PHASE I REPORT

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS IN SOUTHWESTERN UTAH

Earth Sciences Associates

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OF EIGHT SCS DAMS
IN SOUTHWESTERN UTAH

Prepared for

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IN

SOUTHWESTERN UTAH

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PHASE I REPORT

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS in SOUTHWESTERN UTAH

I. INTRODUCTION

A. General

An investigation of geologic, tectonic, and seismic conditions in the vicinity of eight Soil Conservation Service (SCS) flood control dams located in southwestern Utah (see Figure 1) was conducted during late 1981 and early 1982 by Earth Sciences Associates. The conditions of the embankments and their foundations was also investigated by a drilling, test pitting, sampling, and testing program. Results of the first phase of this investigation (as described under Purpose and Scope below) are presented in this report. Detailed descriptions of the field investigation, laboratory investigations, regional geology and tectonics, and seismicity of the region are presented in the appendices contained in a separate volume.

B. Purpose and Scope

The two major purposes of the overall investigation are:

- To determine the safety of these dams with respect to potential for surface fault rupture in the foundation areas (and consequent offset of the embankments); and

- To evaluate the ability of the embankments to resist strong seismic shaking likely to occur in the region, along with determination of the characteristics of shaking that is probable at each dam site.

This "Phase I" report is a mid-investigation report being written after the completion of the field investigation phases of the investigation, but before the embankment stability analyses have been performed. It primarily reports on geologic/tectonic/seismic conditions in southwestern Utah and in the specific dam site areas, but also describes embankment conditions found to exist during the drilling and test pit excavation portions of the field investigation. The specific tasks reported on herein are listed in the ESA proposal for this project dated September, 1981 under "Phase I - Seismic Hazard Study" as Tasks a through m. A portion of the laboratory testing program (which is part of Phase II (Tasks IIa and b)), has been performed and is reported on in Appendix D.

End products of the overall study will include an evaluation of the safety of the dams with respect to faulting and seismic shaking, the development of recommendations for remedial measures should hazards be found to exist, and the development of recommendations for courses of action for the SCS to take both under existing conditions and following an earthquake (if any of the dams is determined to have significant safety problems). These matters will be addressed in the Phase II report to follow.

C. Background Information

The dams investigated during this investigation are relatively low earthfill embankments. They were constructed for the purpose of temporarily retaining flood waters that flow down the drainages of this semi-arid environment during infrequent periods of heavy rainfall ("thunder showers"). They were constructed by the SCS in order to protect downstream areas from flooding that had periodically occurred before construction of these dams. Since construction of the dams, rapid increases in population in the St. George and Cedar City areas has changed the downstream land use markedly. Areas that were once dominantly agricultural or rural are becoming more urbanized, and houses have been constructed in areas just downstream of some of the dams (Green Lakes 2 and 3, and Ivins, in particular).

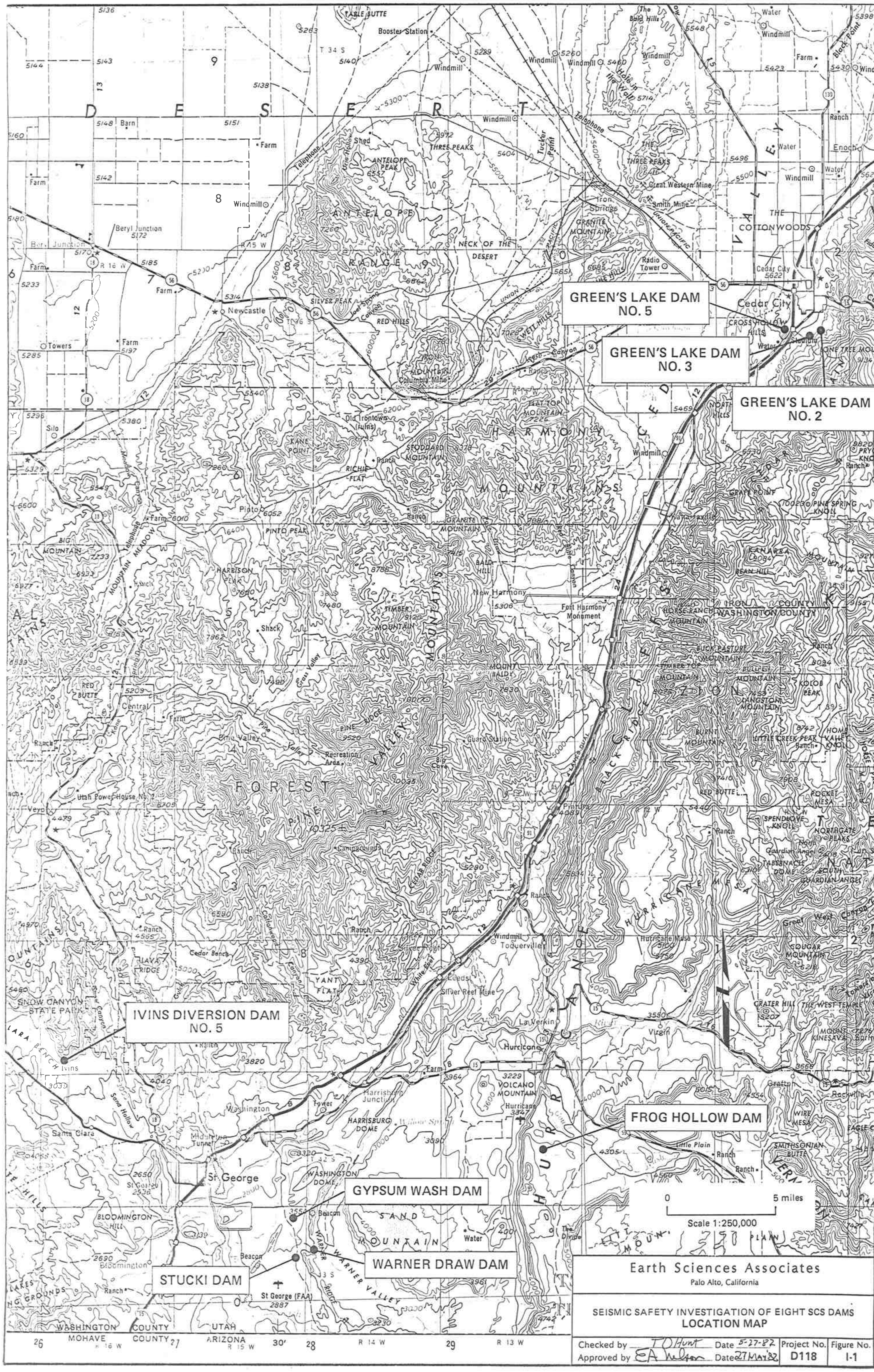
As a result of these rapid changes in downstream land use, the consequences of failure of some of these structures has increased markedly. Consequently, even though these reservoirs are infrequently filled, the SCS has contracted to have the safety of these dams evaluated. This was done in order that remedial measures can be developed in the event that hazards are determined to exist, and so that there would be a basis for decisions about the dams' relative usefulness in mitigating versus creating potential hazards to downstream residents and property.

D. Performance

Work on this project was performed for the SCS West Technical Center in Portland, Oregon. C. Edward Stearns is the Project Coordinator for the SCS, and Joan K. Johnson is the Contract Administrator. Other SCS personnel who have been directly involved with this project are Don Wallin, Bob Nelson, Bob Rasely, and Claud Scoles.

ESA personnel who have worked on this project include: Douglas M. Yadon, who logged the drill holes and supervised the initial field operations; Richard Morris, who logged the test pits and performed the field density tests; Robert H. Wright, who performed the photogeologic studies, and developed the strip map of the Hurricane fault zone and the site specific photogeologic mapping; T. Dwight Hunt, who performed the field geologic mapping, logged the trenches, and developed the site specific geologic maps and trench logs; Michael L. Traubenik, who analyzed the existing SCS data and made engineering evaluations of the embankments; Julio E. Valera, who was Project Manager and coordinated the engineering and budget control portions of the project; and Eugene A. Nelson, who was Principal in Charge and coordinated the geologic portions of the work. The report was written by Wright, Hunt, Traubenik, Valera and Nelson, and typed by Kathleen McCracken. Tom Camara and Dave O'Shea performed the drafting.

Working as a consultant to Lindvall Richter and Associates (LRA), who are subcontractors to ESA on this project, Dr. Walter J. Arabasz performed the evaluations of seismic and tectonic conditions in the region, and wrote the extensive discussions on these subjects that appear in Appendices E and F. Richard J. Proctor of LRA coordinated the seismic studies for LRA.


GREEN'S LAKE DAM NO. 5
GREEN'S LAKE DAM NO. 3
GREEN'S LAKE DAM NO. 2
IVINS DIVERSION DAM NO. 5
FROG HOLLOW DAM
GYPSUM WASH DAM
WARNER DRAW DAM
STUCKI DAM
0
5 miles
Scale 1:250,000
Earth Sciences Associates
Palo Alto, California
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOCATION MAP
Checked by T.O. Hunt
Date 5-27-82
Approved by
Date 27 May 82
Project No. D118
Figure No. I-1

II. CONCLUSIONS AND RECOMMENDATIONS

Preliminary conclusions and recommendations pertaining to the subject matter of this initial report are presented below.

1. Trenches excavated near the south corner of Gypsum Wash Dam expose offsets in young-appearing sedimentary deposits that have been estimated to be of Holocene age by ESA's consultant on soil stratigraphy, Dr. Roy J. Shlemon (see Chapter VIII). This finding differs with previously available information regarding recency of faulting in southwestern Utah. Nevertheless, ESA believes that these near-surface offsets may be of consequence to the dam. The potential for damage to the embankments depends upon the recurrence interval between episodes of surface faulting and the amount of displacement possible during a single event. These factors, and the consequent potential for damage to the embankments, will be evaluated during Phase II of this investigation.

2. No evidence of faulting was found in trenches excavated at the Green's Lake 2 and 3 Dams, but it is obvious from the photogeologic studies that these dams are within a zone containing several strands of the Hurricane fault (see Figures IV-2 and VIII-5). Charcoal samples from the deposits exposed in these trenches have been submitted for age dating, and should provide an indication of the age of unfaulted surficial deposits at these sites. The potential for damage to the embankments of Green's Lake Dams No. 2 and 3 will be evaluated during Phase II of this investigation.

3. Relatively young (late Pleistocene) faulting was exposed in a trench excavated along the eastern margin of Green's Lake No. 5 Reservoir, and faults of similar age probably exist along the eastern front of the basalt near the main dam (see Figure VIII-5). These faults do not pass beneath the main dam, however, which is located west of the western edge of the fault-bounded north-south valley (see Figure VIII-10).

4. There is no potential for surface fault offset at the other four dam sites (Frog Hollow, Warner Draw, Stucki, and Ivins) (see detailed descriptions of geologic

conditions at the dam sites in Chapter VIII of this report). Strong ground shaking is likely to occur at all of these sites (see Conclusion 7), and the seismic stability analyses performed during Phase II of this investigation will include consideration of the characteristics of shaking likely to occur at the dam sites during their useful life.

5. A drill hole located on the crest of Frog Hollow Dam encountered very loose soil deposits in one portion of the foundation. Further drilling to either side of the first hole did not encounter similar conditions. SCS records indicate that the loose materials encountered may represent improperly placed backfill of a trench containing a pipe removed from the smaller original dam that was buried beneath the raised embankment. The SCS is evaluating this situation outside the scope of this contract.

6. The regional tectonic/seismic environment of southwestern Utah is complex, and has been comprehensively described by Dr. Walter J. Arabasz in Appendices E and F, which are summarized in Chapters IV, V, VI, and VII. The Cedar City-St. George area lies along a tectonically active intraplate boundary. While the level of seismicity is not as high as that along the Pacific/North American plate boundary, the historical record contains more than 20 earthquakes in the Magnitude 5 to 6½+ range within 200 km of the study area (see Table F-1). The recurrence interval for larger events is longer than the available record (see Table F-3), but a Magnitude 7 to 7½ event is thought to be the maximum credible earthquake for the region with a recurrence of 200 to 700 years for all of southwestern Utah.

7. Magnitudes of both the maximum credible and maximum probable earthquake which could occur on the major fault zones located in close proximity to each of the dam sites are tabulated in Table II-1. Also presented in this table are the recurrence intervals for these two earthquake levels. Assuming that they can occur in close proximity to each dam site, it can be seen from this table that the magnitude of the maximum credible earthquake ranges from 7 to 7½ with a recurrence interval of 1,000 to 10,000 years. The magnitude of the maximum probable earthquake for all dam sites is a 6 with a recurrence interval ranging from 200 to 300 years.

Table II-1

Estimated Magnitude and Recurrence Interval of Maximum Credible and Maximum Probable Earthquakes in the Vicinity of Dam Sites

Dam	Closest Fault to Dam Site	Distance to Fault (miles)	Total Fault Length (miles)	Maximum Credible Magnitude	Maximum Credible Recurrence Interval (yrs)	Maximum Probable Magnitude	Maximum Probable Recurence Interval (yrs)
Green's Lake No. 2	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Green's Lake No. 3	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Green's Lake No. 5	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Gypsum Wash	Washington	0	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	10	160	7.5	1,000-10,000	6.0	200-300
Warner Draw	Washington	1	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	9	160	7.5	1,000-10,000	6.0	200-300
Stucki	Washington	0.5	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	10	160	7.5	1,000-10,000	6.0	200-300
Frog Hollow	Hurricane	2	160	7.5	1,000-10,000	6.0	200-300
Ivin's	Grand Wash	5	100	7.5	2,000-10,000	6.0	200-300

For purposes of this study, the maximum probable earthquake represents an event which has a reasonable probability of occurring during the life of these facilities. Although the magnitude of the earthquake selected for design should be based on the level of risk which the owner of the facility is willing to accept for each specific dam site, it is our judgment, and that of our consultant Dr. Arabasz, that a Magnitude 6 event represents a reasonable earthquake which could occur during the life of these facilities and one which each dam should be able to withstand without catastrophic consequences.

III. OPERATIONAL HISTORY AND PHYSICAL CHARACTERISTICS OF THE DAMS

The eight dams investigated during this study were constructed by the SCS in order to protect downstream areas from flood waters and to trap sediment. The three dams in the Cedar City area were constructed in 1958. The five dams near St. George were constructed during the period of 1974-78 (the existing Frog Hollow Dam represents a raise of an existing dam that was first constructed in 1956).

The intended purpose of the dams is to retain the infrequent large flows of water that result from thundershowers in this arid area, and then to release the water at diminished flow rates over the next few days. Consequently, the reservoirs behind the dams are dry except after heavy rainfalls. Available information indicates that the dams and reservoirs have performed in this manner since construction with one exception. The original trash rack on the outlet of Green's Lake No. 3 became plugged by debris in 1967, which caused water to remain in the reservoirs for 3 months. The standing water resulted in settlement of portions of the reservoir area and embankment (see Figure VIII-2). Table III-1 follows this page and presents information compiled from SCS records on performance of the dams since construction, along with observations on present conditions as noted during the field investigation.

The dams are relatively low earthfill embankments ranging in height from 17 to 60 feet. Information from the SCS files and ESA's current field investigation on the physical characteristics of the embankments and their foundations is presented in Table III-2. A detailed discussion of the nature and condition of each dam is presented in Appendix G.

Table III-1

History of Performance and Present Condition of Dams

Dam	Performance[1]	Conditions[2]
Green's Lake No. 2	Satisfactory. Some minor slumping of embankment occurred in 1980.	Some differential settlement along axis of embankment, and some cracks which run parallel to the embankment centerline were observed. Cracks were also noted in the foundation in vicinity of embankment.
Green's Lake No. 3	Operational problems caused by subsidence of foundation soils when water remained in reservoir for 3 mo. Extensive subsidence near east end of dam which extended under embankment. Erosion and piping caused cracks to widen. Some block rotation of embankment occurred as a result of subsidence. Cracks repaired by grouting with a soil-slurry mixture.	Cracks along upstream face and transverse to embankment crest were observed. Settlement of dam crest also noticeable.
Green's Lake No. 5	Satisfactory.	Some minor cracking observed.
Gypsum Wash	Satisfactory.	Some buldges noted along downstream slope of embankment. No evidence of settlement or excessive cracking along crest of embankment.
Warner Draw	Satisfactory.	Good.
Stucki	Satisfactory	Good.
Frog Hollow	Extensive transverse cracking of embankment since 1978 raise. Longitudinal cracking along upstream face also noted.	Longitudinal crack along upstream face of embankment observed. Zone of weak soil encountered in foundation in one borehole, accompanied by an anomalous loss of drilling water.
Ivins Diversion No. 5	Satisfactory.	Some minor cracks and erosion of embankment noted.

Notes:

(1) Performance of dams based on available SCS reports and correspondence.

(2) Condition of dams noted during field investigation phase of this investigation.

TABLE III-2
SUMMARY OF EMBANKMENT AND FOUNDATION CHARACTERISTICS

							EMBANKMENT MATERIALS			FOUNDATION MATERIALS		
DAM	DATE OF CONSTRUCTION	TYPE	MAX. HEIGHT (FEET)	LENGTH (FEET)	UPSTREAM SLOPE (H:V)	DOWNSTREAM SLOPE (H:V)	CLASSIFICATION	RELATIVE COMPACTION - (%) [1]	SPT BLOW COUNTS (BLOWS/FOOT)	CLASSIFICATION	RELATIVE COMPACTION - (%) [2]	SPT BLOW COUNTS (BLOWS/FOOT)
Green's Lake No. 2	1958	Zoned	20	1315	3:1	2:1	Zone II/Core ML,CL	81 to 111/ –	25 to 100	Alluvial and Colluvial Deposits Gravelly with Increasing Depth	82 to 96	12 to 82 (Typically 20 to 40)
							Zone I/Shells SM,ML with Gravel and Cobbles	105/ 85 - 90	–			
Green's Lake No. 3	1958	Zoned	17	2030	3:1	2:1	Zone II/Core ML,CL	93 to 102/ –	20 to 52	Alluvial and Colluvial Deposits Gravelly with Increasing Depth	87 to 93	9 to >100 (Typically 15 to 30)
							Zone I/Shells SM, ML with Gravel and Cobbles	98 to 106/ 79 to 95	–			
Green's Lake No. 5	1958	Homogenous	22	235	3:1	2:1	ML,CL	95 to 107/ 70 to 82	17 to 63	Alluvial and Colluvial Deposits Generally Gravelly	84 to 91	48 to >100
Gypsum Wash	1974-1975	Zoned	30	3128	3:1	2:1	Zone I/Core SC,SM,ML	95 to 105/ –	23 to >100 (Typically 30 to 40)	Thin Deposits of SC,SM,ML over Siltstone and Shale	76 to 106	25 to >100
							Zone III/Shells GM,SM with Cobbles	95 to 104/ 85 to 88	–			
Warner Draw	1974	Zoned	60	1300	3:1	2:1	Zone I/Core SC,SM	95 to 107/ –	15 to 74 (Typically 40 to 60)	Sandstone, Siltstone and Shale. Left Abutment - SP,SM,SC	96 to 106	Left Abutment– 16 to >100 (Data from SCS Borings)
							Zone III/Shells SM,SC with some Gravel and Cobbles	95 to 101/ 92 to 104	50 to 60			
Stucki	1974	Zoned	30 (Above Ground Surface) 45 (Total Fill)	1400	3:1	2:1	Zone I/Core SC,SM	95 to 103/ –	20 to 84 (Typically 30 to 50)	Alluvial and Colluvial Deposits. Left Abutment - Silty Sandstone	92 to 97	25 to >100 (Typically 30 to 50)
							Zone III/Shells SM with Gravel and Cobbles	96 to 105/ 93 to 106	40 to 50			
Frog Hollow	1956 Raised in 1978	Zoned	48	1900	3:1	2:1	Zone I/Core SC,SM, CL,ML with Gravel and Cobbles	94 to 128/ 95 to 100	26 to 48 (Typically 30)	Basalt Flows and Alluvial and Colluvial Deposits Near Toes of Embankment	81 to 89	13 to >100 (Typically 30 to 60)
							Zone II/Shell GM in CL	–/ 79 to 92	–			
							Original (1956) Embankment GM,SM	–	–			
Ivins Diversion No. 5	1977	Homogenous	20	5300	3:1	2:1	SM,ML with some Gravel	95 to 101/ 91 to 105	30 to 90	SM,ML Over Siltstone	82 to 95	14 to 80 (Typically 40 to 50)

NOTES:

1) First range of relative compactions from construction records as determined by either the Standard Proctor test procedure or ASTM D678-70 method A or C. (See Appendix). Second range of relative compactions from tests performed in test pits excavated as part of this investigation. (See Appendices B, C, and D).

2) Ranges of relative compactions from tests performed in test pits excavated as part of this investigation. Test pits were dug at either the upstream or downstream toe of embankment. Tests were performed in the soils present beneath outer shells of the embankments. (See Appendices B,C, and D).

IV. SUMMARY OF REGIONAL GEOLOGY AND TECTONIC FRAMEWORK

This chapter summarizes regional geologic and tectonic conditions in the St. George and Cedar City areas of southwestern Utah as they relate to the performance of the eight dams that are the subject of this report. A detailed discussion of regional geology and tectonics, including an account of the events that led to the development of present-day geologic structure in this area, appears in Appendix E.

Although the details of geologic and tectonic conditions in this area are complex, the controlling factors related to the safety of the dams are: 1) the faults present within the vicinity of the dam sites, 2) the potential for ground rupture on these faults at the dam sites, and 3) the size of earthquake that is likely to occur in the vicinity of the dam sites during their useful life (along with the characteristics of the shaking that will be generated at the base of the embankments).

A brief description of the tectonic framework of the region surrounding the dams follows, along with descriptions of the fault zones that are of concern to the dams. Chapter V presents a discussion of what is known about rates of fault movements in this region, which relates to the potential for ground rupture at the various dam sites. Chapters VI and VII discuss "Historic Seismicity and Earthquake Recurrence", and "Maximum Credible and Maximum Expectable Earthquakes", respectively.

A. Tectonic Framework

The SCS Utah dams study area lies within a transitional intraplate boundary zone between the Basin and Range and Colorado Plateau physiographic/geologic provinces. This boundary zone is coincident with a segment of the Intermountain Seismic Belt, a major zone of seismicity within western North America between the Basin and Range province and the Middle Rocky Mountains-Colorado Plateau (see Appendices E and F and Figures E-1 and F-1).

Regardless of specific models proposed to explain the tectonics of the region, it is clear that there is a major, though gradual, change across the boundary zone from generally thin weak crust and lithosphere on the west, to thicker, more stable crust and lithosphere on the east. In addition, stress orientation changes across this boundary from extensional WNW-ESE along the eastern basin and range, to compressional WNW-ESE within the Colorado Plateau.

Although the boundary zone between the Basin and Range and Colorado Plateau tectonic provinces is transitional, it is roughly delineated by major tectonic features of the region. The eastern boundary of the northern Basin and Range tectonic province is represented by (from southwest to northeast) the Grand Wash-Cedar Pocket Canyon-Gunlock-Veyo fault system, the north boundary of Pine Valley Mountains, the Hurricane-Parawon-Paragonah/Monocline-fault system, and the Wasatch fault zone (see Figure IV-1).

The three SCS dams in the Cedar City area (the "Cedar City dams") are essentially within the northernmost portion of the Hurricane fault zone (see Figures IV-2 and VII-11). In this area, a complex fault-monocline structure forms a "bridge" between the northernmost segment of the Hurricane fault and the Parawon-Paragonah fault, which is located about 35 km northeast of Cedar City.

The five SCS dams being investigated in this study in the Hurricane-Frog Hollow, St. George, and Ivins areas (the "St. George area dams") are within the northern part of the Grand Canyon subprovince of the Colorado Plateau, which is characterized by NNE-trending, west-down normal faults. The Washington fault, which follows a north-south trend through the vicinity of Gypsum, Warner Draw and Stucki Dams (see Figures IV-1 and VIII-12), is one of these normal faults located about 10 miles west of the Hurricane fault. Descriptions of the major fault zones in the study region follow.

B. Hurricane Fault Zone

The Hurricane fault zone is a major tectonic feature in northwestern Arizona and southwestern Utah. The fault zone has been mapped northward from the vicinity of Peach Springs, Arizona (Wilson and others, 1969), to Kanarraville, Utah, where it turns northeastward and continues to the vicinity of Cedar City, Utah, over a total distance of approximately 256 km (Hintze, 1980). Throughout much of its length, particularly north of the Grand Canyon, the Hurricane fault zone is marked by a prominent west-facing topographic escarpment called the Hurricane Cliffs.

The Arizona portion of the Hurricane fault zone and that portion in Utah south of Kanarraville, lie within the Grand Canyon subprovince of the Colorado Plateau tectonic province (see Appendix E, Figure E-3). Within this subprovince the Hurricane fault is one of several major west-down normal faults. These faults bound the series of northeastward - tilted fault blocks which form the Grand Staircase transition from the eastern Basin and Range province to the higher-standing Colorado Plateau to the east.

Northeast of Kanarraville, the Hurricane fault zone is coincident with the boundary between the Basin and Range province and the High Plateaus subprovince of the Colorado Plateau Province (at least as far northward as Cedar City). This boundary becomes progressively more complex north of Cedar City, where it involves horsts, grabens, and ramp structures with scissors-like displacement (Best and Hamblin, 1978). The Hurricane fault zone cannot be clearly extended northeast of Cedar City to connect with the Parawon-Paragonah fault (see Appendix E, Figures E-9 and E-10, and Section E 3.2.)

The age of initiation of movement on the Hurricane fault zone is not certain, but its formation may have been related to relative down-dropping of the eastern Basin and Range province as a result of collapse of regional upwarping during late Cenozoic time. Dating of ash-flow tuffs of regional extent suggests that structural differentiation of the provinces began some time after 29 m.y. ago, with vertical movement along faults including the northeasternmost segment of the Hurricane fault that bounded the west side of the Colorado Plateau province.

This faulting began about 26-18 m.y. ago in late Oligocene - early Miocene time (Rowley and others, 1978, 1979; Best and Hamblin, 1978). Anderson and Mehnert (1979) suggest that major movement on the Hurricane fault zone occurred after Miocene time. Total displacement across the fault zone seems to be at least 2,000 m, with current displacements rated on the order of 300-500 m/m.y. (0.03-0.05 cm/yr) (see Appendix E, Section E3.1).

The Hurricane fault zone in Utah is considered to be both seismically active and geologically active in the sense that strands of the fault displace Quaternary geologic units. The fault zone is located within the intermountain seismic belt (see Appendices E and F), a major zone of intraplate seismicity within western North America. Two historic earthquakes thought to be in the range of 5 to 5½ magnitude have occurred on the Hurricane fault zone in the Cedar City area (see Appendix F, Section F.1.2., and Figure F.3), and several earthquake swarms have also occurred in the vicinity of the fault zone in the Cedar City area during historic time (see Appendix F, Figure F.4)

Quaternary movement along the Hurricane fault zone in Utah is well documented (Anderson and Miller, 1979). At several locations along the zone, Pleistocene basalt units and latest Pleistocene alluvial and alluvial fan deposits are displaced.

As part of this study, new, high quality, 1:24,000 scale low-sun angle (both AM and PM), black and white stereoscopic aerial photography was flown in October, 1981 along the mapped location of the Hurricane fault zone in Utah. The photography was analyzed for lineations suggestive of tectonic origin, and possibly related geomorphic and geologic features. The results of this analysis is presented in map form on Figure IV-2. In summary, this map shows that the Hurricane fault zone in Utah is generally represented by a single, usually continuous trace, along the base of the Hurricane cliffs escarpment.

In two areas, south of Ash Creek Reservoir and south of Cedar City, the generally steep and narrow Hurricane cliff escarpment is complicated by large-scale, complex, westward directed landsliding. These landslides have created a wider, less steep escarpment, with a base that bulges out over the projected fault trend. At these locations, the Hurricane Fault zone projects across the landslide as a wide zone of discontinuous traces which offset the landslide masses.

There are several locations where strands of the Hurricane fault zone appear to offset late Pleistocene alluvial fan deposits. Such relations exist just north of the Utah-Arizona border, southwest of the Wart, at several locations between the Hurricane airport and Taylor Creek, northeast of Pintura, and at Shurtz Creek, south of Cedar City. new mapping

The drainage basin of Shurtz Creek between the Hurricane fault zone and the crest of Cedar Mountain to the east is unique among west-draining basins along the Hurricane cliffs. Landslides at higher elevations on Cedar Mountain have shed significant amounts of debris westward. This debris has ponded behind high-standing, elongate NE-SW aligned bedrock ridges just east of the fault zone, creating large areas of upland alluvial fan deposits. Only locally, at Shurtz Creek and an unnamed creek just to the north, is there evidence that this alluvial material spilled through narrow gaps in the bedrock ridges, across the Hurricane fault zone, and out into the valley to the west. Displacements along strands of the Hurricane fault zone probably played a role in the ponding of alluvial deposits upslope to the east as indicated by prominent fault scarps in the alluvial fans at locations where they cross the escarpment. A more subdued and probably older scarp in alluvial fan deposits occurs upslope to the east of the main escarpment.

The 20 m high fault scarp at the mouth of Shurtz Creek is the most prominent and youngest appearing scarp along the entire Hurricane fault zone in Utah. The age of the displaced alluvial materials is pre-Holocene and possibly more than 50,000 years b.p., and the age of displacement is thought to be latest Pleistocene (see Appendix F, Section F.2.1.2.).

Several apparent graben structures were identified along the Hurricane fault zone during this study. Just north of Toquerville, immediately north of the mouth of Shurtz Creek, and in the landslide area south of Cedar City, there are apparent small-scale graben structures within the main Hurricane fault zone. A short distance north of the Utah-Arizona border, lineations and the distribution of alluvial units suggest that a zone of Quaternary faulting extends several miles west from the main Hurricane fault zone, forming an apparent horst and graben structure.

On a larger scale, a zone of complex horst and graben structures at least 5 km wide extends northwest from the main Hurricane fault zone in the area northeast of Anderson Junction. Prominent fault scarps occur in both late Pleistocene alluvium and in Pleistocene basalt flows NNE-trending structures associated with the Virgin Anticline project to intersect the Hurricane trend in this area.

Another large apparent graben structure occurs southwest of Cedar City. Fault traces exposed in trenches excavated during this investigation in this area cut Pleistocene alluvium and overlying basalt, and may cut late Pleistocene colluvium along the east side of the Cross Hollow Hills (see Chapter VIII, and Figure VIII-1). These discontinuous fault traces and associated air photo lineaments were mapped to the southwest along the east side of North Hills to a projected intersection with the main Hurricane fault zone near Murie Creek. This relationship suggests that the alluvial valley(s) southwest of Cedar City between the Hurricane Cliffs and the Cross Hollow and North Hills may be a late Pleistocene graben, here referred to as the Shurtz Creek graben. This structure is similar to structures located northeast of Cedar City along the southern part of the Paragonah fault (see Figure E-11).

C. Washington Fault Zone

The Washington fault is one of the major tectonic features in northwestern Arizona and southwestern Utah (see Figure IV-1). The fault has been mapped northward from just south of Wolf Hole, Arizona to just north of Washington, Utah, a total distance of approximately 68 km (Dobbin, 1939; Cook, 1960; Cook and Hardman, 1967; Hamblin, 1970a,b; Best and Hamblin, 1978; Wilson and others, 1969). Along much of its length in Utah, the Washington fault lies just west of, and parallel to prominent west-facing topographic escarpments and high ground, including the southwest end of Washington Dome, Warner Ridge, and the west side of Beehive Dome.

The Washington fault lies within the Grand Canyon subprovince of the Colorado Plateau Tectonic Province (see Appendix E, Figure E-3). The Washington fault is one of several major west-down normal faults within this subprovince. These faults bound the series of northeastward-tilted fault blocks which form the Grand Staircase transition from the Basin and Range province to the higher-standing Colorado Plateau to the east.

The age of initiation of movement on the Washington fault is not certain, but its formation may have been related to relative down-dropping of the eastern Basin and Range province as a result of collapse of regional upwarping during Late Cenozoic time. Structural differentiation of the provinces began some time after 29 m.y., with vertical movement along faults including the Washington fault.

Displacement on the Washington fault increases southward. Vertical displacement has been estimated to range from several hundred feet (a few hundred meters) near the Virgin River, where the fault breaches the northeast-trending, pre-Quaternary Virgin anticline (Washington Dome, in part), to 2,500 feet (760 m) at the Arizona state line (Dobbin, 1939; Cook and Hardman, 1967).

The Washington fault in Utah is considered to be both seismically active and geologically active (this report), in the sense that strands of the fault displace Quaternary geologic units. The fault is located within the intermountain seismic belt (see Appendices E and F), a major zone of intraplate seismicity within western North America. One historic earthquake thought to be in the range of 4 to 4½ magnitude occurred in 1891 in the St. George area (see Appendix F, Section F.1.2, and Figure F3), and may have been associated with the Washington fault.

Prior to the present investigation, Late Quaternary movement along the Washington fault in Utah had not been documented. Consequently, the Washington fault is not shown on the Quaternary Fault Map of Utah (Anderson and Miller, 1979), and is shown as concealed (dotted) beneath Quaternary deposits on the Geologic Map of Utah (Hintze, 1980). As part of this study, however, detailed field mapping and exploration were conducted in the immediate vicinity of the SCS dams in the St. George area. The results of these investigations are discussed in Chapter VIII C, D and E of this report and shown in Figure VIII-2 (scale 1:24,000). In summary, the results of the detailed field mapping and exploration in the Gypsum Wash-Warner Draw-Stucki area indicate that the Washington fault, which passes between Warner Draw and Stucki Dams and through Gypsum Wash Dam, displays probable early Holocene, normal, east-side-up displacement.

In addition to field mapping and exploration, new, high quality, 1:24,000 scale low-sun angle (both AM and PM), black and white stereoscopic aerial photography was flown in October, 1981 along the mapped location of the Washington fault in Utah. The photography was analyzed for lineations suggestive of tectonic origin, and possibly related, geomorphic and geologic features. South of the Stucki dam area, the Washington fault appears on the aerial photography as a prominent, apparently single linear. This linear sharply juxtaposes a bedrock pediment along the base of Warner Ridge against dissected, Quaternary older alluvial fan (Qof on Figure VI-2) bajadas along a subtle west-facing scarp.

From just southeast of Stucki dam northward toward Washington, the fault appears as a number of discontinuous bedrock lineations, tonal lineations in Quaternary alluvium (Qa) and alluvial fan deposits (Qaf), and west-facing scarps juxtaposing Quaternary older alluvial fan deposits (Qof) and/or alluvium (Qa; see Figure VI-1). North of Gypsum dam, the Washington fault is not readily identifiable on the aerial photography.

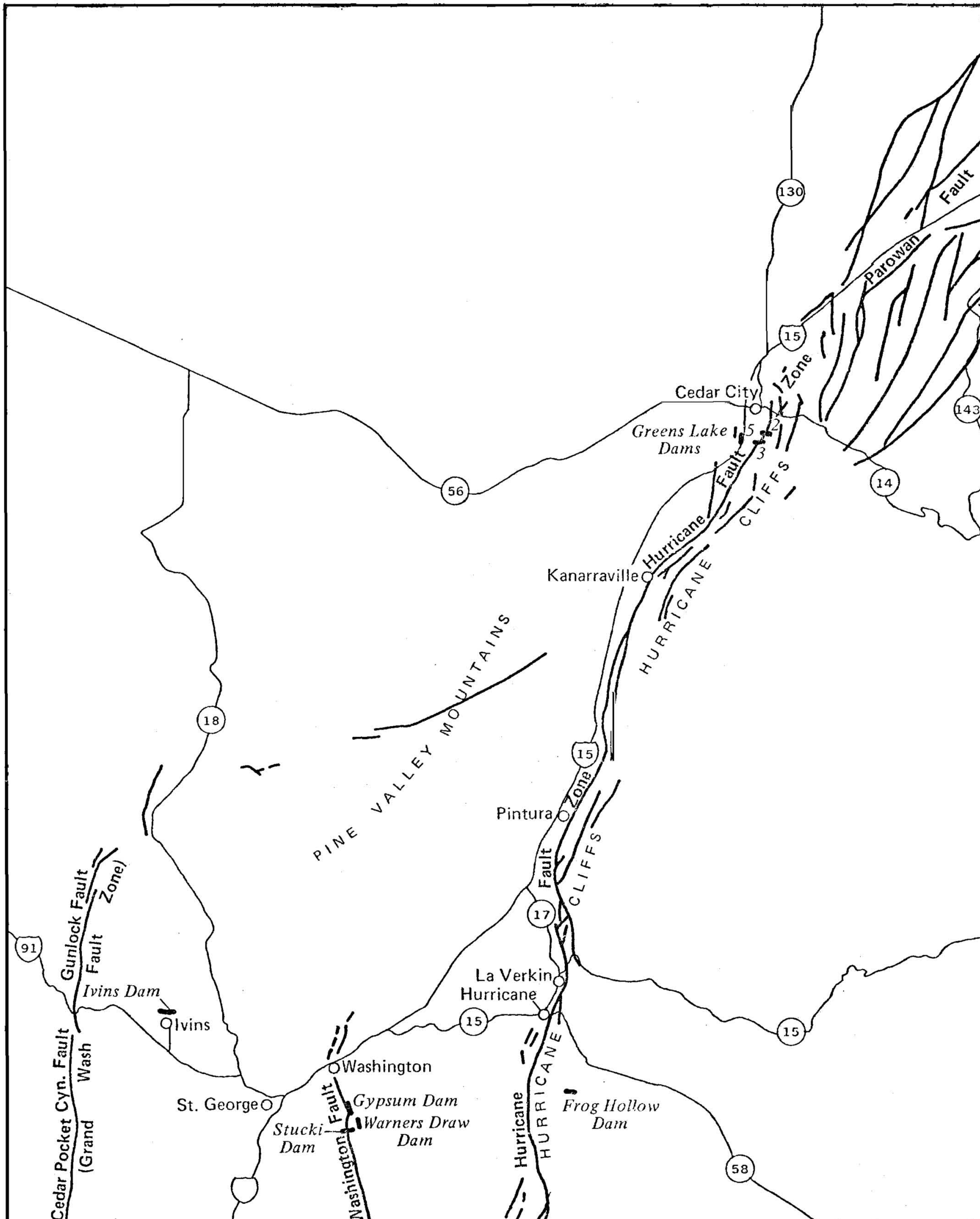
D. Grand Wash Fault Zone

The Grand Wash fault zone, also designated the Cedar Pocket Canyon-Gunlock fault (Figure IV-1 and Figure E-13), and the Gunlock-Veyo fault (Figure E-9), is a major tectonic feature in northwestern Arizona and southwestern Utah (Cook, 1960; Dobbin, 1939; Anderson and Mehnert, 1979; Best and Hamblin, 1978). The fault zone has been mapped as extending from the vicinity of Grapevine Wash in northwestern Arizona (Wilson and others, 1969), northward to the vicinity of Gunlock, Utah, a total distance of approximately 159 km.

The Grand Wash fault forms the boundary between the Basin and Range and Colorado Plateau provinces in northwestern Arizona. North of the Utah Border, the boundary is less well defined, but is interpreted (Anderson and Mehnert, 1979) to follow the Cedar Pocket Canyon-Gunlock-Veyo fault zone (the northern continuation of the Grand Wash fault). The boundary then apparently steps eastward along the north side of the Pine Valley Mountains to join the Hurricane-Parowan-Paragonah/Monocline-fault system near Cedar City. The structural block between the west-down normal Grand Wash fault zone and the Hurricane fault has been uplifted at least 64 m/m.y. in Late Cenozoic time (Hamblin and others, 1981).

The age of initiation of movement on the Grand Wash fault is not certain, but its formation may have been related to relative down-dropping of the eastern Basin and Range province as a result of collapse of regional upwarping during Late Cenozoic time. Structural differentiation of the provinces began sometime after 29 m.y., with vertical movement along faults including the Grand Wash.

The Grand Wash fault zone in Utah is considered to be seismically and probably geologically active (Anderson and Miller, 1979). The fault zone is located within the intermountain seismic belt (see Appendices E and F), a major zone of intraplate seismicity within western North America.



From: *Geologic Map of Utah*, by Lehi F. Hintze, 1980.

Earth Sciences Associates

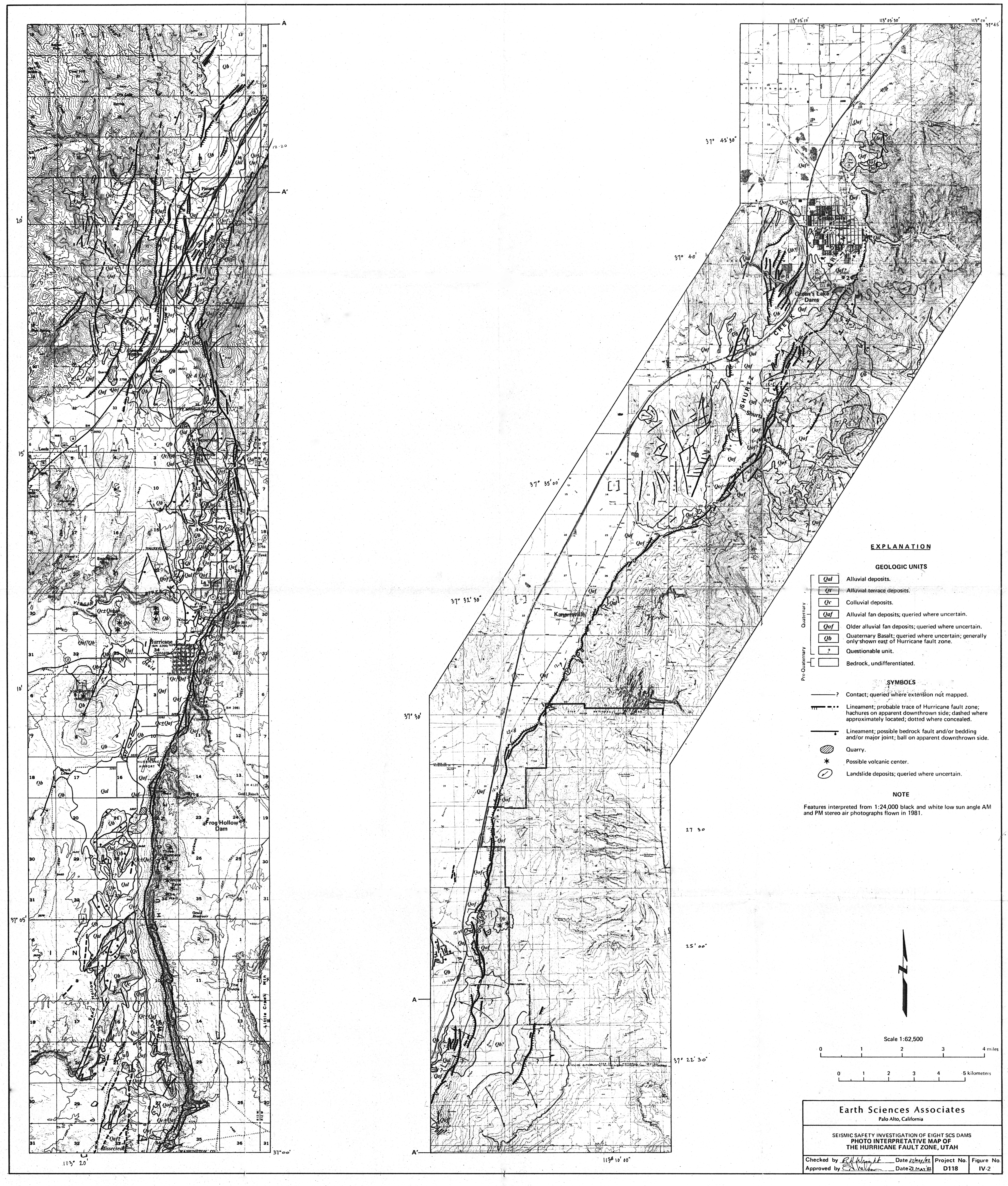
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

REGIONAL FAULT MAP

Checked by RJ Wright Date 27/MAY/82	Project No.	Figure No.
Approved by [signature] Date 27 MAY 82	D118	IV-1

Figure IV-2 PHOTO INTERPRETIVE MAP OF THE HURRICANE FAULT ZONE, UTAH


A
A'
Hurricane
Leeds
Frog Hollow Dam
Kanarraville
Cedar City
Green's Lake Dams
SHURTZ CREEK
Shurtz
37° 43' 30"
37° 40'
37° 35' 00"
37° 32' 30"
37° 30'
37° 27' 30
37° 25' 00"
37° 22' 30"
37° 05'
37° 00'
113° 20'
113° 10' 00"
EXPLANATION
GEOLOGIC UNITS
Quaternary
Pre-Quaternary
Qal Alluvial deposits.
Qt Alluvial terrace deposits.
Qc Colluvial deposits.
Qaf Alluvial fan deposits; queried where uncertain.
Qof Older alluvial fan deposits; queried where uncertain.
Qb Quaternary Basalt; queried where uncertain; generally only shown east of Hurricane fault zone.
? Questionable unit.
Bedrock, undifferentiated.
SYMBOLS
Contact; queried where extension not mapped.
Lineament; probable trace of Hurricane fault zone; hachures on apparent downthrown side; dashed where approximately located; dotted where concealed.
Lineament; possible bedrock fault and/or bedding and/or major joint; ball on apparent downthrown side.
Quarry.
Possible volcanic center.
Landslide deposits; queried where uncertain.
NOTE
Features interpreted from 1:24,000 black and white low sun angle AM and PM stereo air photographs flown in 1981.
Scale 1:62,500
0 1 2 3 4 miles
0 1 2 3 4 5 kilometers
Earth Sciences Associates
Palo Alto, California
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
PHOTO INTERPRETATIVE MAP OF
THE HURRICANE FAULT ZONE, UTAH
Checked by R H Wright Date 27/MAY/82
Approved by E A Nelson Date 27 MAY '82
Project No. D118
Figure No. IV-2

V. FAULT DISPLACEMENT RATES AND RECURRENCE OF SURFACE FAULTING

A. Summary

Although both the Colorado Plateau and the Basin and Range provinces are presently being uplifted, their rates of uplift are not the same. The Colorado Plateau is rising faster than the area to the west, and this differential movement is being accommodated by displacements on the predominantly north-south faults that mark the boundary zone between these two provinces.

Fault displacement rates for the faults in southwestern Utah indicate average slip rates of fractions of a millimeter to a few millimeters per year (see data compiled by Doser and Smith, 1982). Based on these slip rates, very long recurrence intervals (of the order of thousands of years) for surface rupture events at any one location on these faults are probable.

B. Fault Displacement Rates

Systematic age dating of late Cenozoic basalts displaced by major faults, such as the Hurricane and Grand Wash faults, provides some of the best estimates of fault-displacement rates in southwestern Utah and northwestern Arizona (Hamblin and others, 1981; Anderson, 1980; Anderson and Mehnert, 1979). Hamblin and others (1981) have carefully studied the stratigraphic offset of dated basalt flows in drainage systems along the Basin and Range-western Colorado Plateau border and conclude the following:

> "The Grand Wash area in the Basin and Range is rising about 26 m/m.y. and reflects the regional relative uplift rates between the southwestern Colorado Plateau and adjacent Basin and Range province. The block between the Grand Wash and Hurricane faults is rising at an additional minimum rate of 64 m/m.y. (a total of 90 m/m.y.), and the block east of the Hurricane fault is rising at an additional rate of 300 m/m.y. (a total of at least 390 m/m.y.)" (Hamblin and others, 1981, p. 298).

Anderson (1980, p. 535) cites displacement rates for the Hurricane fault of 470 m/m.y. near Pintura, 40 km south-southwest of Cedar City, and 400 m/m.y. in the North Hills area, about 15 km south-southwest of Cedar City.

A summary of fault-displacement data compiled by Doser and Smith (1982) as part of their study of seismic moment rates in southwest Utah supports the interpretation of fault-displacement rates of the order of a millimeter or less per year (1 mm/yr = 1,000 m/m.y.) An anomalously high displacement rate of several millimeters per year at Braffits Creek is now judged to be related to a tensional collapse structure, apparently deforming aseismically (Anderson, 1980). It should be noted that many of the displacement or slip rates listed by Doser and Smith (1982) involve significant uncertainty because of the approximate age estimated for a measured offset. Data for the Shurtz Creek fault scarp are a case in point. Nevertheless, the observations indicate the correct order of magnitude, and they basically agree with the more precise rate estimates of less than a millimeter per year derived from displacements of accurately dated basalt flows.

Elsewhere in the Utah region, the most reliable information on rates of fault displacement have come from recent studies of the Wasatch fault. Fission-track dating of apatites within the uplifted Wasatch Mountain block imply a long-term late Cenozoic slip rate of 0.4 mm/yr, but detailed trenching studies indicate Holocene slip rates of about 1-2 mm/yr and late Pleistocene slip rates as high as 4 mm/yr along certain segments of the Wasatch fault (see Swan and others, 1980).

