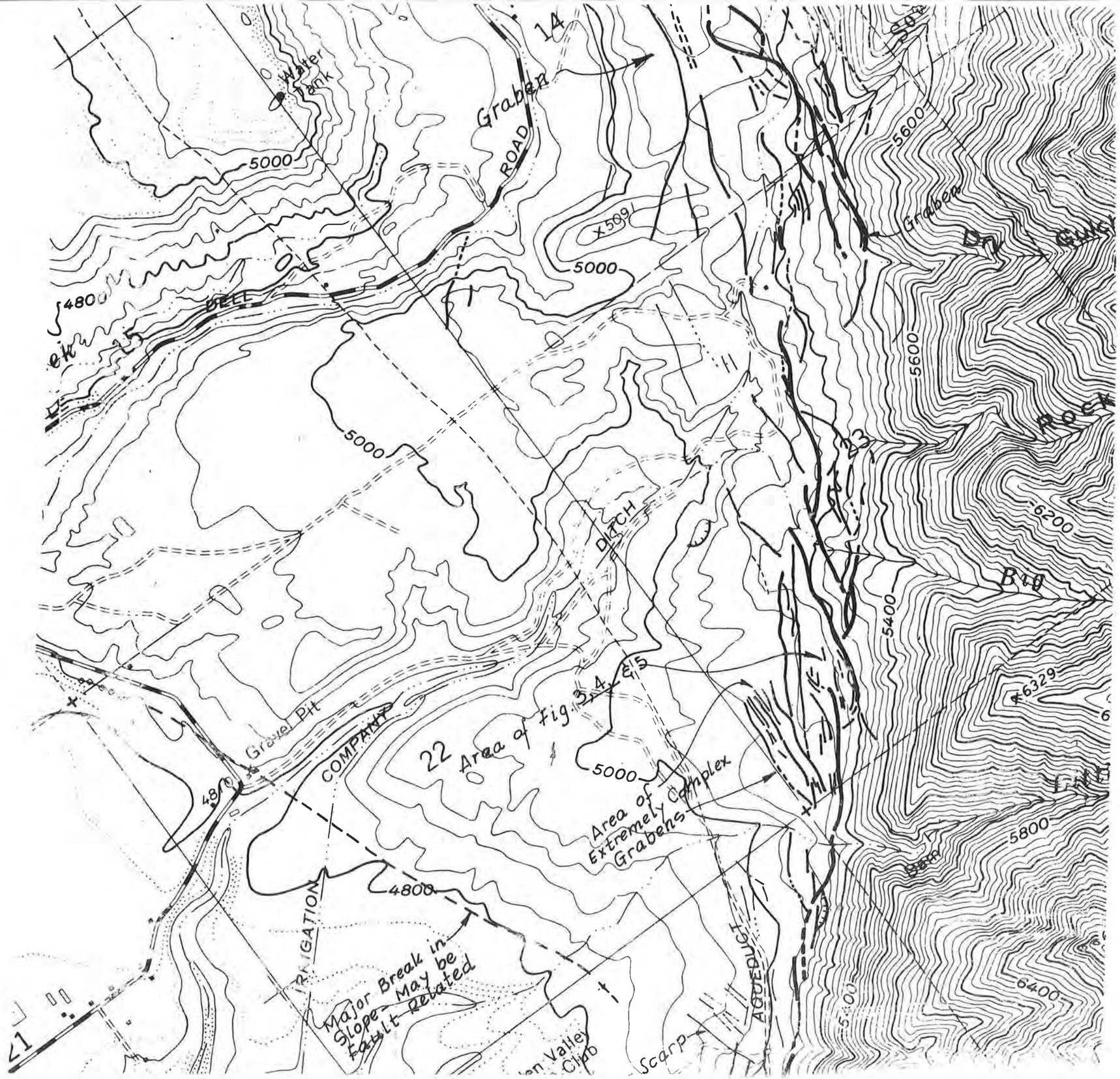
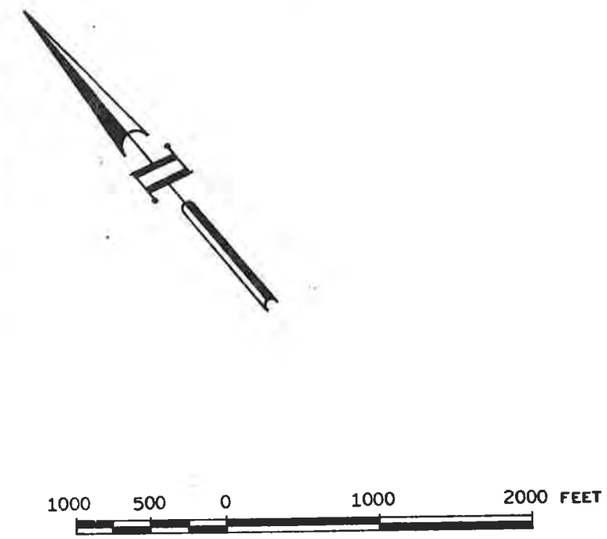
Wasatch Fault Investigation
DETAILED STUDY