C. Recurrence Intervals

Extraordinarily long recurrence intervals (of the order of thousands of years) for the repetition of surface faulting at the same site are now well recognized for faults in the Basin and Range province (e.g., Wallace, 1981). The Wasatch fault, which has been perhaps the most active locus of recurrent surface faulting along the eastern Great Basin, displays average recurrence intervals for surface faulting of the order of several hundred years to three thousand years at the same site--as determined from detailed trenching studies across four different fault segments (Swan and others, 1980; Hanson and others, 1981). The average net vertical tectonic displacement for surface faulting earthquakes on the Wasatch fault is about 1-4 m per event (Hanson, 1981), and the recurrence interval for such scarp-forming earthquakes is 50-430 years for the entire 370 km-long fault zone (Swan and others, 1980).

Recurrence rates of surface faulting on the Wasatch fault probably represent an upper limit for any active faulting in the Utah region. In western Utah, some prominent Holocene fault scarps have been estimated to reflect recurrence intervals for surface faulting greater than 10,000 years (see Wallace, 1981). In the Cedar City-St. George area, the northern Hurricane fault appears to have the greatest displacement rate associated with tectonic earthquakes, but the rate of recurrence of surface faulting along it is unknown. Arguments of Bucknam and others (1980) and Anderson (1980) suggest a surface faulting recurrence interval greater than 10,000 years for the Hurricane fault. Additionally, the Hurricane fault is apparently moving at a grossly similar slip rate to other faults in southwestern Utah, and recurrence intervals for surface faulting at the same site of at least a few thousand years are indicated for these other faults at all studied locations.

VI. SUMMARY OF HISTORIC SEISMICITY AND EARTHQUAKE RECURRENCE

A comprehensive discussion of the historic seismicity of southwest Utah by Dr. Walter Arabasz, Jr., is presented in Appendix F of this report. The major findings related to historic seismicity and earthquake recurrence are summarized in this chapter.

A. Historic Seismicity

Historic seismicity in the region surrounding the dam sites (as defined below) was documented for the period of record from 1850 to 1981 by reviewing the earthquake data files of the University of Utah.

The University of Utah master catalog for the Utah region comprises three parts (Arabasz and others, 1979, 1980): (1) the 1850 - June 1962 historical catalog; (2) a catalog for the period July 1962 - September 1974, consisting of systematically revised, instrumental earthquake locations and magnitudes; and (3) a catalog of seismicity since October 1974 based upon data from an extensive network of telemetered seismic stations.

The earthquake data for the regions of interest have been considered in several different ways:

1) All earthquakes of 3.0 or Magnitude greater within 200 km of the center of the study area (lat. 37° 25'N, long. 113° 15'W) have been listed and plotted. The listing of these earthquakes is provided in Appendix G.

2) All earthquakes of 3.0 or greater Magnitude within 150 km radial distance of four specific points, corresponding to the locations of the various dam sites have been listed. The geographic coordinates of the four points are as follows:

Cedar City:	37°	39.00'N	113°	04.30'W
Frog Hollow:	37°	07.00'N	113°	15.30'W
St. George:	37°	03.30'N	113°	29.00'W
Ivins:	37°	10.30'N	113°	40.00'W

Listings for the Cedar City and St. George sites are included in Appendix H.

3. A list of all earthquakes within a rectangular area encompassing St. George and Cedar City (lat. 36.75°N - 38.00°N, long. 112.00°W - 114.25°W), appearing in the University of Utah earthquake catalogue, has been compiled and the epicenters plotted. This earthquake listing is contained in Appendix I. A plot of the instrumental earthquake epicenters for the period from July 1962 - December, 1981, is presented in Figure VI-1. In this illustration, instrumental seismicity is plotted with different symbols to distinguish earthquake epicenters located during the period July 1, 1962 - September 30, 1974 (open circles) from more accurately located epicenters (closed circles) corresponding to the period October 1, 1974 - December 31, 1981.

Twenty-two earthquakes of estimated Richter magnitude 5 or greater have occurred within 200 km of the Cedar City-St. George study area between the period 1850 - 1981. These are tabulated in Table VI-1. Nine of these have had an instrumentally determined magnitude of $5\frac{1}{2}$ or greater. The largest within the 200 km radius region of interest occurred in 1901 near Richfield, Utah (182 km NE of the center of the study area) and had a maximum Modified Mercalli intensity of 8 to 9. This event did not produce any observed surface faulting, and Arabasz and Smith (1979) estimate that it had a local Magnitude (M_L) of $6\frac{1}{2}$+. A map showing the epicenters of the largest historical earthquakes known from the Utah region during the period of 1850 - 1978 is also presented as Figure F-3 of Appendix F.

The largest historical earthquakes within the immediate vicinity of Cedar City and St. George are the following:

(1) An earthquake of April 20, 1891 (I_o = 6, $M_L \sim 5$), which shook Washington County and caused minor damage in St. George (Williams and Tapper, 1953).

(2) An earthquake of November 17, 1902 (I_o = 8, $M_L \sim 6$) near Pine Valley, Utah, about 30 km north of St. George. Many buildings in St. George

Table VI-1. Largest Earthquakes Within 200 km of Study Area, 1850 through 1981[1]

Date (GMT)	Lat. (°N)	Long. (°W)	I_o	Magnitude (M_L)	Location	Distance (km)
1887 Dec 05	37.1	112.5	7	(5½)	Kanab, Ut.	77
1891 Apr 20	37.1	113.6	6	(5)	Washington Co., Ut. (St. George)	34
1901 Nov 14	38.8	112.1	8-9	(6½+)	Richfield, Ut.	182
1902 Nov 17	37.4	113.5	8	(6)	Pine Valley, Ut.	24
1902 Dec 05	37.4	113.5	6	(5)	Pine Valley, Ut.	24
1908 Apr 15	38.4	113.0	6	(5)	Milford, Ut.	110
1910 Jan 10	38.7	112.1	6-7	(5-5½)	Elsinore, Ut.	171
1910 Jan 12	38.7	112.1	6	(5)	Elsinore, Ut.	171
1912 Aug 18	36.5	111.5	6-7	(5½)	Williams, Ariz.	186
1921 Sep 29	38.7	112.1	8	(6)	Elsinore, Ut.	171
1921 Sep 30	38.7	112.1	7	(5½)	Elsinore, Ut.	171
1921 Oct 01	38.7	112.1	8	(6)	Elsinore, Ut.	171
1933 Jan 20	37.8	112.8	6	(5)	Parowan, Ut.	60
1934 Apr 15	38.0	115.0	-	5.0	SE Nevada	167
1942 Aug 30	37.7	113.1	6	(5)	Cedar City, Ut.	34
1942 Sep 26	37.7	113.1	6	(5)	Cedar City, Ut.	34
1945 Nov 18	38.8	112.0	6	(5)	Glenwood, Ut.	186
1952 May 24	36.1	114.7	6	5.0	Ariz.-Nev. border	195
1959 Feb 27	38.0	112.5	6	(5)	Panguitch, Ut.	93
1959 Jul 21	37.0	112.5	6	5½-5-3/4	Kanab, Ut.	81
1966 Aug 16	37.5	114.2	6	5.6	Nev.-Ut. border	80
1967 Oct 04	38.5	112.2	7	5.2	Marysvale, Ut.	158

[1]Summarized from compilation of regional seismicity ($M \geq 3.0$) within 200-km radial distance of study area. Table includes earthquakes of estimated Richter magnitude 5 or greater. I_o = maximum Modified Mercalli intensity. Magnitudes in parentheses estimated from I_o($M=1+2/3\ I_o$). Distance measured from a point half-way between Cedar City and St. George.

sustained damage and almost every chimney reportedly went down in Santa Clara (Williams and Tapper, 1953).

(3) An aftershock of the 1902 Pine Valley earthquake that occurred on December 5, 1902 ($I_o = 6$, $M_L \sim 5$).

(4) An earthquake of January 20, 1933 ($I_o = 6$, $M_L \sim 5$) near Parowan, 30 km northeast of Cedar City. Minor damage occurred in Parowan and Minersville (Williams and Tapper, 1953).

(5) Two earthquakes, apparently as part of a swarm sequence, near Cedar City on August 30, 1942, and September 26, 1942 (each with $I_o = 6$, $M_L \sim 5$). Minor damage occurred in Cedar City during both of these shocks (Williams and Tapper, 1953).

B. Earthquake Recurrence

Rates of earthquake recurrence in any seismically active region can be estimated using both seismological and geological data. If a catalog of historical and/or instrumental seismicity is available, then relationships of earthquake frequency versus magnitude can be used to estimate the average recurrence interval or inter-event time for earthquakes of a specified magnitude. Recurrence estimates can also be made from seismic moment rates determined from available geologic data on Quaternary faulting.

Each of these approaches has been recently applied to seismically active areas in Utah, and available information on earthquake recurrence in southwestern Utah is summarized here. A detailed discussion of this subject is presented in Section F.3 of Appendix F.

Estimates of the frequency of occurrence for a range of earthquake sizes were made for the southwestern Utah region, which encompasses an area of 56,160 km^2. In making these estimates, several relationships derived from the historical and instrumental seismicity were used (Smith and Arabasz, 1979). The three different cases considered are listed at the bottom of Table VI-2, which also

Table VI-2 - Estimated Frequency of Occurrence of Damaging Earthquakes (in years)

Earthquake Size	Recurrence for Entire SW Utah Case I	Case II	Case III	Recurrence Within 50 km of any Site Case I	Case II	Case III
$M_L \geq 7.5$	313	241	660	2,240	1,720	4,720
$M_L \geq 7.0$	148	125	282	1,060	894	2,020
$M_L \geq 6.5$	70	65	120	500	465	858
$M_L \geq 6.0$	33	34	51	236	243	365
$M_L \geq 5.5$	16	18	22	114	129	157
$M_L \geq 5.0$	7.4	9.5	9.3	53	68	66

After Smith and Arabasz (1979)

Case I: Historical data, 1850-1978: $\log N_c = 2.38 - 0.65\ M_L$

Case II: Historical data, 1850-1978: $R = 1/[-F(x)]$

where

$$F(x) = \exp\{-[-\exp[-(x-3.50)/1.14]\}, \quad -\infty < x < +\infty$$

Case III: Instrumental data, 1962-1978: $\log N_c = 2.73 - 0.74\ M_L$

M_L = Local Richter magnitude.

N_c = Annual number of events equal to or greater than a given magnitude.

$F(x)$ = Probability that the largest earthquake in a year will have intensity less than or equal to x.

R = Return period.

presents rates of recurrence for a range of earthquake sizes. These values were determined assuming that the seismicity of the southwest Utah study area is uniformly distributed over the area. This is a reasonable assumption for earthquakes up to Magnitudes 6 to 6½.

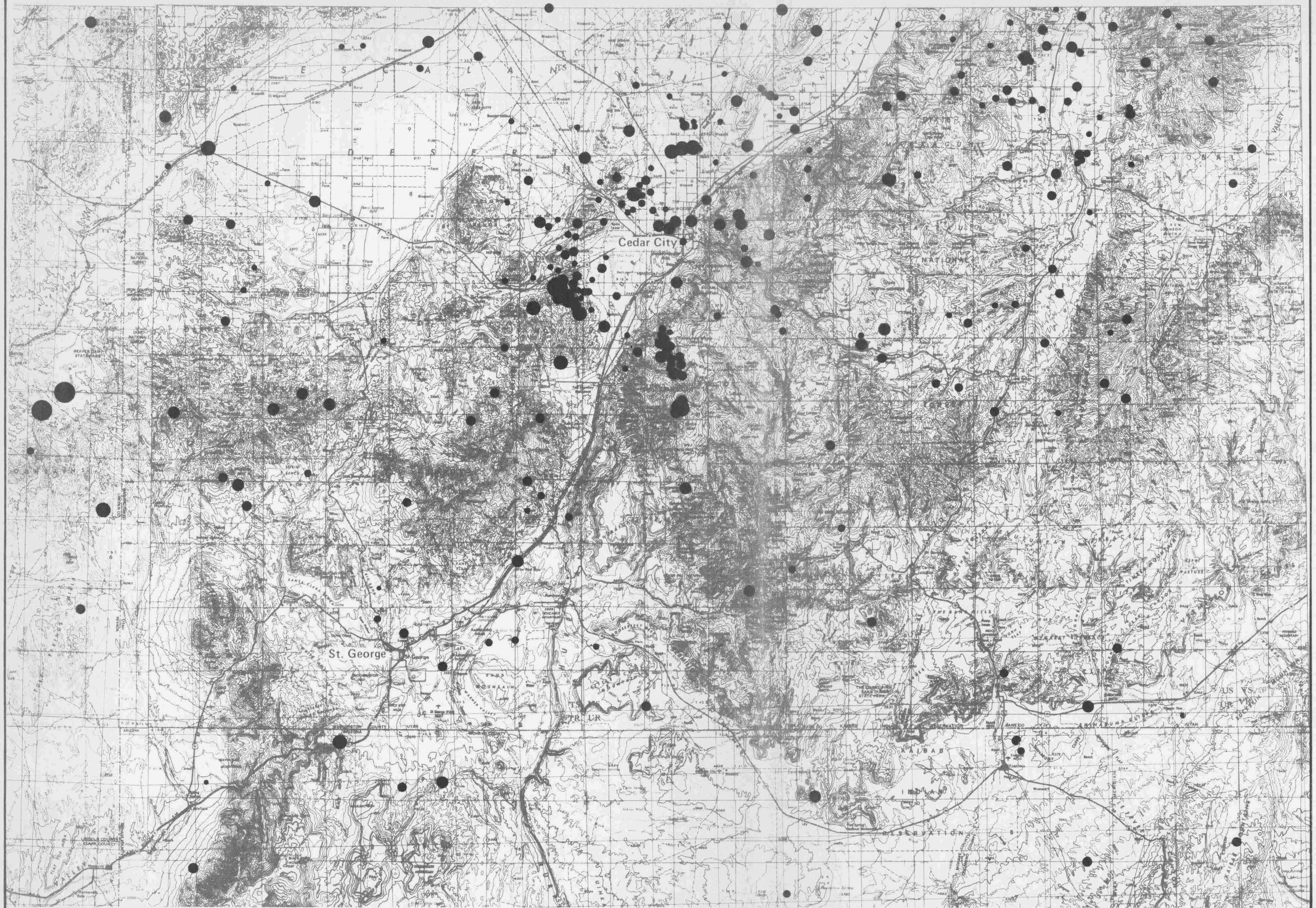
A fundamental assumption regarding the estimation of earthquake recurrence is that the data used to calculate the required parameters accurately represent the long-term seismicity of a region. Ideally, the data should represent a period of time long enough to include at least one repeat interval of the largest earthquake. Consequently, while rates of earthquake recurrence for magnitudes up to about 6-6½ in southwest Utah can be estimated with a high degree of confidence on the basis of historical and instrumental seismicity, there is clearly considerable uncertainty in extrapolating recurrence intervals for earthquakes of larger size.

Since the seismicity of the region has been assumed to be uniformly distributed, it is possible to obtain an estimate of the frequency of occurrence of earthquakes within a smaller area. If we consider an area within 50 km of any of the eight dam sites (which amounts to 7,854 km^2), the recurrence interval within this smaller area is inversely proportional to the ratio of the two areas. Thus, as can be seen from Table VI-1, the recurrence interval for an earthquake of any given size occurring within 50 km of any of the eight dam sites is about 7 times longer than the recurrence interval within the entire southwest Utah region.

The frequency of occurrence of moderate-to-large earthquakes can also be estimated from geologic data by relating geologically determined slip rates on individual faults to seismic moment rates (Anderson, 1979; Molnar, 1979). Such an approach complements analyses based on the historic record of seismicity, which is generally too short for valid evaluation of the long-term seismic activity over hundreds or thousands of years. Doser and Smith (1982; see also Doser, 1980) have applied the moment rate method to various regions in Utah, including the southwest Utah region (Region III, Figure F-12a) defined by Smith and Arabasz (1979) for recurrence analysis of seismicity. They first determined a moment-magnitude scale for Utah based on the spectral analysis of 19 earthquakes in the Utah region in the magnitude (M_L) range 3.7 to 6.6. Moment rates were calculated from a compilation of geologic information on slip rates of Quaternary faulting in southwest Utah. Earthquake recurrence rates were then calculated using the slopes of the relationships established by Smith and Arabasz (1979) and an appropriate coefficient defining the moment-magnitude relationship.

For southwest Utah, the frequency of earthquake occurrence based on geologically determined moment rates is essentially in agreement with that calculated from historical earthquake data. The estimated recurrence interval for an earthquake of $7.0 \leq M_L \leq 7.5$ somewhere in the southwest Utah region is between 200 and 600 years (Doser and Smith, 1982), where the range results from an uncertainty in the moment-magnitude scale for Utah. For the same magnitude range and area, extrapolated seismicity (Smith and Arabasz, 1979) would predict a recurrence interval between 200 and 500 years. The discrepancy between such an expectation of a scarp-forming earthquake somewhere in southwestern Utah every few to several hundred years and the apparent absence of Holocene fault scarps in southwest Utah may in large part be the result of the extremely active erosional/depositional environment. Anderson (1980) and Bucknam and others (1980) believe that there has been no radical change in the rate of occurrence of large earthquakes during Holocene time compared to the late Quaternary record in southwest Utah. Two possible implications of the lack of evidence of surface faulting are: (1) the recurrence interval of surface faulting on individual faults in southwest Utah may be very long, and (2) there may be different frequency-magnitude relations for earthquakes smaller than and larger than, respectively, about magnitude 6-6½ in southwest Utah.

Based on consideration of the historical seismicity and the geology of the region, it is our opinion that the recurrence interval for an earthquake of Magnitude 7 to 7½, in close proximity to any of the dam sites, would range from 1,000 to 10,000 years. For earthquakes of Magnitude 6 to 6½ or smaller, the values given in Table VI-2 for an area within a 50 km radius of any of the dam sites are appropriate.



EXPLANATION

Magnitude

6
4
2
1

0 5 10 miles

Scale 1:600,000

INSTRUMENTAL
EARTHQUAKE EPICENTERS
FOR
SOUTHWEST UTAH
(1962 - 1981)

FIGURE VI-1

VII. MAGNITUDE OF MAXIMUM CREDIBLE AND MAXIMUM PROBABLE EARTHQUAKES

The largest historical earthquake in southwest Utah (which produced no observed surface faulting) had an estimated magnitude of $6\frac{1}{2} \leq M_L \leq 7$. The largest historical earthquake in the entire Intermountain seismic belt had a measured magnitude (M) of 7.1--resulting in a normal fault scarp with a maximum surface displacement of 6.7 m.

The selection of a maximum size earthquake for any area conventionally is based on consideration of: the structural and geological features of a region; the historical experience of faulting within the same (or a similar) tectonic province; and empirical relations between observations of fault-rupture length, fault displacement, and earthquake magnitude (e.g., Slemmons, 1977).

The maximum size earthquake for the entire Utah region is generally considered as a "Magnitude $7\frac{1}{2}$". The U.S. Geological Survey (1976) postulated the occurrence of earthquakes as large as magnitude (unspecified) 7.5 on the Wasatch fault. In the latter study, mention is made of the magnitude (M) 7.1 Hebgen Lake, Montana, earthquake of 1959 and the magnitude (M) 7.6 Pleasant Valley, Nevada, earthquake of 1915 as plausible upper limits for the "maximum credible" earthquake on the Wasatch fault. Here M refers to a "revised magnitude" determined by the Seismological Laboratory in Pasadena that is distinct from, but essentially equivalent to, a surface-wave magnitude M_S (see Geller and Kanamori, 1977, regarding differences between various magnitudes computed and published by Gutenberg and Richter).

Swan and others (1980) relate measurements of pre-historic fault displacements on the Wasatch fault to Slemmons' (1977) curve for normal-slip faults to assert that "surface faulting events associated with earthquakes in the magnitude range $6\frac{1}{2}$ to $7\frac{1}{2}$ have occurred repeatedly along (segments of the Wasatch fault)" (Swan and others, 1980, p. 1458).

Bucknam and others (1980) review data on historic surface faulting in the Basin and Range province. Their tabulation shows that, excluding the $M_L = 8.0$ Owens Valley, California, earthquake of 1872 (max. displacement = 6.4 m), the largest event (coincident with the largest maximum displacement of 5.6 m) is the M_L = 7.8 Pleasant Valley, Nevada, earthquake of 1915. Bucknam and others (1980) also note that all seven historic earthquakes in the Great Basin larger than M_L = 6.3 have produced surface ruptures. Without clear explanation, they assume a maximum magnitude (unspecified) of 7.6 for the Wasatch fault zone, and they discuss the likelihood of infrequent large earthquakes of "M = 7.0 to 7.6" in southwest Utah (Bucknam and others, 1980, p. 306-308). M in their usage is simply "magnitude". The value M_L = 7.8 for the Pleasant Valley earthquake is ascribed by Bucknam and others (1980) to a NOAA data file summary, in which some conversion was apparently made from the published value of M = 7.6 for that earthquake (e.g., Richter, 1958).

In the Cedar City-St. George area, Anderson (1980) states that "the 20 m high scarp in alluvium along the trace of the Hurricane fault at Shurtz Creek clearly implies a displacement history comparable to other faults in the Great Basin for which a credible magnitude of 7½ would readily be assigned". Anderson also sees no evidence that the Shurtz Creek scarp is a composite scarp (although evidence for multiple movements admittedly would be difficult to recognize in the coarse bouldery alluvium), and he believes that it may represent a single displacement event (oral communication to geologists participating in a field inspection of SCS dam sites in the Cedar City-St. George area, January 1982).

ESA considers it likely that the 20 M high Shurtz Creek scarp is the result of multiple movements. A 20 M high single displacement scarp on the Hurricane fault is not a credible event within the context of the historic record. The largest historic vertical displacement on a normal fault is 14.34 M on the Yakutat Bay fault in Alaska in 1899 (Bonilla, 1970). This displacement was the result of a 8.5-8.6 M earthquake, a magnitude significantly greater than that assigned to the Hurricane fault. Evidence of multiple events in the Shurtz Creek environment would not be expected to be well preserved. Robert E. Wallace of the U.S. Geological Survey estimates that a one meter scarp in the Shurtz Creek environment would not last more than 500-1,000 years, and a two meter scarp not more than two to three thousand years (R. E. Wallace, USGS, oral communication, 5/82).

A maximum earthquake size of Magnitude 7½ is a reasonably conservative value to assign to the study area. The precise number--within differences of a few tenths of a magnitude unit--is insignificant, in our opinion, in view of: (1) inconsistent specification of magnitude scales, (2) general problems with magnitude, in general, as a reliable measure of earthquake source properties, and (3) the range of uncertainty involved in relating magnitude to a predicted value of displacement, rupture length, or any ground-motion parameter. Adoption of a maximum earthquake magnitude of 7½, which in practice will likely be measured as a surface-wave magnitude will be a larger magnitude than that for any historic earthquake which has occurred in the Intermountain Seismic Belt (ISB). This value will be consistent with the general consensus of geologists and seismologists familiar with earthquake risk in the ISB.

On the basis of the historical record of seismicity, the pattern and nature of known faults, the anticipated distribution of known faulting and the inferred temporal relationships of regional strain, an earthquake of magnitude 7.5 is concluded to be a conservative maximum credible event for the southwest Utah region.

Magnitudes of both the maximum credible and the maximum probable earthquakes which could occur on the nearby faults and which could produce significant ground shaking at the various dam sites have been estimated and are summarized in Table VII-1, together with estimates of their recurrence intervals. For purposes of this study, the maximum probable earthquake represents an event which has a reasonable probability of occurring during the life of these facilities. Although the magnitude of the earthquake selected for design should be based on the level of risk which the owner of the facility is willing to accept for each specific dam site, it is our judgment, and that of our consultant Dr. Arabasz, that a magnitude 6 event represents a reasonable earthquake which could occur during the life of these facilities and one which each dam should be able to withstand without catastrophic consequences.

Table VII-1

Estimated Magnitude and Recurrence Interval of Maximum Credible and Maximum Probable Earthquakes in the Vicinity of Dam Sites

Dam	Closest Fault to Dam Site	Distance to Fault (miles)	Total Fault Length (miles)	Maximum Credible Magnitude	Maximum Credible Recurrence Interval (yrs)	Maximum Probable Magnitude	Maximum Probable Recurence Interval (yrs)
Green's Lake No. 2	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Green's Lake No. 3	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Green's Lake No. 5	Hurricane	0	160	7.5	1,000-10,000	6.0	200-300
Gypsum Wash	Washington	0	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	10	160	7.5	1,000-10,000	6.0	200-300
Warner Draw	Washington	1	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	9	160	7.5	1,000-10,000	6.0	200-300
Stucki	Washington	0.5	40	7.0	2,000-10,000	6.0	200-300
	Hurricane	10	160	7.5	1,000-10,000	6.0	200-300
Frog Hollow	Hurricane	2	160	7.5	1,000-10,000	6.0	200-300
Ivin's	Grand Wash	5	99	7.5	2,000-10,000	6.0	200-300

VIII. GEOLOGIC CONDITIONS IN THE VICINITY OF THE DAM SITES

The investigation of the geological environment of each specific dam site began with photo-geologic evaluation and identification of lineaments which could represent active fault traces, followed by field reconnaissance mapping, with emphasis on the nature of the air photo lineaments and certain geologic features mapped by previous investigators. Sites determined by the field reconnaissance to be located on or near suspected active faults were investigated by exploratory trenching. A discussion of geologic conditions determined to exist at each of the dam sites is presented in the order listed below:

A. Green's Lake No. 2 and No. 3 (GL-2 and GL-3)
B. Green's Lake No. 5 (GL-5)
C. Gypsum Wash
D. Warner Draw
E. Stucki
F. Frog Hollow
G. Ivins Diversion No. 5

Of the eight dams investigated, five are located on faults, or within fault zones, and these sites are discussed first.

A. Green's Lake No. 2 and No. 3

1. General Geology

Green's Lake Dam Embankments No. 2 and No. 3 (GL-2 and GL-3) are located at the toe of a major N-S-trending escarpment which rises eastward to the Kolob Terrace of the Colorado Plateau province. The escarpment or hillfront is considered to be the locus of the main trend of the Hurricane fault. South of Cedar City, the escarpment is characterized by moderate to very steep slopes which are underlain by complex landslides of varying ages, and by areas of tectonically deformed bedrock. Figure VIII-10 defines bedrock and landslide areas within the escarpment, and shows a prominent strand of the Hurricane fault which cuts both bedrock and landslide zones south of GL-3. This strand apparently extends beneath young alluvial fan deposits to the north.

The hillfront escarpment in this area has been dissected by numerous drainage channels. Periodic torrential runoff has deposited coarse rubble and boulders of sandstone, limestone, and basalt up to five or more feet in size in these ravines. The coarse material deposited in the re-entrants grades finer and less chaotic to the west across the front of the escarpment, grading to well stratified alluvial fan deposits which form an apron along the hillfront and underlie the GL-2 and 3 dam site areas. The fan deposits consist of silt, sand, and gravel. Rock types present in the gravel clasts include limestone, siltstone, sandstone, and gypsiferous shale derived from bedrock sources to the east. Gravel clasts are typically angular to flat and up to 2 or 3 inches in size, although cobbles and boulders are common within the fans near the toe of the hillfront to the east. The alluvial fan sediments are commonly medium dense to dense silt and sand mixtures with lesser coarser lenses of sand and gravel. As determined by the trench excavations, the fan deposits will stand vertically without support for an indefinite time. Site geology in the vicinity of Green's Lake No. 2 and No. 3 is shown in Figures VIII-1 and VIII-2, respectively.

2. Faults

Previous geologic reconnaissance mapping of the Green's Lake dam sites by R. L. Bridges and D. H. Griswold (data compiled from SCS files) during the late 1950's indicated fault-like features trending generally south-southwest to north-northeast near the toe of the hills and underlying portions of the embankments. The locations of these suspected faults, as interpreted from the available SCS literature, are plotted in Figure VIII-3 (see also Figures VIII-1 and VIII-2), and are assigned letters A, B, C, D and E.

Air photo studies during the current investigation confirmed the existence of several lineaments at or near the previously mapped faults on the alluvial fan deposits. However, subsequent field reconnaissance revealed extensive man-made alterations to the original ground surface both within and outside of the main dam embankments. These modifications include cutting and filling operations that were apparently carried out during dam construction or subsequent repair operations associated with basin maintenance and spreader dike construction. Because surficial geologic evidence for faulting or fault-like features on the fan deposits were not observed at many of the locations previously mapped by Bridges and/or Griswold, it is assumed much of the surficial reworking occurred after their studies. Most of the air photo lineaments currently identified on the alluvial fans apparently result from anomalous surficial features not related to subsurface geologic conditions.

Earth Sciences Associates' current field reconnaissance located two prominent scarp-like features at the approximate fault locations previously mapped by Bridges and/or Griswold. These scarps also coincide with lineaments identified on air photos, and are shown in Figure VIII-3 as Scarps I and II. Scarp I trends N35E and is located at the west edge of the present tree cover. Several air photo lineaments are located in this same area and it is near previously mapped fault traces "A" and "B". The relief of scarp I is approximately 5 to 6 feet, and the surface dips at about 25° to the west. Trench GL-2a was excavated across Scarp I and encountered locally stratified alluvial fan and chaotic boulder fanglomerate deposits, indicating the extreme agradation-degradation processes which have occurred here. Trench exposures revealed no indication of displaced or faulted stratigraphy at the scarp location, but a sharp discontinuity exists to the west of the topographic scarp at Station 0+98. At this station, carbonate-cemented gravels and a silt lens are juxtaposed across a vertical contact with loose, coarser gravels (see log of Trench GL-2a and Photograph VIII-1). This discontinuity is overlain by 6 to 7 feet of younger, unbroken fan deposits. Trench GL-2d was excavated 40 feet north of GL-2a across the N5E-striking trend of the discontinuity in order to determine the extent of the feature, but no similar discontinuities or other disruptions of stratigraphy were exposed. To the north, Trench GL-2c extends across the projection of the break found in Trench GL-2a, but no disruptions of the stratified, fine-to-coarse-grained alluvial deposits were observed in this exposure. Although it is possible the discontinuity at Station 0+98 in Trench GL-2a resulted from faulting, in view of the additional unbroken trench exposures along the projection, we believe that the feature most likely represents a buried stream channel margin.

North-northeast of the GL-2 dam site and parallel to the GL-1 dam embankment, Scarp II (Figure VIII-3) trends approximately N20E. It is generally irregularly defined, but typically has 2 to 4 feet of relief with the west side down. Trench GL-2b intersected Scarp II (which conceivably coincides with fault "A" or "C" as mapped by Bridges), and exposed unbroken fine-grained alluvial fan deposits.

Trench GL-2c was excavated across the southern projection of Scarp II, across the previously-mapped fault trace "A", as well as across the northward projection of the break found in Trench GL-2a. As noted above, no evidence of faulting was detected in the exposed stratified alluvial fan deposits. Scarp-like features I and II are apparently either the result of earlier excavations or natural erosional features, or are a combination of both.

Surficial features similar to Scarps I and II (which projected through GL-2) were not observed during reconnaissance mapping near GL-3. The prominent air photo lineament located in the hills immediately south of Site No. 3 (Figure VIII-10), which is likely a major strand of the Hurricane fault, and previously-mapped suspected fault "D" intersect the embankment, however. Trench GL-3a was positioned on a zone of ground apparently undisturbed by construction activity across the northward projection of the prominent air photo lineament and suspected fault "E". Trench GL-3c intersects mapped fault D, which trends N20E from approximately Station 11+00 of the GL-3 dam embankment (as plotted from SCS data). Both trenches exposed well stratified, fine-grained alluvial fan deposits which displayed no evidence of fault disturbance.

Trench GL-3b was located on ground where minor surficial alteration had occurred during the past, but extended across the prominent Hurricane fault lineament where it traverses directly along the toe of the hillfront immediately west of GL-3's right abutment. Extensively sheared and faulted bedrock was exposed at this location, although the rocks are clearly overlain by an undisturbed, younger sequence of fine-to-coarse-grained alluvial fan deposits (see trench log).

Materials in the SCS files show that an area within the GL-3 reservoir subsided substantially when water remained in the reservoir because of a clogged outflow trash rack during 1967. The area of subsidence extended beneath a portion of the embankment, and is shown in Figure VIII-2. Because GL-3 dam is located within the Hurricane Fault Zone, it was suggested that the subsidence was in some way related to faulting.

Other than the settlement of this zone, no additional evidence was found during the current investigation to suggest Holocene faulting at this site. Nearby zones where suspicious fault-like features were identified and subsequently trenched revealed no indication of fault disturbance or subsidence deformation in the alluvial deposits (Trenches GL-3a, 3b, 3c). Furthermore, it is doubtful that the subsidence occurred as a result of differential settlement of underlying weak, sheared bedrock materials within a fault zone. Such deformation would likely have been present in Trench GL-3b where sheared bedrock conditions were exposed, but were found to be overlain by flat-lying, undeformed alluvial sediments. Both the intact bedrock materials and the weak, sheared bedrock zones are considerably harder and denser than the overlying alluvial deposits exposed in the site area.

In summary, all known evidence suggests that the subsidence which occurred here is the result of solution of gypsiferous materials within the alluvial fan materials, or collapse of porous mud flow deposits with associated settlement of near-surface soil deposits.

Because of the proximity of the Hurricane fault zone and the associated lineament or lineaments which project into the alluvial fan deposits from the flanking hills, the positions of the GL-2 and GL-3 trenches (and GL-3 subsidence zone) may very well overlie a strand or strands of the Hurricane fault. However, if such fault traces exist, they are buried by sequences of younger, unfaulted alluvial fan deposits which are at least as thick as the depth of the exploratory trenches. Figure VIII-5 is a sketch of inferred geologic conditions in the Green's Lake dams vicinity, and illustrates suspected fault-alluvial fan relationships.

A determination of the age of the undisturbed fan deposits would indicate the minimum amount of time an underlying fault, if present, has been inactive. Although attempts to assign ages to the alluvial sediments were hampered because of the general lack of soil development, the exposed sediments overlying the discontinuity in Trench GL-2a contained a weakly developed soil with cambic and locally weak argillic horizons. Underlying these deposits (adjacent to the discontinuity of probable erosional origin) near the base of the exposure, an incipient buried paleosol is present within channel fill material. Estimated ages of these two horizons are approximately 3,500 to 5,000 years and 5,000 to 10,000 years B.P. (before present), respectively (Dr. R. J. Shlemon, written communication), indicating that no fault activity has occurred at this location for at least 5,000 years. Detrital charcoal samples collected from specific stratigraphic horizons within trenches GL-2d, GL-3a, and GL-3b have been submitted for Carbon 14 age-dating, but results are not expected until early June, 1982.

B. Green's Lake No. 5

1. General Geology

The Green's Lake No. 5 site (GL-5) is a flood basin formed by the main retarding dam at Cross Hollow, the north and south dikes, and the natural topography. Quaternary-age basalt forms the west, south and southeast margins of the basin, and underlies the relatively high Cross Hollow Hills area west of the site. In the GL-5 vicinity, the basalt is underlain by older alluvial deposits which comprise the GL-5 basin floor, and, as determined by exploratory Trench GL-5a, the right abutment of the north dike and the northeast margin of the basin. These deposits were penetrated by exploratory borings GL-5-1 and 2 at the main dam during the current study, and are exposed beneath the basalt approximately two miles southwest of the GL-5 site in road cuts.

The basalt is characterized by rough, prominent outcrops where steep scarps exist, notably along the Cross Hollow drainage west of the main dam, and along the northeast-southwest-trending hillfront adjacent to the GL-5 basin. Where exposed, the basalt is very hard and prominently fractured, typically forming crude blocks several feet in size. At the top of the east-southeast-facing hillscarp which flanks the main dam site, the exposed basalt exhibits a gentle, east-dipping downward warp, conceivably the result of either gravatational slump-type movement along this upper margin, or a tectonically induced flexure which may be associated with adjacent faulting.

The older, underlying alluvial deposits consist of dense, stratified sandy silt, sand, and gravel lenses which consist of sandstone, limestone, siltstone, shale and basalt clasts. As determined in Trench GL-5a, most gravel clasts are angular or flat in shape, with re-worked or rounded clasts comprising an estimated 5 to 10% of the volume. The alluvium ranges from medium dense to very dense, and stands vertically in unsupported excavations.

At the base of the hillslopes and below the more prominent scarps on the east side of the Cross Hollow Hills, talus and colluvial deposits have accumulated in poorly defined zones which extend outward over the alluvium. The colluvial deposits exposed in Trenches GL-5b and GL-5c consist of silt to boulder-sized material. They are commonly a gravelly silt containing erratic basalt cobbles and blocks with a prominent, overlying hardpan zone of leached calcium carbonate. Where uncemented by the carbonate, the colluvium is typically loose to medium dense. Site geology in the vicinity of Green's Lake No. 5 is shown in Figure VIII-4.

2. Faults

Figure VIII-10 illustrates the locations of the GL-5 embankments, the prominent topographic scarps which trend northeast-southwest and form the margins of the GL-5 basin, and the numerous air photo lineaments present in the Cross Hollow Hills to the west. Approximately two miles southwest of the site and along the projected trend of the scarps and lineaments, road cut excavations expose both the basalt and underlying older alluvium. At this location, both pre- and post-basalt age shear planes are present as illustrated by photographs VIII-2 and VIII-3 (both north-facing views). Photograph VIII-2 defines a steeply east-dipping shear within the older alluvium which is clearly truncated by the overlying basalt. Photograph VIII-3 shows another east-dipping shear which offsets both the alluvium and younger overlying basalt.

At the northeast margin of the GL-5 basin, exploratory Trench GL-5a is located along a northeast-southwest scarp where basalt outcrops are absent. The trench exposures indicate this scarp is underlain by apparent down-to-the-west displacements within alluvium which is similar in character to the alluvium underlying basalt at the road cut to the southwest. Several high angle and apparent dip-slip offsets which displace well stratified sand and gravel and a well developed overlying carbonate horizon are present. The age of the latest offsetting movement (based on the development of carbonate within the trench exposures) is estimated to be latest Pleistocene, or at least 10,000 B.P. (before present) (Dr. R. J. Shlemon). Detrital charcoal sampled from strata cut by one of the high angle shears (see log of Trench GL-5a) has been submitted for Carbon 14 dating, and results from this analysis are expected in June, 1982.

The prominent, southeast-facing scarp underlain by basalt at the west margin of the basin is locally mantled by colluvial deposits which were exposed by exploratory Trench GL-5b. A nearly vertical discontinuity was observed at Station 0+62 (see trench log) which juxtaposes a distinctive carbonate hardpan (Unit 2a) on the east side with a stratigraphically older colluvial gravelly sand (Unit 3) on the west. The apparent east-side-down displacement of Unit 2a coincides with the overall sense of displacement along the west margin of the GL-5 basin. Overlying the discontinuity, a well developed and undisturbed carbonate layer (Unit 2) is present, which is expected to be similar in age to the offset carbonate horizon exposed (Unit 5) in Trench GL-5a to the east (R. J. Shlemon).

Southwest of Trench GL-5b and along the trend of the same scarp (but southwest of the main retarding dam at the Cross Hollow hills drainage), colluvial deposits of unknown depth are exposed by Trench GL-5c below a relatively smooth, consistent slope. The location of this trench is plotted in Figure VIII-10. At this locale, a continuous, well-developed leached carbonate horizon is displaced approximately 1 foot on a near-vertical plane in an apparent east-side-down sense (Photograph VIII-4). This feature may be associated with faulting, or alternatively the result of gravity induced down-slope movement occurring entirely within the colluvium.

All the offsets observed along the east margin of the Cross Hollow Hills are apparently normal (or dip-slip) displacements. The schematic cross section, Figure VIII-5, illustrates the likely geologic configurations in the GL-5 basin area.

C. Gypsum Wash

1. General Geology

Gypsum Wash dam is located on a gently westward-sloping surface west of Warner Ridge. The eroded core of a north-south trending anticline lies between the dam and Warner Ridge. The dam site is on the eroded (or planed-off) west-dipping flank, and Warner Ridge forms the prominent east-dipping flank. These relationships are shown on the schematic cross section presented in Figure VIII-7.

Bedrock underlying the site is mapped as Triassic-age Moenkopi Formation, consisting primarily of thinly bedded gypsiferous shale and siltstone with minor interbeds of sandstone and limestone. These rocks locally display tight, contorted warps and randomly oriented gypsum or calcite-lined shear planes, but exposures in the vicinity indicate that bedding is typically coherent for extended distances.

Between the dam site and Warner Ridge and along the eroded anticline core, the topography is characterized by low, rounded hog-back hills with sharp "badlands" relief, which has resulted from erosion of the weak shale bedrock. Thin, older alluvial fan deposits overlie minor portions of the bedrock terrain. Both the older fans and the bedrock are well dissected by erosion.

In the vicinity of the dam embankment and the diversion berm to the south, exposures of the bedrock and old fan deposits (which are common to the east of the site) are buried beneath younger alluvial fan deposits. These younger fans thicken westward toward the center of the valley.

The mapped trend of the Washington fault strikes approximately north-south through this transition area between exposed and buried bedrock, and locally forms a sharp demarcation between bedrock and alluvial materials at nearby locations.

Exploratory trenches excavated along the trend of the Washington fault encountered both the older fan deposits exposed at the surface to the east, and the younger, overlying fan deposits. The younger deposits are typically well stratified and consist of loose-to-medium dense silt, fine-to-coarse-grained sand, and minor fine gravel. The sand is characterized by medium- to coarse-grained, weakly stratified lenses with a "salt and pepper" contrast. Loose silt and fine gravel zones are common, and form conspicuous, short, discontinuous lenses with sharp contacts. Soil profiles are virtually absent in these sediments.

The older alluvial fans are typified by relatively denser and coarser-grained materials. They consist of well stratified silt, sand, and gravel mixtures of varying percentages with internally chaotic gravelly beds or lenses common locally. The coarser lenses contain abundant angular and flat clasts of siltstone and gypsiferous shale. As with the younger fan deposits, no soil profiles or paleosols were observed in the older fans, since they either have been removed by erosion or were never developed.

2. Faults

The trace of the Washington fault has been documented along the east side of the valley in which Gypsum Wash Dam is located. The fault zone extends northward beyond the town of Washington, and southward into Arizona for a total distance of approximately 42 miles. The main trace of the fault is clearly exposed approximately two miles south of the site. In this area, a prominent scarp with sharp relief separates dissected Triassic-age bedrock on the east from Quaternary-age alluvial fan deposits on the west (see Figure VIII-11). Between the well-defined scarp and the dam site to the north, the fault traverses the drainage which extends westward from Warner Draw. No clear exposure of faulting is present where the mapped location of the Washington fault crosses the primary Warner Draw drainage ravine, but a prominent, high-angle fault cuts the Moenkopi bedrock somewhat east of the mapped trace of the fault. This offset probably represents a major splay of the fault, if not the actual main trace. At this location, the faulted bedrock is capped by unbroken, deeply dissected alluvial fan deposits which may be of similar age to the older fans exposed at the dam site to the north. Photograph VIII-6 illustrates the prominent shear and capping alluvial deposits at this location.

The trace of the Washington fault near the dam site was apparently located by pre-construction exploration, which involved excavation of test pits at the embankment site. These pits exposed ruptured bedrock and fan materials (Test Pits 118A, 118B, 120B, SCS data) which resulted in re-location of the dam further east to the present position. Subsequent studies during this investigation indicate that a wider zone of sheared earth materials than the pre-construction excavations revealed is present, and that the zone extends further eastward beneath portions of the dam.

Exploratory trenches excavated during the current study were located along lineaments or anomalous topographic features observed on air photos and during field reconnaissance mapping. Figure VIII-6 shows geologic conditions at the dam site along with the locations of the trenches. Trench G-1 was positioned across a north-northwest trending photolineament which coincides with the abrupt western end of the low, dissected hills located immediately south of the south end (or bend) of the dam embankment. Pre-construction test pit excavations to the north exposed discontinuities with trends approximately parallel to this lineament. Exposures in Trench G-1 reveal dense, approximately horizontally stratified fan deposits which are cut by numerous high angle shears (see log). The shears trend north-northwest with displacements commonly ranging from a few inches to several feet. Both down-to-the-west and down-to-the-east relative displacement are present, resulting in a Horst and Graben structure. However, most offsets are down-to-the-west and coincide with the normal displacement associated with the Washington fault. At the west end of trench G-1, a thickening wedge of less consolidated, younger alluvial fan deposits (Units 1 and 9) overlie the older material. These younger deposits do not appear to be involved in the shearing which disrupts the underlying older fan deposits.

Trench G-4, located at the toe of the dam between the pre-construction test pits and Trench G-1, revealed offsets in older fan materials similar to those exposed in G-1. At the G-4 location, well stratified younger fan deposits are thicker and more clearly exposed. The uppermost deposits identified as Unit 8 on the trench log are clearly unbroken. Unit 1, underlying Unit 8 and overlying the older fan deposits, consists of a generally massive, loose zone of sandy silt. This zone is apparently involved in the offsetting shears. It conforms to the irregular surface (which is disrupted by offsets) of the older underlying fan, and is present as in-filling material in fissures and pull-apart structures along certain shear planes (Stations 0+26, 0+30, 0+39). The character of the Unit 1 material more closely resembles the younger of the fan deposits. The age of Unit 1 is estimated to be in the 5,000 to 10,000 year old range (Dr. R. J. Shlemon, written communication).

South of Trench G-1, Trenches G-2 and G-3 were sited at the western end of an exposure of gypsiferous shale which forms small, hog-back type ridges. These trenches exposed a sharp, nearly vertical shear plane which juxtaposes gypsiferous shale bedrock on the east with dense, older alluvial fan on the west. The shear plane trends N-S through both the G-2 and G-3 trench exposures, and extends upward to within 2 feet of the ground surface (see logs of Trenches G-2 and and G-3, and Photograph VIII-5). Young alluvial fan materials overlie and are in sharp contact with the older fan deposits, and are clearly offset by 2 inches on the shear plane in a down-to-the-west sense (the amount of bedrock and older fan offset is at least 4 feet). These offsets are located at Sta. 0+25 in trench G-2 and at Sta. 0+15 in Trench G-3 (see logs). The displacement of the young fan material most likely results from either direct tectonic fault displacement along the shear plane (indicating recurrent movements), or differential settlement across the shear plane by dissolution of gypsiferous material, or differential compaction across the shear plane (conceivably as a result of strong seismic shaking). Information on the depths and nature of alluvial deposits underlying the trench west of the shear plane could lend weight to one of the above possibilities. In any case, it is assumed the bedrock offsets exposed in G-2 and G-3 define a major trace of the Washington fault at this site.

Between Trenches G-3 and G-1, Trench G-X was excavated and inspected during a field meeting at the site on January 26, 1982. This trench was not logged, since it was excavated in an attempt to resolve to those present, the nature of the offset relationships between the younger and older alluvial units as defined in Trenches G-2 and G-3. Trench G-X revealed a single zone of rupturing within older alluvial deposits. An overlying sequence of loose, young alluvium a few inches in thickness was found to be unbroken.

The relationship of the Gypsum Wash dam embankment and the main trace of the Washington fault or fault zone is shown on Figure VIII-6. At the southeast end of the dam, the fault location is based on the northward projection of the fault as exposed in Trenches G-2 and G-3, the observed location of the bedrock/alluvium contact just south of the dam embankment, and bedrock exposures within the basin just to the north. Bedrock is at least 10 feet below the surface just to the west, where Trenches G-1 and G-4 expose the sheared alluvial deposits. Within the trenches, these shears increase in frequency eastward (see trench logs), supporting the concept that fault activity has been concentrated along the projection of the locally exposed bedrock/alluvium contact, as illustrated on Figure VIII-6.

Near the central and northern portion of the dam embankment, areas where the low, rounded hills are present generally coincide with areas underlain by bedrock. Here the available evidence indicates the Washington fault is located along the western edge or toe of the hills as shown in Figure VIII-6, separating bedrock from the essentially flat-lying alluvial fan deposits to the west.

The exact location where the trend of the Washington fault trace or zone intersects the dam alignment between its location at the southeast end of the dam and the generally well-defined hillfront scarp just northwest of the dam is speculative because of the lack of bedrock exposures and locally altered topography near the dam. An available SCS construction drawing ("Cracks Exposed in Bedrock Foundation and Cutoff Excavation, Gypsum Site", 5/74) indicates a series of northwest-southeast trending cracks exposed on the surface and within (?) the embankment cutoff trench between Stations 28+30 and 30+25, which may represent the fault location. The geologic logs of the foundation excavation and cutoff excavation ("Geologic Profile - Cutoff Trench and Foundation Excavation, Gypsum Site", 4/74; SCS data) only illustrate lithologic zones and do not indicate the presence of cracks or shears at these or other locations along the dam alignment.

Figure VIII-7 is a schematic sketch of a simplified south-facing cross section of geologic conditions at the Gypsum Wash site. The shear relationships exposed in the trenches during the field investigation are summarized by the fault offsets illustrated at the circled letter "A", "B", and "C". "A" represents the northward projection of the shear located in Trenches G-2 and G-3 through the low hills just south of the southernmost corner of the dam. It is assumed the contact of bedrock and old alluvium existing at this location is a fault contact, although no excavations were made here because no potentially datable soils are present.

"B" represents the conditions exposed in Trenches G-2 and G-3 where the prominent shear plane offsets bedrock, older and younger alluvial deposits as described above. The estimated age of the young fan deposits in these trenches is no older than 1,000 to 1,500 years (Dr. R. J. Shlemon, written communication).

"C" illustrates the relationships in Trench G-4, where alluvial Unit 1 with an estimated age of 5,000 to 10,000 years is involved in shear offsets. The youngest, uppermost sediments at this site (Unit 8) are estimated to be of late Holocene age, and are unbroken. The older alluvial fan deposits exposed in all of the Gypsum Wash trenches are estimated to be late Pleistocene, or between 10,000 and 25,000 years old (Shlemon). Although no materials were found in the trenches which could be positively dated, conditions exposed indicate that fault-related displacements of the alluvial materials underlying the dam are likely to have occurred during Holocene time.

D. Warner Draw

1. General Geology

In the dam site locality, Warner Ridge strikes approximately north-south and forms the western margin of Warner Valley. The ridge is underlain by the east flank of an anticline, the axial zone and western flank of which are now eroded away. Runoff from Warner Valley has eroded a low gap in the ridge forming Warner Draw, a narrow westward-draining channel where Warner Draw Dam is sited. Most of the foundation and right abutment of the dam is underlain by well-bedded Triassic-age rocks of the Moenkopi and Chinle Formations, which also underlie Warner Ridge and dip eastward approximately 20 degrees from horizontal. These rocks consist mainly of weak shale with prominent interbeds of harder siltstone and fine-grained sandstone, and individual beds can commonly be traced for many hundreds of feet where exposed. The character of these rocks is described further in materials contained in the SCS files.

The left abutment and a portion of the southerly foundation area is underlain by old alluvial sand deposits, which are at least partially eolian. The alluvial deposits range from well sorted (poorly graded) silty sand to sandy silt, and are typically massive with a few minor stratified pockets of coarse sand and gravel. Leached carbonate commonly cements the alluvial sediments, forming dense, stable deposits which have been locally incised by erosion. According to previous records produced during dam construction, the alluvium extends to considerable depths, filling an old stream channel meander located just south of the present drainage channels (SCS data).

2. Faults

The prominent gap at Warner Draw suggests the presence of a weakness or discontinuity in the Warner Ridge bedrock at this location. Nearby, prominent shears cut the conspicuous promintory located about 3,000 feet southwest of the site, where the point of the ridge has been displaced downward to the west (see Figure VIII-12). The possibility that a weak zone at Warner Draw resulting from another similar fault splay was considered, since the Washington fault is located only ½ mile to the west.

Several air photo lineaments which extend close to or in the direction of the Warner Draw gap were identified during this investigation. Their orientation was anomalous to the general north-south trend of the Washington fault, however, and field examination of bedrock outcrops and ravine channels cut in alluvium where the air photo lineaments were plotted revealed no evidence that the lineaments were fault related. Reconnaissance of the Warner Draw drainage indicates that the bedrock is essentially coherent near the dam, with a progressive increase in fracturing and distortion westward to the Washington fault zone. (The major shear displayed in Photograph VIII-5 and described in Section VIII-C.2 is located at the eastern margin of the fault zone.) However, a small bedrock fault exists near the Warner Draw channel bottom which intersects the downstream toe of the dam (Figure VIII-8, fault (A)). The fault has an apparent thrust offset of three feet and is oriented N20E, dipping 30 southeast. Photographs VIII-7 and 8 illustrate this feature which is a continuous, consistent tight plane traceable throughout the bedrock exposure. An offset of similar orientation is locally exposed in bedrock higher in the stratigraphic section, approximately 1,000 feet to the south. During dam construction, another bedrock fault (Figure VIII-8, fault (B)) was mapped at Station 15+70 of the embankment alignment in the foundation cut-off trench (SCS data). Information as to the strike and amount of displacement is not available, but it is conceivable this shear parallels the above described offsets.

Inspection of the adjacent alluvial deposits along the projection of the dam site faults revealed no signs of disturbance. Exploratory trenches WD-1 and WD-2 were excavated across the projected strike of the fault shown in Photographs VIII-7 and 8, and across the speculated trend of the fault mapped in the foundation cut-off trench. The trench exposures revealed dense-to-very-dense, fine-grained silty sand deposits which display no evidence of faulting or other disturbances. The faults present in the adjacent bedrock are considered to be ancient features which most likely resulted from compressional stresses associated with folding of the Warner Ridge anticline.

E. Stucki

1. General Geology

Stucki dam extends for 1,400 feet across a broad, north-draining Valley which parallels the Washington fault and Warner Ridge. These features are located approximately 2,000 feet and 3,000 feet to the east, respectively (see Figure VIII-11).

Alluvial fan deposits extend westward from the ridge front and obscurely merge with valley fill and stream channel alluvium along the lower east side of the basin (see Figure VIII-9). The fan and alluvial deposits underlie all but the extreme western end of the dam embankment. The west (left) abutment of Stucki dam and the southward-extending basin margin is formed by a continuous, east-facing slope which is eroded into older, very dense sandy alluvium. The flat upper surface of the old alluvium west of the left abutment slope is underlain by a well developed calcrete or hardpan layer, which results in a prominent ledge at the top of the east-facing slope. At the toe of this erosional escarpment, the alluvium within the drainage basin is in disconformable contact with the older, dense alluvium. A description of the lithology of the earth materials present at the site is presented by Deming and Bridges 1971 construction report in the SCS files.

2. Faults

The Washington fault is prominently exposed east of the site, where alluvial fan deposits on the west are juxtaposed with Triassic rocks on the east. The current investigation disclosed no traceable surficial evidence of westward-branching splays extending toward the embankment, but the prominent left abutment and basin margin (which forms a continuous, north-northwest south-southeast escarpment) was regarded as a suspicious feature in view of the similar configuration of the nearby Washington fault.

Field reconnaissance along the escarpment just south of the embankment established the continuity of horizontal beds at and just below the calcrete. These beds can be traced several tens of feet westward within a prominent erosional gully present here. The central and lower portions of the escarpment were further investigated by exploratory trenches SD-1 and SD-2. These trenches exposed very dense sand and silt in thick, poorly defined flat-lying beds, overlain locally by colluvial deposits (see log of Trench SD-1). At the toe of the slope, Trench SD-1 exposed the dense old alluvium at an abrupt, near-vertical contact with loose, younger alluvium. Rubbly material derived from the older alluvium extends eastward from the contact for a few feet below the overlying younger deposits as illustrated on the trench log. Shear planes, dragged structures or other features indicative of faulting were not exposed. Trench SD-2, excavated 100 feet to the north at the toe of the slope and along the trend of the vertical contact, exposed an eastward-thickening wedge of younger, looser, valley alluvium, forming a smooth, shallowly-east-dipping contact with the underlying dense old alluvium. The above conditions indicate the vertical contact configuration of the alluvial units in Trench SD-1 represent an old wash or ravine bank which was subsequently in-filled by the younger alluvial deposits. On the basis of the exposures afforded by the erosional gully below the calcrete and the exploratory trenches, the left abutment escarpment is considered to be a natural erosional feature and not the result of faulting.

Additional geologic investigation concerning the remainder of the dam site was performed by the SCS during construction operations when a cut-off trench was excavated into the alluvial deposits prior to placement of the embankment. Faults or shear planes were not reported during construction, and none are illustrated on the log of the cut-off trench (SCS data). Considering the extent of the site exploration, it is reasonable to assume the foundation and abutments of Stucki dam are free of active fault traces.

F. Frog Hollow

1. General Geology

Frog Hollow dam site is located approximately 2 miles east of the conspicuous north-south trending Hurricane fault scarp. Quaternary-age basalt flows (which are common in the vicinity of the fault) extend eastward from vents near the scarp and underlie the dam site. North and east of the site, alluvium of varying thickness overlies basalt flows which have been mapped as Stage 3, or oldest of the flows in the vicinity (SCS construction reports). South and west of the dam, a younger basalt flow (Stage 4) forms an obvious contact at the western margin of the alluvium that underlies the drainage basin upstream from the dam (see Figure VIII-12).

Geologic conditions exposed in Workman Wash (the Frog Hollow dam site channel) before and during placement of embankment materials were investigated by the SCS and are described in pre-construction geologic reports available in SCS files. These studies indicate relatively pervious zones at the upper and lower margins of the basalt flows, and a southerly-dipping alluvium/basalt contact underlying the present embankment. Basalt exposures currently observed near the dam indicate only hard, fresh materials, particularly in the channel bottom where abrasion from stream flow has scoured the rock. Earlier reports indicated "extremely weathered" basalt apparently in or along the channel, but only fresh rock was observed at the available downstream exposures during the current study.

Basalt exposed in the channel downstream from the dam is fractured along two major joint set orientations, both of which are nearly vertical. One set strikes north-south to N15W, with joint spacing ranging from 2 or 3 feet to 10 feet, but typically about 5 to 6 feet (Photograph VIII-9). The second joint set cuts the basalt at approximately right angles to the first mentioned set, striking N40 to 60E with spacing from about 3 to 10 feet, averaging 6 feet or greater (Photograph VIII-10). Near the rock surface, many of these joints are open several inches or more as a result of erosion and scouring, but appear to be generally tight at depth. Surface exposures in the channel indicate these joint sets are poorly developed, generally extending for a few tens of feet where they die out or are truncated by other fractures. Near-horizontal flow structures, including fractures and cooling vesicules, are exposed throughout the channel, and result in more prominent and continuous zones of discontinuity than the joint sets.

Alluvium overlies bedrock upstream from the site. At least 8 feet of alluvial cover is currently exposed where deep gullying exists at the margin of present storage basin. Preconstruction excavations and borings in the upstream area indicate the alluvium has a maximum thickness of several tens of feet in the areas explored.

2. Faults

Both the review of previous geologic mapping and reports together with the current air photo analysis and field reconnaissance, indicates the Frog Hollow site is free from active faulting. The Triassic sedimentary rocks which underlie the basalt in this area may be faulted, but no evidence of such faults, if they exist, are found in the younger, overlying Quaternary basalt or alluvium.

G. Ivins Diversion No. 5

1. General Geology

The Ivins Diversion No. 5 embankment is sited on an alluvial fan deposit which extends south-southeastward from the prominent erosional scarp at the south end of the Red Mountains. The steep escarpment is cut in nearly horizontal beds of gypsiferous shale, siltstone and sandstone of the Triassic-age Kayenta Formation, above which Navajo formation sandstone forms vertical, prominent cliffs. At the west end of the diversion dams and just north of the town of Ivins, an old block slide is present which rests on the lower portion of the escarpment (see Figure VIII-13). Large, integral masses of both the Navajo and Kayenta formations are exposed in this slide deposit. The degree of erosional dissection and amount of colluvial debris which masks portions of the block slide suggest this feature is most likely pre-Holocene in age.

2. Faults

Several prominent lineaments are present in the Navajo sandstone which caps the southern end of the Red Mountains (see Figure VIII-13). Field reconnaissance revealed no evidence to indicate these lineaments extend below the Navajo sandstone into the underlying weaker shales. Prominent, vertical fractures cut the Navajo sandstone at the cliff-top exposure and presumably account for the lineaments observed.

Additional reconnaissance of an air photo lineament in Quaternary deposits east of the site failed to disclose any evidence of disturbed materials. Based on the conditions observed, the Ivins dam site is considered to be free of faulting.

Major faults which are present in the region include the Grand Wash fault located approximately 5 miles west of the site, and the Washington and Hurricane faults, located 10 miles and 21 miles east, respectively. Each of these faults has experienced normal, down-to-the-west displacements.

Photo VIII-1 View of south wall and floor of Trench GL-2a, Station 0+98. Coarse, rubble zone with locally loose gravel to left of sharp discontinuity; lighter-toned carbonate cemented gravels and underlying silt lens (on floor) to right. Most observers agreed this feature represents an old erosional channel margin. Overlying sediments at red flagged nail are continuous.

Photo VIII-2 View approximately north of road cut at south end of the Cross Hollow Hills. Basalt mapped as Quaternary in age disconformably overlies older, stratified alluvial deposits which have been offset. Sharp, continuous basalt/alluvium contact indicates rupturing occurred prior to basalt flow.

Photo VIII-3 View of the same road cut just east of Photo VII-2. At this location, both the alluvium and younger overlying basalt are displaced by shearing, indicating a post-basalt flow rupture. Assuming the basalts of Photos VII-2 and VII-3 are the same age, recurring displacements are indicated.

Photo VIII-4 View of south wall of Trench GL-5c. Colluvium derived from Cross Hollow Hills basalt to right mantles slope. Prominent carbonate (hard pan) horizon 1 or 2 feet below surface is disrupted locally along near-vertical planes. Trench GL-5c is located along southern projection of prominent scarp and an offset exposed in Trench GL-5b.

Photo VIII-5 View of south wall of Trench G-2. Shear plane extends from bottom of wall just left of shore upwards to 1 inch from top of photo. Gypsiferous shale bedrock at lower left, bedrock debris and older alluvial fan at lower right across shear. Young alluvial fan overlying is pale gray and is offset 2 inches at base.

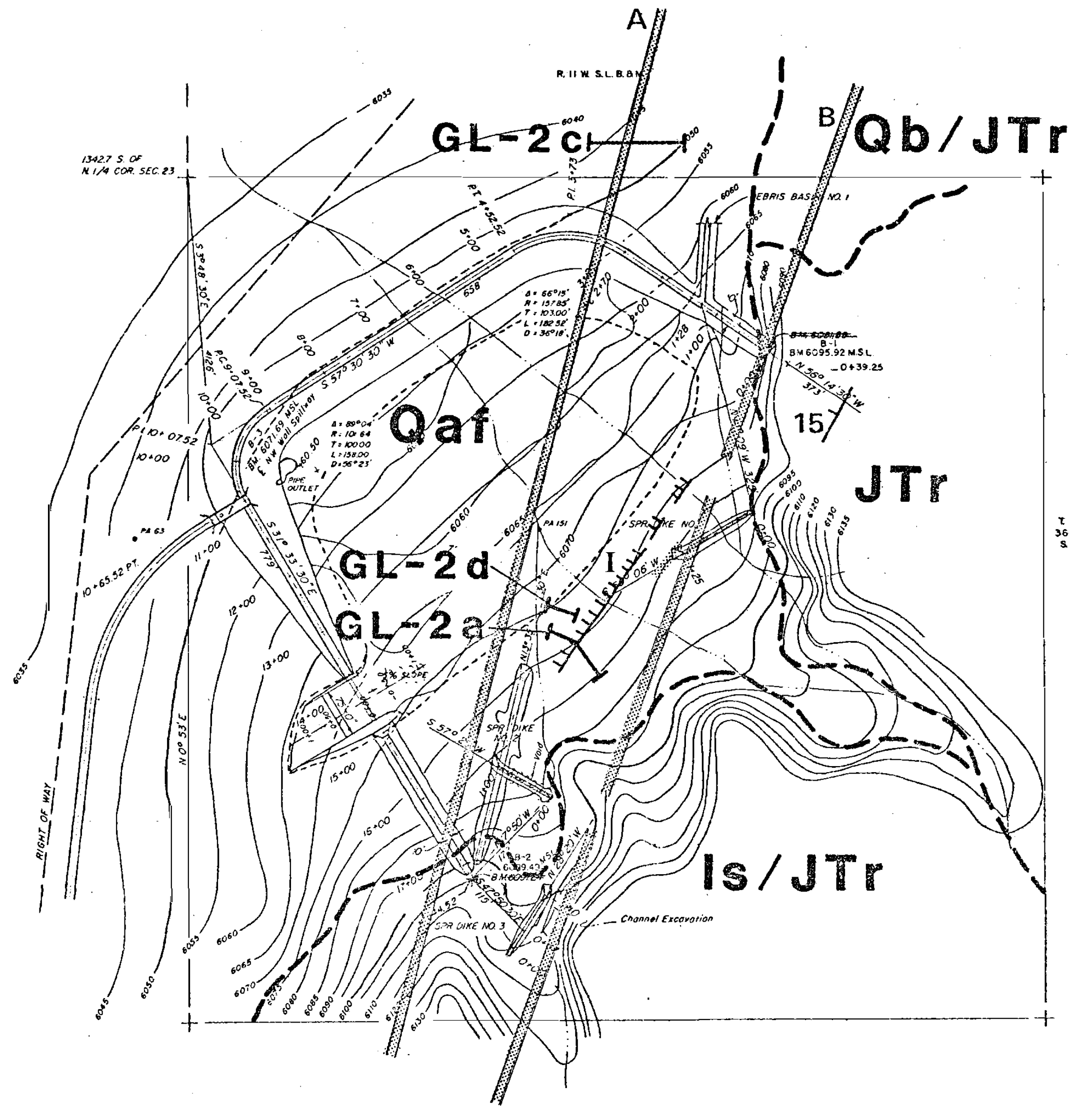
Photo VIII-6 View of north wall of ravine which extends westward from Warner Draw. Deeply eroded vertical channel in disrupted shale and siltstone of Moenkopi Formation is prominent shear zone associated with Washington Fault. Undisturbed alluvial fan deposits unconformably overlie Moenkopi Formation at contact approximately 1.75 inches below top of photo. Pine Valley Mountains north of St. George in background.

Photo VIII-7 View northeast of Chinle Formation outcrop on southeast side of ravine approximately 100 feet downstream from toe of Warner Draw dam. Rock hammer inserted in bedrock fault plane with apparent 3 feet of thrust displacement. Shear plane is a tight, continuous plane oriented N20E dipping 30% SE. No evidence of disturbance was found within younger materials explored along the projection of this fault.

Photo VIII-8 View southeast of same fault plane as in Photo VIII-7 where it intersects outlet pipe at toe of Warner Draw dam. Plane is located just above head of rock hammer and appears to coincide with bedding planes at this configuration.

Photo VIII-9 View north of basalt (mapped as Stage 3 in SCS data) approximately 500 feet downstream from toe of Frog Hollow dam. Prominent joints oriented N5W are well defined at the surface but appear to tighten with depth. Abrasion-polishing of basalt in lower portion of channel obvious.

Photo VIII-10 View east of basalt downstream from Photo VIII-9. A second well defined joint set oriented N55E is exposed here. Rock hammer located where erosion has cut laterally into the channel wall along joint plane. Approximately horizontal flow banding and associated fractures are apparent here and form the most continuous structures within the basalt.



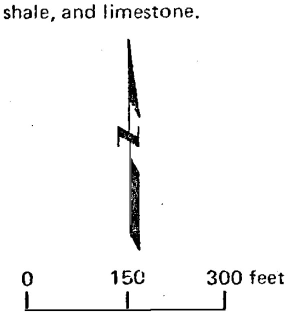
EXPLANATION

GEOLOGIC UNITS

Quaternary	Qaf	Alluvial fan deposits: silt, sand, and gravel; locally rubbly.
Quaternary	Qb	Basalt: poorly defined zones of limited areal extent.
Quaternary	Is	Landslide deposits: poorly defined accumulations of Qb and JTr.
Jurassic-Triassic	JTr	Jurassic and Triassic rocks, undifferentiated: includes sandstone, siltstone, gypsiferous shale, and limestone.

SYMBOLS

— — — —	Geologic contact; approximately located.
I	Topographic scarp located during ESA field reconnaissance; hachures on down-dip side.
A	Suspected fault traces located from SCS data; refer to Section VI. A-2 for discussion.
15	Strike and dip of bedding.
GL-2a	Exploratory trench location.



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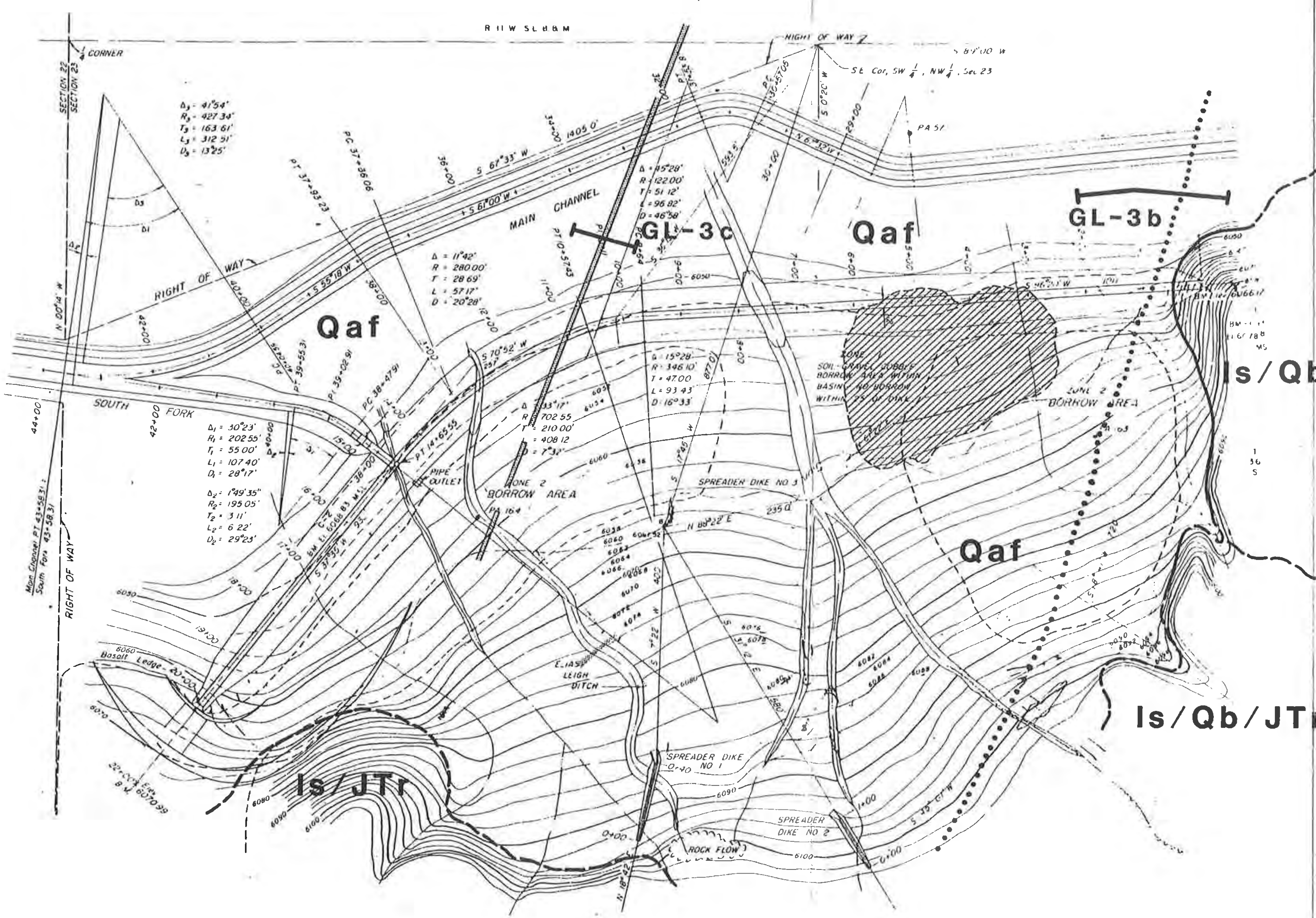
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
GREEN'S LAKE DAM NO. 2

Checked by T D Hunt Date 5-27-82	Project No.	Figure No.
Approved by E A Nelson Date 27 May 82	D118	VIII-1



EXPLANATION

GEOLOGIC UNITS

Quaternary

- **Qaf** — Alluvial fan deposits: stratified, silt, sand, gravel.
- **Qb** — Basalt: poorly defined zones of limited areal extent.
- **ls** — Landslide deposits: poorly defined accumulations of **Qb** and **JTr**.

Jurassic-Triassic

- **JTr** — Jurassic and Triassic rocks, undifferentiated: includes sandstone, siltstone, gypsiferous shale, and limestone.

SYMBOLS

- Geologic contact; dashed where approximately located.
- Projected major trace of Hurricane fault below unbroken **Qaf**.
- Suspected fault trace of D. H. Griswold (SCS data).
- GL-3c — Exploratory trench location.
- Approximate area of subsidence that resulted from standing water in 1967.

0 100 200 feet

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
GREEN'S LAKE DAM NO. 3

Checked by T.D. Hurst	Date 5-27-82	Project No. D118	Figure No. VIII-2
Approved by E.A. Nelson	Date 27 MAY 82		

EXPLANATION

A — Suspected fault as mapped by R. L. Bridges and/or D. H. Griswold during previous studies for SCS; locations determined from available SCS data.
- A - Bridges(?) 'Hicks Creek fault'
- B - Griswold
- C - Bridges
- D - Griswold
- E - Bridges

Prominent air photo lineament and probable major fault trace within Hurricane fault system.

Topographic scarp identified during 1981 ESA field investigation; hachures on down-dip side

GL-2c — Exploratory trench location

N

Scale 1:12,000

0 1,000 2,000 feet

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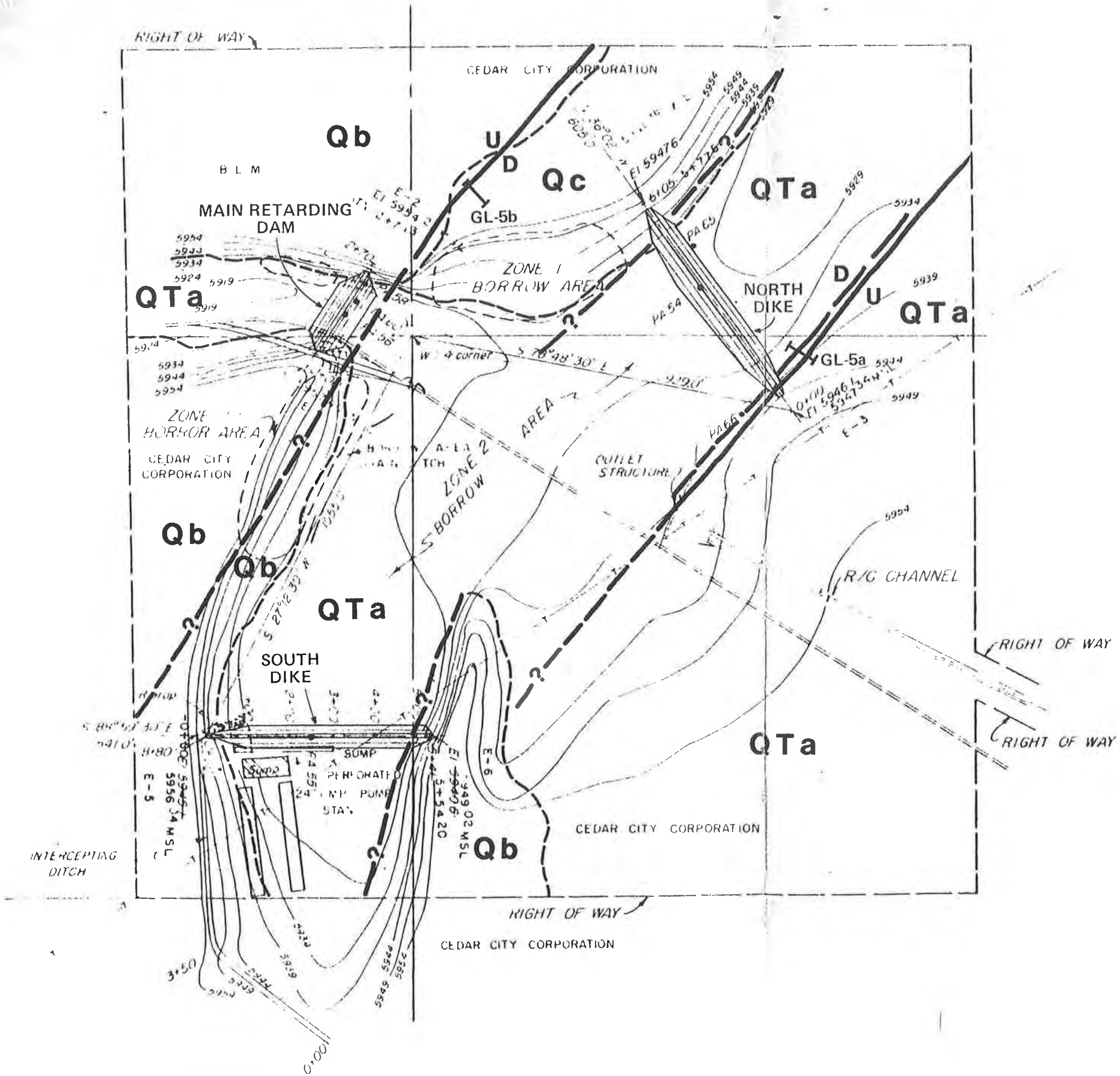
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SUSPECTED FAULTS AND EXPLORATION MAP
GREEN'S LAKE DAMS NOS. 1, 2, and 3

Checked by	Date 5-27-82	Project No.	Figure No.
Approved by	Date 27 MAY 82	D118	VIII-3



EXPLANATION

GEOLOGIC UNITS

Tertiary | Quaternary

- **Qc** Colluvium: loose to medium dense calcareous silt, sand; locally rubbly.
- **Qb** Basalt: hard, fresh.
- **QTa** Alluvium: dense, well stratified silt, sand gravel.

SYMBOLS

- Geologic contact; approximately located.
- D/U — ? Fault; dashed where approximately located; queried where uncertain; relative displacment indicated by D - down, U - up.
- GL-5a Exploratory trench location.

NOTE

See Figure VIII-10 for location of Trench GL-5c.

0 200 400 feet

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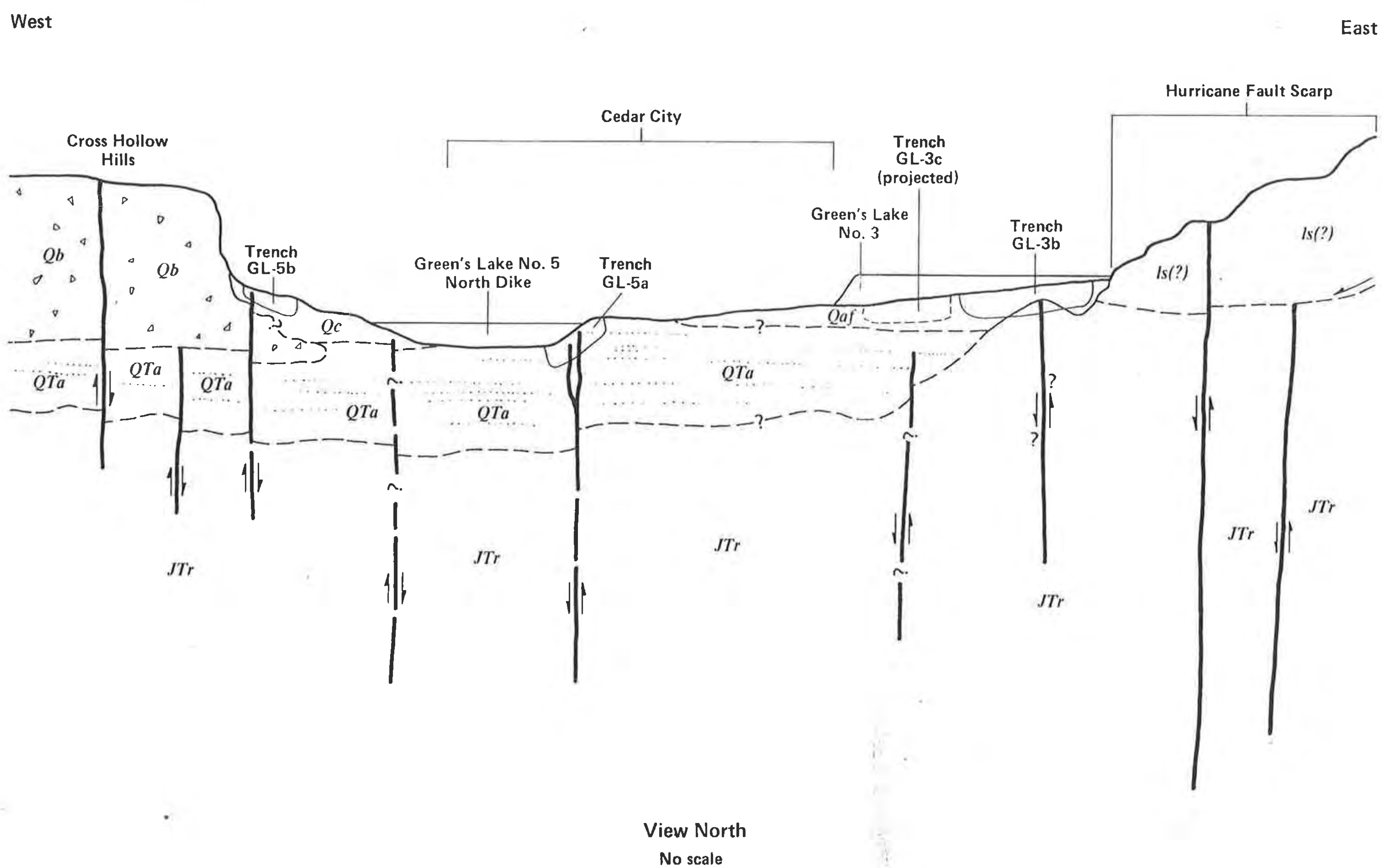
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
GREEN'S LAKE DAM NO. 5

Checked by D Hunt	Date 5-27-82	Project No.	Figure No.
Approved by E A Nelson	Date 27 May 82	D118	VIII-4



GEOLOGIC UNITS

Qaf	Alluvial fan.
Qb	Flow basalt.
QTa	Alluvium.
ls	Landslide deposits.
JTr	Jurassic and Triassic rocks (includes local intrusions of basalt).

SYMBOLS

– – – – Geologic contact: approximately located; queried where uncertain.

Normal fault within Hurricane fault zone: arrows indicate relative displacement; queried where displacement or existance speculative.

NOTES

Section is a diagrammatic sketch summarizing the geologic conditions determined during the current investigation; locations of faults and geologic contacts will vary from actual field conditions.

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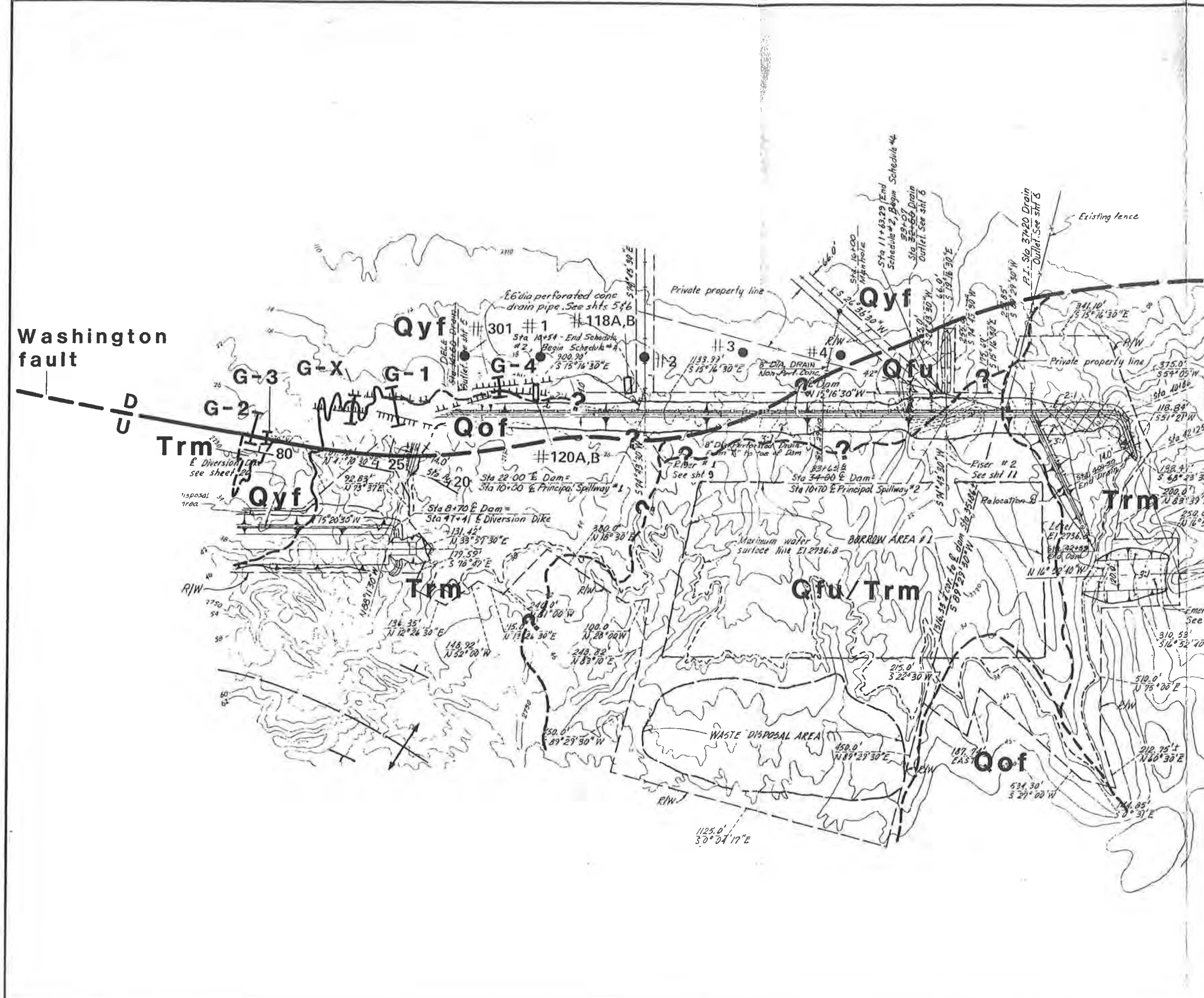
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SCHEMATIC GEOLOGIC SECTION
CEDAR CITY VICINITY

Checked by TD Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY '82	D118	VIII-5



EXPLANATION

GEOLOGIC UNITS

Quaternary

- **Qyf** — Alluvial fan deposits, Holocene: loose silt, sand, minor gravel; mapped where estimated thickness greater than approximately 4 feet.
- **Qof** — Alluvial fan deposits, late Pliestocene estimated age: dense silt, sand, and gravel.
- **Qfu** — Alluvial fan deposits: undifferentiated.

Triassic

- **Trm** — Moenkopi Formation rocks, undifferentiated: predominately gypsiferous shale, siltstone; with lesser limestone, sandstone.

SYMBOLS

- ? — Geologic contact: approximately located; queried where uncertain.
- D U ? — Washington fault: dashed where approximately located; queried where uncertain; relative displacement indicated by D - down, U - up.
- Shear planes exposed in exploratory trenches; hachures on apparent downthrown side
- Anticline axial plane trace.
- 20 — Strike and dip of bedding
- G-2 — Exploratory trench location.
- #118A,B — SCS exploratory trench, pre-construction.
- #1 — SCS exploratory boring, pre-construction.

0 200 400 feet

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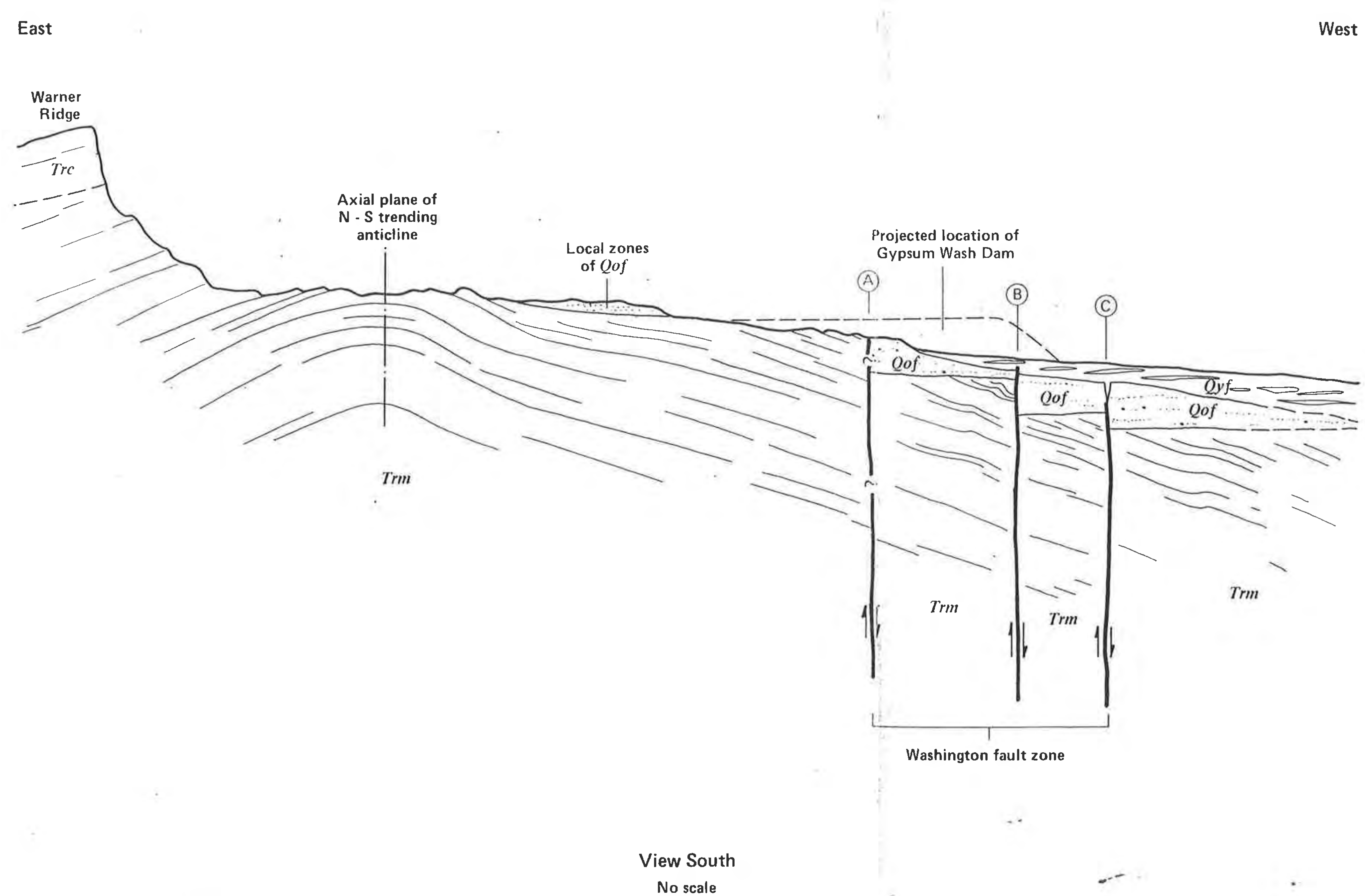
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
GYPSUM WASH DAM

Checked by J D Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	VIII-6



GEOLOGIC UNITS

Quaternary
- **Qyf** Young alluvial fan.
- **Qof** Old alluvial fan.

Triassic
- **Trm** Moenkopi Formation.
- **Trc** Chinle Formation.

NOTES

(A) Structural relationship apparent in low hills located at south end of embankment and north of trenches G-2 and G-3; major fault trace juxtaposes gypsiferous shale on east with old alluvial fan on west; no surficial scarp or younger overlying sediments to aid in dating of last displacement.

(B) Structural relationship exposed in trenches G-2 and G-3, bedrock offset down to west with older alluvial fan juxtaposed on west side; overlying young alluvial fan broken by shear at contact with older fan; shear dies out upward in young fan.

(C) Structural relationship exposed in trench G-4; shears present in older alluvial fan deposits. Younger fan deposits overlie older fan, and are involved in shears as in-filling material in pull-away structures; no through-going shears into youngest alluvial lenses near surface.

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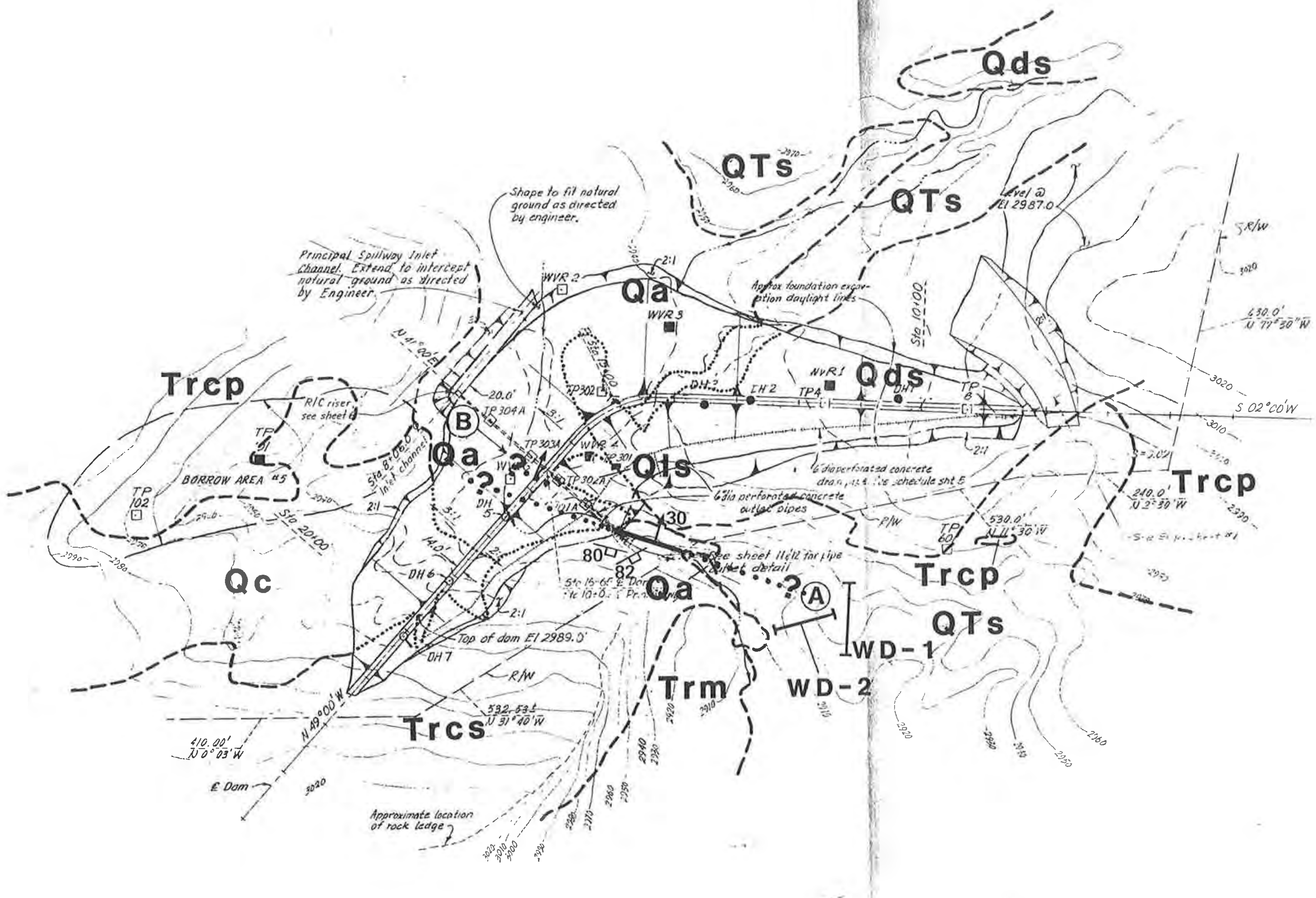
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SCHEMATIC GEOLOGIC SECTION
GYPSUM WASH DAM SITE VICINITY

		Project No.	Figure No.
Checked by T.D. Hunt	Date 5-27-82	D118	VIII-7
Approved by EA Nelson	Date 27 MAY 82		



EXPLANATION

GEOLOGIC UNITS

Quaternary

Qds	Dune sand: fine- to medium-grained eolian quartz sand; loose.
Qa	Alluvium: fine-grained silty sand with local sand and gravel; gypsiferous.
Qc	Colluvium: clay, sand, and gravel mix; dry, dense.

Tertiary

QTs	Sand deposits: predominantly fine-grained poorly graded quartz sand; locally silty or clayey; dense; abundant carbonate, locally cemented; typically massive.

Triassic

Trcp	Chinle Formation - Petrified Forest member: clayey shales with lenses of sandstone and conglomerate.
Trcs	Chinle Formation - Shinarump member: fine- to coarse-grained sandstone and rounded pebble conglomerate; siltstone and shale interbeds.
Trm	Moenkopi Formation - Upper Red member: interbedded siltstone and shale; local fine-grained sandstone.