By: L.S.Cluff, C.Glass, G.Brogan
Dwn. By: D.L.H., C.R.E. June, 1970

Sheet B





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DETAILED STUDY

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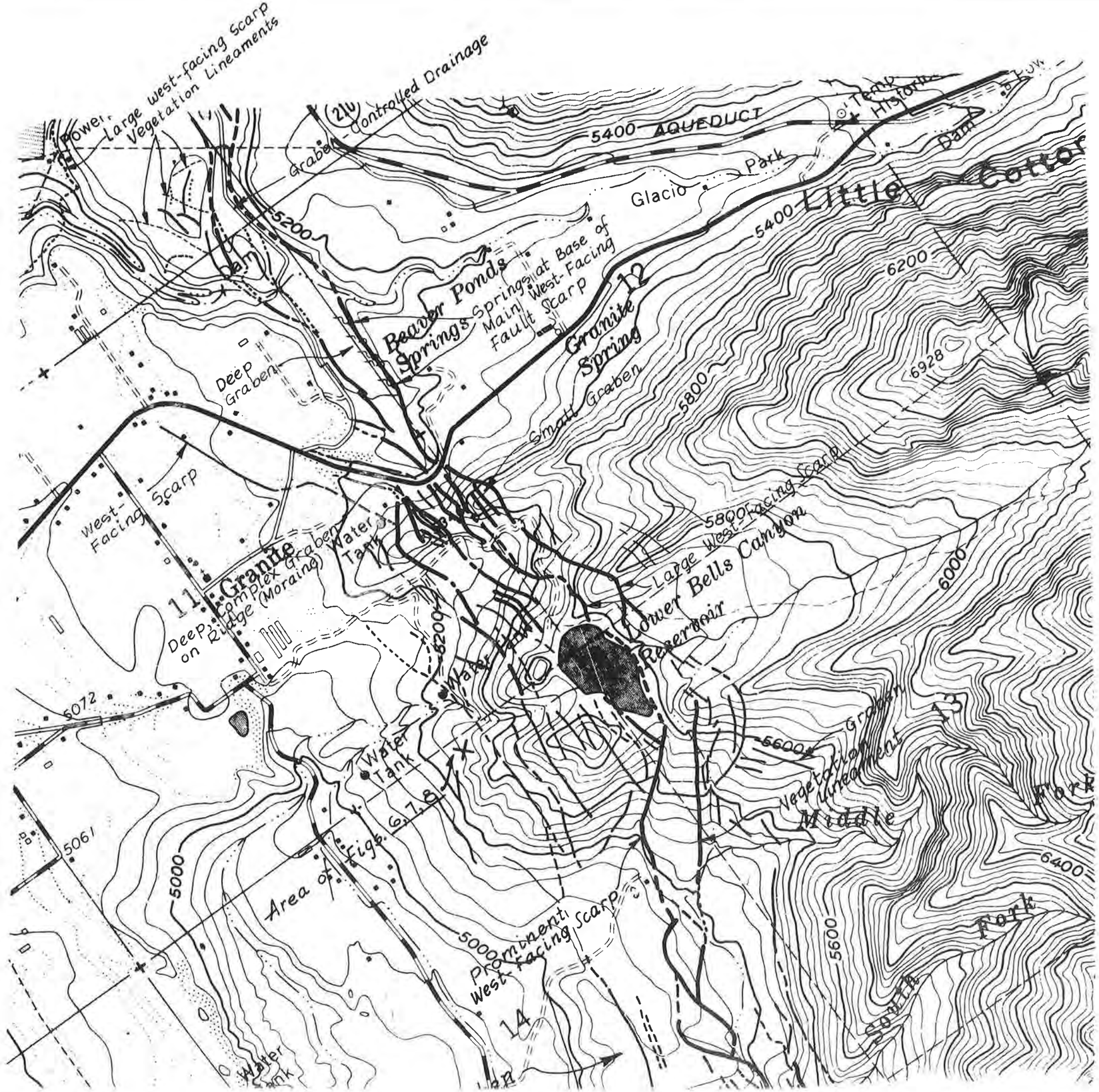
Dwn. By: D.L.H., C.R.E. June, 1970