SYMBOLS

Geologic contact: approximately located; dotted where concealed

Bedrock fault: dotted where concealed; queried where existance uncertain; arrow indicates dip of plane; letters A and B refer to text, chapter VIII.D-2.

82 Strike and dip of joint set in bedrock.

WD-2 Exploratory trench location

NOTE

Geology derived from SCS map dated 6-30-71 and from ESA field reconnaissance, 1982.

0 100 200 feet

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
WARNER DRAW DAM

Checked by TD Hunt	Date 5-27-82	Project No. D118	Figure No. VIII-8
Approved by EA Nelson	Date 27 May 82		

EXPLANATION

GEOLOGIC UNITS

Quaternary

Qal	Alluvium: loose to dense silt, sand, minor gravel
Qaf	Alluvial fan deposits: typically dense silt, sand and gravel
Qoal	Older alluvium: dense to very dense horizontally bedded silt and sand, locally cemented with carbonate

SYMBOLS

Geologic contact, approximately located

SD-1 Exploratory trench location

NOTE

Topography inaccurate in vicinity of exploratory trenches

0 200 400 feet

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SITE GEOLOGY
STUCKI DAM

TDHunt	5-27-82	Project No. D118	Figure No. VIII-9
EA	27 MAY 82		

EXPLANATION

GEOLOGIC UNITS

Quaternary
- *Qf* Fill.
- *Qc* Colluvium.
- *Qr* Talus deposits.
- *Qa* Alluvium.
- *Qfc* Alluvial fan and colluvium, undifferentiated.
- *Qaf* Alluvial fan deposits.
- *Qof?* Questionable older alluvial fan deposits.
- *Qb* Flow basalt, queried where uncertain.

Jurassic - Triassic
- *JTr* Jurassic and Triasssic rocks, undifferentiated, queried where uncertain.

- ? Questionable bedrock.

SYMBOLS

- Geologic contact; dashed where approximately located, queried where uncertain.
- Trace of apparent bedding in Jurassic - Triassic (JTr) rocks.
- Strike and dip of bedding:
  - 35 Inclined; showing dip
  - 70 Inclined; questionable; showing dip
  - Vertical; questionable.
- Trace of Hurricane fault: identified in exploratory trenches; hachures on downthown side.
- Probable trace of Hurricane fault zone: hachures on apparent downthown side; dashed where approximately located; dotted where concealed.
- Possible bedrock fault or major joint set: ball on apparent downthrown side.
- GL-5a Exploratory trench location.
- Landslide; showing headscarp area and internal scarp: arrow shows direction of downslope movement; queried where uncertain; may include unrecognized Quaternary basalt (Qb) flow structures.

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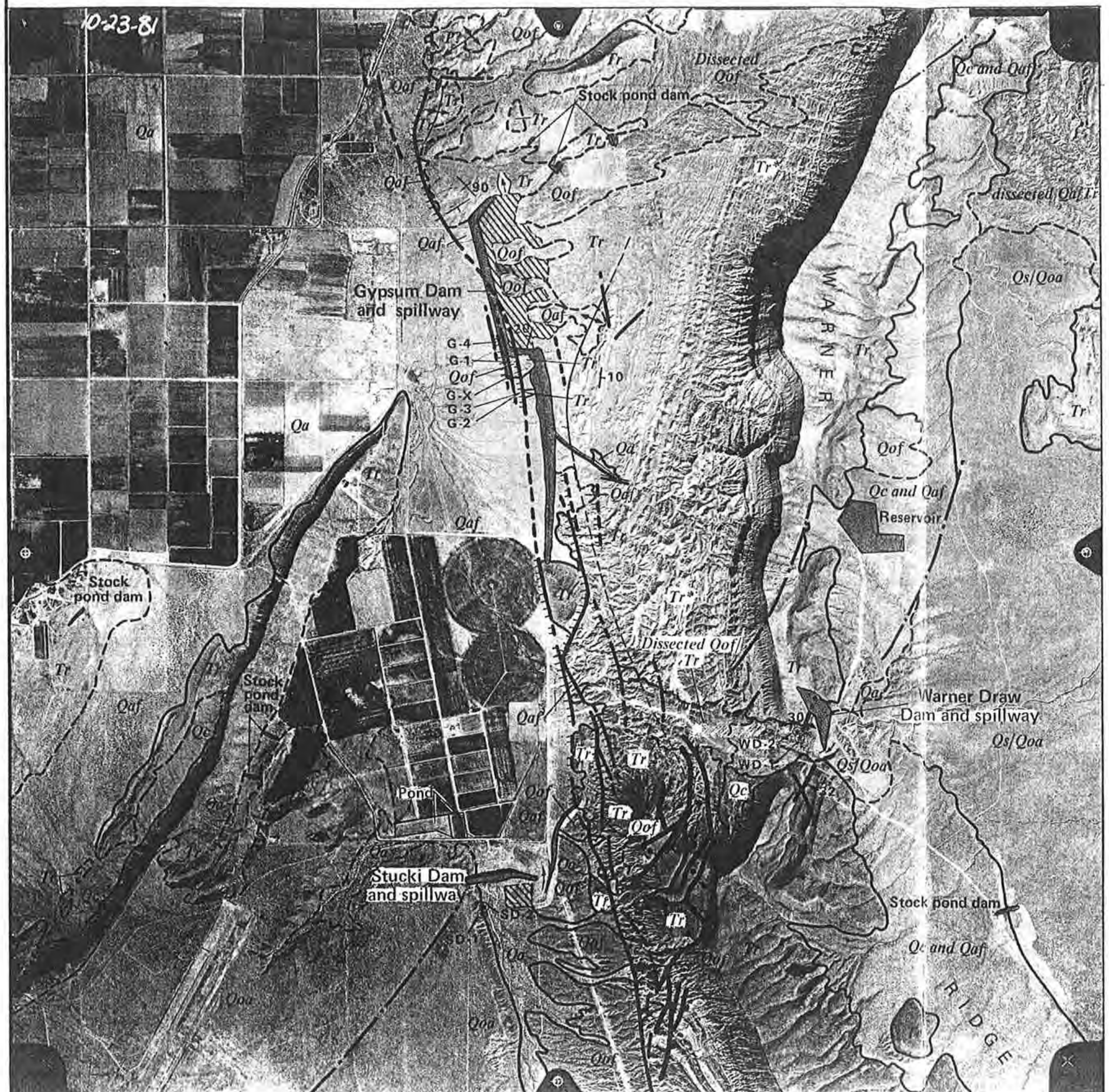
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REGIONAL GEOLOGY
CEDAR CITY AREA

Checked by [signature]	Date 27/may/82	Project No.	Figure No.
Approved by [signature]	Date 27 May '82	D118	VIII-10



EXPLANATION

GEOLOGIC UNITS

Quaternary	*Qc*	Colluvium.
	Qa	Alluvium.
	Qs	Wind blown sand deposits.
	Qaf	Alluvial fan deposits.
	Qoa	Older alluvial deposits.
	Qof	Older alluvial fan deposits.
Triassic	*Tr*	Triassic rocks, undifferentiated.
Permian	*P?*	Permian rocks, undifferentiated.

SYMBOLS

Geologic contact; dashed where approximately located. Contacts between surficial units are locally gradational over large lateral distances and are not shown.

Known and probable traces of Washington fault: hachures on apparent downthrown side, dashed where approximately located.

Strike and dip of bedding:

35 Inclined; showing dip.

Vertical.

30 Bedrock fault: dip of plane indicated; ball on apparent downthrown side.

Aerial photograph lineament.

Anticline: showing direction of plunge; dashed where approximately located.

Approximate borrow area: includes bedrock locally at or near the surface and recent alluvial material behind embankments.

G-1 Exploratory trench location.

NOTE

*Qof locally present on remnant pediment surfaces west of Warner Ridge.

N

Scale 1:24,000

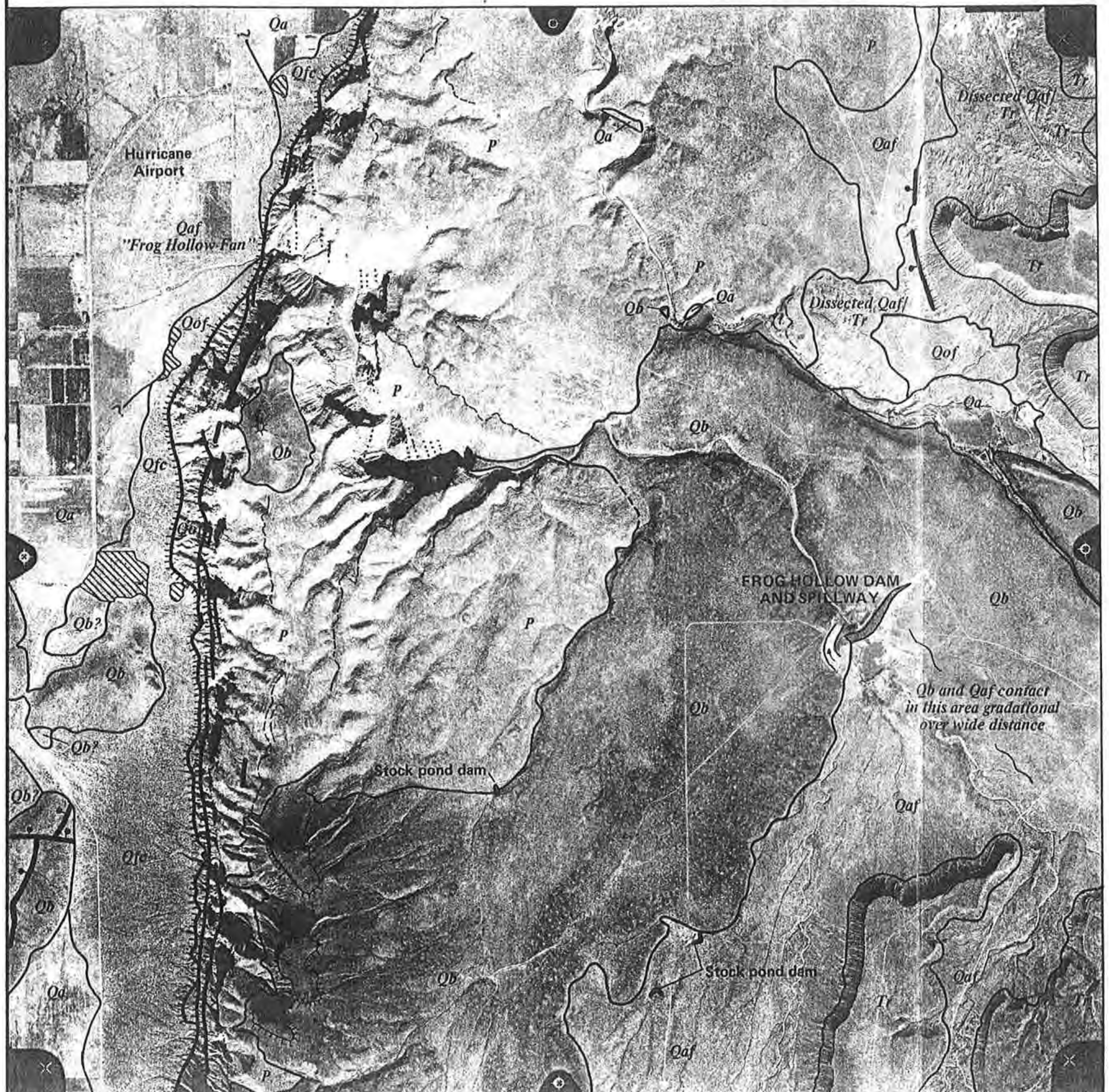
0 1,000 2,000 feet

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS IN SOUTHWESTERN UTAH

PHOTO BASE MAP OF GYPSUM, WARNER DRAW, AND ST. GEORGE AREA

Checked by Bill Wright	Date 27/may/82	Project No. D118	Figure No. VIII-11
Approved by E.A. Nelson	Date 27 MAY 82		



EXPLANATION

GEOLOGIC UNITS

Quaternary	Qa	Alluvium.
	Qfc	Alluvial fan deposits and colluvium, undifferentiated.
	Qaf	Alluvial fan deposits.
	Qof	Older alluvial fan deposits.
	Qb	Flow basalt; queried where uncertain.
Triassic	Tr	Triassic rocks, undifferentiated.
Permian	P	Permian rocks, undifferentiated.

SYMBOLS

——— ? Geologic contact; queried where uncertain.

Trace of apparent bedding in Permian rocks:

- - - - - Shallowly east dipping bedding in stratigraphically higher (?) unit.

. . . . . . Steeply dipping bedding in stratigraphically lower (?) unit.

Aerial photograph lineament:

Probable trace of Hurricane fault; hachures on apparent downthrown side.

Possible bedrock fault; ball on apparent downthrown side.

Sand and gravel quarry.

Volcanic center; hachures show rimming cliffs.

N

Scale 1:24,000

0 1,000 2,000 feet

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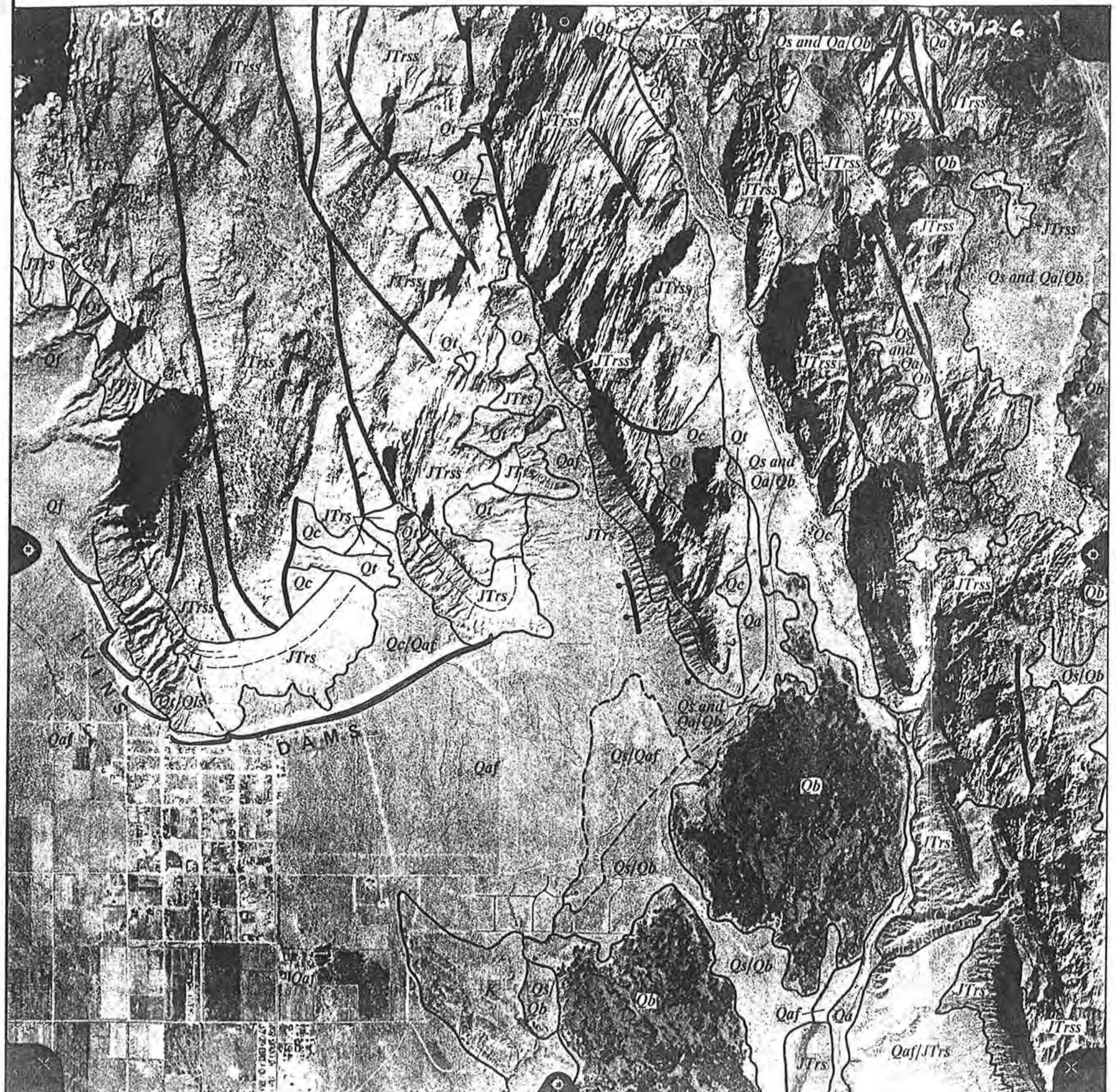
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REGIONAL GEOLOGY
FROG HOLLOW AREA

Checked by R H Wright	Date 27/may/82	Project No.	Figure No.
Approved by E A Nelson	Date 27 MAY 82	D118	VIII-12



EXPLANATION

GEOLOGIC UNITS

Quaternary

Qs	Dune and wind blown sand deposits.
Qc	Colluvium.
Qt	Talus deposits.
Qls	Landslide deposits.
Qa	Alluvium.
Qaf	Alluvial fan deposits.
Qb	Flow basalt.

Cretaceous

K	Cretaceous rocks, undifferentiated.

Jurassic - Triassic

Jurassic - Triassic rocks:

JTrss	Jointed, resistant, cross-bedded sandstone.
JTrs	Massive shale.

SYMBOLS

——— – – ? Geologic contact; dashed where approximately located, queried where uncertain.

– – – – – – Trace of apparent shallowly dipping bedding in Jurassic - Triassic shales (JTrs).

Aerial photograph lineament; probable traces of major joint set and/or bedding and/or bedrock faults: ball on apparent down side.

N

Scale 1:24,000

0 1,000 2,000 feet

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Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REGIONAL GEOLOGY
IVINS AREA

Checked by R.H. Wright	Date 27/may/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	VIII-13

APPENDICES
TO
PHASE I REPORT
SEISMIC SAFETY INVESTIGATION
OF EIGHT SCS DAMS
IN SOUTHWESTERN UTAH

Earth Sciences Associates

APPENDICES

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APPENDIX A

TRENCHING

Appendix A
TRENCHING

The exploratory trenching program began in the Cedar City vicinity on December 10, 1981. Reconnaissance geologic mapping at and in the vicinity of Green's Lake Dams 1, 2, 3 and 5 prior to selection of trench sites was conducted during the four following days, and occurred intermittently at later dates as the project required. Exploratory trenches GL-2a, GL-2b, GL-2c and GL-2d investigated subsurface conditions near Green's Lake dams nos. 1 and 2; trenches GL-3a, GL-3b and GL-3c were located near dam no. 3. Trenches GL-5a and GL-5b were excavated along the margins of the Green's Lake No. 5 debris basin located west of the above sites. Trench GL-5c consisted of an existing bulldozer cut along a mapped lineament, and this exposure was included in the study.

Reconnaissance mapping in the St. George vicinity included the Gypsum Wash, Warner Draw, Stucki, Frog Hollow, and Ivins sites. Mapping commenced on January 6, 1982 in the Gypsum Wash, Warner Draw, and Stucki dam area. Prior to trenching operations, a field tour of the proposed sites was conducted on January 9 for the Bureau of Land Management in order to obtain an archaeological clearance permit.

Four exploratory trenches (G-1, 2, 3, and 4) were excavated at the Gypsum Wash site, followed by two trenches each at Warner Draw and Stucki dam; these excavations occurred between January 13 and January 20, 1982.

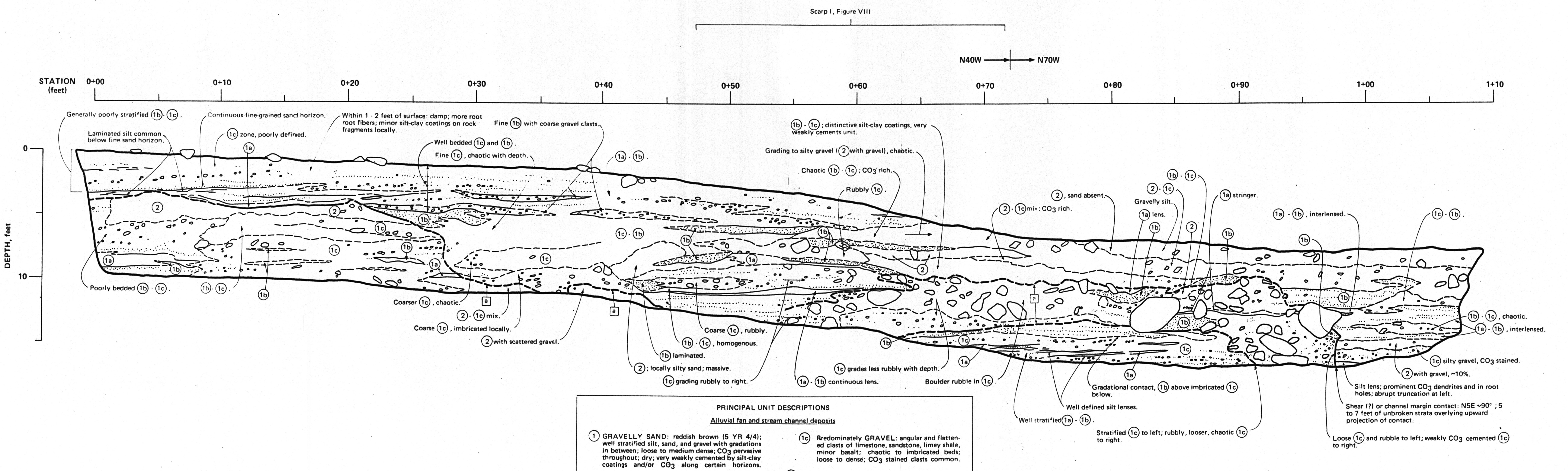
Trench exposures in the Cedar City and St. George areas which revealed faulting or suspicious fault-related features were examined by Dr. R. J. Shlemon, consulting soil stratigrapher, during the week of January 25, 1982. A field tour of these sites attended by SCS personnel, Dr. Shlemon, R. E. Anderson of the U.S. Geological Survey, Denver, Walter Arabasz of the University of Utah, in addition to ESA geologists was conducted on January 26 and 27, 1982. Following the field meeting, subsequent work was planned at the Green's Lake No. 3 site. Reconnaissance mapping of the Frog Hollow and Ivins sites and the additional study at Green's Lake No. 3 was completed by February 12, 1982.

The field investigation was interrupted by bad weather throughout the term of the project.

Exploratory trenches were logged in detail at a scale of 1 inch equals 5 feet, and reached depths of 14 feet below the ground surface. The trenches were supported by portable hydraulic shoring and locally by timber shoring where support was needed for extensive time periods. Barbed wire fencing provided protection for the excavations when left unattended. All trenches were backfilled by February 9, 1982.

In the Cedar City area trenches, charcoal samples were obtained from key stratigraphic horizons for Carbon-14 age-dating purposes. Samples of charcoal submited for age-dating were recovered from the following sites: Trench GL-2d, Sta. 0+05; Trench GL-3a, Sta. 0+57, Sta. 1+54; Trench GL-3b, Sta. 0+42, Sta. 1+27; Trench GL-5a, Sta. 0+05, Sta. 0+10.

Field reconnaissance mapping, trench logging, and charcoal sample recovery was performed by T. D. Hunt of Earth Sciences Associates. Backhoe service was provided by George Ziegler and Son of Cedar City, Utah. Dr. R. J. Shlemon provided geomorphic and soil stratigraphy analysis for geologic age determinations. The charcoal samples are presently at Teledyne Isotopes (New Jersey), and Geochron, Krueger Enterprises (Cambridge, Massachusetts) laboratories for age-dating analyses. The results of these tests are expected in May, 1982.



PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan and stream channel deposits

1 GRAVELLY SAND: reddish brown (5 YR 4/4); well stratified silt, sand, and gravel with gradations in between; loose to medium dense; CO_3 pervasive throughout; dry; very weakly cemented by silt-clay coatings and/or CO_3 along certain horizons.

1a Predominately SILT: nonplastic fines; commonly grades to very fine sand; CO_3 spots, gypsum dendrites common; medium dense/firm to stiff; generally graded bedding with sand.

1b Predominately SAND: very fine- to coarse-grained, typically graded bedding; angular and flattened grains of shale, limestone, sandstone; loose to medium dense; silt matrix generally 10+%.

1c Rredominately GRAVEL: angular and flattened clasts of limestone, sandstone, limey shale, minor basalt; chaotic to imbricated beds; loose to dense; CO_3 stained clasts common.

2 SANDY SILT : unstratified, massive; rootholes, roots common; prominent dendritic CO_3, fine pattern; dense; dry.

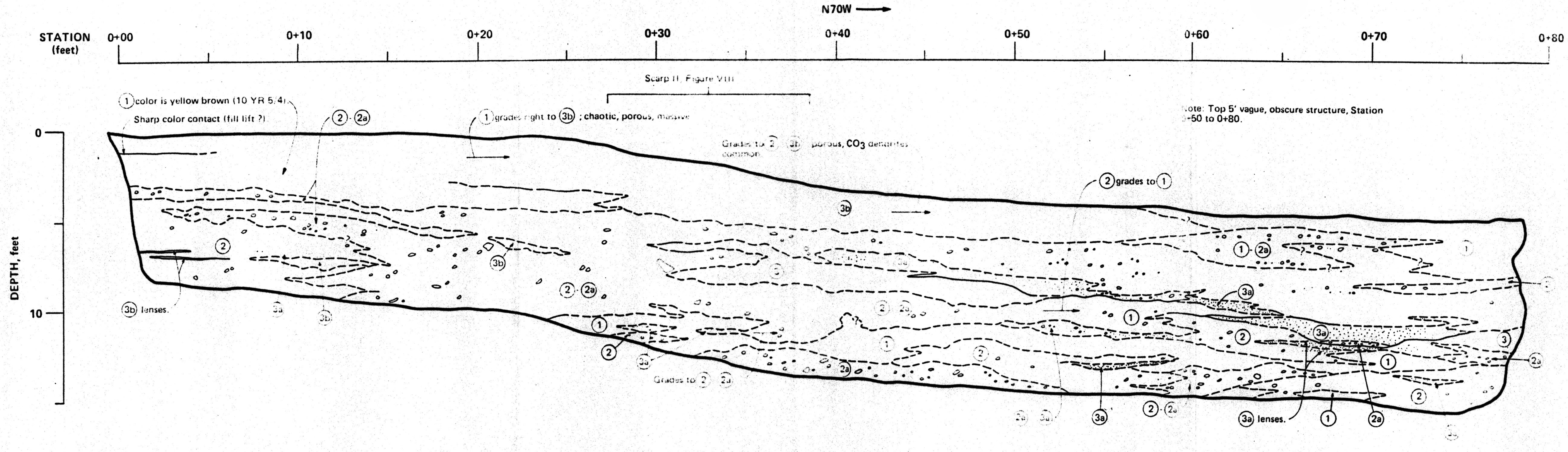
a Major unconformable contact.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-2a
GREEN'S LAKE DAM NO. 2

Checked by TD Hunt	Date 5-28-82	Project No. D118	Figure No. A-1
Approved by EA Nelson	Date 27 MAY 82		



PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan and stream channel deposits

(1) **SILT:** Reddish brown (5 YR 4/4); non- to slightly plastic fines 80+%; slight dilatency; fine- to coarse-grained sand, fine gravel typically ~15%; variable: damp to dry; medium dense; root pinholes common; CO_3 stains, minor CO_3 or gypsum dendrites; CO_3 pervasive throughout (HCl fizz extreme); massive; chaotic typically, very weak stratification of sand and gravel locally, very weak illuvial skins on hackly break.

(2) **GRAVELLY SILT:** reddish brown (5 YR 4/4); similar to (1), with sand and gravel fragments, 15 to 50%; gravel is typically angular shale, weathered sandstone, and indurated sandstone; limey shale and limestone less abundant; typically < 1" up to 6" size; dense; commonly in gradational lenses, discontinuous.

(2a) SILTY GRAVEL: as (2), with gravel > 50%; chaotic lenses, discontinuous typically.

(3) **SILTY SAND - SANDY SILT:** reddish brown (5 YR 4/4) as (1), with variable % of fine- to coarse-grained sand; loose to dense, typically medium dense; angular fragments; commonly in gradational, poorly defined lenses, discontinuous.

(3a) Predominately SILT.

(3b) Predominately SAND.

Scale: 1" = 5'

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **GEOLOGIC LOG OF TRENCH GL-2b** **GREEN'S LAKE DAM NO. 2**		
Checked by T.O. Hunt Date 5-28-82 Approved by EA Nichols Date 21 May 82	Project No. D118	Figure No. A-2

PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan and stream channel deposits

1 **SILT, SANDY SILT**: reddish brown (5 YR 4/4); non to slightly plastic fines; medium to dense/firm to stiff; dry; CO_3 pervasive throughout, dendritic CO_3 and gypsum common; characteristically grades to very fine sand in poor-to-well defined lenses; sand very fine- to coarse-grained up to 50%.

1a **GRAVELLY SILT**: as 1, with 10 - 50% angular clasts typically ≤1" size.

2 **SAND, SILTY SAND**: reddish brown (5 YR 4/4); very fine- to coarse-grained sand, typically moderate to well bedded; locally unstratified lenses; loose to medium dense angular and flattened grains of shale and limey shale; sandstone, limestone, and basalt clasts also; silt forms matrix up to 50%, very weakly cemented with CO_3 locally.

2a **GRAVELLEY SAND**: as 2, with 10 - 50% angular clasts typically ≤1" size.

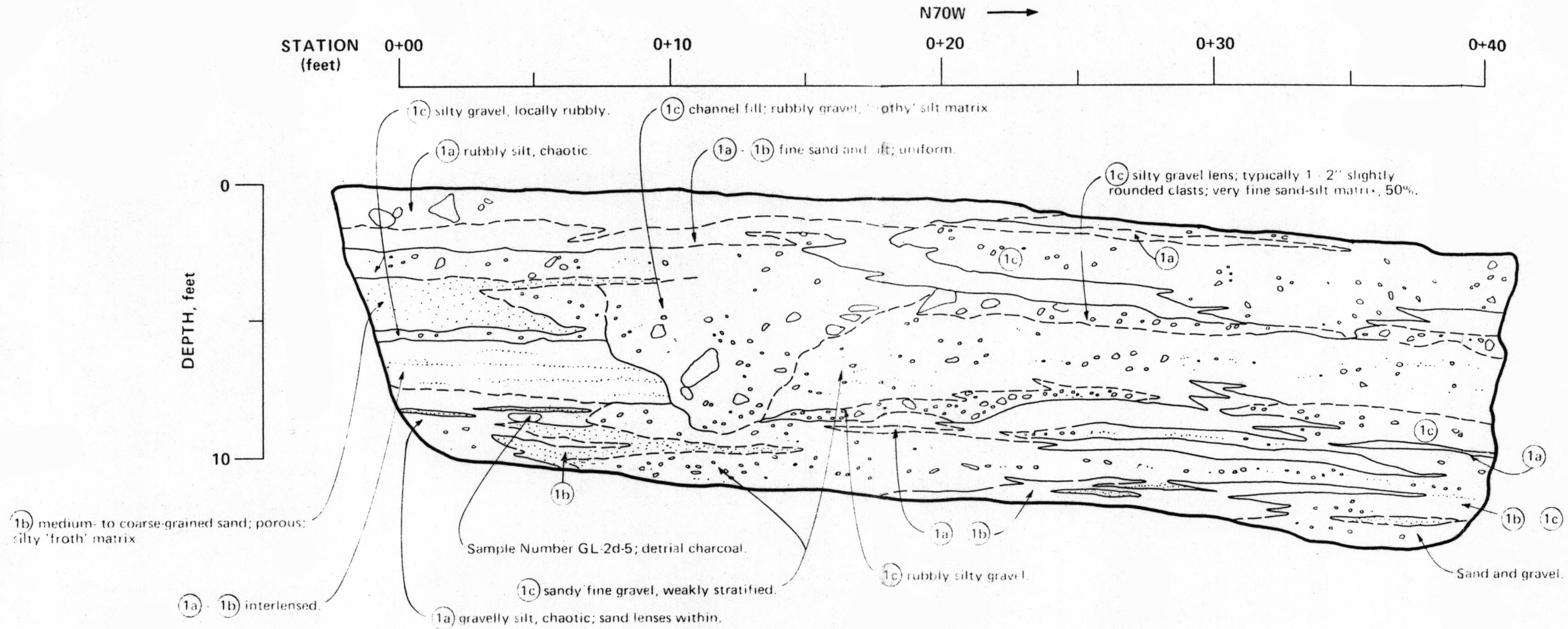
3 **SILTY and SANDY GRAVEL**: loose to dense zones of gravel with silt or sand up to 50%; angular clasts of sandstone, limestone, shale, and minor basalt; CO_3 stained clasts common; very weakly cemented by silt/CO_3 locally; clasts up to 6", typically ~1" or less, poorly to well stratified.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-2c
GREEN'S LAKE DAM NO. 2

Checked by TR Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY 82	D118	A-3



PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan and stream deposits

(1) SILTY SAND and GRAVEL: reddish brown (5 YR 4/4); poorly to well stratified, with gradations in between; medium dense; CO_3 common through out; very weakly cemented by silt-clay coatings and/or CO_3 locally

(1a) Predominately SILT: nonplastic fines, typically grades into very fine sand.

(1b) Predominately SAND: fine- to coarse-grained; angular and flattened grains of shale, sandstone, limestone, and gypsum; loose to medium dense

(1c) Predominately GRAVEL: angular and flattened clasts of limestone, shale, sandstone, and minor basalt; chaotic to imbricate beds; loose to dense. CO_3 stained clasts common

Scale: 1" = 5'

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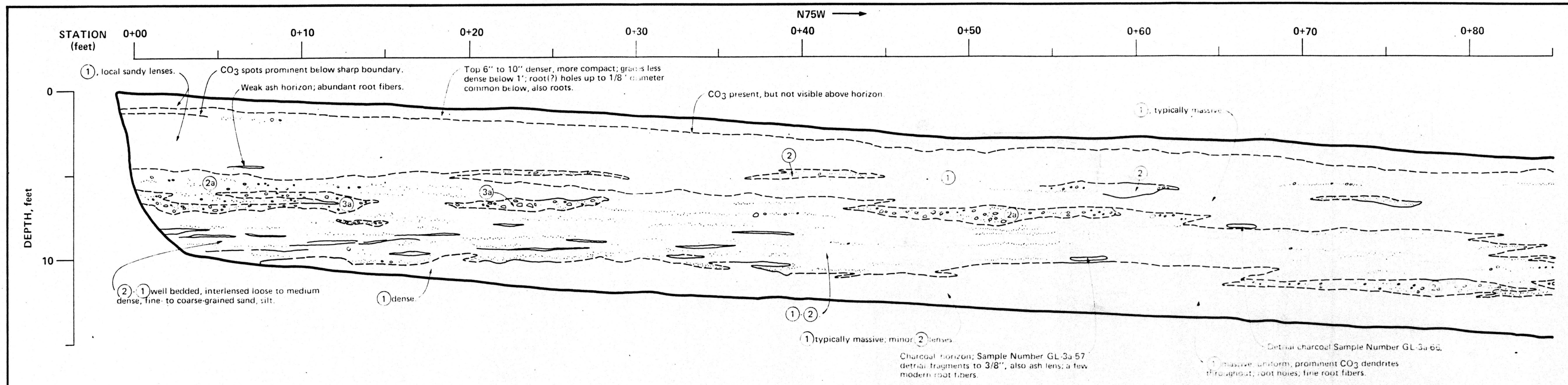
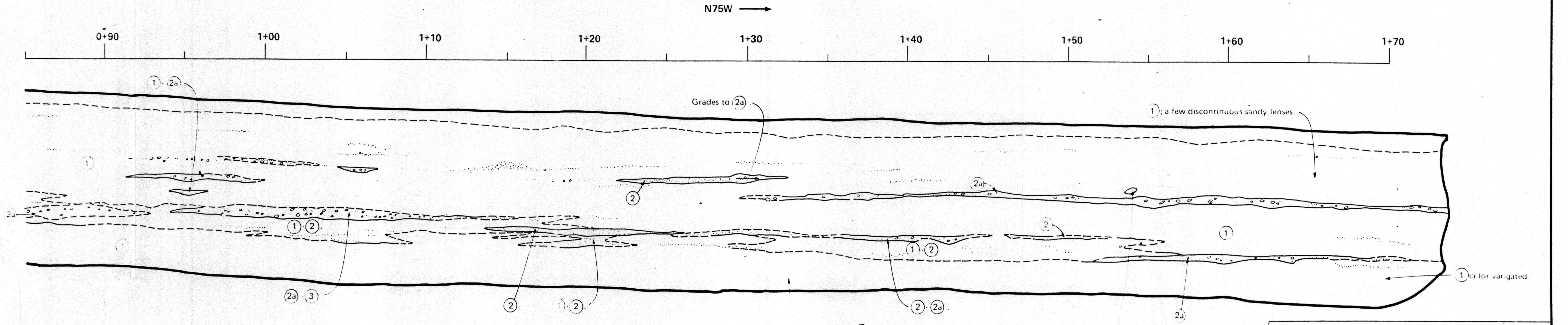
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-2d
GREEN'S LAKE DAM NO. 2

Checked by TD Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	A-4





Lower unit 1 color grades from reddish brown (5 YR 4/4) towards grayer dark reddish gray (5 YR 4/2); very faint mottle.

Un-carbonized wood block Sample Number Gl-3a-154.

PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan deposits

(1) SILT, SANDY SILT: reddish brown (5 YR 4/4); non- to slightly plastic fines; medium dense/firm to stiff; dry; CO_3, gypsum throughout, dendritic form common; grades to very fine-grained sand in weak lenses locally.

(2) SAND, SILTY SAND: reddish brown (5 YR 4/4) very fine- to coarse-grained sand; moderately to well stratified with (1), (2a); loose to medium dense; angular and flattened grains of shale, limestone, and sandstone.

(2a) GRAVELLY SAND: as (2), with 10 - 50% angular gravel clasts.

(3) GRAVEL, SILTY GRAVEL: angular and flattened clasts of shale, sandstone, and limestone; chaotic to crudely stratified lenses; medium dense; silt matrix up to 50%.

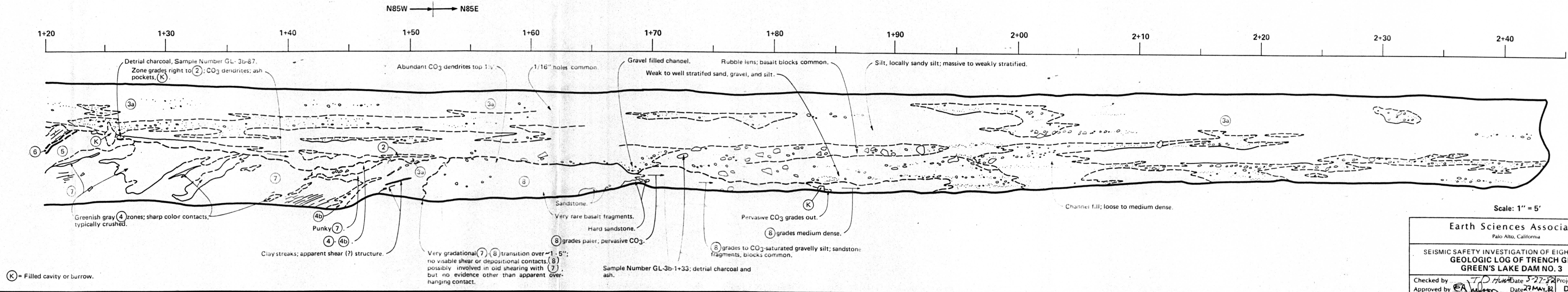
(3a) SANDY GRAVEL: as (3), with fine- to coarse-grained sand up to 50%.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-3a
GREEN'S LAKE DAM NO. 3

Checked by [signature]	Date 5-27-82	Project No. D118	Figure No. A-5
Approved by [signature]	Date 27 MAY 82		



PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan deposits

(1) SANDY SILT: yellowish red (5 YR 4/6); nonplastic fines; very fine-grained sand, gradational lenses; root or insect/worm holes common; medium dense; root fibers; slighly brittle, crumbly; CO_3-HCl fizz; grades to silty sand commonly.

(2) SILT: dark reddish brown (5 YR 3/4); slightly plastic fines; scattered fine- to coarse-grained sand, angular gravel fragments < 15%; prominent white gypsum and/or CO_3 dendrites; fine pattern; lenses of (1) within, mottled; dense; root/insect holes; typically massive.

(3) GRAVELLY SILT: dark reddish brown (5 YR 3/4); locally silty gravel in crude lenses; as (2) with up to 50% angular limestone, siltsone, sandstone, gypsiferous shale fragments; medium dense to dense; generally massive, structureless.

(3a) As (3), but denser; poor to moderately well stratified.

Bedrock

(4) Deformed SILTSTONE/SHALE/LIMESTONE: olive (5 Y 5/3); stained pale yellow (2.5 Y 7/4), mottled.

(4a) Punky weathered zones with hard, angular fragments, CO_3 stained.

(4b) Hard, indurated coherent zones; blocky fracturing; predominantly limestone, siliceous siltstone (?).

(5) MYLONIZED BEDROCK: crushed, sheared, deeply weathered.

(6) FAULT GOUGE: grayish brown, bluish gray clay, mottled; highly plastic; intensely crushed, sheared; CO_3 stained white planes within; damp; stiff.

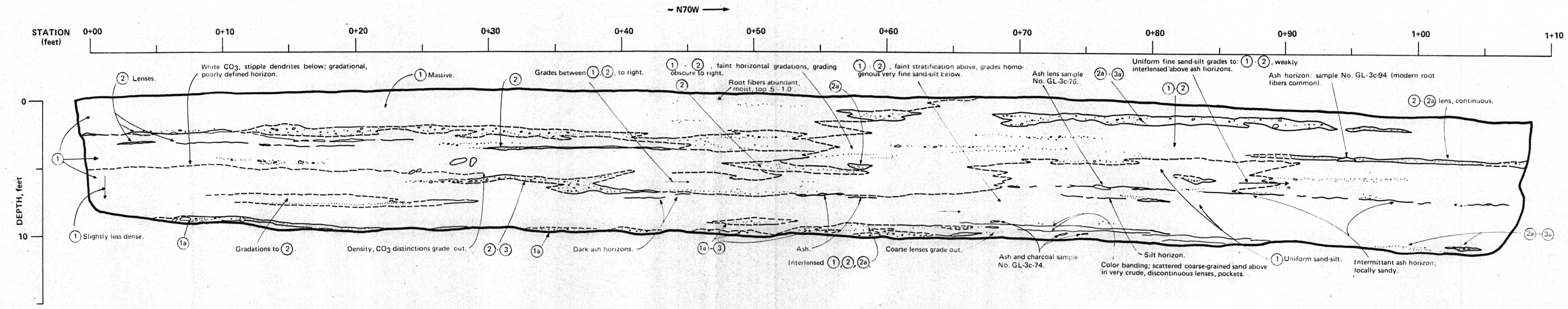
(7) SHALE: dark reddish brown (5 YR 3/4); weak, low hardness; soft, punky commonly; very fissile where fresh; typically crushed, shear planes throughout, generally along bedding; no primary CO_3; indurated angular clasts within, <1%.

Colluvium

(8) GRAVELLY SILT: reddish brown (5 YR 3/4); massive, chaotic; resembles unit (7) but has slightly less CO_3, is slightly coarser, and has less well developed fine desiccation structure than (7).

Scale: 1" = 5'

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **GEOLOGIC LOG OF TRENCH GL-3b** **GREEN'S LAKE DAM NO. 3**		
Checked by T D Hunt Date 5-27-82 Approved by EA Nelson Date 27 MAY, 82	Project No. D118	Figure No. A-6



PRINCIPAL UNIT DESCRIPTIONS

Alluvial fan deposits

(1) SILT, SANDY SILT: reddish brown (5 YR 5/3); non- to slightly plastic fines; commonly porous with root or insect holes; dry; CO_3 pervasive; dense, slightly brittle; predominately fine- to very fine-grained sand; coarse-grained sand, fine gravel <2%.

(1a) GRAVELLY SILT: as (1), with 10 - 50% angular shale, sandstone, limestone clasts.

(2) SAND, SILTY SAND; yellowish red (5 YR 4/6); as (1), with very fine- to course-grained sand >50%; typically in lenses well stratified with (1).

(2a) GRAVELLY SAND: as (2), with 10 - 50% angular shale, sandstone, limestone clasts.

(3) SILTY GRAVEL; as (1a), with >50% gravel; predominately angular shale, sandstone; lesser limey clasts.

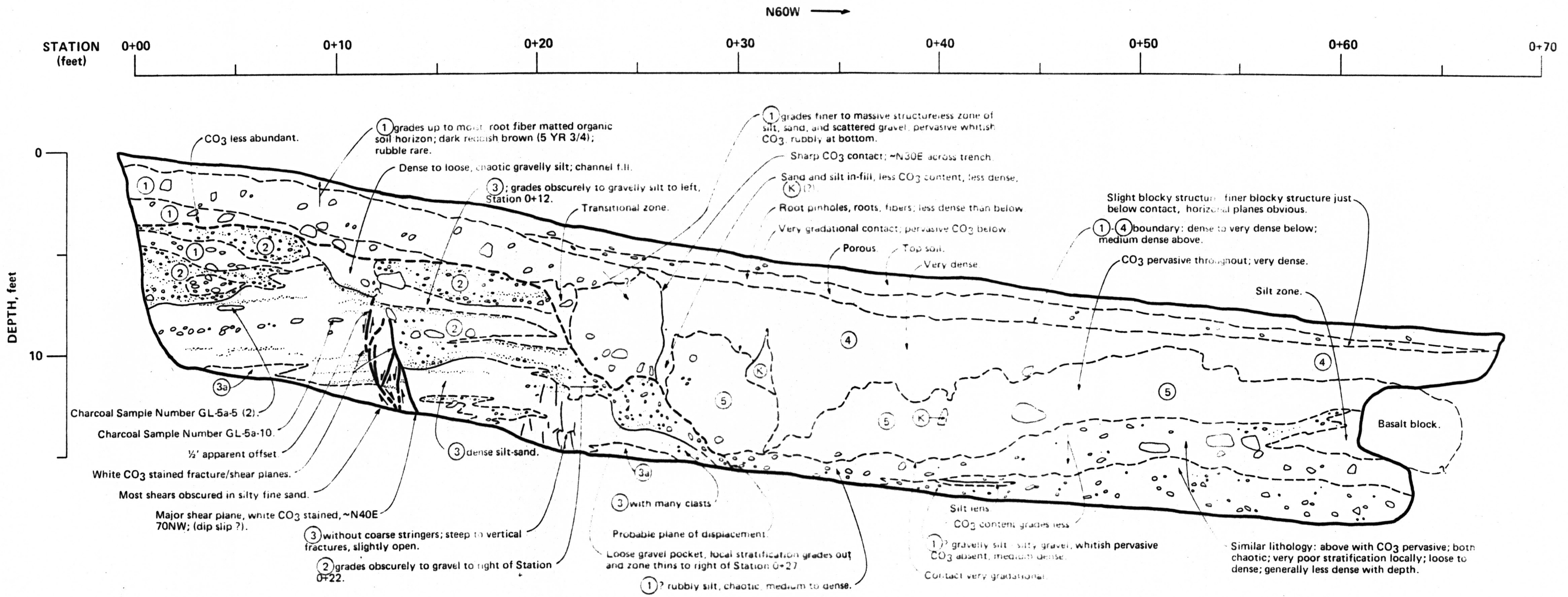
(3a) SANDY GRAVEL: as (2a), with >50% gravel; predominately angular shale, sandstone; lesser limey clasts.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-3c
GREEN'S LAKE DAM NO. 3

Checked by T.D. Hunt	Date 5-27-82	Project No.	Figure No.
Approved by E A Nelson	Date 27 MAY 82	D118	A-7



PRINCIPAL UNIT DESCRIPTIONS

1 Colluvium: RUBBLY SILT: light reddish brown (5 YR 6/4) (wet); nonplastic fines; gravel, cobbles scattered within; chaotic; pervasive CO_3 concentration.

2 Fan/stream channel deposits: SILTY and SANDY GRAVEL: locally well sorted, well rounded clasts, average ~½" size; medium dense; chaotic to locally well stratified.

3 SANDY SILT - SILTY SAND: very dense, weakly cemented; fine to very fine sand; locally coarse stringers.

3a SILTY SAND: uniform; fine-grained; medium dense.

4 Colluvium/alluvium: SANDY SILT: yellowish red (5 YR 4/6); massive, unstratified; scattered rock fragments; very fine root holes commonly CO_3 lined; a few CO_3 spots or weakly developed concretions < ½" typically; minor CO_3 coating on fractured surfaces; grades downward to locally well developed CO_3 dendritic structure, and abundant CO_3 on fracture surfaces.

5 Pervasive CO_3; very dense; CO_3 grades less at dashed upper contact.

Note: Units 2, 3, 4: yellowish red (5 YR 4/6); predominately sandstone, limestone, and shale clasts; minor basalt; clasts are typically subangular to angular, flattened; minor subrounded, ~5 - 10%.

K = Filled cavity or burrow.

Scale: 1" = 5'

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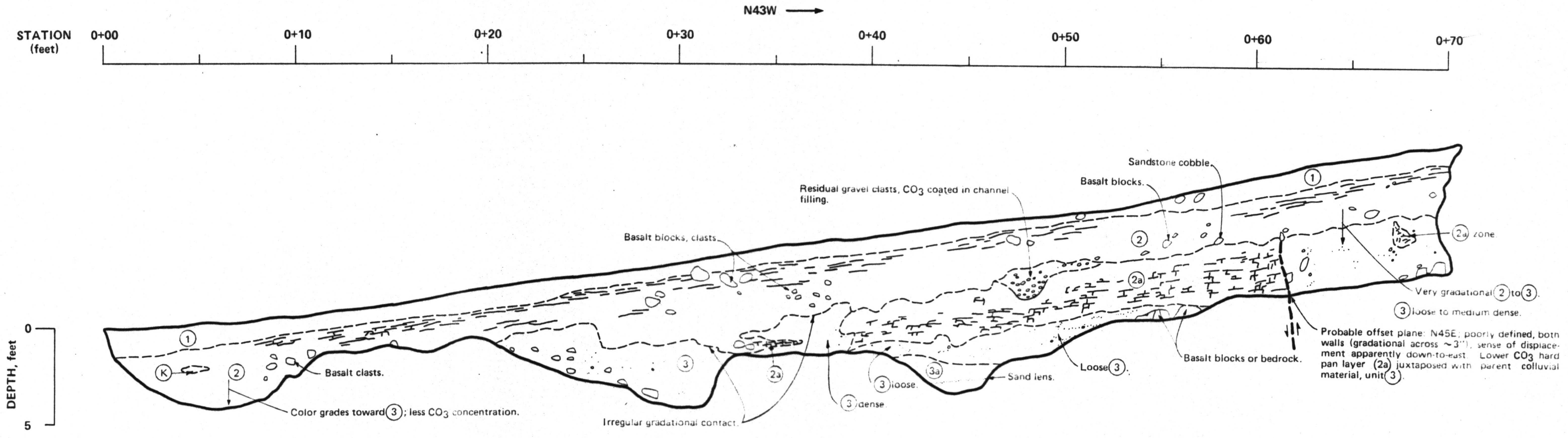
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-5a
GREEN'S LAKE DAM NO. 5

Checked by T.O. Hunt	Date 5-27-82	Project No.	Figure No.
Approved by E.A. Wilson	Date 27 MAY 82	D118	A-8



PRINCIPAL UNIT DESCRIPTIONS

(1) Colluvial topsoil SILT - SANDY SILT dark brown (7.5 YR 3/4); nonplastic fines 90+%; medium dense, porous; granular; root fibers abundant; fine- to coarse-grained sand, gravel scattered throughout.

(2) Colluvium: SILT and SAND: pink (7.5 YR 8/4); CO_3 encrusted; scattered rock fragments (basalt); distinctive fracturing sub-parallel to ground surface blocky to tabular structure near soil contact; structure grades massive below; very dense; weakly cemented 'hard pan'.

(2a) Zone of (2) with less CO_3 concentration; distinct fine blocky structure; planes ~right angles and approximately parallel with ground surface.

(3) Colluvium: GRAVELLY SAND yellowish red (5 YR 5/6), nonplastic fines variable, typically 20 - 40%; very fine- to coarse-grained sand, structureless; chaotic colluvium; medium dense to dense; minor roots, rootholes; minor CO_3 mottle; local blocks, cobbles of basalt.

(3a) SAND: light yellow brown (8 YR 6/5) very fine-grained ~98%; scattered fine- to coarse-grains; massive; dense; nonplastic; fines >5% grades into unit (3).

(K) = Filled burrow or cavity.

Scale: 1" = 5'

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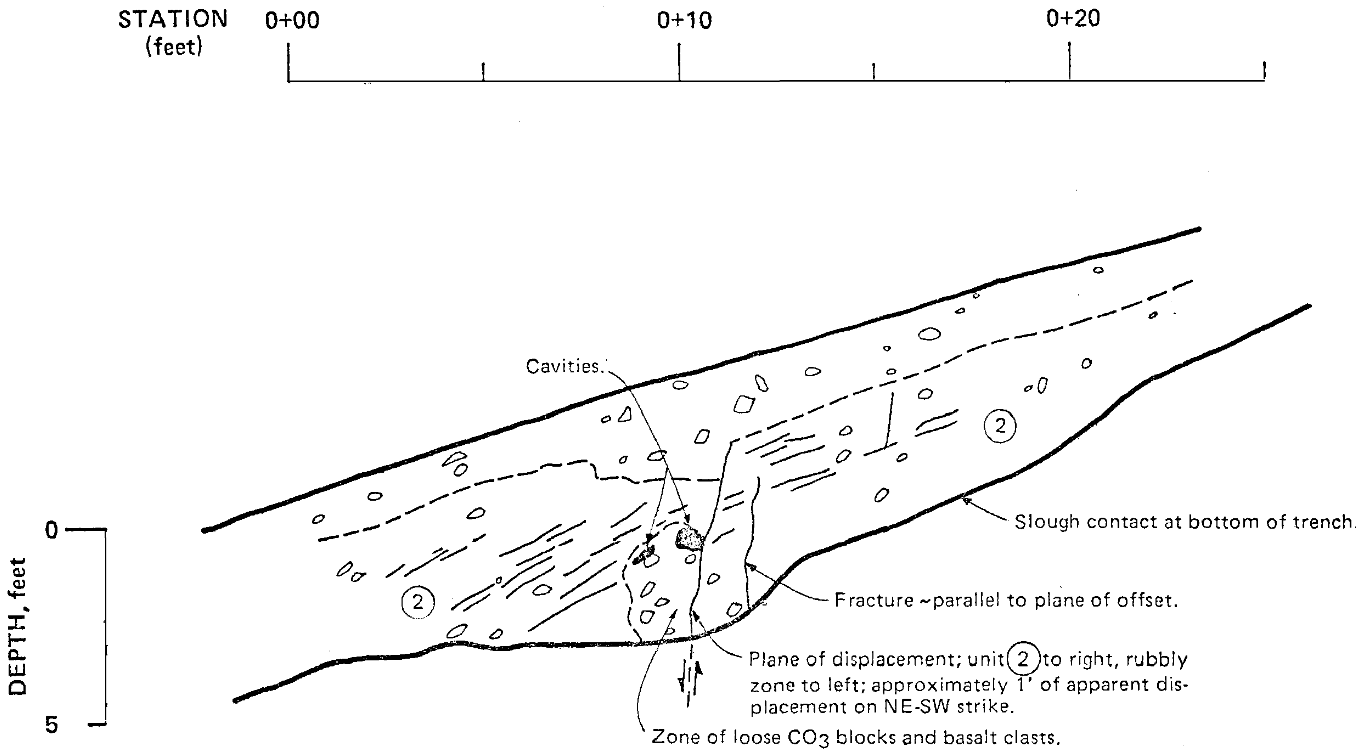
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-5b
GREEN'S LAKE DAM NO. 5

Checked by TDHunt	Date 5-27-82	Project No.	Figure No.
Approved by EA [illegible]	Date 27MAY,82	D118	A-9



VIEW SW

PRINCIPAL UNIT DESCRIPTIONS

① Colluvium: SANDY SILT: dark brown (7.5 YR 3/4); weakly developed organic (A) horizon; limey; gradational into hardpan ② ; angular clasts of basalt throughout.

② Hardpan: CARBONATE CEMENTED SILT and SAND: pink (7.5 YR 8/4); colluvial debris cemented by CO_3; irregular, poorly developed linear structure like lenses or bedding (layered), dips down slope; basalt fragments common within.

Scale: 1" = 5'

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Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH GL-5c
GREEN'S LAKE DAM NO. 5

Checked by T. D. Hunt	Date 5-27-82	Project No. D118	Figure No. A-10
Approved by [signature]	Date 27 May 82		

PRINCIPAL UNIT DESCRIPTIONS

Young alluvial fan deposits

1 SILT: yellowish red (5 YR 4/6); characterized by white gypsum specks; loose to very weakly compacted; very fine root fibers within; slight blocky structure, parallel with surface; CO_3-HCl fizz.

Old alluvial fan deposits

2 SILT and SAND: local discontinuous gravel stringers, flat and angular pale green siltstone fragments.

2a GRAVELLY SILT: reddish brown (2.5 YR 4/4); massive, chaotic, dense to very dense.

3 SAND, GRAVELLY SAND: reddish brown (4 YR 4/5); grades gravelly at base; typically fine-grained, locally gypsiferous; dense.

4 SAND: yellowish red (5 YR 4/6); typically fine- and medium-grained; dense; characterized by color and uniformity.

5 GRAVELLY SAND, locally SANDY GRAVEL: dense, poorly stratified; local cobbles; rubbly.

6 SAND and GRAVEL: very dense; faint stratification and imbrication.

7 GYPSIFEROUS SILT: dense; massive; slightly porous.

8 GRAVELLY SILT: coarse, granular zone of green-gray shale chips and gypsum crystals and transported fragments.

Young alluvial fan deposits.

9 SILT - GRAVELLY SILT: gypsum forms prominent porous honeycombs; also coarse blotches, whitish, where concentrated.

K = Filled cavity or burrow.

Note: Measured offsets are apparent on plane of displacement.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH G-1
GYPSUM WASH DAM

Checked by T D Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY 82	D118	A-11

PRINCIPAL UNIT DESCRIPTIONS

(1) Young alluvial fan deposits: SAND, SANDY SILT: dark reddish brown (5 YR 3/4) poor to very well stratified; loose to medium dense; silty lenses denser; sand typically loose; sand is fine- to coarse-grained flat shale fragments typically; gypsum clasts ~15 - 35% of sand volume; minor gravel, (~1 - 2%) consists of shale, sandstone, and siltstone; roots common.

Older alluvium

(2) SANDY SILT: reddish brown (5 YR 4/4) non-plastic fines, variable %, typically 70+%; locally stratified, medium dense to dense; gypsum speckled locally, also very fine honeycomb texture of gypsum at base; gradational contact with (4).

(3) SILT: yellowish red (5 YR 4/6)(wet); fine- to coarse-grained sand 1 - 10%; gypsum rich; very dense, hard, massive, uniform; fine gypsum-lined rootholes present rarely.

(3a) SANDY SILT: locally gravelly; very dense; no stratification, massive, gradational with (3).

(4) Bedrock: SHALE and GYPSUM, interbedded: typically dark reddish brown (2.5 YR 3/4) with gray (5 Y 6/1) lenses; moderately to deeply weathered; punky to moderately hard; fissile; close to intensely fractured, locally crushed; local thin white gypsum interbeds; weathers to silty clay.

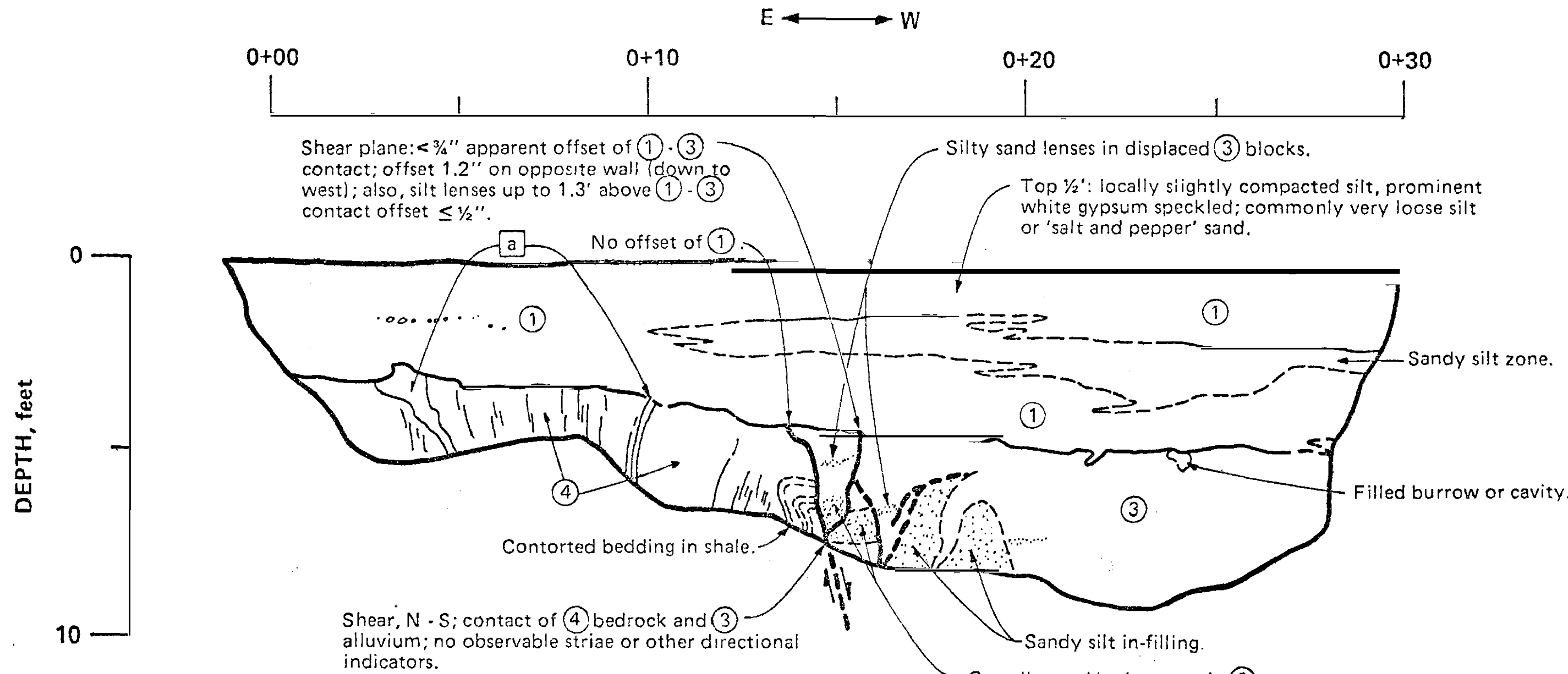
[a] Light gray (5 Y 6/1) marker beds of gypsum; hard, fissile; offset along old bedrock fault.

Scale: 1" = 5'

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH G-2
GYPSUM WASH DAM

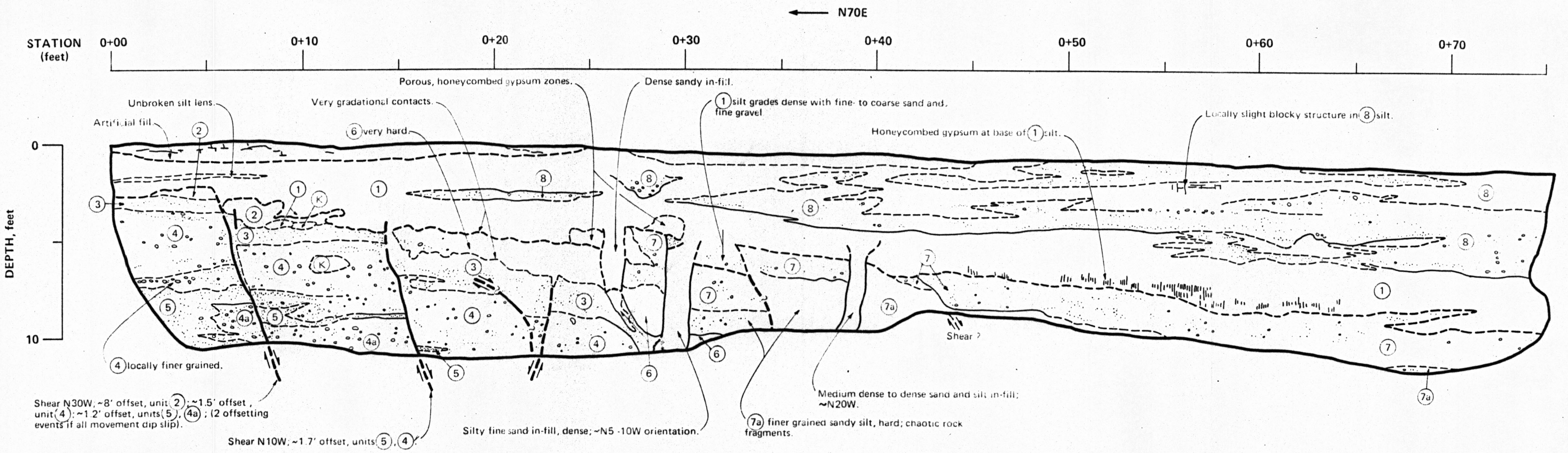
Checked by TO Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	A-12



Note: Units described on trench G-2.

Scale: 1" = 5'

Earth Sciences Associates Palo Alto, California			
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **GEOLOGIC LOG OF TRENCH G-3** **GYPSUM WASH DAM**			
Checked by T.D. Hunt	Date 5-27-82	Project No.	Figure No.
Approved by E.A. Nelson	Date 27 MAY '82	D118	A-13



PRINCIPAL UNIT DESCRIPTIONS

Young alluvial fan deposits

(1) **SANDY SILT**: yellowish red (5 YR 4/6); nonplastic fines 50 - 80%; typically very fine- to fine-grained sand; gypsum crystals common; loose to dense; scattered coarse sand, fine gravel clasts; CO_3 locally cements, grades out with depth.

Older alluvial fan deposits

(2) **GYPSIFEROUS SAND and GRAVEL**: mottled white, brown, and red; dense; chaotic fine- to coarse-grained sand and gypsum clasts; typically angular shale fragments, minor subrounded; some siltstone, very fine sandstone clasts; gravel ~5%.

(3) **SAND**: red; (2.5 YR 4/6); very fine- to coarse-grained; loose to dense; (K)? locally; weakly stratified in short discontinuous lenses; scattered coarse-grained and fine gravel ~5%.

(4) **GRAVELLY SAND**: fine- to coarse-grained sand, typically medium- to coarse-grained; silt 10 - 20%; gravel distinctive angular and flat gray shale clasts, ¼ - ¾" typically; lesser red and pink sandstone, dark shale; very dense, very weak stratification; gypsum (clasts) throughout; no CO_3.

(4a) **SANDY GRAVEL**: rubbly locally.

(5) **SILTY SAND**: red (2.5 YR 4/6); dense to very dense; very fine- to medium-grained; massive.

(6) **SANDY SILT - SILTY SAND**: yellowish red (5 YR 4/6); pervasive fine gypsum crystals throughout; porous; very dense; fine-grained sand; massive.

(7) **GRAVELLY SAND**: fine- to coarse-grained sand and gypsum clasts; scattered fine gravel throughout; characteristically massive, unstratified, very dense; variable silt %, 15 - 50%; CO_3 rare.

(7a) **SANDY SILT**: as (7) with sand less than 50%; hard; massive; scattered gravel fragments; CO_3 abundant.

Young alluvial fan deposits

(8) **SAND and SILT**, interlensed: fine- to coarse-grained gypsum and shale clasts, medium to well stratified; medium dense, locally loose and porous; 'salt and pepper' color; local root fibers; gypsum speckled near surface where silty; CO_3 in silt, not in sand; discontinuous gravel stringers of gray shale chips common.

(K) = Filled cavity or burrow.

Note: Measured offsets are apparent on plane of displacement.

Scale: 1" = 5'

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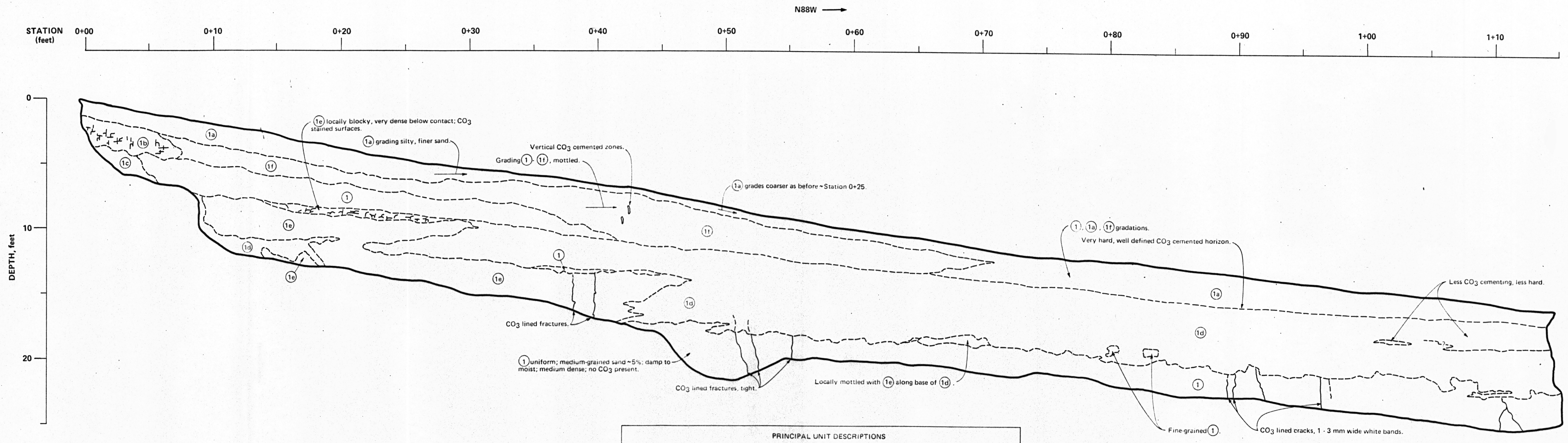
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

GEOLOGIC LOG OF TRENCH G-4

GYPSUM WASH DAM

Checked by D Hunt	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	A-14



PRINCIPAL UNIT DESCRIPTIONS

Alluvium

1 SAND: red (2.5 YR 4/6); nonplastic fines <10%; very fine- to medium-grained; medium size grains well rounded quartz, slighty frosty, comprise ~20% of volume; remainder quartz (?), more angular; dark grains < 10%; massive, unstratified; loose to medium dense; CO_3-HCl reaction moderate to strong; dry to damp.

1a As 1 with roots scattered throughout, damp.

1b CO_3 cemented 1; pink (5 YR 8/4) dry; reddish yellow (5 YR 6/6) when wet; prominent blocky structure; root holes, fine root fibers abundant; very strong CO_3-HCl fizz; dense to very dense.

1c As 1b without blocky structure or roots.

1d As 1b; very fine- to fine grained-sand; medium grains <2%; hard to very hard; mottled color locally.

1e As 1 but finer grained sand; dense; hackly break; CO_3 mottle locally.

1f As 1b but no blocky structure; hackly break; few roots, holes; gradational between 1 and 1a.

Note: All contacts gradational, mottled.

Scale: 1" = 5'

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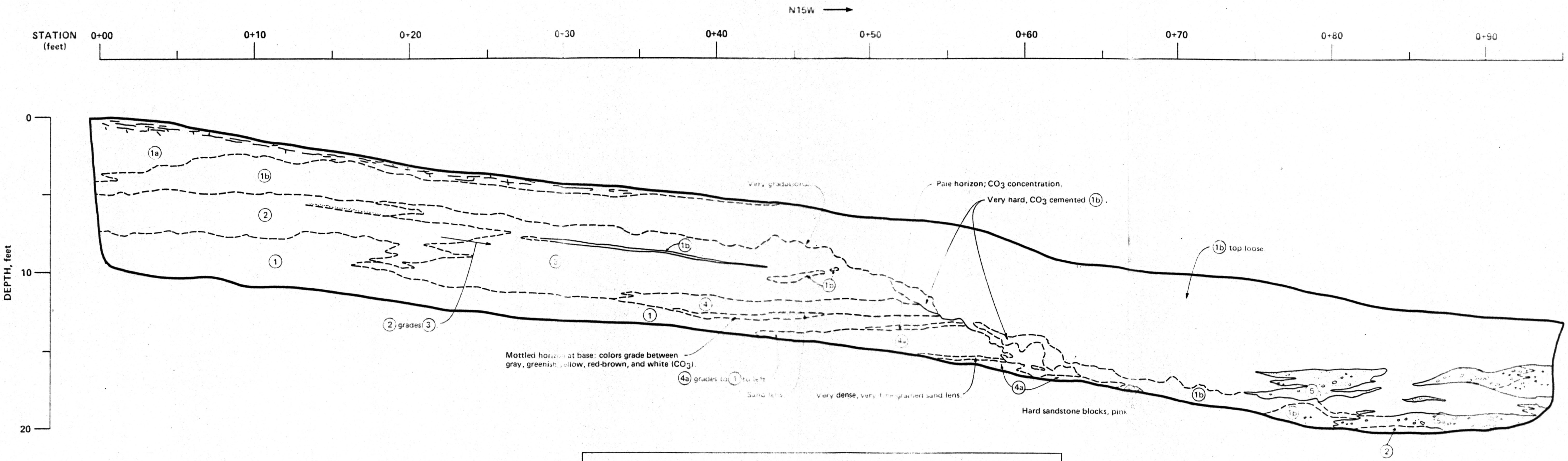
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH WD-1
WARNER DRAW DAM

Checked by TD Hunt Date 5-27-82	Project No.	Figure No.
Approved by EA Wilson Date 27 May 82	D118	A-15



PRINCIPAL UNIT DESCRIPTIONS

Old alluvium

(1) SAND: red (2.5 YR 4/6); nonplastic fines < 10%, very fine- to fine-grained; 85+%; well rounded medium- and coarse-grained quartz, slightly frosted, ~5%; remainder more angular, dark grains < 1%; massive; dense, damp; black Mn or Fe spots mottle locally; minor white CO_3 and gypsum spots.

(1a) SAND: red (2.5 YR 4/6) to pink (5 YR 8/4), very dense, hard CO_3 cemented; blocky layered structure within 1' of surface, CO_3 cemented.

(1b) SAND: very dense, both gypsum and CO_3 mottle unit locally at base; slight blocky or 'slabby' break; massive; well graded between fine- and medium-grained; brittle; weakly cemented by fe ox and/or CO_3.

(2) SILTY SAND: red (2.5 YR 4/6); nonplastic fines 10 - 30% of volume; prominent white CO_3 mottle; dense.

(3) SANDY SILT: color as 1a; very fine- to fine-grained sand; variable % of silt-sand; massive; dense to very dense, hard; abundant rootholes; stained, mottled throughout with CO_3 and gypsum.

(4) CLAYEY SILT: color grades toward dark red, (2.5 YR 3/6); low plasticity; very porous; fine gypsum crystals abundant; hard; massive.

(4a) SILTY CLAY: dark red (2.5 YR 3/6); moderate plastic fines; very stiff; abundant root channels, black Mn stained; gypsum crystals present.

(5) SAND AND GRAVEL: very fine- to coarse grained sand 50 - 70%, angular gravel up to 3" size, typically ½", dense; weakly stratified.

(5a) SANDY GRAVEL: coarse, angular; dense; weakly stratified; local faint imbrication; clasts predominately platy limestone, sandstone, and shale; hard.

Scale: 1" = 5'

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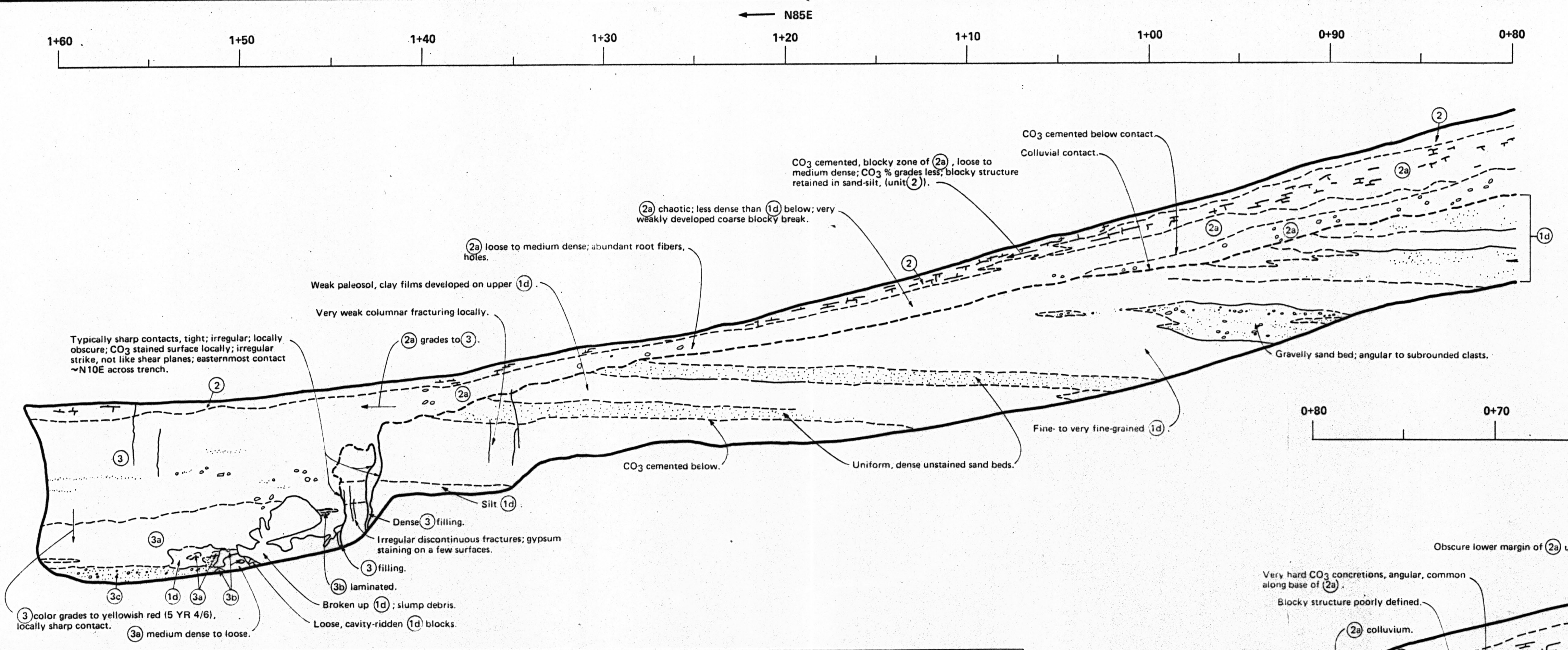
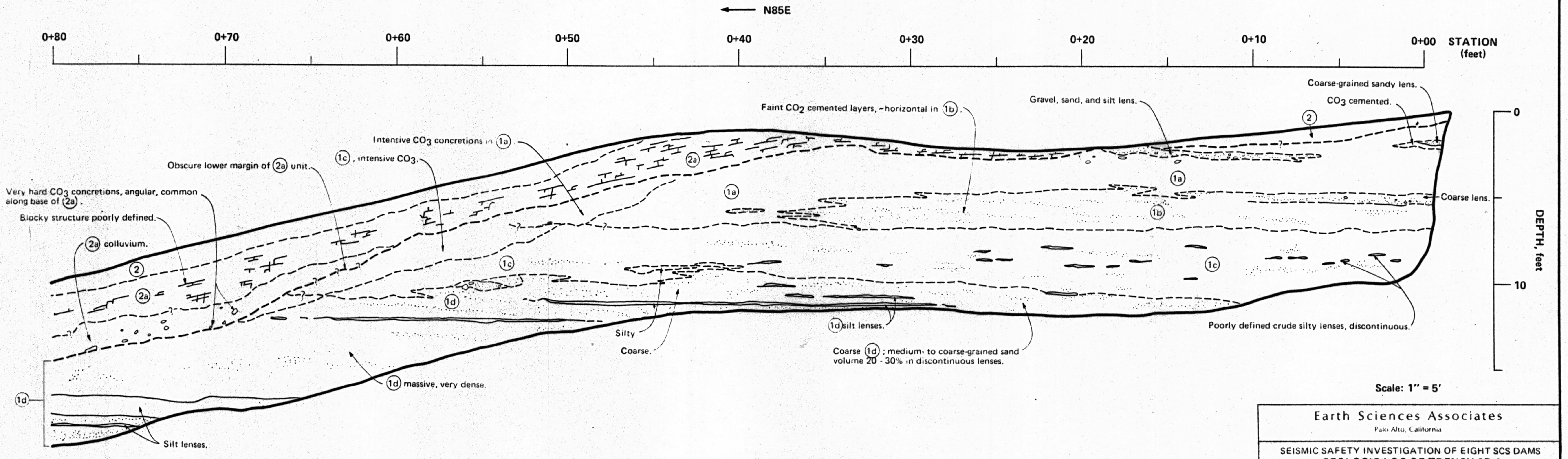
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH WD-2
WARNER DRAW DAM

Checked by T.D. Hurst	Date 5-27-82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY 82	D118	A-16





PRINCIPAL UNIT DESCRIPTIONS

Old alluvium

(1) SAND: red (2.5 YR 4/6); fines <5%; very poorly graded, predominantly very fine- and fine-grained; medium-grained faction ~15% typically; frosted grains, rounded to subrounded; quartz/silica 98+%; dark grains<1%, weakly cemented by fe-ox, locally by CO_3.

(1a) Massive; medium dense to dense; locally silty in obscure gradations; scattered fine gravel <1%.

(1b) Weakly stratified; very fine- to medium-grained sand, scattered coarse grains, medium dense.

(1c) Weakly stratified; very fine- to fine-grained sand gradations with local dense silty stringers; slightly darker shade than above material; medium dense to very dense where CO_3 locally concentrated.

(1d) Dense to very dense silt lenses within; very fine- to medium-grained; weakly to well stratified; locally loose.

Colluvium

(2) SILTY SAND: yellowish red (5 YR 4/6); medium dense to loose; locally compact, slightly blocky; roots common; gravel scattered within.

(2a) Dense, blocky, layered zone of (2), CO_3 cemented; prominent from approximately Station 0+30 to Station 1+00.

Young alluvium

(3) SAND: red (2.5 YR 4.5/6) nonplastic fines <15%; very fine- to coarse-grained, poorly graded, typically very fine- to medium-grained; massive, chaotic; locally very crudely stratified coarse grains; scattered CO_3 rind gravel; medium dense; homogenous; CO_3-HCl reaction strong; a few tight vertical fractures from surface downward; no CO_3 mottle.

(3a) SILTY SAND: yellowish red (5 YR 4/6); nonplastic fines ~20%; very fine- to coarse-grained, moderate to poorly graded; white CO_3 grains speckle unit; lower % of CO_3 than above.

(3b) SANDY SILT: Medium dense, very fine-grained sand; locally laminated horizontally; blocky structure.

(3c) SAND and GRAVEL: moderately stratified; medium dense; flat and angular clasts of limestone, sandstone, and shale, up to 3", typically <½".

Scale: 1" = 5'

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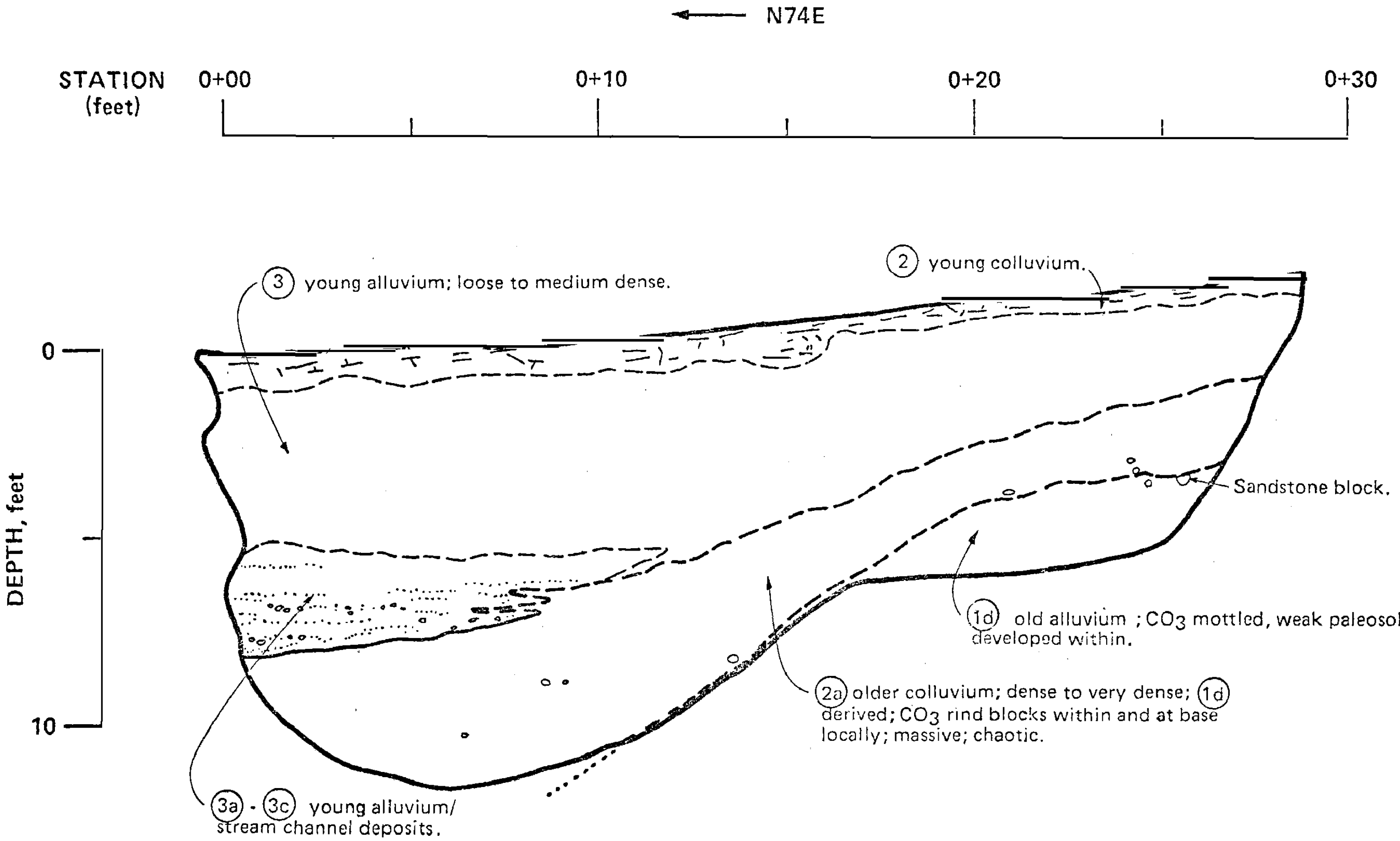
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH SD-1
STUCKI DAM

Checked by TDHunt	Date 5-27-82	Project No. D118	Figure No. A-17
Approved by EA Wilson	Date 27 May, 82		



Note: Units described on trench SD-1.

Scale: 1" = 5'

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GEOLOGIC LOG OF TRENCH SD-2
STUCKI DAM

Checked by TD Hunt	Date 5-27-82	Project No. D118	Figure No. A-18
Approved by EA Nelson	Date 27 MAY '82		

APPENDIX B

DRILLING AND SAMPLING

Appendix B
DRILLING AND SAMPLING

The geotechnical field investigations for the seismic evaluation of eight SCS dams in the Cedar City-St. George, Utah area were conducted from September 28 through October 20, 1981. The sampling and drilling phase of the investigations was performed by Douglas Yadon (Engineering Geologist) of Earth Sciences Associates. Drilling operations were subcontracted to Pitcher Drilling Company of East Palo Alto, California.

The objectives of the drilling and sampling phase of the investigations were:

1. To provide information on the materials comprising the reservoir embankments and their underlying foundation.

2. To perform Standard Penetration Tests (SPT).

3. To obtain disturbed and undisturbed samples for laboratory testing.

Twenty-six exploratory borings were drilled in the embankment and foundation of all eight dams totaling 1096.7 lineal feet. All borings penetrating embankment materials were drilled along the dam centerline from the crest and then into the underlying foundation soil or rock. Most of the foundation borings were located adjacent to the upstream toe of the embankment. The locations of the borings are summarized in Table B-1 and are shown in Figures B-1 through B-8.

A Failing 1500 rotary drill rig was used to advance all borings. Holes were drilled using the direct rotary method with water circulation. In most cases drilling fluid additives were unnecessary due to relatively low fluid losses. Bentonite drilling mud and/or salt-gel were added in some instances to retard fluid loss and help flush heavy gravel cuttings. Each boring was started with a 6-inch flight auger and a short section of surface casing was set and sealed with bentonite.

All of the borings were sampled as continuously as possible with a 3-inch Pitcher barrel sampler and a standard penetration split spoon sampler. The usual procedure employed was to cut a 2½ foot relatively undisturbed sample with the Pitcher barrel, conduct a standard penetration drive test (SPT) through the next 1½ feet, clean out the hole with a 4-7/8-inch tricone rock bit to the bottom of the SPT, and then repeat the procedure to total depth. If significant debris remained in the hole after the Pitcher barrel sampling, the hole was cleaned with the rock-bit before conducting the SPT. Where coarse gravel and cobbles prevented undisturbed sampling or meaningful drive testing, the rock bit was used to penetrate the coarse interval. Table B-2 summarizes the drilling and sampling performed.

Details of the design and operation of the Pitcher barrel sampler are described in the accompanying manufacturer's literature. Shelby tubes recovered were processed as follows:

- Excess drilling fluid and slough drained from top.
- Sample recovery measured.
- Ends of sample logged.
- Samples weighed.
- Spacer placed on top of sample and wax-sealed.
- Plastic caps placed on ends of tubes.
- Caps sealed with tape and waxed.
- Sample identification marked on tube.
- Samples boxed and stored.

In spite of the presence of some gravel in most of the materials sampled, the overall average Pitcher barrel sample recovery for each dam site was good to very good as summarized in Table B-2.

Standard penetration tests were conducted by driving the thick-walled standard split spoon sampler with a 140-pound slide hammer falling freely through a distance of 30 inches. The number of hammer blows required to drive the sampler through three successive 6-inch intervals were recorded. The number of blows to penetrate the last 12 inches is referred to as the standard penetration resistance, N_{STD}. In some instances the sampler met refusal before being driven the full 18 inches due to the presence of gravel, cobbles, very hard soil or rock. In these instances a minimum of 50 blows was applied to the last 6-inch increment or fraction thereof. Samples from the split spoon were logged and placed in labeled heavy-weight zip-lock plastic bags for storage.

Details of materials encountered and data on the samples recovered are recorded on the Drilling and Sampling Logs accompanying this appendix. Results of SPT tests are shown in Figures B-9 through B-21 of this appendix.

In general, the field exploration program proceeded smoothly and, with the exception of Frog Hollow Dam, conditions encountered in the field were about as anticipated from review of SCS files. Data on Frog Hollow dam available to ESA prior to field exploration were incomplete, particularly in regard to the as-built configuration of the embankment, foundation (and old embankment) and location of the old and new service outlets. This situation resulted in siting boring FH-1 on the dam crest very close to or directly on the alignment of the old outlet pipe. Severe drilling fluid loss occurred in this hole below a depth of approximately 50 feet and either a void or very soft, unrecoverable material was present from a depth of 50.5 to 54.8 feet. Two additional borings were authorized by SCS and were drilled 6.5 feet on either side of FH-1. No fluid loss or voids were encountered in these holes. This condition is currently under review by SCS and it is ESA's understanding that some additional exploration is planned.

Table B-1

Locations of Exploratory Boreholes

Dam	Boring	Station	℄ Offset (ft)	Approx. Elevation (ft)
Green's Lake No. 2	GL2-1	7+00	--	6070
	GL2-2	5+75	64 u/s	6053
Green's Lake No. 3	GL3-1	11+20	--	6067
	GL3-2	9+45	50 u/s	6053
	GL3-2A	9+30	50 u/s	6053
Green's Lake No. 5	GL5-1	1+29	--	5940
	GL5-2	1+73	82 u/s	5926
Warner Draw	WD-1	15+33	--	2989
	WD-2	17+49	--	2989
	WD-3	15+45	210 u/s	2940
Stucki	STK-1	14+06	--	2814
	STK-2	17+85	--	2814
	STK-3	12+79	97 d/s	2782
Gypsum Wash	GW-1	33+65	--	2740
	GW-1A	33+55	--	2740
	GW-2	20+01	68 u/s	2725
	GW-3	26+83	--	2740
Frog Hollow	FH-1	11+26	--	119[1]
	FH-2	10+52	106 u/s	80[1]
	FH-3	11+19	--	119[1]
	FH-4	11+33	--	119[1]
Ivins Diversion No. 5	IV-1	12+48	--	3189
	IV-2	20+00	--	3189
	IV-3	36+11	--	3189
	IV-4	19+62	43 u/s	3179
	IV-5	20+02	42 d/s	3175

[1] arbitrary datum.

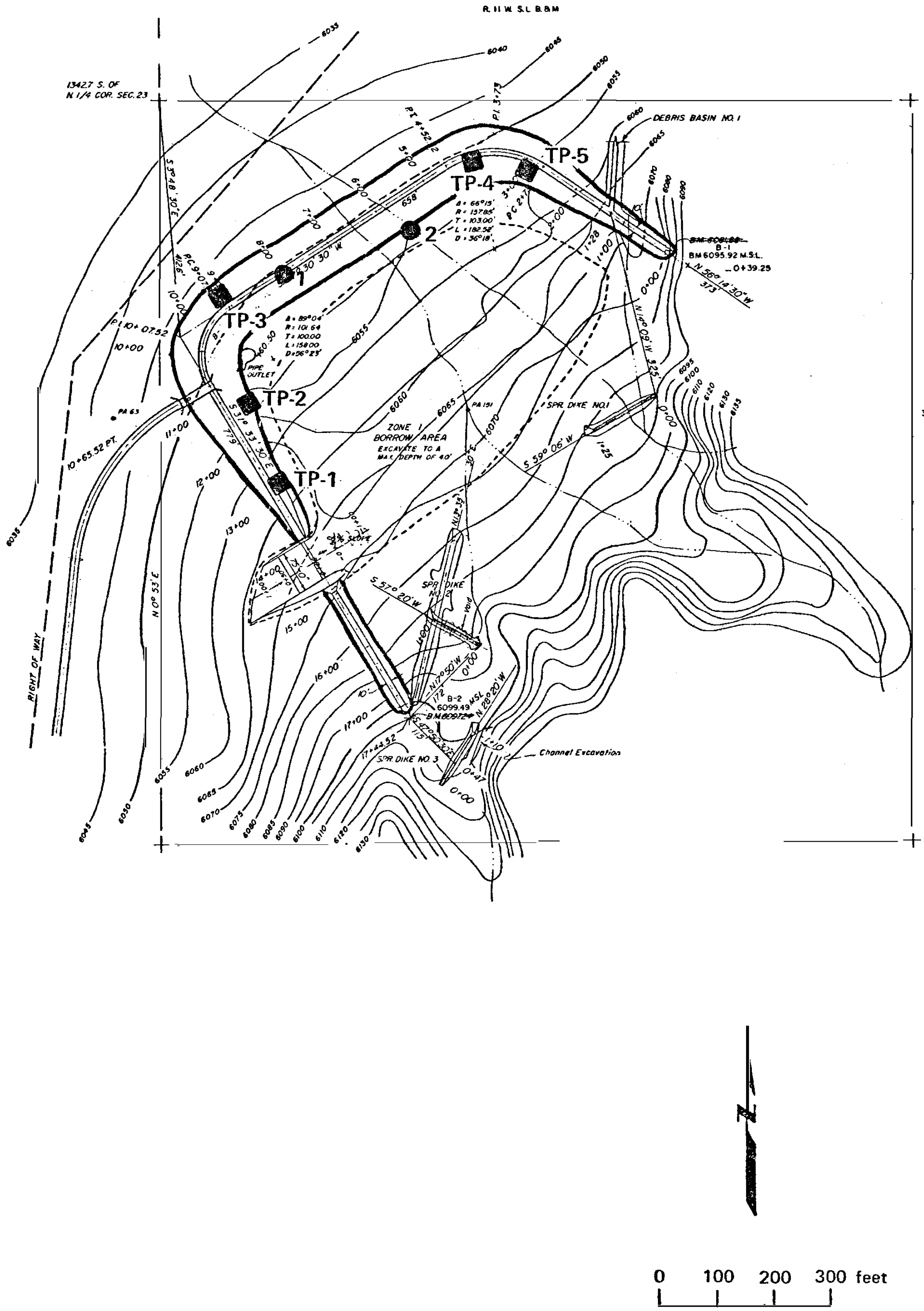
Table B-2

Summary of Drilling and Sampling

Dam	# of Borings	Total Footage	# PB Samples	# SPTs	AD/RD[1] Footage	Average Recovery Percent (Includes Embankment and Foundation)
Green's Lake No. 2	2	90.0	22	24	8.9	78
Green's Lake No. 3	3	98.3	23	23	16.2	75
Green's Lake No. 5	2	85.8	18	20	24.7	77
Warner Draw	3	160.9	38	40	12.2	95
Stucki	3	189.0	42	42	31.0	89
Gypsum Wash	4	115.7	26	26	21.8	92
Frog Hollow	4	224.0	31	31	104.9	90
Ivins Diversion No. 5	5	133.0	26	41	8.0	78
TOTALS	26	1,096.7	226	247	227.7	

[1]AD - Auger drilling.