Sheet C



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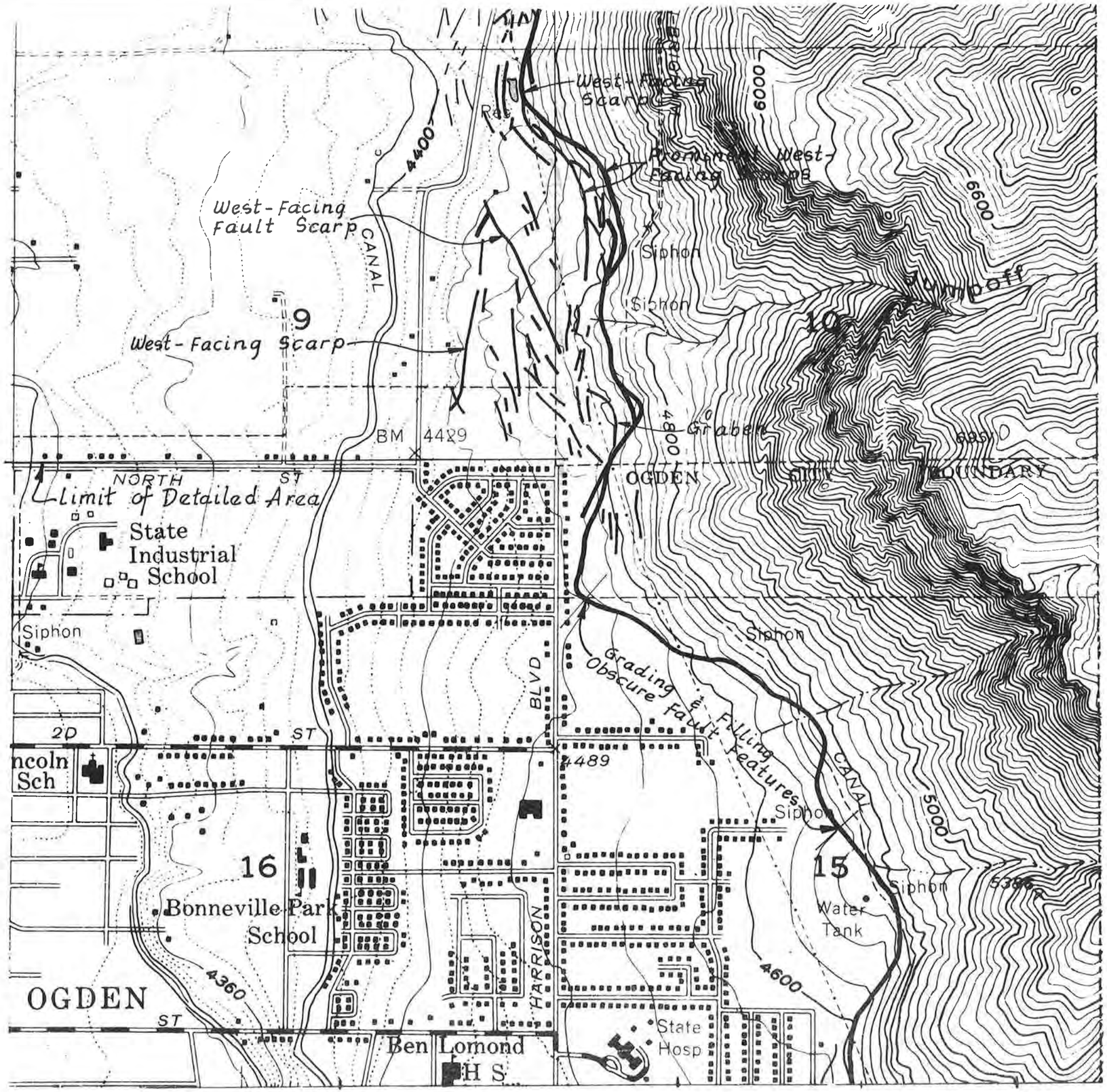
Sheet D