RD - Rotary drilling.



Key

- ● ESA Borehole.
- ■ ESA Test Pit.

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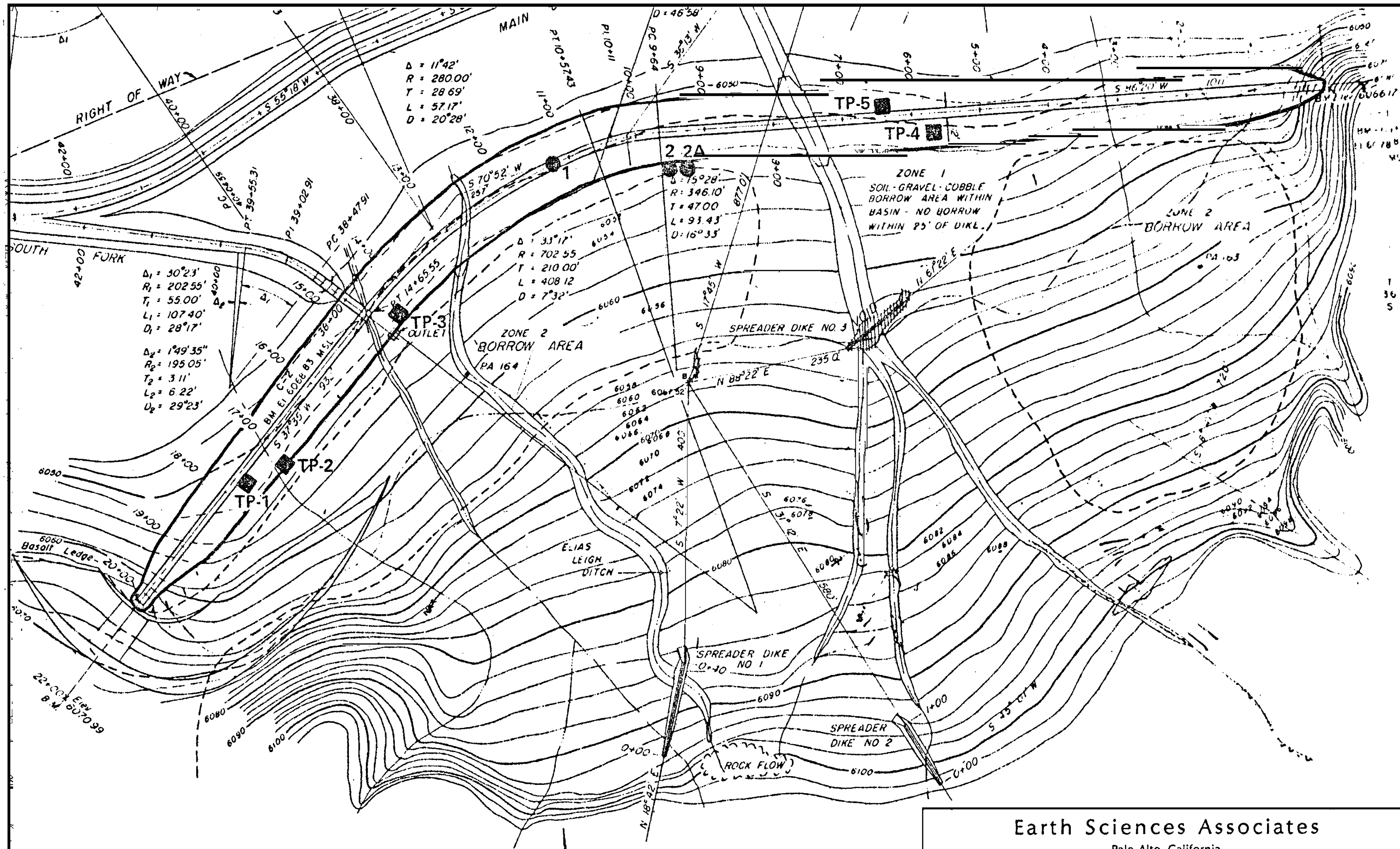
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

FIELD EXPLORATION LOCATION MAP
GREEN'S LAKE DAM NO. 2

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by [signature] Date 27 MAY 82	D118	B-1



Key

● ESA Borehole.

■ ESA Test Pit.

0 100 200 feet

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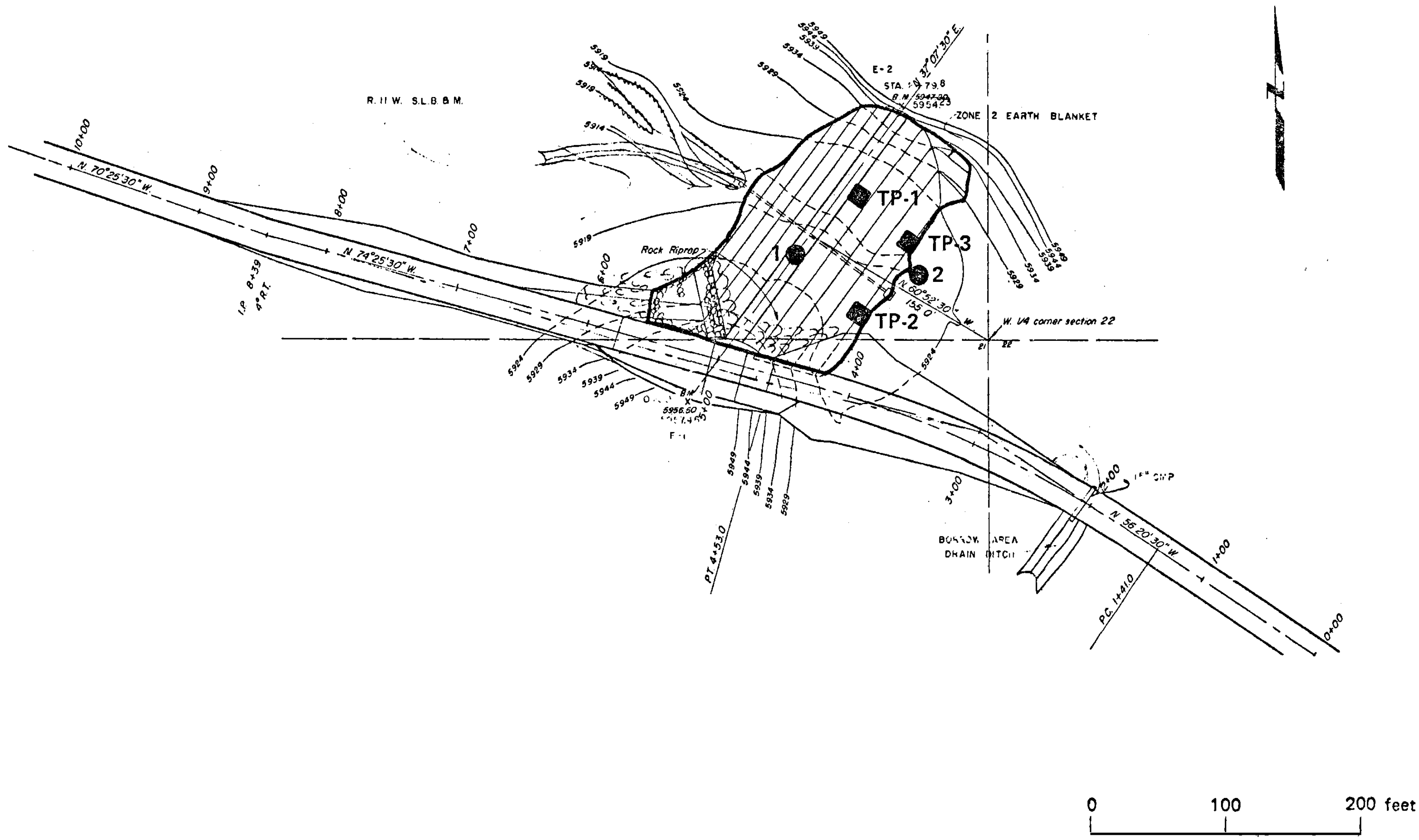
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
FIELD EXPLORATION LOCATION MAP
GREEN'S LAKE DAM NO. 3

Checked by MJT Date 5/27/82	Project No.	Figure No.
Approved by [signature] Date 27 May 82	D118	B-2



Key

● ESA Borehole.

■ ESA Test Pit.

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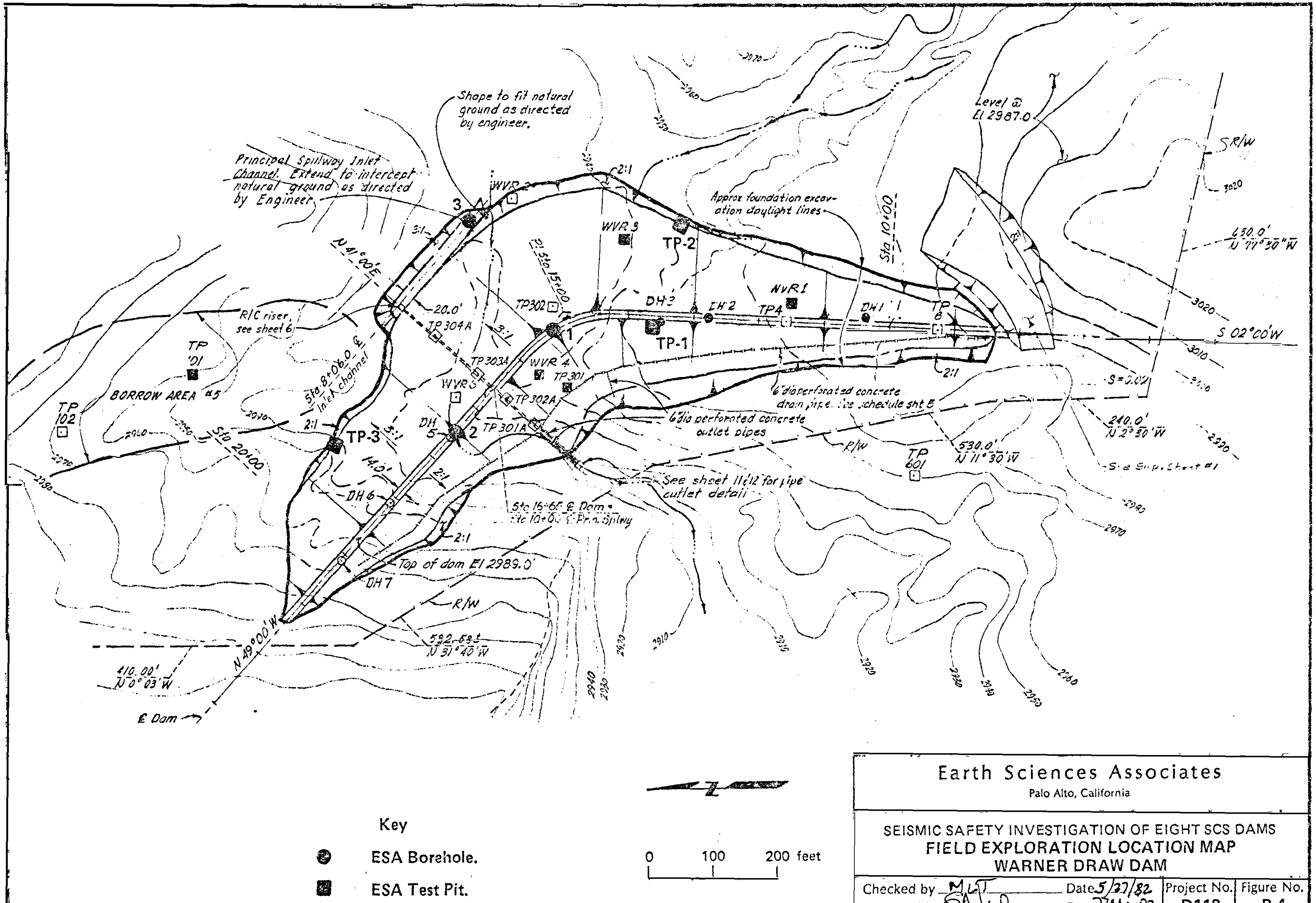
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
FIELD EXPLORATION LOCATION MAP
GREEN'S LAKE DAM NO. 5

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by EA Wilson Date 27 MAY 82	D118	B-3



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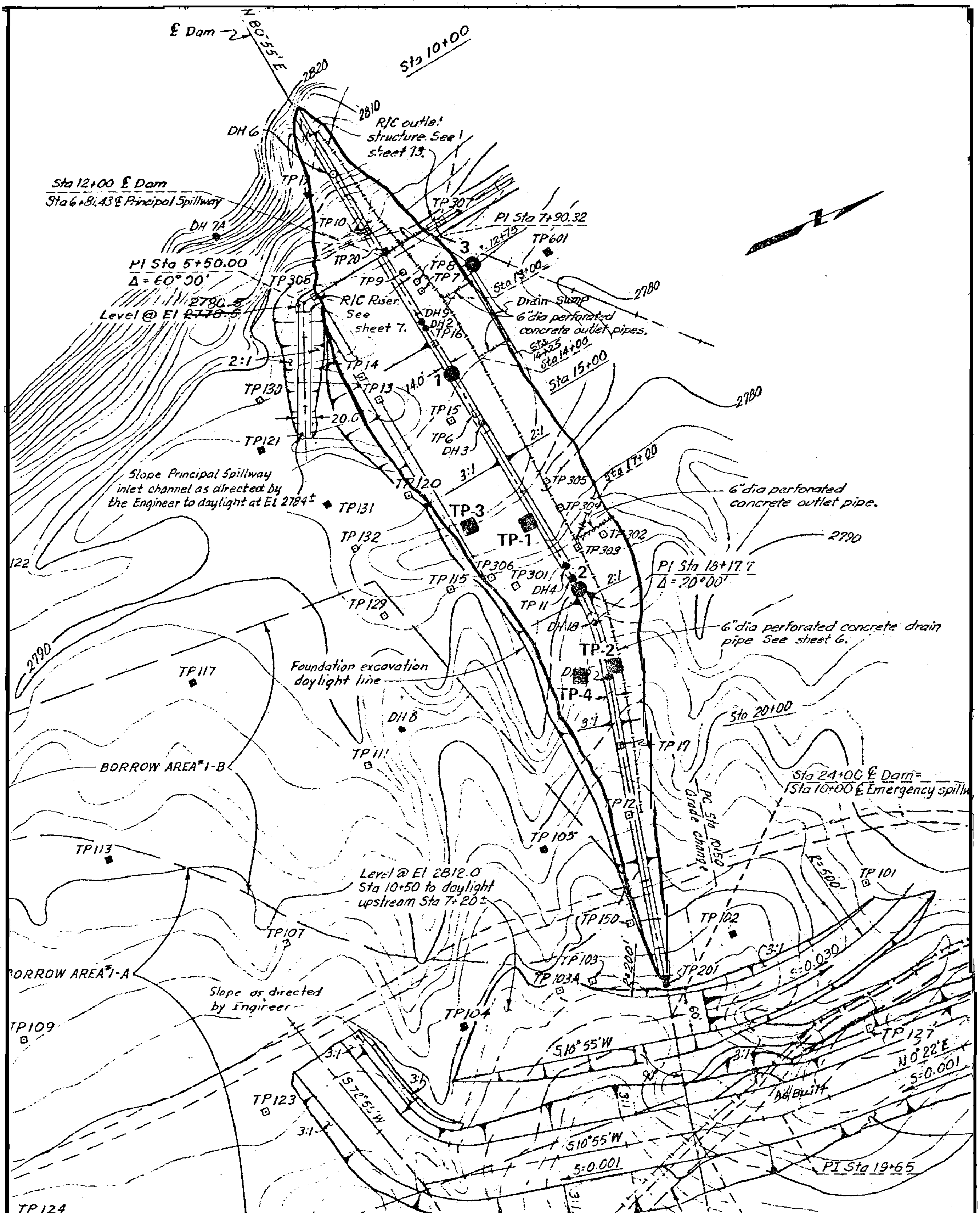
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
FIELD EXPLORATION LOCATION MAP
WARNER DRAW DAM

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by EA Wilson Date 27 May 82	D118	B-4



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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

FIELD EXPLORATION LOCATION MAP

STUCKI DAM

Key

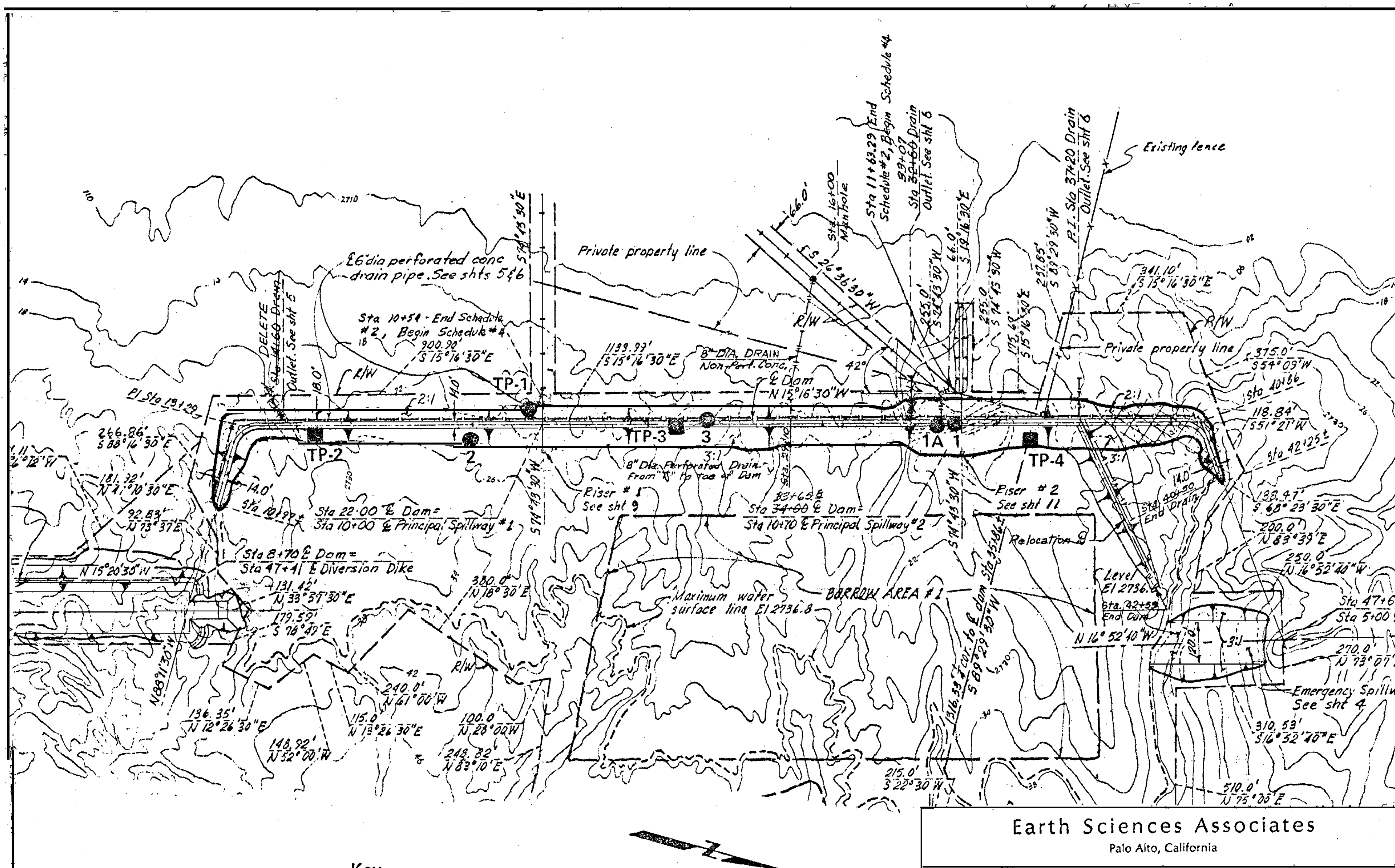
● ESA Borehole.

■ ESA Test Pit.

0 100 200

feet

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by E A Walton Date 27 May 82	D118	B-5



Key

● ESA Borehole.

■ ESA Test Pit.

0 200 400 feet

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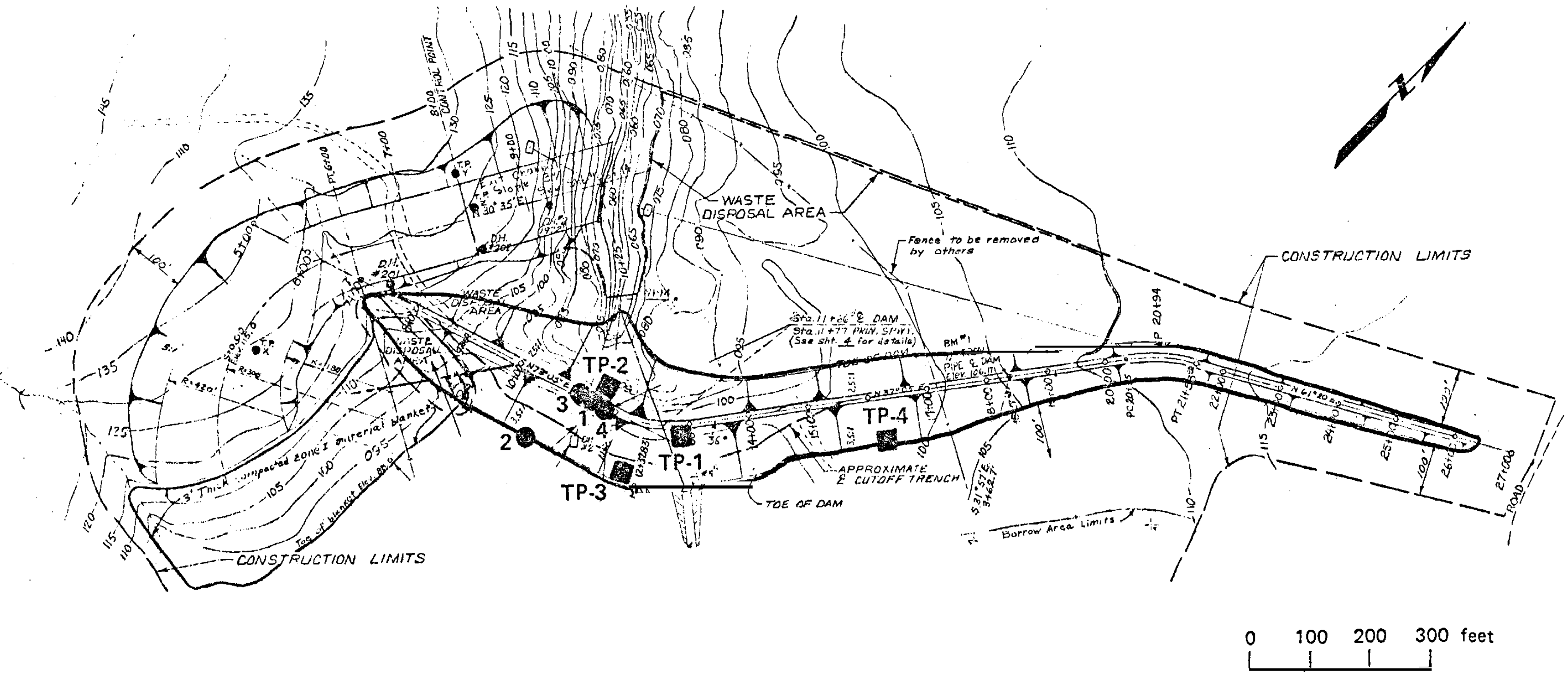
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

FIELD EXPLORATION LOCATION MAP

GYPSUM WASH DAM

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by [signature] Date 27 MAY 82	D118	B-6



Key

ESA Borehole.

ESA Test Pit.

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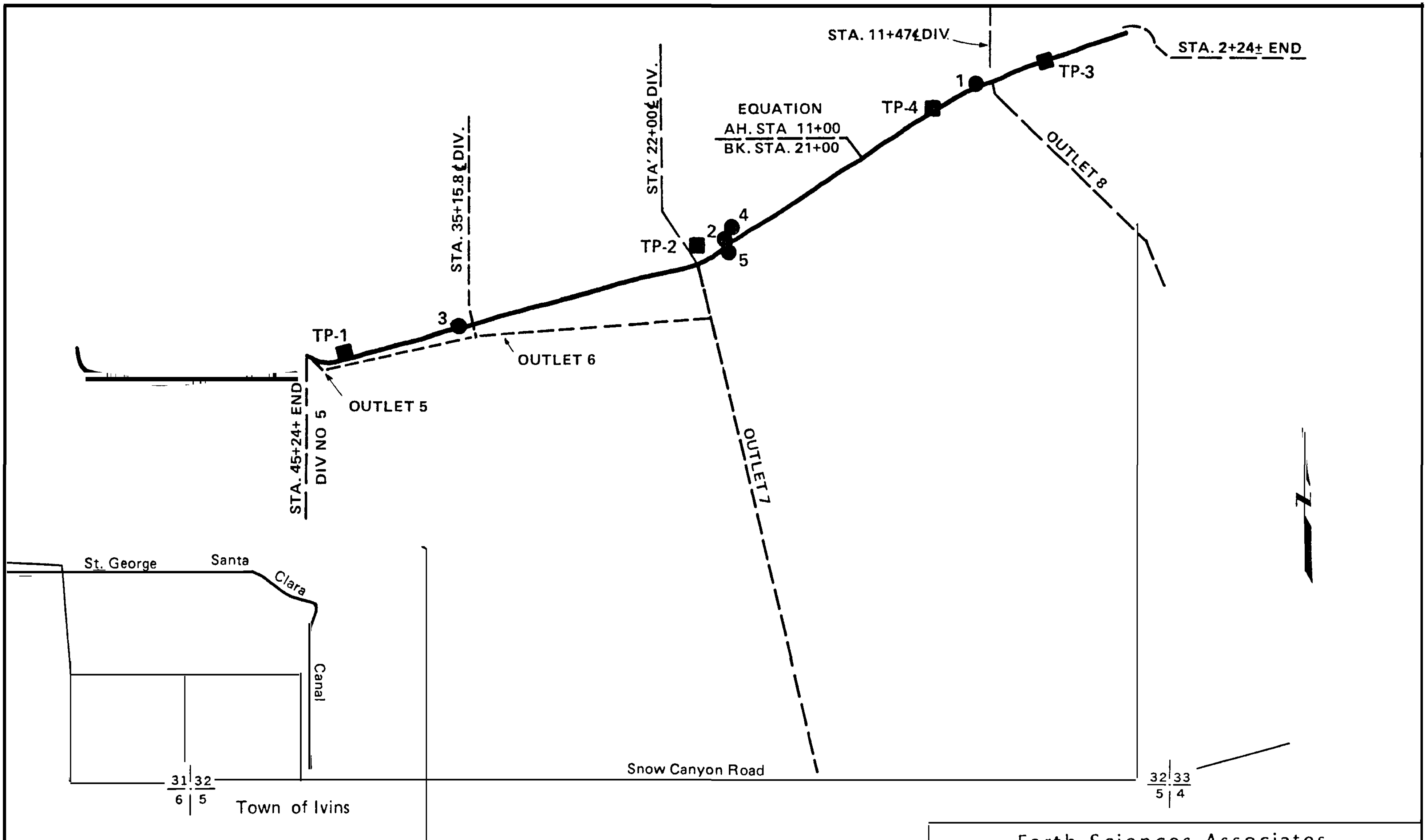
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

FIELD EXPLORATION LOCATION MAP
FROG HOLLOW DAM

Checked by MCT Date 5/27/82 Approved by [signature] Date 27 MAY 82	Project No. D118	Figure No. B-7



Note:
Advance copy of "AS BUILT" drawings: Alignment in respect to section corners is in error.

Key

● ESA Borehole.

■ ESA Test Pit.

0 500 1000
feet

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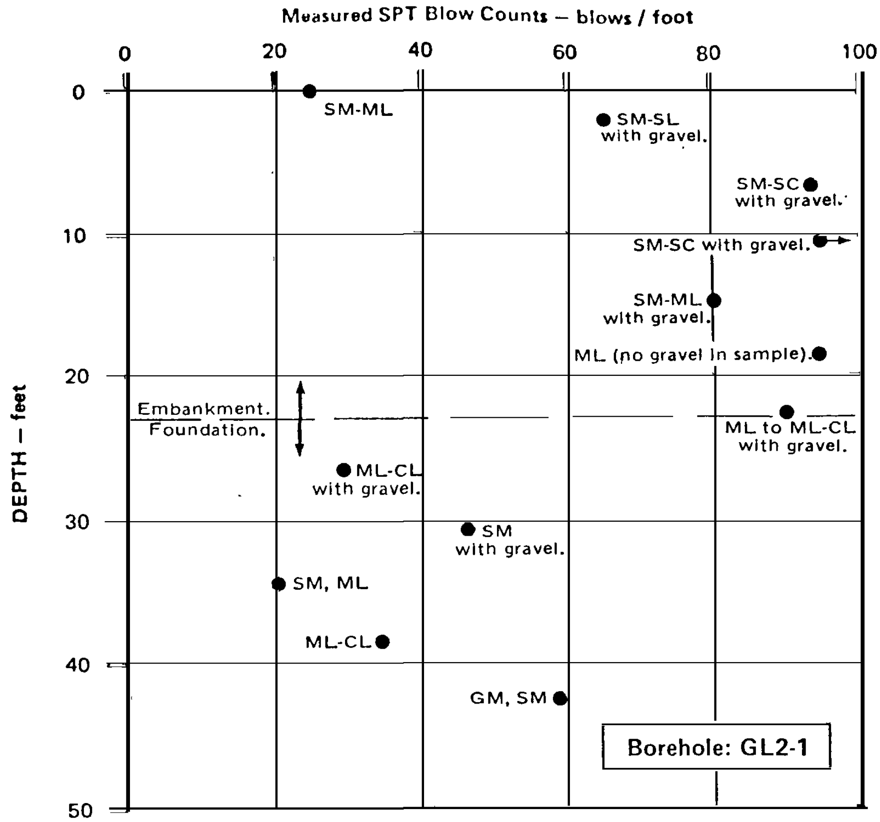
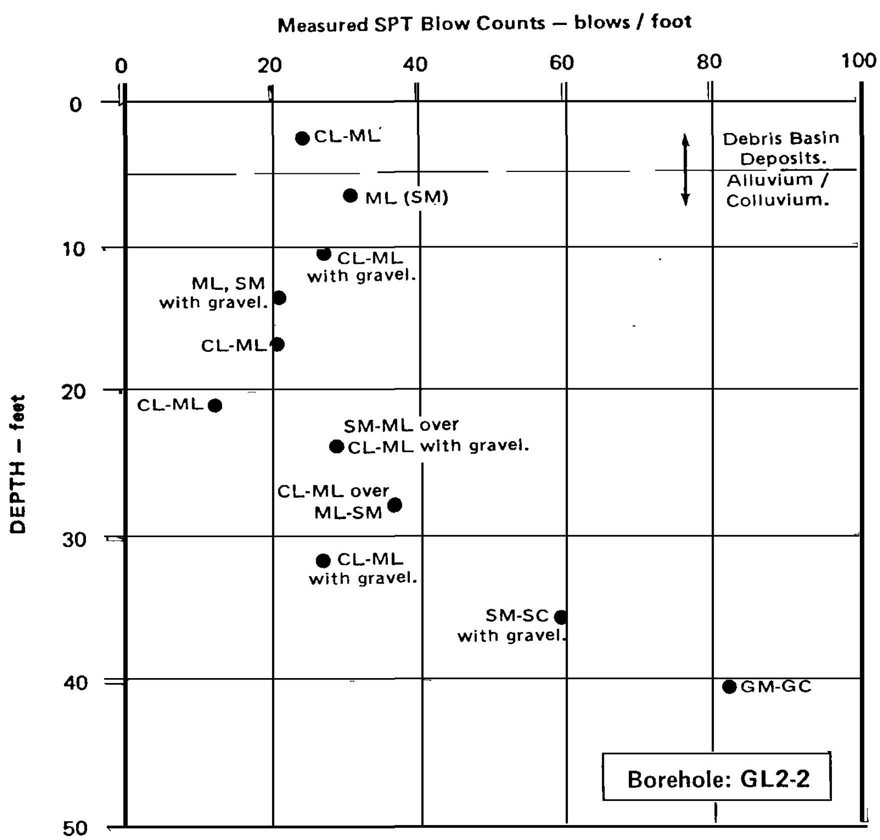
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
FIELD EXPLORATION LOCATION MAP
IVINS DIVERSION DAM NO. 5

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	B-8





Note: Soil classification next to symbol based on field observation.

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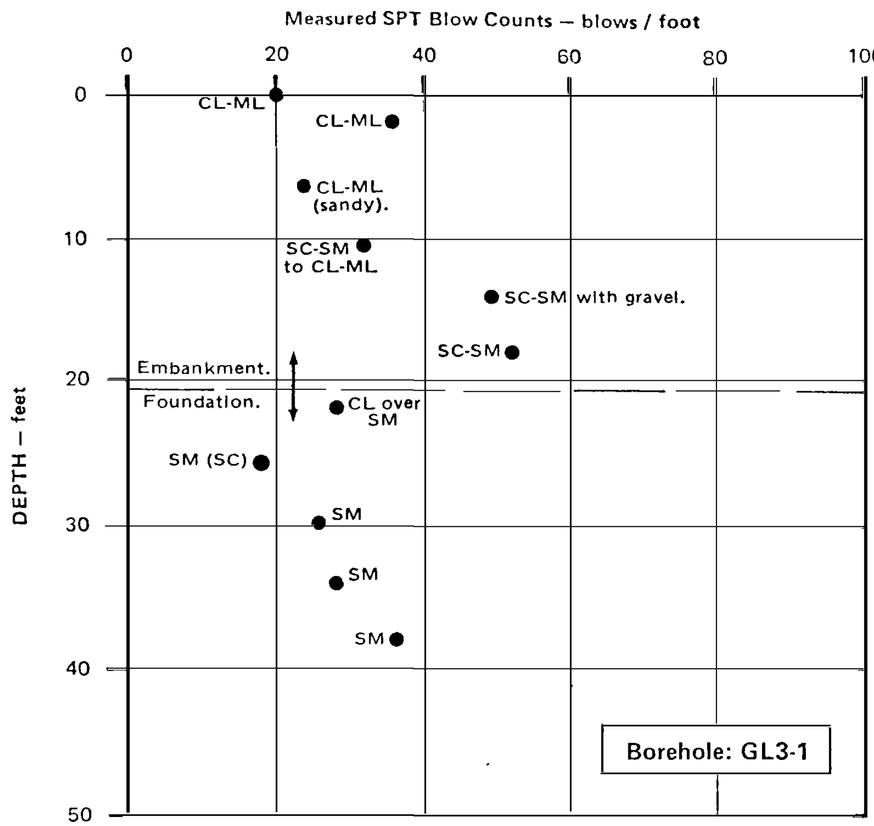
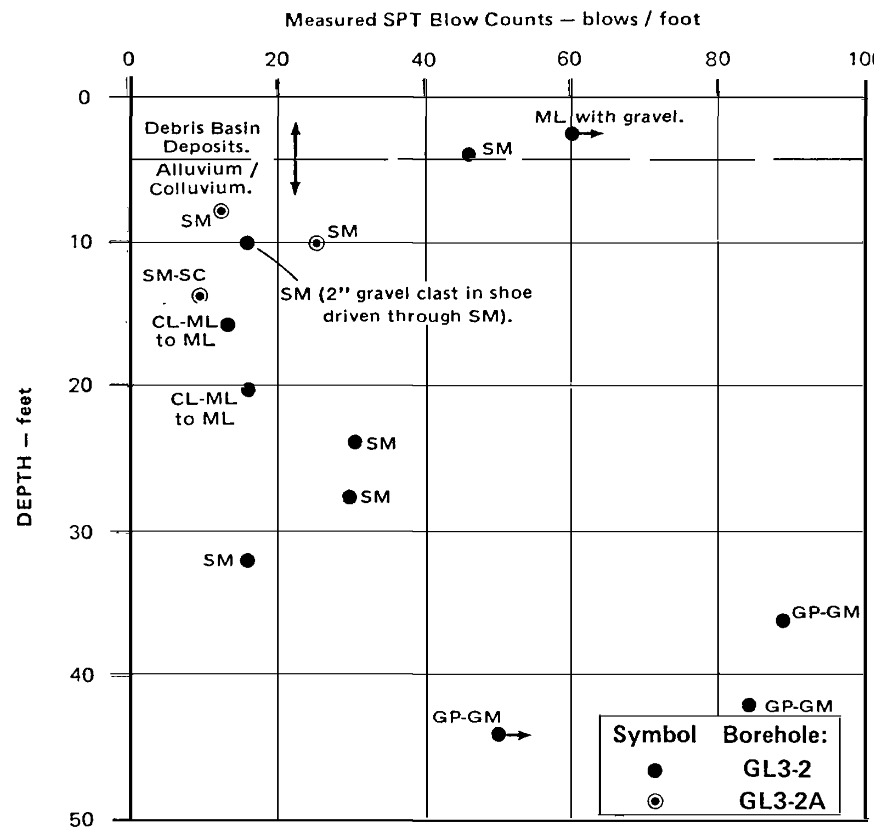
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **GREEN'S LAKE DAM NO. 2**		
Checked by MLT Date 5/27/82 Approved by EA Wilson Date 27 May 82	Project No. D118	Figure No. B-9





Note: Soil classification next to symbol based on field observation.

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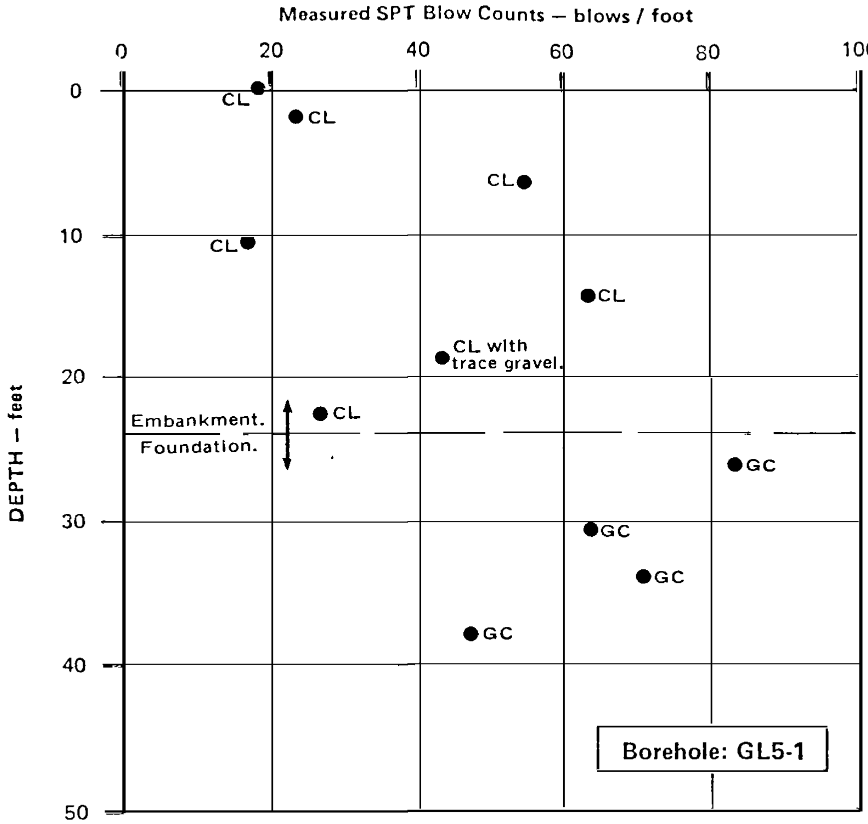
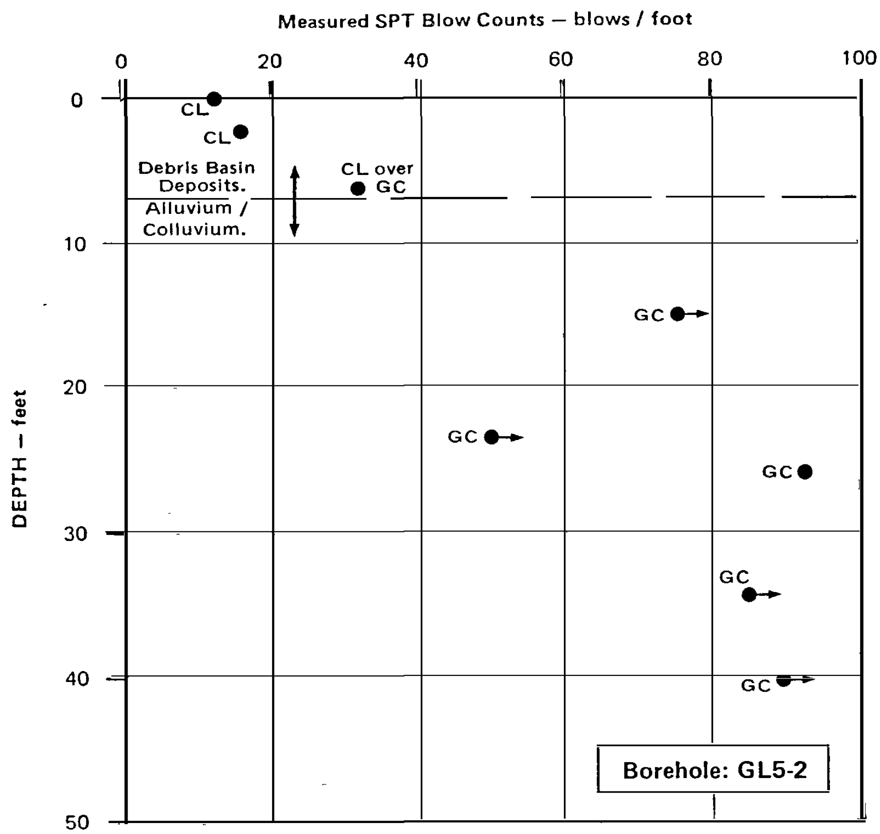
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

STANDARD PENETRATION TEST RESULTS

GREEN'S LAKE DAM NO. 3

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. B-10
Approved by EA Nelson	Date 27 May 82		



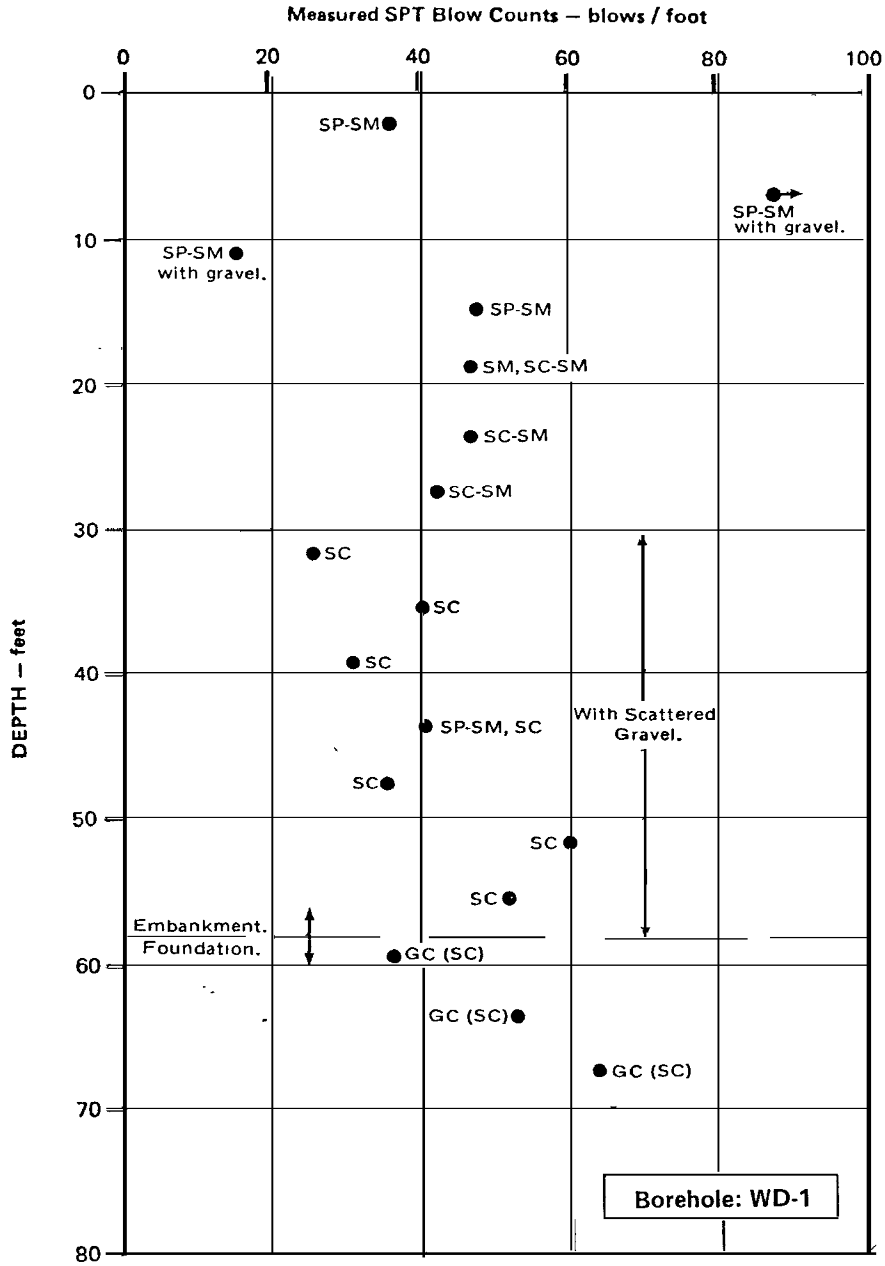


Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates
Palo Alto, California

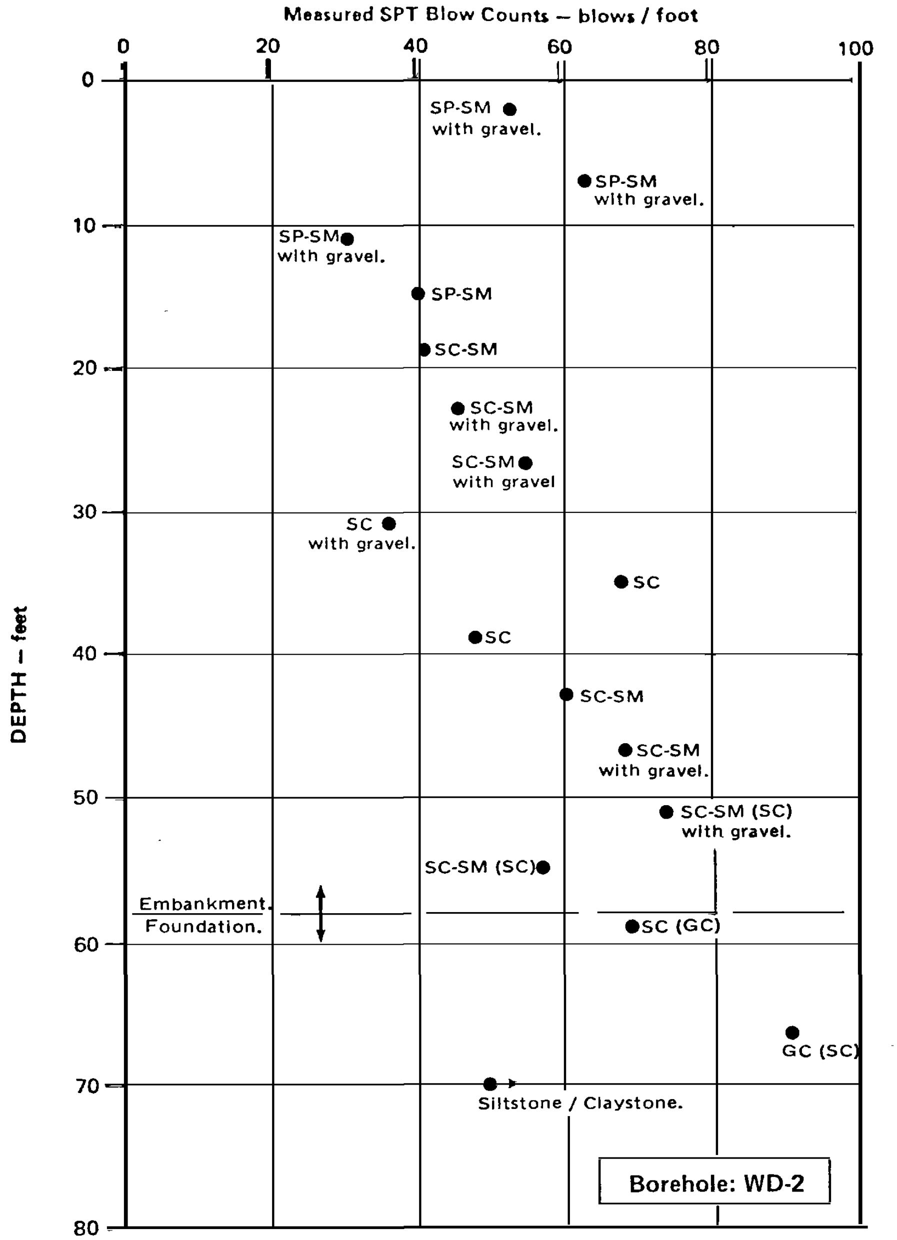
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
STANDARD PENETRATION TEST RESULTS
GREEN'S LAKE DAM NO. 5

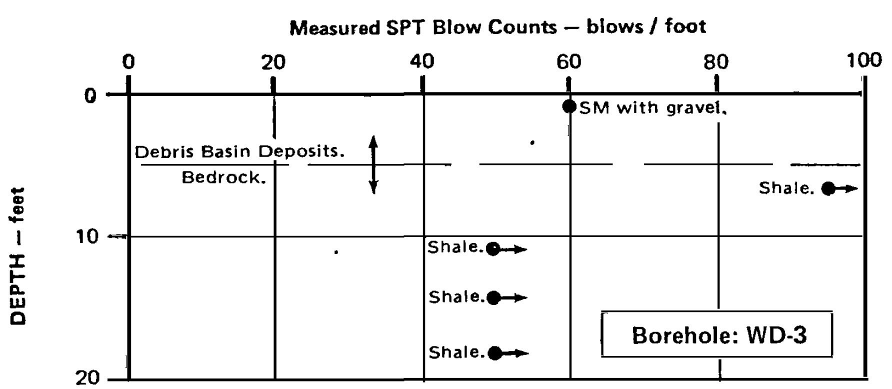
Checked by MLT	Date 5/27/82	Project No. D118	Figure No. B-11
Approved by EA Wilson	Date 27 May 82		



Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **WARNER DRAW DAM**		
Checked by MLT Date 5/27/82 Approved by [signature] Date 27 May 82	Project No. D118	Figure No B-12





Note: Soil classification next to symbol based on field observation.