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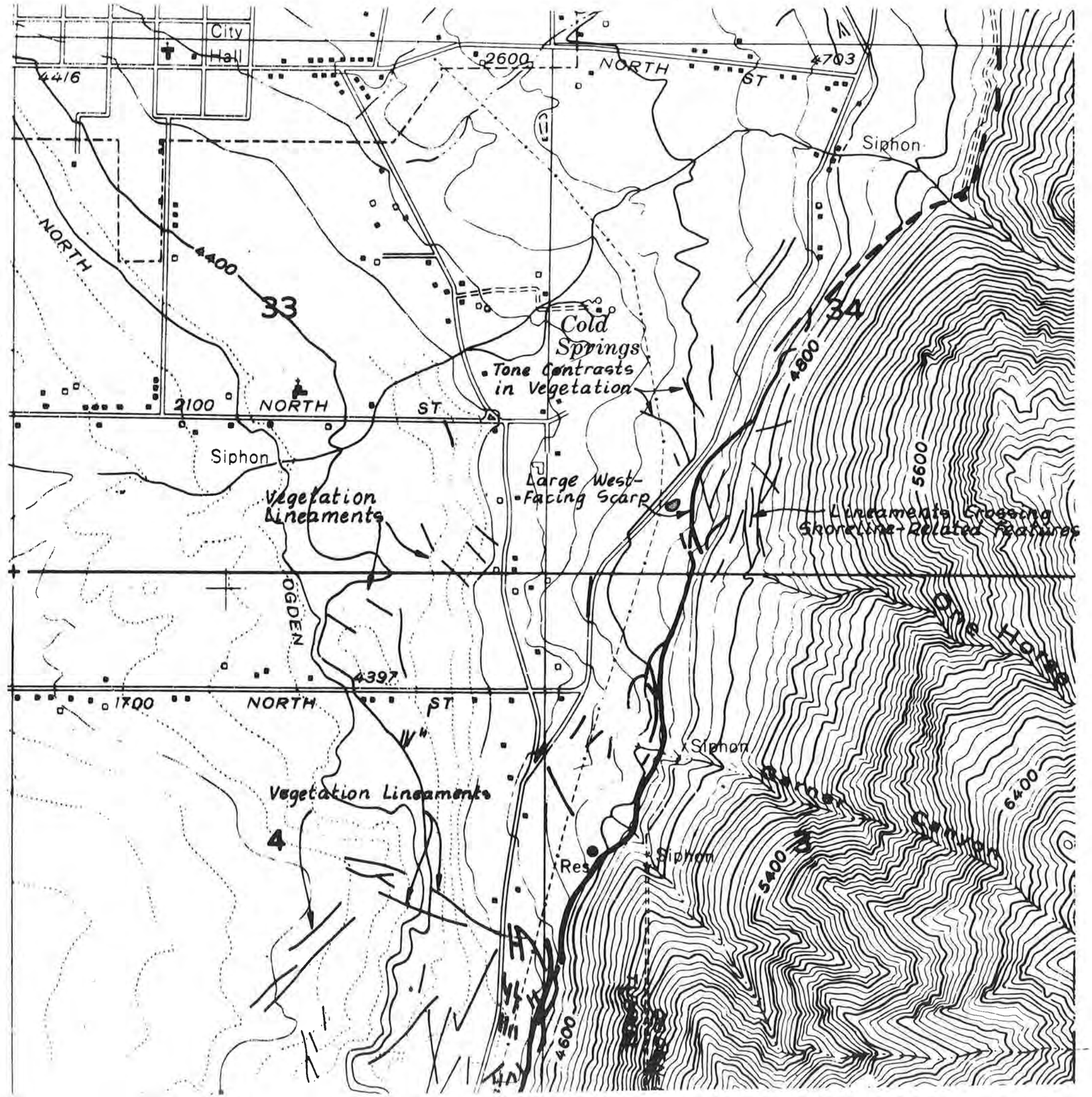
Sheet E