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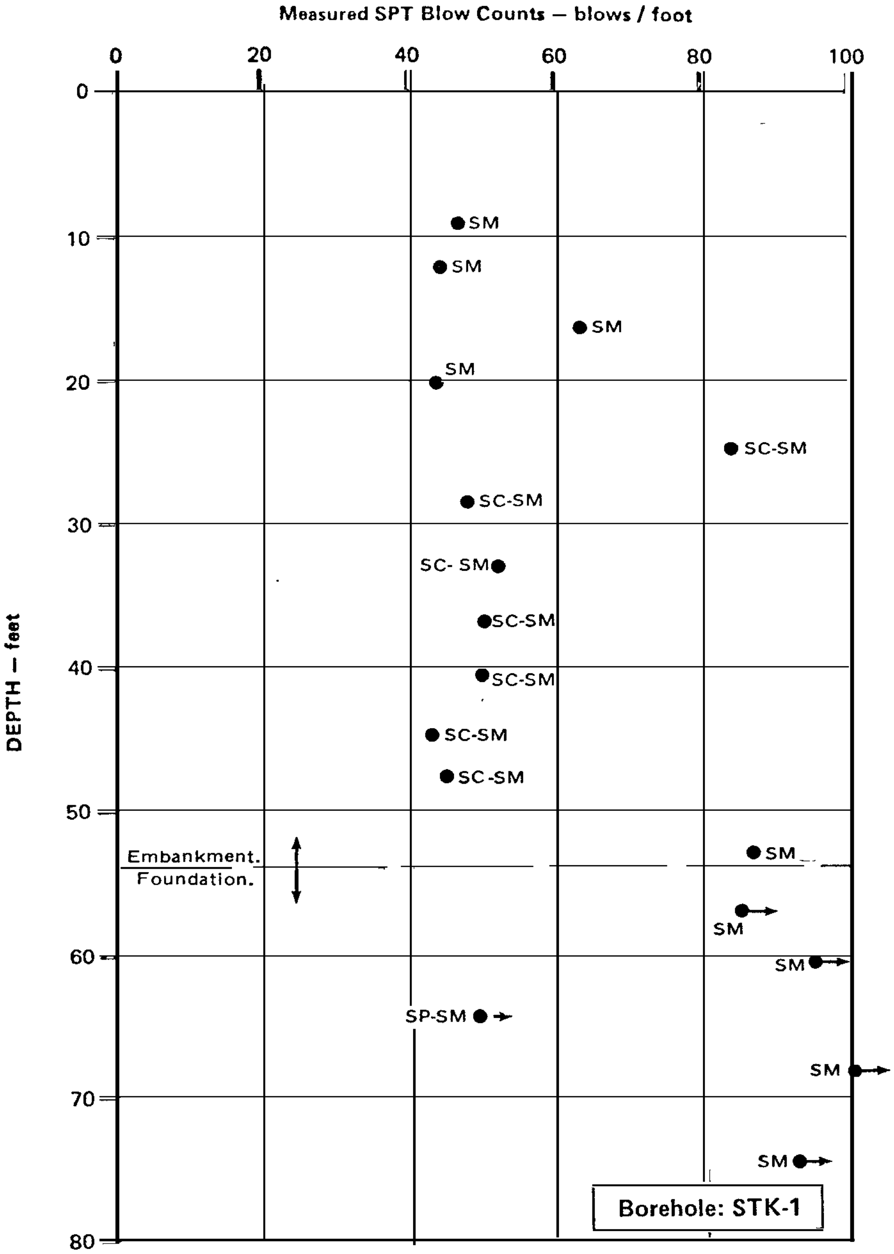
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

STANDARD PENETRATION TEST RESULTS

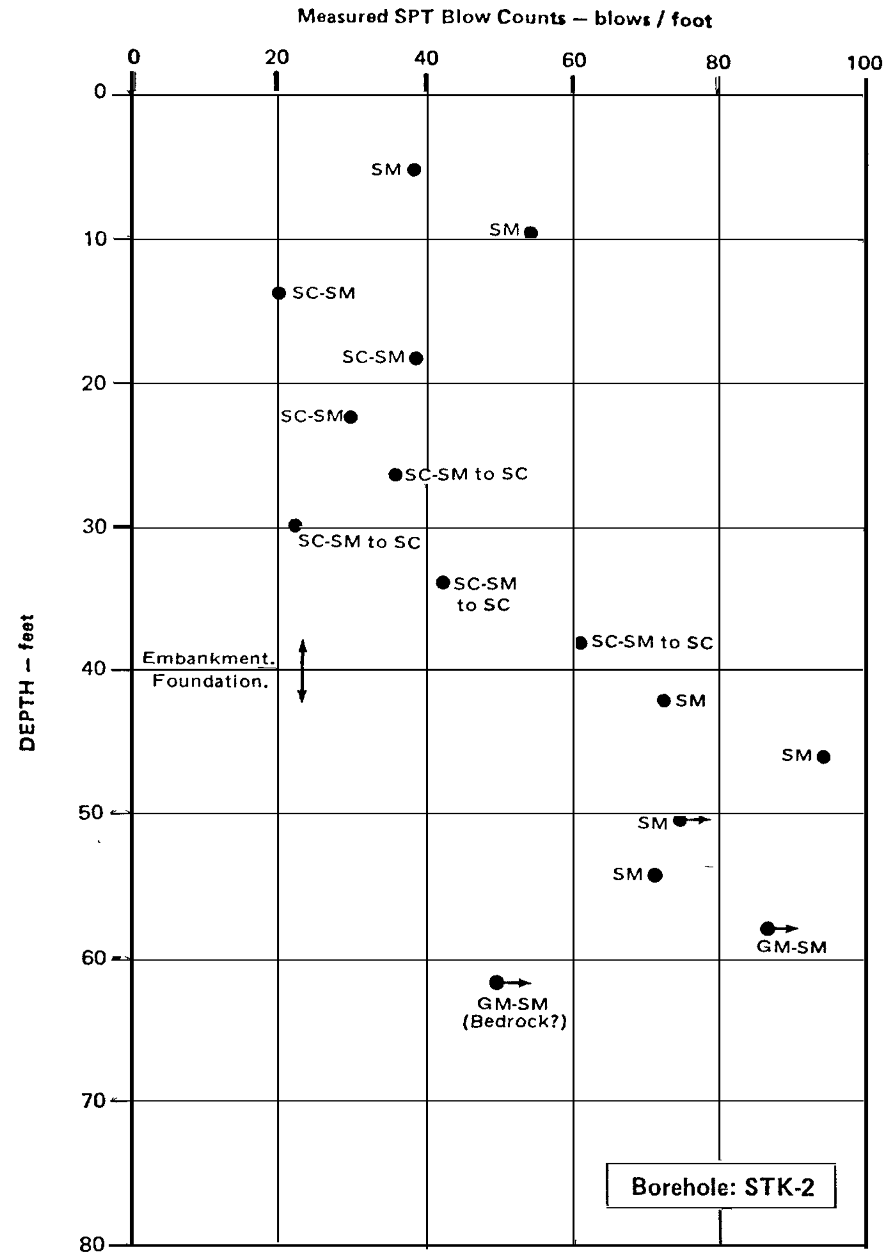
WARNER DRAW DAM

Checked by MLT	Date 5/27/82	Project No. D118	Figure No B-13
Approved by EA Nelson	Date 27 MAY 82		



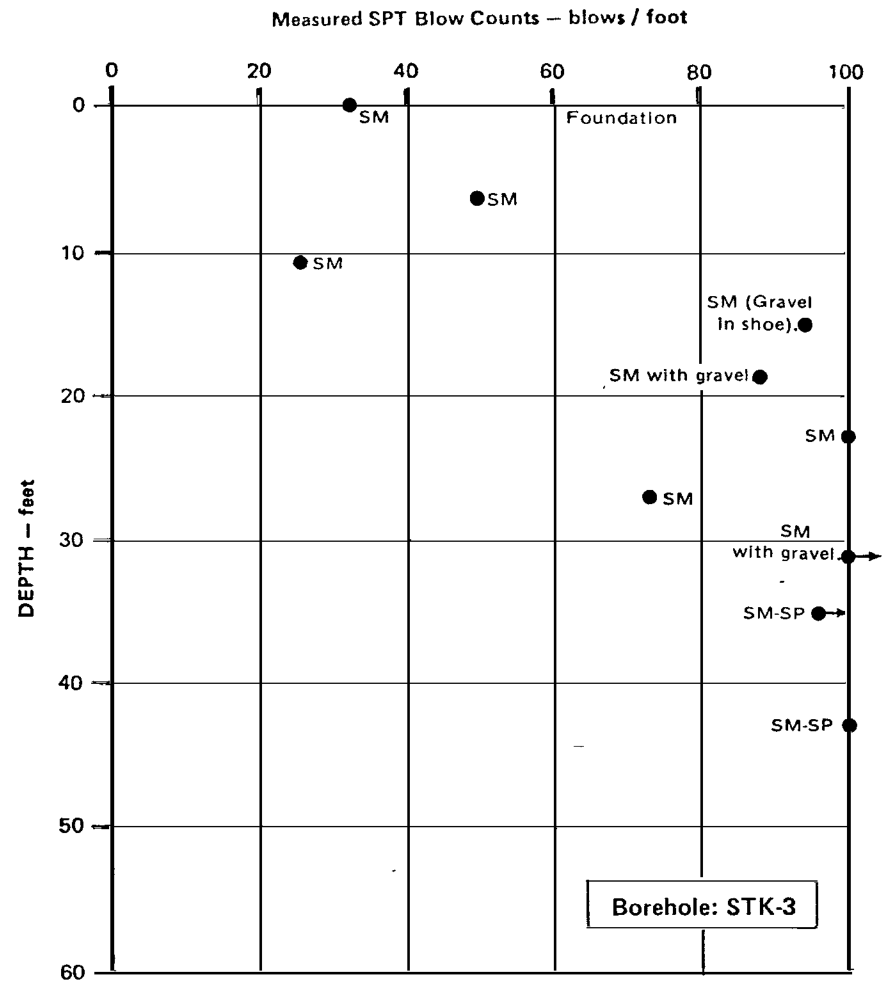
Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates Palo Alto, California			
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **STUCKI DAM**			
Checked by MLT	Date 5/27/82	Project No.	Figure No
Approved by EA Wilson	Date 7 MAY 82	D118	B-14



Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates Palo Alto, California			
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **STUCKI DAM**			
Checked by MGT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 29 May 82	D118	B-15



Note: Soil classification next to symbol based on field observation.

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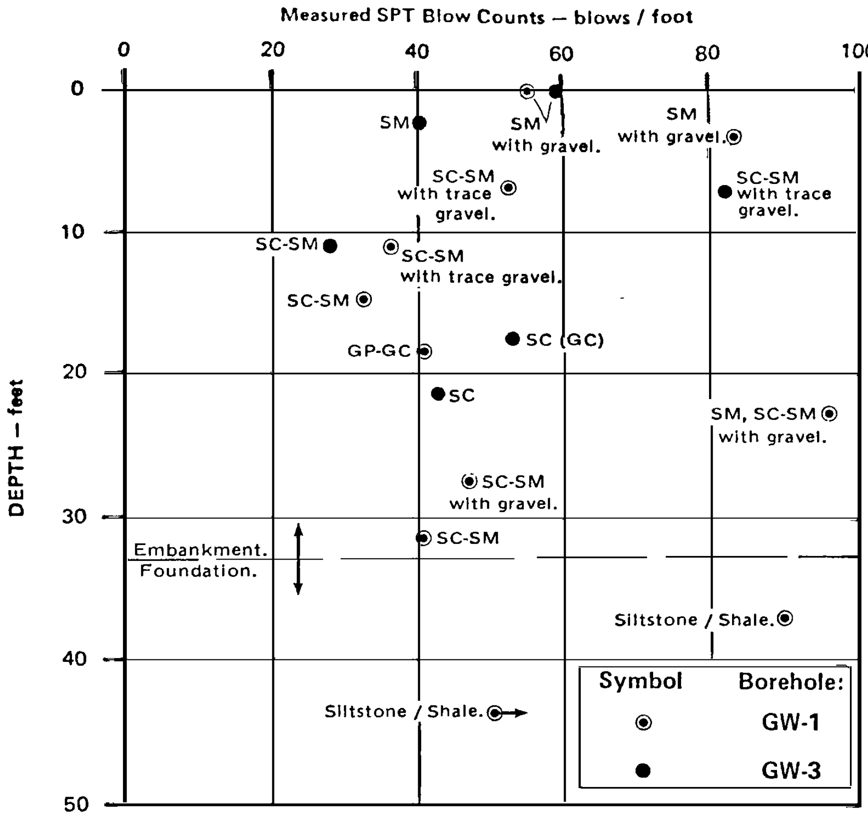
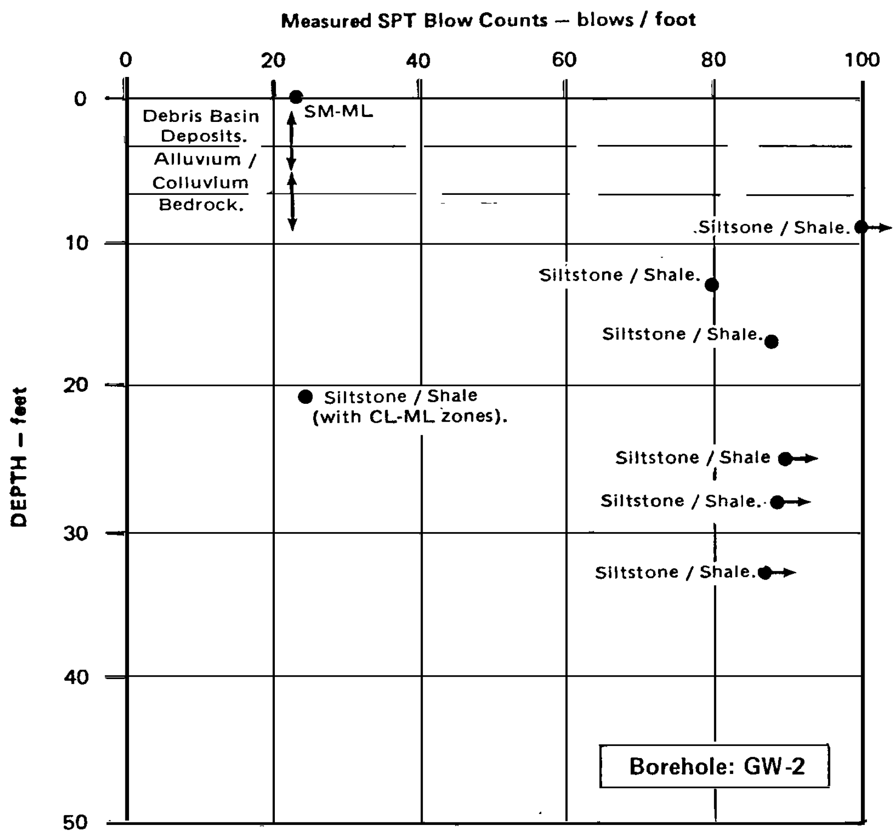
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

STANDARD PENETRATION TEST RESULTS

STUCKI DAM

Checked by MGT	Date 5/27/82	Project No.	Figure No.
Approved by EA Wilson	Date 27 MAY 82	D118	B-16



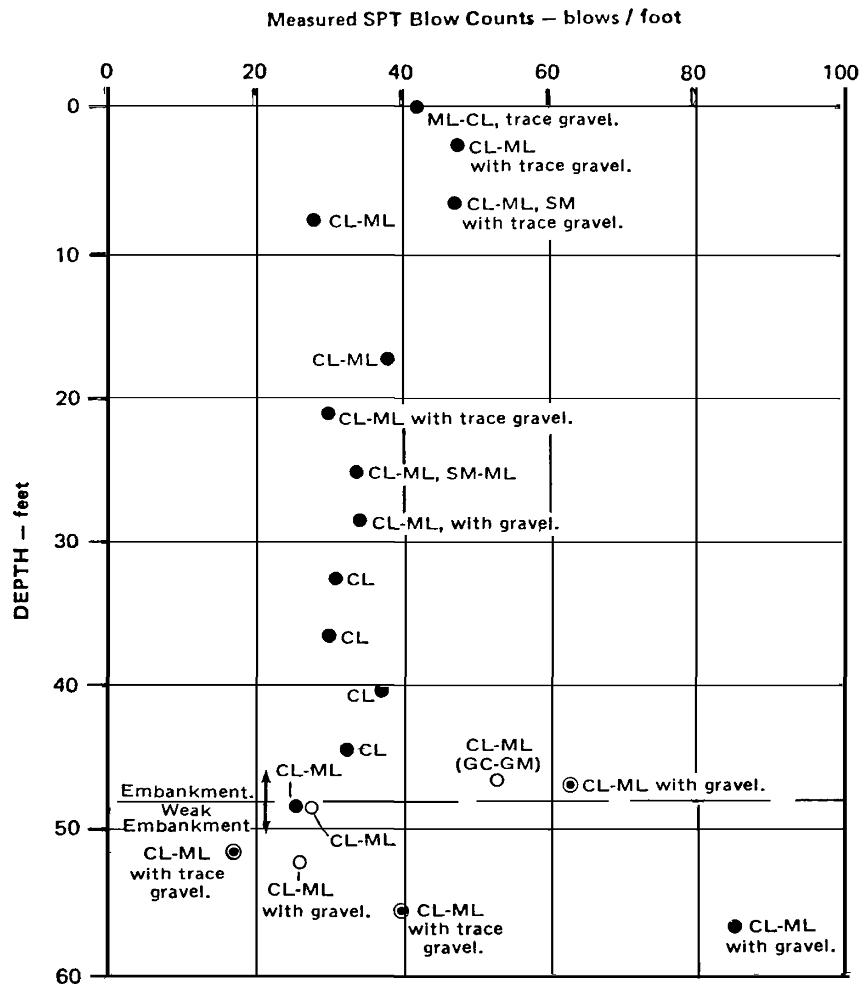


Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
STANDARD PENETRATION TEST RESULTS
GYPSUM WASH DAM

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. B-17
Approved by [signature]	Date 27 MAY 82		



Key

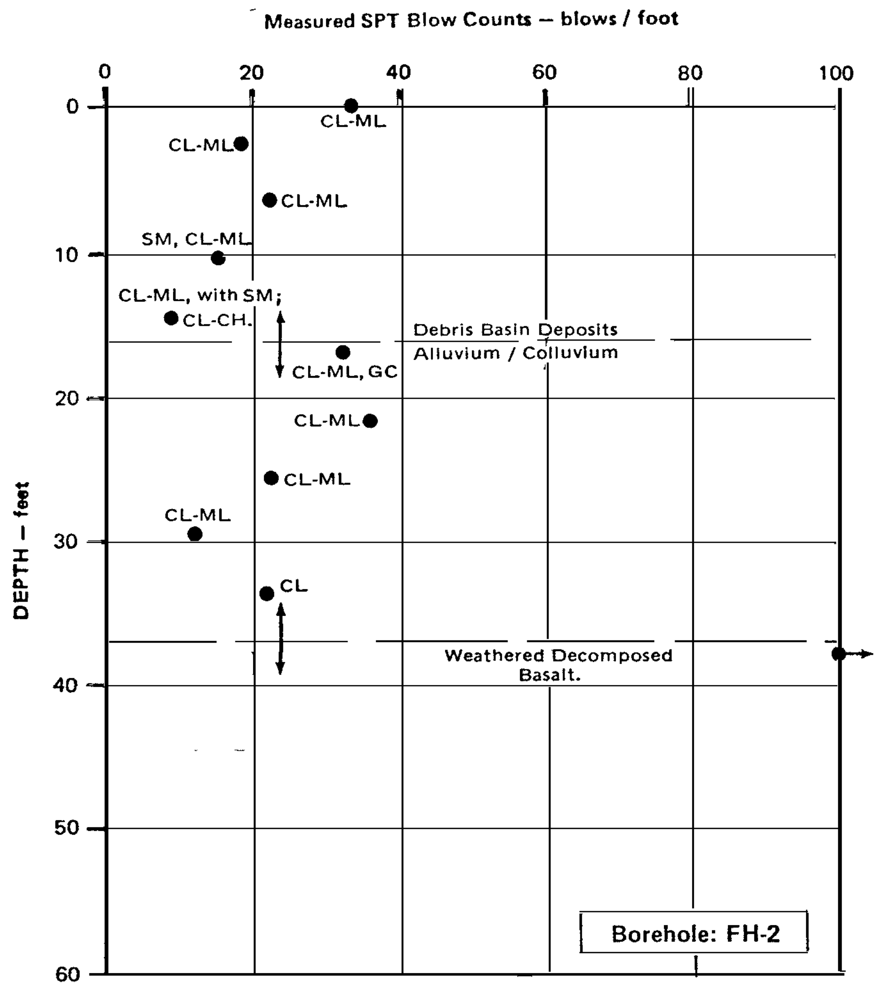
Symbol	Borehole:
●	FH-1
○	FH-3
◉	FH-4

Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates
Palo Alto, California

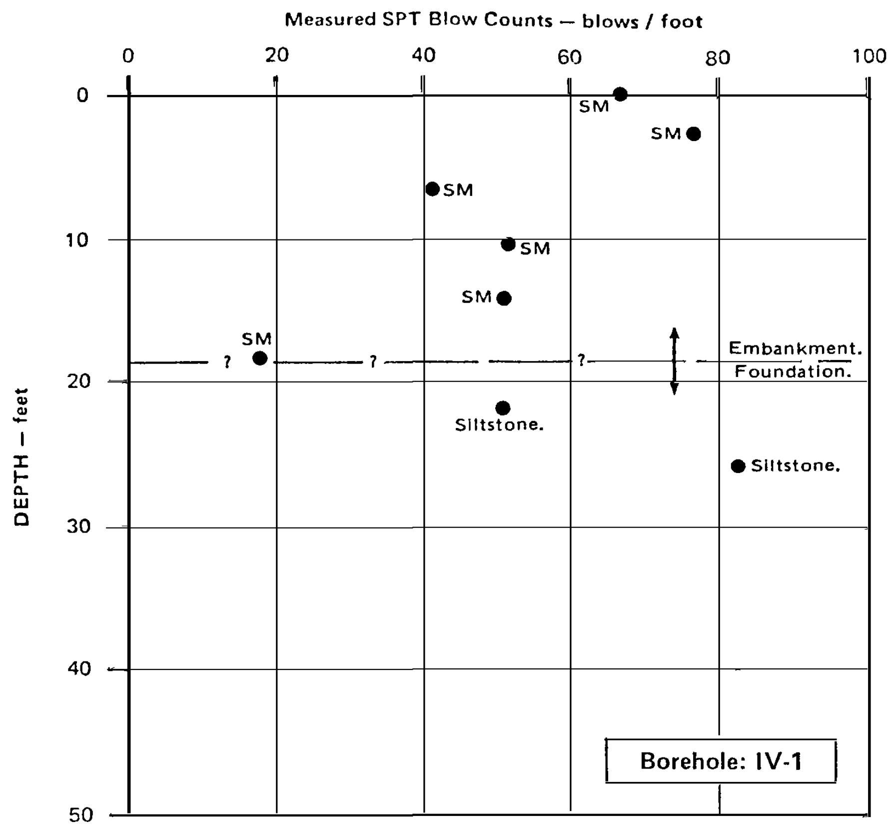
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
STANDARD PENETRATION TEST RESULTS
FROG HOLLOW DAM

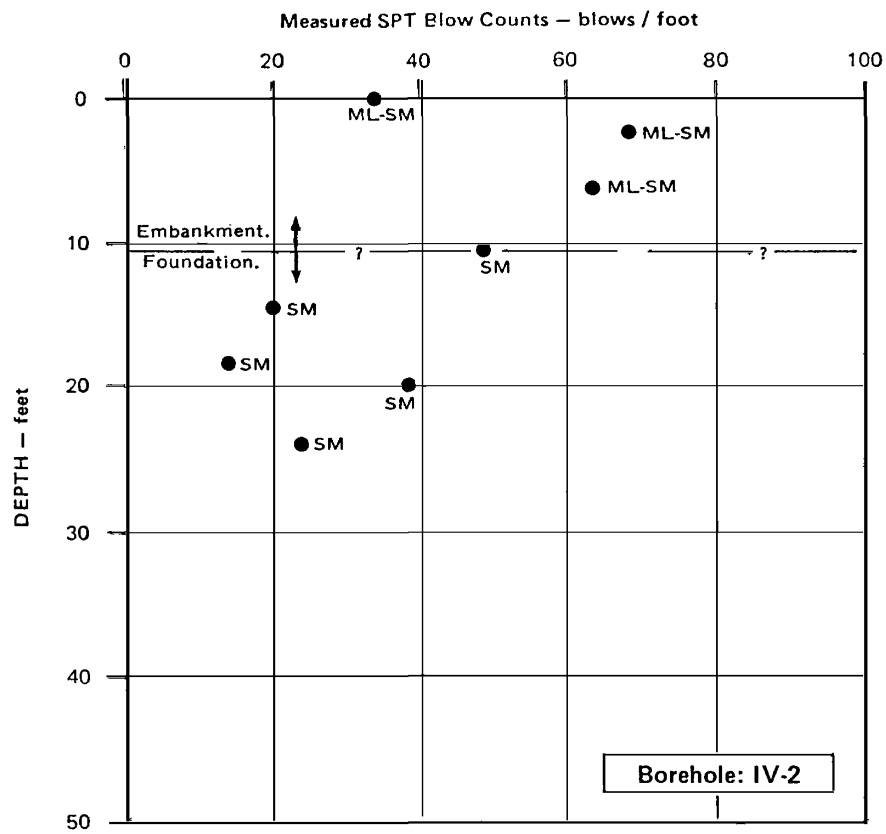
Checked by MGT	Date 5/27/82	Project No. D118	Figure No. B-18
Approved by CA Wilson	Date 27 May 82		



Note: Soil classification next to symbol based on field observation.

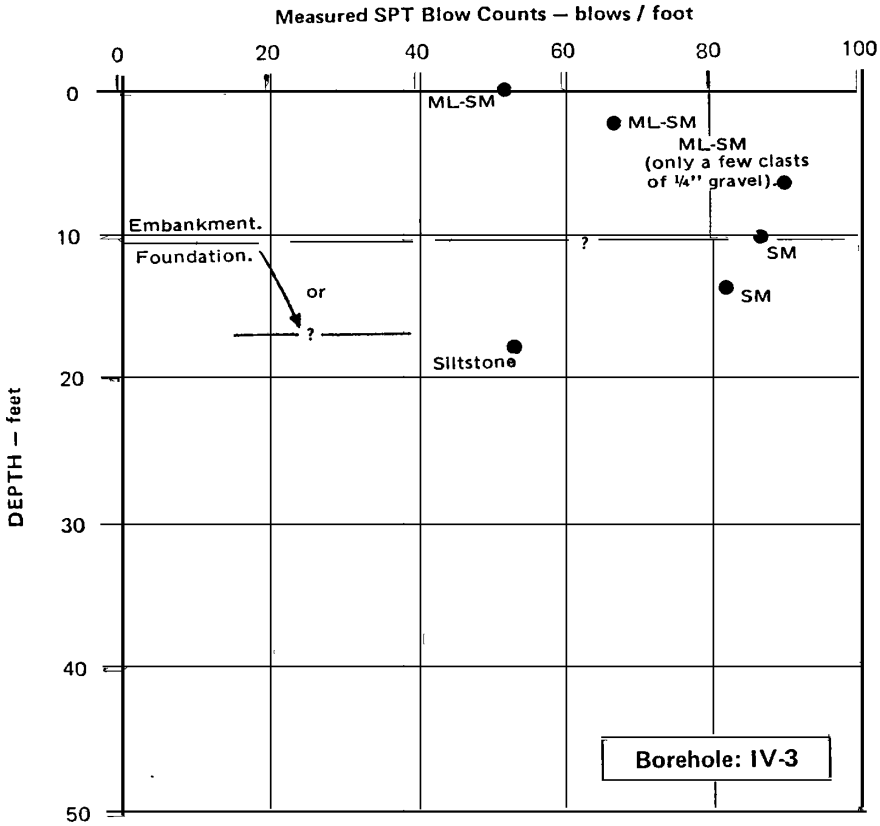
Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **FROG HOLLOW DAM**		
Checked by MLT Date 5/27/82 Approved by EAWilson Date 27 May 82	Project No. D118	Figure No. B-19

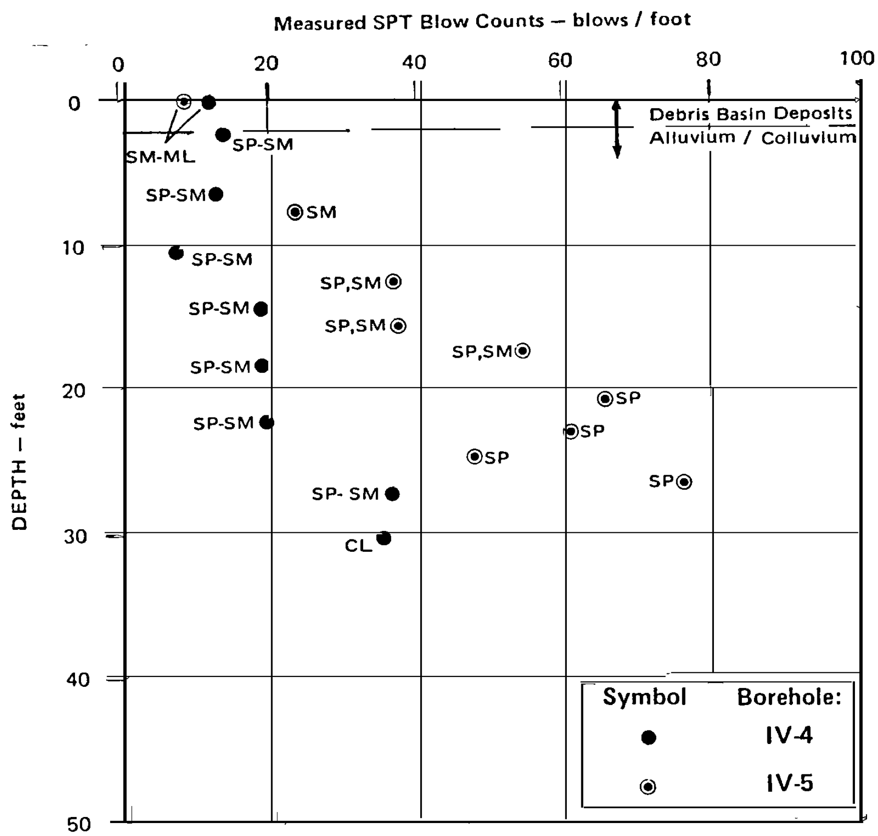




Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **IVINS DIVERSION DAM NO. 5**		
Checked by MGT Date 5/27/82 Approved by EA Nelson Date 27 MAY 82	Project No. **D118**	Figure No. **B-20**





Note: Soil classification next to symbol based on field observation.

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **STANDARD PENETRATION TEST RESULTS** **IVINS DIVERSION DAM NO. 5**		
Checked by MLT Date 5/27/82 Approved by EA Nelson Date 27 May 82	Project No. D118	Figure No. B-21

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams-Utah DATE DRILLED 10/2-3/81 HOLE NO. GLZ-1

LOCATION ℄ of crest, Dam #2 @ ~ sta. 7+00 GROUND SURFACE ELEV. ~6070' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb. 30"

SURFACE CONDITIONS dirt embankment WEATHER scattered clouds; cool; occ. v. light showers

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SM-ML	EMBANKMENT FILL 0.0-5.0' SILTY SAND to SANDY SILT: fines vary 40-60%, quick dilatancy, no toughness, non-v. low plastic; sand skip-graded w/ 5-10% m. to c. grained, 30-55% f.-v.f. grained; trace f. sandst., limest. gravel; strong reac. to HCl; dense; dry.	B-1	SPT-1 1.2/1.5	start drilling @ 5:00 w/ standard split spoon 4/0.5 9/0.5 16/0.5	25
2.0				RD		
			B-2	SPT-2 1.0/1.5	15/0.5 50/0.5 - gravel in shoe 10/2 end shift @ 5:45	65
4.0		2.0-3.5' - 1" st. gray grn. sandst clast in shoe of split spoon; specks, small soft nodules of $CaCO_3$	40	RD PB-1	10/3 start shift @ 7:30 sample w/ 3" Pitcher Barrel large (~3") cobble in end of tube - sample loose, disturbed - not weighed	
	SM-SC	5.0-11.5' SILTY to CLAYEY SAND: fines 10-30%, vary non- to low plastic; sand 55-85% pred. f. grained sand, about 15-20% of sand is m.-c. grained locally; gravel varies 5-15%, most 1/4-3/4", some 1" to 1½", pred. sandst. and limestone, subrounded to subang., mod. hard clasts; much disseminated $CaCO_3$ w/ strong reac. to HCl; dense to very dense; moist to wet (may be due to drill fluid).	B-3	1.18/2.5		
6.0						
			B-4	SPT-3 1.25/1.25	33/0.5 43/0.5 50/0.5 (hammering gravel)	93
8.0			41	RD PB-2	RD to clean past some coarse gravels	
			S-1	2.01/2.5	end of tube bent over, some slough on top of sample We = 5 lb. 13 oz. Wf = 17 lb. 2 oz.	
10.0						
			B-5	SPT-4 0.7/0.7	45/0.5 50/0.2 (no gravel in spoon - may be cobble at bottom)	95+
12.0	ML	11.5-14.4' SANDY SILT: 60-70% non-plastic fines; 30-40% f.-c. grained sand, w/ more c. sand than above unit as scattered grains; less to no gravel; compactness uncertain; moist to wet (may be due to drill fluid). grades to -	42	RD PB-3	RD to 12' to clean hole of large cobble - use 300 psi down-pressure	
	↓ grades		S-2	1.6/2.4	end of tube bent - 2" gravel slough (?) on top We = 5 lb. 13 oz. Wf = 15 lb 8¼ oz.	
14.0	SM-ML	14.4-18.8' SANDY SILT to SILTY SAND: fines vary 30-60%, non-v. low plasticity, quick dilatancy, low-no toughness; sand poorly to skip graded to 40-70% locally, ~5-10% is m.-c. grained; trace to few % f.-m. gravel, some black basalt, some sandst; strong reac. to HCl shows much dissem. $CaCO_3$; dense to v. dense; moist (drill fluid?). 18.6-18.8' mixing of units	B-6	SPT-5 1.0/1.0	30/0.5 50/0.5 refusal on cobble or gravel	80+
16.0			43	RD PB-4	RD to 16' to clean hole end of tube dented	
			S-3	2.54/2.5	We = 5 lb. 12 oz. Wf = 17 lb 6½ oz	
18.0						
	ML	18.8-22.8' SANDY SILT to SILT: mod. reddish brown (10R 4/6), 85-90% non-plastic fines, quick dilat., no toughness; 10-15% pred. v.f.-f. sand,	B-7 B-7A	SPT-6 1.3/1.45	35/0.5, 45/0.5 50/0.45 (no gravel in sample)	95+
20.0				RD		

SHEET 1 OF 2

PROJECT 0118, SCS Dams-Utah DATE DRILLED 10/2-3/81 HOLE NO. GGZ-1

base of embankment according to design drawings

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0 – 22.0	ML	18.8-22.8' SANDY SILT to SILT: (con't.) trace m.-c. sand as sandst. grains; no gravel; $CaCO_3$ as soft, white pods from 1/16" to 1/2", some dissem. $CaCO_3$ from mod. reac. to HCl; very dense; slightly moist.	44 S-4	PB-5 2.28/2.5	end of tube badly bent; w_e = 5 lb. 12½ oz.; w_f = not weighed	
		ALLUVIUM				
24.0	ML-CL	22.8-30.5' SANDY to GRAVELLY CLAY-SILT: mottled w/ ; fines 55-65%, vary from v. low-low plastic; 25-35% mod. well graded sand from f.-c. grained, commonly 10-20% f.-m. gravel, clasts 1/4-1" sandst, sltst, limest, clasts mod.-deeply weath., subang-subrnd-mod.-strong reac. to HCl, some nodules of $CaCO_3$; may be some gypsum; dense; moist.	B-8	SPT-7 0.8/1.0	35/0.5 55/0.5 refusal on gravel clast	90
				RD	RD to clean out hole	
26.0	GM-GC (?)		45 S-5	PB-6 2.30/2.5	end of tube dented; w_e = 5 lb. 11¾ oz.; w_f = 19 lb. 9 oz.	
28.0	ML-CL w/ gravel	24.0-26.5' may grade to >50% gravel in this interval (check S-5); otherwise as for rest of unit	B-9	SPT-8 1.1/1.5	19/0.5 14/0.5 15/0.5	29
30.0			46 B-10	PB-7 0.3/2.5	most of sample slipped from tube; remaining sample not weighed due to disturbance	
32.0	SM w/ gravel	30.5-34.5 SILTY SAND w/ GRAVEL: 30-40% low-non-plastic fines; 55-65% f.-c. sand, mod. well graded to skip-graded w/ most f. grained; 5-15% f.-m. gravel, most sandst. or gypsiferous (?) sltst. w/ distinctive gray color; strong HCl reac. to dissem. and pod-nodule $CaCO_3$; gypsum as white-gray subang. rlds - becomes soft, pasty in water, no reac. to HCl; dense to v. dense; slightly moist.	B-11	SPT-9 0.9/1.5	21/0.5 23/0.5 23/0.5; 2" gravel clast in shoe	46
34.0			47 S-6	PB-8 1.89/2.5	end of tube dented; w_e = 5 lb. 11¾ oz.; w_f = 16 lb. 12½ oz.	
36.0	SM, ML	34.5-38.5' SANDY SILT to SILTY SAND: fines 40-60%, v. low-non-plastic; 35-55% pred. f. grained sand, w/ some m.-c. sand; 5-10% scattered, pred. f. gravel of sandst, limestone; $CaCO_3$ and gyp. as in prev. unit; dense; slightly moist.	B-12	SPT-10 1.1/1.5	8/0.5 9/0.5 11/0.5	20
38.0			48 S-7	PB-9 1.45/2.5	end tube o.k.; no. 1' of sample slipping out end of tube; some slough on top; w_e = 5 lb. 12¼ oz.; w_f = 13 lb. 10½ oz.	
40.0	ML-CL	38.5-41.0(?) SANDY CLAY-SILT: similar to fine-grained portion of 22.8-30.5' above; varying is apparent in finer intervals w/ some darker, organic-rich layers; $CaCO_3$ as small pods and mottling is common; some charcoal present; dense-v. dense; slightly moist.	B-13	SPT-11 1.3/1.5	12/0.5 14/0.5 20/0.5	34
42.0	? GM, SM	41.0(?)-44.0' INTERBEDDED SILTY SAND and SILTY, SANDY GRAVEL: ; similar to 30.5-34.5' but w/ gravel 20-60%; gravels are limestone, some sandst.; dense-v. dense (?); slightly moist.	49 S-8	PB-10 2.22/2.5	end of tube badly bent; w_e = 5 lb. 12¼ oz.; w_f = 17 lb. 6¾ oz.	
44.0		B.H. @ 44.0	B-14	SPT-12 0.9/1.5	16/0.5 22/0.5 37/0.5	57

SHEET 2 OF 2

Terminated hole @ 44.0 w/ softy data; backfilled w/

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118, SCS Dams - Utah DATE DRILLED 10/3-4/81 HOLE NO. GCZ-2

LOCATION Upstream toe, Dam #2, ~ sta. 5+75; 64' u/s GROUND SURFACE ELEV. ~6053 (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lbs; 30"

SURFACE CONDITIONS brushy flat WEATHER scattered clouds; cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0 2.0	CL-ML	BASIN DEPOSITS 0.0-5.0' SANDY CLAYEY SILT: dark reddish brn. (5YR3/4); fines 50-60%, low to non-plastic, mod. quick dilatancy, low-no toughness; sand 35-45%, mod. well graded v.f.-m., only scattered c. grains; gravel to 5%, mostly 1/4-1/2", sandst., basalt, siltst.; strong reac. to HCl; some gyp. as white-gray nodules to 1/16"; dense; dry to slightly damp	50 S-1	ST-1 2.55/2.5	Pushed shelby tube (3") sample loose in tube w_e = 5 lb. 12 1/4 oz. w_f = 16 lb. 15 1/2 oz.	
			B-1	SPT-1 0.7/1.5	Drove standard splitspoon 10/0.5 11/0.5 13/0.5	24
4.0 6.0	? ML (SM)	ALLUVIUM 5.0-9.0 SANDY SILT to SILTY SAND: dk. red. brn. (5YR3/4); similar to above except fines are 40-60%, slightly less plastic; may be interbedded	51 S-2	PB-1 2.49/2.5	Sample w/ 3" Pitcher Barrel tube end bent, small void @ bottom, sample loose in tube w_e = 5 lb. 12 1/2 oz. w_f = 18 lb. 6 3/4 oz.	
8.0			B-2	SPT-2 1.0/1.5	16/0.5 15/0.5 16/0.5	31
10.0	? CL-ML	9.0-12.5' SANDY CLAYEY SILT: similar to 0.0-5.0', but may have slightly less f. sand.	52 S-3	PB-2 1.61/2.5	tube v. badly bent on end; some slough on top w_e = 5 lb. 15 1/2 oz. w_f = 14 lb. 2 3/4 oz.	
12.0	CL-ML (w/ gravel)	10.5-12.5' as above, but w/ several 0.1-0.2' zones w/ 5-10% c. sand and f. gravel; gyp. as 1/16" nodules common 12.5' color grading less reddish	B-3	SPT-3 /1.5	6/0.5 13/0.5 14/0.5	27
				RD	RD w/ drag bit, then w/ tricone bit to push lg. cobble into sidewall	
14.0	SM-ML	12.5-17.0' INTERBEDDED SANDY SILT, SILTY SAND, GRAVELLY-SANDY SILT: fines are all low-non-plastic, quick dilatancy, low-no toughness; sand from f.-c. grained, commonly subang.; gravel from 1/4" to 2 1/2", sandst, basalt common; gyp present; strong reac. to HCl; dense to med. dense; moist to wet (may be due to drill fluid):	53	PB-3 0.0/1.0	PB-3 run on cobble - end badly bent, no sample recovered	
	ML, SM		B-4	SPT-4 1.0/1.5	21/0.5 7/0.5 14/0.5	21
16.0	ML	12.5-13.9' gravels to 1/2" w/ most 1/8-1/4", may be 5-15% of total	54 B-5	PB-4 1.43/2.0	end of tube badly dented, sample not weighed	
18.0	CL-ML	13.9-14.5' intbds 1/2-3/4" of silty sand and sandy silt 13.9-17.0' pred. sandy silt, w/ lg. gravel clasts of basalt to 2 1/2"; probably w/ cobbles	B-6	SPT-5 1.2/1.5	9/0.5 9/0.5 12/0.5	21
20.0		17.0-33.2' SANDY to GRAVELLY CLAYEY SILT: reddish brn. (5YR4/3);	55 S-4	PB-5 0.86/2.5	end of tube bent, sample saturated, disturbed	

PROJECT D118, SCS Dams - Utah DATE DRILLED 10/3-4/81 HOLE NO. GL2-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	CL-ML	17.0-33.2' SANDY to GRAVELLY CLAYEY SILT: (con't)	S-4 (con't.)	PB-5 (con't.)	w_e = 6 lb. 0 oz. w_f = 10 lb. 8 oz. (sample disturbed)	
		fines vary ~50-65%, locally may be 45-50%, low plasticity, mod. quick dilatancy, low-no toughness; sand varies 35-55%, mod. well graded, f.-c. grained, probably more f.-m. than c.; gravel varies 5-20%, pred. f.-m. clasts from 1/4-1", some c. clasts, small cobbles, pred. sandst., limestone, some siltst.; generally strong reac. to HCl throughout; gyp. as small nodules and mottles common; med. dense-dense, stiff-v. stiff; slightly moist.		SPT-6 0.75/1.5	5/0.5 6/0.5 6/0.5	12
22.0			B-7		10/3 end shift @ 5:30	
	SM-ML (w/ gravel)		56	PB-6 0.0/0.8	10/4 start shift @ 7:45 PB-6 on gravels/cobbles	
24.0				RD	RD to 24' to pass gravels/cobbles	
			B-8	SPT-7 1.1/1.5	20/0.5 15/0.5 14/0.5	29
	CL-ML		B-9			
26.0			57	PB-7 1.18/2.0	end of tube badly torn, may be some slough on top w_e = 5 lb. 15½ oz. w_f = 12 lb 11¼ oz.	
	SM-ML (w/ gravel)	22.5-24.5' more gravelly to 20-25% w/most clasts <½"; locally may grade to sand; fines slightly less plastic	S-5			
28.0	CL-ML	26.0-27.8' similar to 22.5-24.5'		RD	RD to clean hole to 28'	
	ML-SM	28.4-29.1' grades to sandy silt-silty sand w/ up to 5-10% m.-c. grained sand;	B-10	SPT-8 1.1/1.5	11/0.5 16/0.5 21/0.5	37
30.0	CL-ML (w/ gravel)	fines slightly less plastic than rest of unit	58	PB-8	end o.k. good sample w_e = 5 lb. 15½ oz. w_f = 15 lb. 4½ oz.	
		29.1-33.2' gravel more common to 10-15%; crude approx. horizontal stratification; thin stringers, mottled zones of $CaCO_3$, gyp. fairly common	S-6	1.60/2.0		
32.0			B-11	SPT-9 1.0/1.5	10/0.5 12/0.5 15/0.5 (spoon contained 0.5' of c. sand, f. gravel slough)	27
	GM-GC to SM-SC	33.2-46.0' INTERBEDDED CLAYEY SILTY GRAVEL and CLAYEY SILTY SAND: dk. reddish brown (5YR3/4);	59	PB-9 0.0/1.0	PB-9 on gravel/cobble - no recovery	
34.0		fines vary 20-40%, low-v. low plasticity, mod. quick dilatancy, low toughness; sand varies from 15-20% in gravelly sections to 50-60% in sandy sections, mod. well graded; gravel varies 5-15% in sandy sections, 50-60% in gravelly sections, sizes from 1/4"-3" with most 1/4-1" clasts are pred. sandst., limestone w/ some basalt; $CaCO_3$ throughout w/ strong HCl reaction; gyp common; dense-v. dense (?); slightly moist.		RD	RD in gravelly unit & pushing gravels/cobble from above?	
36.0			B-12	SPT-10 1.05/1.5	20/0.5 24/0.5 36/0.5 (1" ss gravel in shoe & bottom of spoon)	60
38.0				RD	RD thru gravelly section, smooths some @ 38.8'	
			60	PB-10 0.87/1.3	tube bent on end, small void @ end of sample w_e = 5 lb. 14¼ oz. w_f = 10 lb. 14 oz.	
40.0		35.5-37.0' crude, approx. horizontal bedding 0.1-0.2' thick apparent in variations of grain size in sand and gravel	S-7			
	GM-GC (SM-SC)		B-13	SPT-11 0.3/0.8	32/0.5 50/0.3 (refusal) (spoon w/ 0.7' c. sand, f. gravel slough)	82+
42.0		40.3-46.0 grades predominantly gravelly w/ less sandy interbeds		RD	RD thru gravelly section	
44.0		43.0' recovered 2½" hd limestone cobble in PB-11 run	61 B-14	PB-11 0.2/1.3	only recovered 2½" cobble	