DETAILED SECTION – NORTH OGDEN



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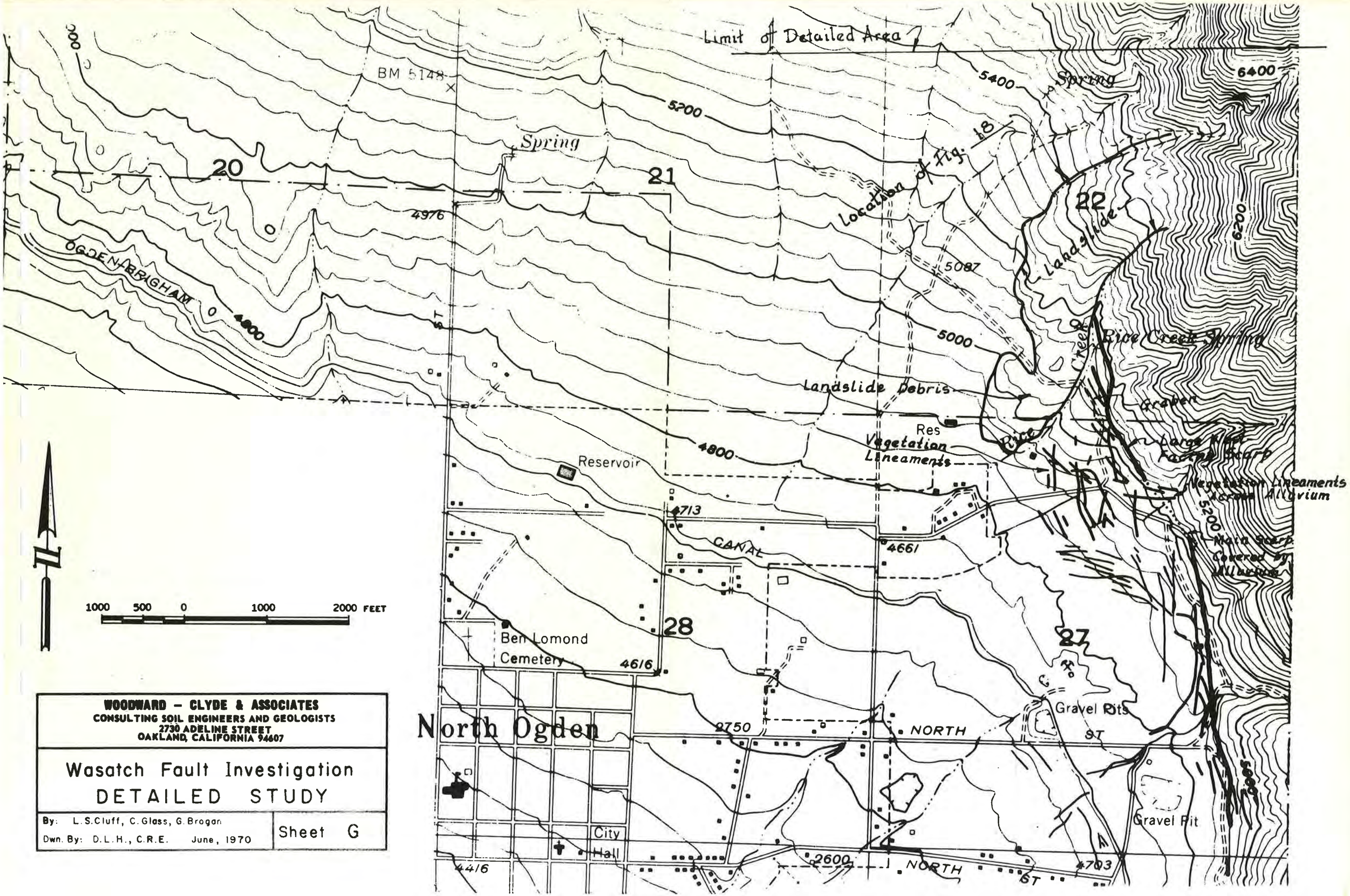
Sheet F



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Sheet G