PROJECT D118, SCS Dams - Utah DATE DRILLED 10/3-4/81 HOLE NO. GZZ-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
44.0	GM-GC	33.2-46.0' INTERBEDDED CLAYEY SILTY GRAVEL and CLAYEY SILTY SAND: (con't)		RD	RD to clean cobbles/gravel from hole
			B-15	SPT-12 0.8/1.5	17/0.5 25/0.5 44/0.5 69
46.0		B.H. @ 46.0'			Terminated hole @ 46' w/sufficient data Backfilled hole w/ mud and cuttings

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams-Utah DATE DRILLED 10/1-2/81 HOLE NO. GL3-1

LOCATION Crest of Dam #3 @ ~ sta. 11+20 on ℄ GROUND SURFACE ELEV. ~6067' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS dirt embankment WEATHER scattered clouds, sprinkles occ., cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N_f
0.0	CL-ML	EMBANKMENT FILL 0.0-5.0 CLAY-SILT: dark grayish brown (10 YR 4/2); fines 85-90%, low plastic, mod. quick dilatancy, low toughness; sand 10-15%, poorly graded, most f.-v.f. grained; trace fine gravel scattered throughout; strong reac. to HCl throughout; med. dense to dense; dry to v. slightly moist w/inc. depth.	B-1	SPT-1 1.0/1.5	Drove standard split spoon 5/0.5 9/0.5 11/0.5	20
				AD	Auger w/5" flight auger to 2.0	
2.0			B-2	SPT-2 1.2/1.5	16/0.5 17/0.5 19/0.5	36
				RD	set surface casing to 1.0' set-up mud tub; no mud	
4.0			19 S-1	PB-1	Sample w/3" Pitcher Barrel, Part of sample slipped from tube @ surface We = 5 lb. 11 oz. Wf = 18 lb. 8 1/4 oz.	
6.0	CL-ML	5.0-7.0 SANDY CLAY-SILT: as for 0.0-5.0' but w/15-25% f.-v.f. sand. w/some flecks of black carbonaceous material; w/ yel. small pods (1/16") of $CaCO_3$.	B-3	2.34/2.5		
	SC-SM to CL-ML	7.0-12.5' CLAYEY SILTY SAND: to SANDY CLAYEY SILT: as above but w/ fines 45-60%; sand pred. f.-v.f. grained, trace of m. grained sand scattered throughout, sandst., basalt are lith. of larger grains.	B-4	SPT-3 1.3/1.5	15/0.5 11/0.5 12/0.5	23
8.0			20 S-2 (B-5)	PB-2 2.07/2.5	Part of sample slipped from tube We = 5 lb. 10 1/4 oz. Wf = 17 lb. 15 oz.	
10.0			B-6	SPT-4 1.3/1.5	10/0.5 14/0.5 18/0.5	32
12.0	SC-SM w/ gravel	12.5-18.0' SILTY CLAYEY SAND: reddish brn. (5YR 4/4); fines 35-40%, low-non-plastic; sand 30-60%, poorly graded, pred. f.-v.f. grained, some m.-c. grained; gravel generally 10-15%, locally 30-40%, some c. gravel to cobbles of basalt, sandst. clasts generally 1/2-1 1/2"; strong HCl reac.; may be some gyp; med. dense(?); slightly moist.	21 B-7	PB-3 0.85/2.0	chatter 0.5' into PB run (sample disturbed, not weighed)	
14.0			B-8	SPT-5 1.4/1.5	12/0.5 22/0.5 27/0.5	49
16.0			22 S-3	PB-4 2.25/2.5	end of tube bent We = 5 lb. 9 3/4 oz. Wf = 17 lb. 12 1/4 oz.	
18.0	SC-SM	18.0-21.0' CLAYEY SILTY SAND: reddish to grayish brn (5YR 4/4 to 10YR 4/2); 40-45% low-non-plastic fines; 50-60% pred. poorly graded f.-v.f. sand, some m.-c sand; trace f. gravel; $CaCO_3$ & gyp present as small	B-9	SPT-6 1.5/1.5	23/0.5 30/0.5 22/0.5	52
20.0			23 S-4	PB-5		

SHEET 1 OF 2

PROJECT D118, SCS Dams-Utah DATE DRILLED 10/1-2/81 HOLE NO. GL3-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SC-SM	18.0-21.0' CLAYEY SILTY SAND: (con't.) soft nodules, strong reac. to HCl throughout; med. dense to dense; slightly moist.	S-4 (con't.)	PB-5 (con't.) 2.46/2.5	end tube badly bent w_e = 5 lb. 12 oz. w_f = 18 lb. 8 3/4 oz.	
22.0	CL	21.0-22.7' SILTY CLAY: dk. reddish brn (5 YR 3/3); 85-90% low-mod. plastic fines; slow dilatancy, mod. toughness; 5-15% f.-v.f. grained sand; no gravel; some cal. fresh organic debris (twigs); strong reac. to HCl; some gyp.; very stiff; slightly moist.	B-10	SPT-7		
			B-11	1.3/1.5	10/0.5 14/0.5 14/0.5	28
	SM (SC)		24	PB-6		
24.0		ALLUVIUM				
		22.7-39.5' SILTY SAND: dk. brown (7.5 YR 4/2) w/ reddish tint when dry; fines vary 20-40%, v. low-non-plastic; mod. quick dilatancy, low-no toughness; sand 60-80%, poorly graded v.f.-f. grained, scattered c.-m. grains; trace widely scattered f.-c. gravel; strong reac. to HCl throughout; gyp. only evid. in coarser zones; med. dense; v. slightly moist.	S-5	1.46/2.5	w_e = 5 lb. 11 1/2 oz. w_f = 13 lb. 15 3/4 oz.	
26.0			B-12	SPT-8 0.9/1.5	10/0.5 11/0.5 7/0.5	18
28.0			25	PB-7		
		26.8-27.0' lens of coarser sand w/ some f. gravel; gyp siferous (?) siltst, sandst.	S-6	1.64/2.5	w_e = 5 lb. 11 1/4 oz. w_f = 13 lb. 14 3/4 oz.	
30.0	SM	22.5-30.4' contains thin lenses or beds where fines grade low plastic to CL-ML	B-13	SPT-9		
			B-14	0.9/1.5	8/0.5 11/0.5 15/0.5	26
					10/1 end shift @ 5:15,	
32.0		30.4-31.5' contains charcoal frags	26	PB-8	10/2 start shift @ 7:35	
			S-7	1.57/2.5	w_e = 5 lb. 11 1/2 oz. w_f = 13 lb. 14 1/4 oz. (some slough on top)	
34.0		34.0' scattered c. sand, f. gravel at end of PB-8	B-15	SPT-10 0.8/1.5	11/0.5 13/0.5 15/0.5	28
36.0			27	PB-9	end tube slightly bent	
			S-8	1.73/2.5	w_e = 5 lb. 11 1/2 oz. w_f = 14 lb. 11 3/4 oz. (some slough on top)	
38.0		39.1-39.5' grades w/ some sm. gravel	B-16	SPT-11 1.2/1.5	14/0.5 15/0.5 22/0.5	37
		B.H. @ 39.5'			Terminate hole @ 8:40 a.m. @ 39 1/2' w/ sufficient data	
40.0					Backfilled hole w/ mud and cuttings	
42.0						
44.0						

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118, SCS Dams - Utah DATE DRILLED 10/2/81 HOLE NO. SC3-2

LOCATION Upstream the Dam #3, ~sta. 9+45; 50' u/s GROUND SURFACE ELEV. ~6053' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb. 30"

SURFACE CONDITIONS brushy flat WEATHER scattered clouds, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
0.0	ML	BASIN DEPOSITS 0.0-4.5' SANDY SILT: reddish brn (5YR 4/3); fines 50-60%, v. low-non-plastic; sand to 50%, poorly graded; mostly f.-v.f. grained; gravel is widely scattered, 0-5%, 1/4-1 1/2"; med. dense (?); dry.	28 S-1	ST-1 2.15/2.2	Push shelby tube (3") 240 psi to 2.0', 350 psi to 2.2', refusal @ 2.2' end badly bent We = 5 lb. 12 oz. Wf = 14 lb. 6 1/4 oz.	
2.0	grades	2.5' sandst. clast in shoe of split spoon	B-1	HD SPT-1 0.2/0.6	Drove standard split spoon 25/0.5 35/0.1 on rock	60+
		3.0-4.0' grades slightly more plastic		RD		
4.0	ML-CL		B-2	SPT-2		
	SM w/ gravel, cobbles	ALLUVIUM 4.5-16.0' SILTY SAND: dk. gray. brn. (10YR 4/2); 25-35% low-non-plastic fines; sand poorly graded w/pred. f.-v.f. grains, scattered m.-c. grains; scattered f.-c. gravel, pred. sandst., basalt; scattered cobbles of basalt; abund. disseminated $CaCO_3$; contains some thin stringers or lenses grading to sandy clay-silt; med. dense; slightly moist.	B-3	1.2/1.5	15/0.5 24/0.5 21/0.5	45
6.0			29	PB-1 0.0/2.5	sample w/3" Pitcher Barrel Sample washed during sampling or slipped from tube	
8.0		8.0-10.5' recovered sev. basalt gravel clasts 1 1/2-2 1/2" in silty to slightly clayey sand matrix	30 B-4	PB-2 0.3/2.5	Sample cuts rapidly - may be washing during sampling	
10.0		10.5-12.0' recovered only a 2" basalt clast - presumably washed silty sand		SPT-3 0.2/1.5	9/0.5 6/0.5 9/0.5 (2" basalt clast in shoe pushed through silty sand in-situ - rock not saved)	15
12.0		12.0-14.0' recovered a 2-3" basalt cobble	31	PB-3 0.0/2.0	one 2-3" basalt cobble in end of tube - not saved in PB-3	
14.0			32	ST-2 0.0/2.0	Push shelby tube 2.0' w/ 180 psi; no recovery; 1 dent in end of tube	
16.0	CL-ML to ML	16.0-24.5 SANDY SILT to SANDY CLAY-SILT: reddish brown (5YR 4/3); fines vary 55-70%, non- to v. low plastic, mod. quick dilatancy, low tough.; 30-45% poorly graded sand, most f.-v.f. grained, few % m.-c. grains; trace, widely scattered f. gravel, most sandst.; strong reac. to HCl; some gyp (?); stiff-v. stiff, slightly moist.	B-5	SPT-4 1.3/1.5	7/0.5 6/0.5 7/0.5	13
18.0				(OD)	Note: over drove spoon 0.5' to retain sample	
			33 S-2	PB-4 1.16/2.5	We = 5 lb. 15 oz. Wf = 13 lb. 6 1/4 oz.	
20.0					SHEET 1 OF 3	

PROJECT 0118, SCS Dams - Utah DATE DRILLED 10/2/81 HOLE NO. 623-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	CL-ML to ML	16.0-24.5' SANDY SILT to SANDY CLAY-SILT: (con't.)	S-2 (con't.)	PB-4 (con't)		
			B-6	SPT-5 1.25/1.5	9/0.5 6/0.5 10/0.5	16
22.0			34 S-3	PB-5 1.33/2.0	We = 5 lb. 10 oz. Wf = 13 lb 2 3/4 oz.	
24.0			B-7	SPT-6		
	SM	24.5-34.0' SILTY SAND: reddish brn (5YR 4/3) w/ yel. brn. tint; fines vary 10-25%, v. low to non-plastic, quick dilatancy, v. low to no toughness; 70-85% poorly graded, mostly f.-v.f. sand, w/ some m.-c. sand locally; trace to 5-10% rnd. f. gravel, mostly sandst.; occasional small specks of black carbonaceous material; some gyp.; mod. reaction to HCl; med. dense; slightly moist.	B-8	1.35/1.5	13/0.5 14/0.5 16/0.5	30
26.0			35 S-4	PB-6 1.88/2.5	small dent in end of tube. We = 5 lb. 8 3/4 oz. Wf = 17 lb. 2 1/4 oz.	
28.0			B-9	SPT-7 1.38/1.5	13/0.5 13/0.5 16/0.5	29
		24.5-31.0' occasional small nodules of soft $CaCO_3$ (1/16") and heavily mottled concentrations of $CaCO_3$	B-10			
30.0		24.5-28.8' generally more c.-m. sand and some f. gravel, rnd. gray sandst.	36 S-5	PB-7 1.80/2.5	end slightly dinged. We = 5 lb. 9 oz. Wf = 15 lb. 11 3/4 oz.	
32.0			B-11	SPT-8		
			B-12	1.1/1.5	6/0.5 6/0.5 9/0.5	15
				RD	rough drilling - RD to 34' before PB-8	
34.0	CL	34.0-36.0' SILTY CLAY: reddish brn. (5YR 4/4); 85-90% low-mod. plastic fines; 10-15% poorly graded f.-v.f. sand; no gravel; traces of black carbonaceous material; gyp. stringers; strong-mod. reac. to HCl; stiff-v. stiff; slightly moist, to moist.	37 B-13	PB-8 1.5/1.5	end of tube v. badly torn, bent	
				RD	Ream hole to 36.5' to clean out gravel	
36.0	GP-GM	36.0-44.3 SILTY to SANDY GRAVEL: multi-colored clasts in reddish brn. (5YR 4/3) matrix; 10-15% non-plastic silty fines; 25-30% mod. well graded sand, ang. to sub-rounded; 50-65% f.-m. gravel w/ most clasts 1/4-1", sandst., sltst., basalt, most clasts v. deeply weathered, sub-ang. to sub-rnd., weak to mod. hd; rel. fresh organic debris as rootlets, twigs present; mod. reac. to HCl in matrix; degree of compactness uncertain; moisture content uncertain.	B-14	SPT-9 0.9/1.5	45/0.5 46/0.5 43/0.5 (hammering in gravel)	89
38.0				RD	rough drilling 38-39.5'. smooths out a little @39.5'	
40.0			38 B-15	PB-9 0.59/1.0	Hard chatter in PB-9 sampling, sample highly disturbed	
				RD		
42.0			B-16	SPT-10 0.7/1.0	34/0.5 50/0.5 refusal on 2½" sandst. clast	84+
44.0				RD	SHEET 2 OF 3	

PROJECT D118, SCS Dams - Utah DATE DRILLED 10/2/81 HOLE NO. GL3-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
44.0	GP-GM	B.H. @ 44.3'			SPT-11 50/0.3 - refusal on gravel/cobble - no recovery
46.0					Terminated hole @ 44.3' w/sufficient information acquired Backfilled hole w/ cuttings and mud Decide to drill auxiliary boring nearby to try to get samples and additional SPTs in the 6.0-16.0' silty sand interval - see log of boring GL3-2A

50+

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams-Utah DATE DRILLED 10/2/81 HOLE NO. 6L3-2A

LOCATION Upstream toe of Dam #3 @ ~ sta. 9+30; 50' u/s GROUND SURFACE ELEV. ~6053' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb. 30"

SURFACE CONDITIONS brushy flat WEATHER scattered clouds, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
0.0		Note: see log of 6L3-2 for description of units from 0.0-8.0'		RD	start drilling @ 3:35 p.m. RD to 8.0' to reach sampling interval	
2.0					Drills erratically from 0-7½' w/ gradations from sandy to silty; some chattering	
4.0						
6.0						
8.0					drilling smoothes notably @ 7½-8	
	SM	8.0-14.5' SILTY SAND: dk. gray brown (10YR4/2); fines v. low to non-plastic, 20-25%; 75-80% poorly graded, pred. f.-v.f. grained sand; trace scattered gravel; reac. to HCl is mod.; mod. dense; moist (may be due to drill fluid).	B-1	SPT-1 1.2/1.5	Drove standard splitspoon 4/1.0 8/0.5	12
10.0			39 S-1 (B-2)	PB-1 1.39/2.0	Sample w/3" Pitcher barrel; cycled pump on/off during PB-1 sampling run to avoid washing sample; end of tube slightly dented; no 1' sample slipping out of tube; we = 5 lb. 12½ oz.; wf = 13 lb. 11½ oz.	
12.0				SPT-2 0.0/1.5	12/0.5 10/0.5 15/0.5	25
	SM-SC	13.0-14.5' grades to 40-45% low-plastic fines w/some ¼-½" gravel B.H. @ 14.5'	B-3	SPT-3 0.1/1.5	(B-2 saved from end of tube) 6/0.5 4/0.5 5/0.5	9
14.0					Terminate hole @ 14½' w/sufficient info. Backfill w/ mud and cuttings	
16.0						
18.0						
20.0						

SHEET 1 OF 1

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams-Utah DATE DRILLED 9/30/81 HOLE NO. GL5-1
LOCATION Crest Dam #5 @ ~ sta. 1+29 ℄; Cedar City GROUND SURFACE ELEV. 5940 (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb.; 30"
SURFACE CONDITIONS dirt embankment WEATHER scattered clouds, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N_f
0.0	CL	EMBANKMENT FILL 0.0-26.5' SILTY CLAY: dk. reddish brown (5YR 3/4); >95% mod. plastic fines, slow dilatancy, mod. to high toughness; trace of v.f. sand - no gravel; trace gyp. as small xystls, nodules; mod. to strong reac. to HCl throughout, w/ small veins, stringers of buff $CaCO_3$; very stiff to hard; slightly moist.	B-1	SPT-1 0.8/1.5	Dwr standard split spoon 7/0.5 8/0.5 10/0.5	18
				AD	Auger w/ 5" flight auger to 2.0'	
2.0			B-2	SPT-2 2.0/1.5	8/0.5 10/0.5 13/0.5	23
				RD	set surface casing to 1.0', set up tub, no mud	
4.0			1 S-1	PB-1 2.25/2.5	sample w/ 3" Pitcher Barrel We = 5 lb. 14½ oz. Wf = 17 lb. 13 oz.	
6.0			B-3	SPT-3 1.2/1.5	10/0.5 27/0.5 28/0.5	55
8.0			2 S-2	PB-2 2.1/2.5	We = 5 lb. 14¾ oz. Wf = 16 lb. 9¼ oz.	
10.0			B-4	SPT-4 1.1/1.5	5/0.5 8/0.5 9/0.5	17
12.0			3 B-5	PB-3 0.5/2.5	most of sample slipped out of tube down hole	
14.0			B-6	SPT-5 1.1/1.5	Ream w/ tricone to 14½' 14/0.5 23/0.5 40/0.5	63
16.0			4 S-3	PB-4 2.33/2.5	We = 5 lb. 14¼ oz. Wf = 18 lb. 15¾ oz. sample loose at bottom of tube - disturbed	
18.0		18.0-26.5' grades w/ trace of widely scattered c. sand to f. gravel sized basalt clasts, angular and hard	B-7	SPT-6 1.2/1.5	14/0.5 20/0.5 24/0.5	44
20.0						

SHEET 1 OF 2

PROJECT D118 - SGS Dams DATE DRILLED 9/30/81 HOLE NO. GZ5-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	CL	0.0-26.5' SILTY CLAY: (con't.)	5 S-4	PB-5 2.1/2.5	We = 5 lb. 14¼ oz. Wf = 17 lb. 10½ oz.	
22.0			B-8	SPT-7 1.05/1.5	10/0.5 12/0.5 15/0.5	27
24.0			6 S-5	PB-6 2.14/2.5	We = 5 lb. 14¼ oz. Wf = 17 lb. 8 oz.	
26.0		ALLUVIUM/COLLUVIUM				
	GC	26.5-42.0' CLAYEY SANDY GRAVEL: multi-colored clasts in reddish brn. (5YR 4/4) matrix; 10-20% low-mod. plastic fines; 20-35% mod. well graded sand, most ang. to subang. grains; 50-70% gravel from ¼-3" w/most ½-1½", limestone, sltst., sandst. and most commonly basalt, all mod. to deeply weathered, weak to hd, ang. to subrounded; degree of compactness uncertain; in-situ moisture uncertain.	B-9	SPT-8 1.0/1.5	15/0.5 33/0.5 50/0.3	83
28.0				RD	Ream to 29' w/tricone; smoother drilling @ 28½'	
30.0			7 S-6 (end of tube cut off)	PB-7 1.83/2.0	We = 5 lb. 15½ oz. Wf = 15 lb. 2¼ oz. cut off end-badly bent end of tube; sample disturbed	
			B-10	SPT-9	15/0.5 48/0.5	63+
				RD	Ream to 32' w/tricone	
32.0		Note: locally unit may be crudely stratified w/ some thin layers of clayey sand to sandy clay as seen in SPT-10 from 34.0-35.5'	8 S-7	PB-8 1.35/2.0	We = 5 lb. 13½ oz. Wf = 12 lb. 0 oz. bent end of tube - disturbed sample	
34.0			B-11	SPT-10 0.95/1.5	27/0.5 37/0.5 34/0.5	71
				RD	Ream hole to 36' w/tricone	
36.0			9 B-12	PB-9 0.2/2.0	2½" basalt clast in tube; Hole taking water; mix 1½ sacks mud	
38.0			B-13	SPT-11 1.3/1.5	20/0.5 25/0.5 22/0.5	47
40.0				RD	bit caught by cobble in hole/unscrewed/ fish & retrieve 1:25-2:10 Ream w/ tricone to 40½'	
			10 B-14	PB-10 0.6/1.5	out of water, used 650 gal. Refusal @ 42'	
42.0		B.H. @ 42.0'			Terminate hole @ 42' w/sufficient info. Backfill hole w/ mud & cuttings	
44.0						

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams-Utah DATE DRILLED 9/30-10/1/81 HOLE NO. GS-2

LOCATION Upstream toe Dam #2 @ ~ sta. 1+73; 82' u/s GROUND SURFACE ELEV. ~5926 (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS sediment behind dam WEATHER scattered clouds, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N_f
0.0	CL	CATCHMENT BASIN DEBRIS(?) 0.0-7.0' SILTY CLAY: dk. red. brown (5YR 3/4); 95-100% low-mod. plastic fines, slow dilat., mod. toughness; few % to trace of f. v.f. sand; no gravel; $CaCO_3$ as thin stringers and disseminated throughout; some partially to fully carbonized fine organic debris; stiff; dry to slightly moist.	B-1	SPT-1 1.0/1.5	Drove standard split spoon 4/0.5 5/0.5 6/0.5	11
2.0				AD	Auger w/5" flight auger to 2'	
			B-2	SPT-2 1.0/1.5	5/0.5 6/0.5 9/0.5	15
4.0				RD	Ream hole w/ 4 7/8" tricone rock bit; mix sample w/ 5" Pitcher Barrel	
			11 S-1	PB-1	We = 5 lb. 14 oz. Wf = 15 lb. 11½ oz.	
6.0			B-3	1.82/2.5	bottom 0.3' of PB-1 slipped out of tube, saved in B-3	
7.0	GC	ALLUVIUM/COLLUVIUM 7.0-43.8' CLAYEY SANDY GRAVEL: multi-colored clasts in reddish brn. (5YR 4/4) matrix; fines vary 10-30%, pred. low-mod. plastic, locally low-non-plastic - sand varies 15-30%, mod. well graded, most ang-sub-ang; gravel varies 40-75%, sandst., limest., sltst., basalt, red volc. (?), ang-subrounded, mod.-deeply weathered; reac. to HCl mod. throughout; locally unit is crudely stratified and some lences grade to sandy or gravelly clay and clayey sand; degree of compactness uncertain; moisture in-situ uncertain. 7.0-8.0 generally sandy clay w/10-20% sand and 5-10% gravel	B-4	SPT-3 1.2/1.5	6/0.5 13/0.5 18/0.5	31
8.0			12 S-2	PB-2 0.79/0.9	We = 5 lb. 13¾ oz. Wf = 10 lb. 5¼ oz.	
10.0				RD	Drill w/ tricone rock bit in gravelly section w/ some cobbles	
12.0					Drilling smooths out at 12.2-12.4	
			13 B-5	PB-3 10.8	(sample not weighed)	
14.0				RD	Drill w/rock bit in gravelly section	
			B-6	SPT-4 0.2/0.8	25/0.5 50/0.3	75+
16.0				RD	Drill w/rock bit in gravelly section ~16' - hard rattling/rig shaking	
18.0		18.0-19.0' crude stratification from clayey sandy gravel to gravelly sandy clay seen in PB-4 w/ fines to 60% in clays	14 B-7	PB-4 1.15/2.5	Drilling smooths out some @ ~18' (sampled highly disturbed, not weighed)	
20.0						

SHEET 1 OF ____

PROJECT 0118, SCS Dams - Utah DATE DRILLED 9/30-10/1/81 HOLE NO. 6C5-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	GC	7.0-43.8' CLAYEY SANDY GRAVEL (con't.)	B-7 (con't)	PB-4 (con't.)	end shift @ 5:20; start shift @ 7:35; hole caved to ~19';	
				RD	RD to 21' to clean hole	
			15 S-3	PB-5 1.15/2.0	end tube badly bent (some gravel slough on top of disturbed sample - not weighed) We = Wf = 12 lb. 4½ oz.	
22.0						
				RD	RD to 23½' to clean hole	
24.0				SPT-5 0.0/0.5	50/0.5 - hammering on gravel	50+
				RD	RD in gravel w/some cobbles	
					Add 2-3 lbs. poly-drill to help flush cuttings	
26.0					Drilling smooths a little @ 26.2'	
		26.2-27.3' v. little to no binder; sandst./basalt gravel	B-8	SPT-6 0.5/1.1	27/0.5 43/0.5 50/0.1 (gravel in spoon)	93+
				RD	RD to slightly smoother drilling	
28.0					← SPT-7, 0.0/0.1 50/0.1 - hammering on gravel/clast (0.3' slough in spoon)	
				RD	Hole caved/sloughed to ~25½' after taking SPT-7	
30.0					Mix 1½ sacks bentonite to help stabilize hole; flush cuttings	
32.0					RD to 32½' where drilling smooths somewhat & more low plastic fines in cuttings	
			16 S-4	PB-6 1.27/2.0	end of tube badly chewed up We = 5 lb. 14¾ oz. Wf = 13 lb. 2¾ oz.	
34.0						
		34.5-35.3' v. little to no fines; pred. basalt, some sandst. gravel, c. sand	B-9	SPT-8 0.4/0.8	35/0.5 50/0.3 w/1½" gravel clast in shoe (rest of sample is slough)	85+
				RD		
36.0		36.5-38.0' grades less gravel			RD in gravelly section to 38, grading less gravelly 36½ to 38'	
38.0			17 S-5	PB-7 1.12/2.5	Cut fairly smooth but end of tube curled back - sample disturbed We = 5 lb. 14 oz. Wf = 12 lb. 12 oz.	
40.0					Note: begin placing cardboard spacer and wax plug @ top of all PB samples	
			B-10	SPT-9 0.8/0.8	39/0.5 50/0.3 gravel in spoon	89+
42.0				RD	RD in gravelly section; grades more gravelly ~42'	
		43.0-43.8' 3½" basalt cobble recovered in PB-8				
44.0		B.H. @ 43.8'	18 B-11	PB-8 0.3/0.8	3½" cobble in end of tube (sample not weighed)	

SHEET 2 OF 2

Terminate boring @ 43.8' w/ sufficient data; Backfill hole w/ [illegible] and cuttings

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/6/81 HOLE NO. WD-1

LOCATION Warner Draw Dam, ~sta. 15+23 on ℄ GROUND SURFACE ELEV. ~2989' (Topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS crest of earth embankment, cobbles WEATHER clear, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SP-SM w/ gravel cobbles	EMBANKMENT FILL 0.0-15.0' SAND to SILTY SAND: reddish brown (2.5YR 4/4); 5-15% non-plastic fines; 85-95% poorly graded f. to v.f. sand, pred. iron-oxide stained qtz. grains; trace to locally 10-20% c. sand to f. gravel, pred. sandst., siltst; slow to mod. reac. to HCl indicates some CaCO3; gyp. as v.f. clear crystals; trace carbonized black organics or MnO coatings(?); med. dense to dense; dry to slightly moist (easily penetrated by drilling fluid). 0.0-2.0' gravelly, cobbly silty sand, w/ 20-30% c. gravel, small cobbles commonly 1-4", few cobbles to 6", clasts pred. red sandst., light color qtzite (?)		AD	Auger w/ 6" flight auger thru surficial gravelly, cobbly material to 2.5' - clean hole by hand for SPT	
2.0	SP-SM		B-1	SPT-1 1.3/1.5	Drive standard split spoon 19/0.5 23/0.5 16/0.5 (scattered f.-m. gravel)	36
4.0				RO	set up, tub, surface casing to 3', mix 1 sack of bentonite, ~2 lb. zeogel	
				PB-1	Sample w/ 3" Pitcher Barrel end of tube bent	
6.0			S-1	2.42/2.5	We = 5 lb. 15 1/2 oz. Wf = 20 lb. 11 1/2 oz.	
8.0			B-2	SPT-2 1.0/1.0	35/0.5 53/0.5 (refusal on gravel clast)	88
				RO		
				PB-2	one ding in end of tube, void along side of sample at top	
10.0			S-2	2.40/2.5	We = 5 lb. 15 oz. Wf = 20 lb. 3 1/2 oz.	
12.0	SP-SM w/ gravel	11.0-12.2' grades w/ 10-20% coarse sand and fine gravel, one 1" clast in center of SPT-3	B-3	SPT-3 1.2/1.5	5/0.5 6/0.5 9/0.5 (scattered gravel, one 1" clast)	15
	SP-SM			PB-3	end of tube o.k. We = 5 lb. 15 oz.	
14.0			S-3	1.8/2.5	Wf = 17 lb. 2 1/4 oz.	
	SC-SM	15.0-30.0' CLAYEY SILTY SAND: reddish brn. (5YR 4/4); 25-30% low plastic fines, mod. quick dilatancy, low toughness; 65-75% poorly graded, f.-v.f. qtz. sand; 0-5% scattered c. sand & f. gravel, clasts 1/8-1/2", most 1/4-3/4", of sandst., siltst., qtzite.; low-mod. reac. to HCl - some CaCO3; gyp. as v.f. crystals and irreg. patches to 1/8-1/4" of soft, powdery gyp.; trace carbonized black organic debris; dense; slightly moist.		SPT-4	17/0.5 15/0.5 33/0.5	48
16.0			B-4	1.1/1.5	(trace f. gravel)	
				PB-4	end of tube ok. (forgot to measure recovery)	
18.0			S-4	?/2.5	We = 5 lb. 15 1/2 oz. Wf = 20 lb. 13 1/2 oz.	
	SM			SPT-5	13/0.5 20/0.5 27/0.5 (scattered f. gravel)	47
20.0	SC-SM		B-5	1.3/1.5		

SHEET 1 OF 4

PROJECT D118-SC,S Dams, Utah DATE DRILLED 10/6/81 HOLE NO. WD-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SC-SM	15.0-30.0' CLAYEY SILTY SAND: (con't.)	B-5 (con't.)	SPT-5 (con't.)		
				RD	RD w/ 4 7/8" tricone to 21' to clear gravelly slough	
				PB-5	end of tube caved in We = 5 lb. 15 1/2 oz. Wf = 20 lb 10 3/4 oz.	
22.0			S-5	2.62/2.5		
		23.5-25.0' slightly more fines		SPT-6	25/0.5 30/0.5 17/0.5	47
24.0			B-6	1.4/1.5		
				PB-6	end dented, either overcut sample ~0.2' or have that much tight slough on top of sample. We = 5 lb. 15 3/4 oz. Wf = 22 lb. 7 1/2 oz.	
26.0			S-6	2.72/2.5		
		27.5' grading more plastic fines to 35-40%; w/ thin laminae of nonplastic silty sand @ bottom of PB-6		SPT-7	27/0.5 21/0.5 21/0.5 (scattered f., deeply weath. sandst. gravel)	42
28.0			B-7	1.3/1.5		
				PB-7	end of tube o.k. We = 5 lb. 14 3/4 oz. Wf = 21 lb. 12 oz.	
30.0	SC w/ occ. gravel	30.0-54.0' CLAYEY SAND: reddish brn. (5YR 4/4), less red tint than prev.; 35-45% low-mod. plastic fines - slow to mod. quick dilatancy, low-mod. toughness; sand to 50-65%, mod. poorly graded, pred. f.-v.f., some m.-c. grains; 0-10-15% gravel, sandst., siltst., shale, subang. to subrounded, deeply weathered; mod. reac. to HCl due to $CaCO_3$; some gyp. as v.f. clear crystals & buff, soft irreg. nodules to 1/8"; trace carbonized black organic specks; contains thin lenses of sand to silty sand and clayey silty sand as described below; med. dense to dense, very stiff to hard (based on blow count); slightly moist to moist.	S-7	2.55/2.5		
				SPT-8	8/0.5 10/0.5 16/0.5 (few 3/8-1/2" gravels)	26
32.0			B-8	1.2/1.5		
				PB-8	end of tube o.k. We = 5 lb. 14 1/4 oz. Wf = 19 lb. 14 1/2 oz.	
34.0			S-8	2.23/2.5		
				SPT-9	10/0.5 20/0.5 20/0.5 (scattered c. sand, f. gravel)	40
36.0			B-9	1.2/1.5		
				PB-9	end of tube dented We = 5 lb. 14 1/2 oz. Wf = 20 lb. 13 oz.	
38.0		31.5-33.0' few % c. sand, gravel to 1/2"	S-9	2.42/2.5		
		35.5' coarse sand to ~10%				
	? SP-SM	35.5'-37.0' grades more c. sand and f. gravel		SPT-10	10/0.5 12/0.5 18/0.5	30
40.0	SC	39.5' brick red-orange sand to silty sand (SP-SM), f.-v.f. grained, trace c. sand	B-10	1.1/1.5		
				PB-10	end of tube slightly dented We = 5 lb. 14 1/2 oz. Wf = 19 lb. 11 oz.	
	? SP	41.5-41.8' clean SP sand, f.-v.f. grained				
42.0	SC		S-10	2.21/2.5		
		43.5' sand to silty sand w/ <10-15% non-plastic fines				
44.0	? SP-SM		B-11	SPT-11		

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/6/81 HOLE NO. WD-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
44.0	SC w/ occ. gravel	30.0-54.0' CLAYEY SAND: (con't)	B-11 (con't)	SPT-11 (con't) 1.3/1.5	15/0.5 17/0.5 24/0.5	41
				PB-11	end of tube badly flared out-not capped, but wax-sealed	
46.0			S-11	2.74/2.5	We = 5 lb. 14 1/4 oz. wf = 22 lb. 5 1/2 oz.	
48.0			B-12	SPT-12 0.4/1.5	11/0.5 16/0.5 20/0.5	36
				PB-12	end of tube o.k.	
50.0			S-12	2.26/2.5	We = 5 lb. 14 1/2 oz. Wf = 20 lb. 1 oz.	
52.0			B-13	SPT-13 1.1/1.5	16/0.5 32/0.5 28/0.5	60
		ALLUVIUM/COLLUVIUM		PB-13	end slightly bent	
54.0	SC (GC)	54.0-67.5' CLAYEY SANDY GRAVEL - GRAVELLY SAND: dk. reddish brown (5YR 3/4) matrix w/ yel. brn to dk. brn clasts; 10-30% low plastic fines; sand varies 20-locally 50%, usually 20-30%, both f.-v.f. and m.-c. fractions present, mod. well graded; gravel varies 20-70%, commonly 50-70%, clasts mostly subang. to subrnd. sandst. and sltst., 1/4-3", most 1/4-1"; scattered cobbles to 4-6"(?); matrix w/ some $CaCO_3$, gyp.; crudely stratified w/ layers either pred. gravelly or sandy, some clayey sands as for 30.0-54.0'; some black carbonized organic debris as small specks; appears mod. compact in PB bag samples, not cemented; slightly moist.	S-13	2.49/2.5	We = 5 lb. 14 oz. Wf = 21 lb. 3 oz.	
56.0			B-14	SPT-14 0.9/1.5	17/0.5 18/0.5 34/0.5 (some c. sand, trace f. gravel)	52
			B-15	PB-14	2 1/2-3" cobble in end of tube; sample disturbed, draining	
58.0	GC (SC)		B-16	2.20/2.5	We = wf = not weighed	
60.0			B-17	SPT-15 1.4/1.5	14/0.5 16/0.5 20/0.5 (some gravels to 1/2")	36
				PB-15	end of tube badly bent	
62.0		54.0-58.0' predominantly clayey gravelly sand	S-14	2.60/2.5	We = 5 lb. 15 oz. Wf = 20 lb. 7 1/2 oz.	
64.0		58.0-67.5' predominantly clayey sandy gravel w/ less clayey gravelly sand	B-18	SPT-16 1.3/1.5	14/0.5 19/0.5 34/0.5 (w/ ~50% sandst. gravel)	5.
		~63-64' color grading less reddish tint		PB-16	end of tube badly bent, sample loose in tube We = 5 lb 13 3/4 oz.	
66.0		BEDROCK	S-15	2.35/2.5	Wf = 18 lb. 1/4 oz.	
68.0		67.5-71.5' SILTSTONE/CLAYSTONE (see next sheet for description)	B-19	SPT-17		

base of embankment acc'd. to design drawings

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/8/81 HOLE NO. WD-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
68.0	SILTSTONE/ CLAYSTONE; 80°	67.5-71.5' SILTSTONE/CLAYSTONE: (con't) very lt. gray (N7½) fresh w/ brownish yellow (10YR 6/6) weath. staining; interbedded rel. softer claystone and harder siltstone to f. grained sandstone; sltst/sandst. w/ blocky fractures, joints @ 10°, 40°, 50°; crude bedding @ 30-40°. Phy. Cond. - mod. to deeply weathered; closely fractured; clayst. w/ low hardness; sltst./sandst. w/ mod. hardness; clayst. weak to friable, sltst./sandst. weak to mod. strong.	B-19 (con't)	SPT-17 (con't) 9/1.5	15/0.5 50/0.5 (refusal on mod. hd. rock)
				RD	RD to 69.5' where drilling is smoother
70.0	10°		B-20	PB-17	Sample disturbed, saved in bags we = wf = not weighed
	50°		B-21	14/2.0	Terminated hole @ 71.5' 4' into rock w/ sufficient data obtained
72.0		B.H. @ 71.5'			Backfilled hole w/ cuttings/mud; poured bentonite-rock slurry into top 3'

65

SHEET 4 OF 4

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/7/81 HOLE NO. WD-2

LOCATION Warner Draw Dam, ~sta. 17+49 on ℄ GROUND SURFACE ELEV. ~2989 (topo)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS crest of earth embankment, cobbly WEATHER clear, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SP-SM w/ gravel, cobbles	EMBANKMENT FILL 0.0-15.7' SAND to SILTY SAND: reddish brown (2.5YR4/4); 5-15% non-plastic fines, quick dilatancy, low-no toughness; 80-90% poorly graded, pred. f.-v.f. grained sand; trace to locally 10-15% f. gravel; few clasts to 1-2"; minor dissem. CaCO3 - little-mod. reac. to HCl; gyp. (?) as v.f. crystals; trace carbon. org. debris; dense; dry to slightly moist. 0.0-2.0' w/ 20-35% c. gravel, some cobbles to 4-6"		AD	Auger w/ 6" flight auger to 2' to clear gravelly, cobbly surficial mantle; clean hole by hand	
2.0	SP-SM		B-1	SPT-1 1.1/1.5	Drove standard splitspoon 15/0.5 21/0.5 32/0.5 (hammering gravel or cobble, shoe empty)	53
4.0				RD	setup, mud tub; casing to 3'; RD in scattered gravel	
6.0			S-1	PB-1 2.24/2.5	sample w/ 3" Pitcher Barrel end of tube o.k. We = 5 lb. 14 oz. Wf = 19 lb. 6 oz.	
8.0		8.3' w/ 1¼" gravel clast, grades slightly clayey	B-2	SPT-2 1.4/1.5	23/0.5 29/0.5 34/0.5 (1¼" gravel clast near bottom of sample)	63
10.0			S-2	PB-2 ?/2.5	end of tube slightly dinged We = 5 lb. 14 oz. Wf = 18 lb 8¾ oz. (forgot to measure recovery, probably > 2')	
12.0			B-3	SPT-3 1.4/1.5	15/0.5 15/0.5 15/0.5	30
14.0			S-3	PB-3 2.25/2.5	end of tube o.k. We = 5 lb 14¾ oz. Wf = 19 lb. 10½ oz.	
16.0	SC-SM	15.7-29.0' CLAYEY SILTY SAND: reddish brn. (5YR4/4); 25-30% low plastic fines; 60-65% v. poorly graded sand, pred. f.-v.f. grained, subang.-subrnd., iron-oxide stained; 0-5% scattered f.-m. gravel 1/4-1½"; generally low reac. to HCl but w/ some mottles, small nodules CaCO3; trace black carbonized organic debris; dense; slightly moist.	B-4	SPT-4 1.1/1.5	16/0.5 18/0.5 22/0.5 (scattered f. gravel bottom 0.4' of sample)	40
18.0			S-4	PB-4 2.2/2.5	end of tube o.k.; sample loose in tube We = 5 lb. 12 oz. Wf = not weighed	
20.0			B-5 B-6	SPT-5 1.5/1.5	14/0.5 19/0.5 22/0.5	41

SHEET 1 OF 4

PROJECT D118 – SCS Dams, Utah DATE DRILLED 10/7/81 HOLE NO. WD-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SC-SM	15.7-29.0' CLAYEY SILTY SAND: (con't.)	B-6 (con't.)	SPT-5 (con't.)		
		19.0-19.7' grades to v. low to non-plastic fines		PB-5	end of tube slightly dinged, 2" clast removed from bottom end	
22.0			S-5	2.53/2.5	w_e = 5 lb. 12½ oz. w_f = 21 lb. 7¼ oz.	
		23.0-24.3' grades slightly more plastic fines	B-7	SPT-6 1.3/1.5	16/0.5 23/0.5 23/0.5 (scattered f. gravel)	46
24.0						
				PB-6	end slightly dinged	
26.0		~25.0-26.0' grades w/ ~10-15% coarse sand, f. gravel as sltst., sandst. clasts	S-6	2.36/2.5	w_e = 5 lb. 14¼ oz. w_f = 20 lb. 4½ oz.	
28.0			B-8	SPT-7 1.4/1.5	14/0.5 26/0.5 29/0.5 (10-15% c. sand, f. gravel as sltst., sandst.)	54
	SC	29.0-43.0' CLAYEY SAND: reddish brown (5YR4/4); 35-45% low-mod. plastic fines; 45-55% mod. poorly graded sand, pred. f.-v.f. grained, but w/ m.-c. grains present; 5-15% gravel common, as weath. sandst, sltst, to ½-1", some dissem. & some mottled $CaCO_3$, trace gyp.?, some small specks black carbonized organic debris, dense to hard (from blowcount); slightly moist.		PB-7	end of tube o.k.	
30.0			S-7	2.34/2.5	w_e = 5 lb. 11½ oz. w_f = 19 lb. 14¾ oz.	
32.0			B-9	SPT-8 1.2/1.5	8/0.5 14/0.5 21/0.5 (10-15% c. sand, f. gravel)	35
				PB-8	end of tube o.k.	
34.0		31.0' w/ 30-35% c. sand, f. gravel	S-8	2.60/2.5	w_e = 5 lb. 16¼ oz. w_f = 22 lb. 6 oz.	
		35.0-35.3' clayey silty sand				
36.0		36.0' grades w/ more charcoal	B-10	SPT-9 1.1/1.5	20/0.5 30/0.5 38/0.5 (10-15% c. sand, f. gravel)	68
				PB-9	end of tube v. slightly dinged	
38.0			S-9	2.32/2.5	w_e = 5 lb. 11¼ oz. w_f = 20 lb. 5¾ oz.	
	? SM	39.0' w/ 15-20% non-plastic fines at end of PB-9				
40.0	SC	39.0-39.3' non-plastic silty sand	B-11	SPT-10 1.4/1.5	19/0.5 19/0.5 28/0.5	47
				PB-10	end of tube o.k., but sample loose in tube	
42.0			S-10	2.42/2.5	w_e = 5 lb. 14¾ oz. w_f = not weighed	
44.0	SC-SM	43.0-50.0' CLAYEY SILTY SAND: v. similar to 15.7-29.0'; dense-v. dense; slightly moist.	B-12	SPT-11 1.2/1.5	27/0.5 33/0.5 27/0.5	60

SHEET 2 OF 4

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/7/81 HOLE NO. WO-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
44.0	SC-SM	43.0-50.0' CLAYEY SILTY SAND: (cont.)	B-12 (cont.)	SPT-11 (cont.)		
				PB-11	end of tube o.k. we = 5 lb. 15½ oz. wf = forgot to weigh	
46.0			S-11	2.44/2.5		
			B-13	SPT-12 1.3/1.5	36/0.5 36/0.5 33/0.5 (scattered deeply weath. sandst. gravel)	69
48.0				PB-12	end of tube bent in one place we = 5 lb. 14¼ oz. wf = 21 lb. 13¾ oz.	
50.0	SC-SM (SC)	50.0-59.0' CLAYEY SAND and CLAYEY SILTY SAND: interlayering of units as described for 15.?-29.0' and 29.0-43.0', but w/ more c. sand, f. gravel common; where most clearly seen in SPT-14, layers were ~0.4-0.6' thick and presumably represent lifts in the compacted fill.	S-12	2.64/2.5		
52.0			B-14	SPT-13 1.4/1.5	19/0.5 34/0.5 40/0.5 (gravelly to 20-30%)	74
	SC (SC-SM)			PB-13	end of tube bent over we = 5 lb. 15 oz. wf = 20 lb 11½ oz.	
54.0			S-13	2.38/2.5		
	SC-SM					
56.0	SC		B-15	SPT-14 1.4/1.5	18/0.5 23/0.5 34/0.5 (scattered sandst. gravel)	57
	SC-SM			PB-14	end of tube dinged. ~1x2" void @ bottom we = 5 lb. 11¾ oz. wf = 20 lb 2 oz.	
	SC					
58.0		ALLUVIUM/COLLUVIUM	S-14	2.44/2.5		
	SC (GC)	59.0-67.5' CLAYEY GRAVELLY SAND - SANDY GRAVEL: dk. reddish brown (5YR 3/4), w/ distinctly less reddish tint than above; 10-30% low-med. plastic fines; 20-30% to as much as 50% mod. well graded sand, more f.-v.f. sand for sandier intervals; 40-70% gravels from ¼-1½" w/most ¼-¾", occasional c. gravel, small cobbles, mostly sandst., sltst.; trace of rel. fresh organic debris (twigs), carbonized spots, specks; some $CaCO_3$ in matrix; trace gyp(?) as f. crystals; compactness uncertain, probably moderate, uncemented; slightly moist. 59.0-62.0' pred. sandy; 62.0-67.5' pred. gravelly				
60.0			B-16	SPT-15 1.5/1.5	23/0.5 36/0.5 33/0.5 (w/40-50% gravel)	69
				PB-15	end of tube dented we = 5 lb. 14 oz. wf = 22 lb. 11 oz.	
62.0	GC (SC)		S-15	2.68/2.5		
64.0			B-17	SPT-16 1.3/1.5	(missed blow count, wasn't anomalously low)	
66.0				RD	RD through somewhat more gravelly section; RD smooths some @ 43½'	
		BEDROCK	B-18	SPT-17 1.5/1.5	30/0.5 45/0.5 46/0.5 (clayst. last 0.5')	91
68.0		67.5-70.8' CLAYSTONE/SILTSTONE: (see next page for description)	S-19			

lase 'em' and 'pcco' to design drawings

SHEET 3 OF 4

PROJECT D118-SGS Dams, Utah DATE DRILLED 10/7/81 HOLE NO. WD-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
68.0	SILTSTONE/ CLAYSTONE	67.5-70.8' SILTSTONE/CLAYSTONE (con't) dk. gray to ol. gray (5Y4/1, 5Y4/2); claystone w/ shaley, crude fissility, has somewhat sheared look, thin CaCO3 veins, w/ few harder sltst. inclusions; Phy Cond. - intensely fractured, but fractures are tight; low hardness; weak; mod. weathered.	5-16	PB-16 1.5/2.5	end of tube chewed up w_e = 5 lb. 13 1/4 oz. w_f = 14 lb. 4 1/2 oz.
70.0			B-20	SPT-18 0.3/0.3	50/0.3 (driving in rock) Terminated hole @ 70.8 3.3' into bedrock w/ sufficient data acquired. Backfilled hole w/ cuttings and mud. 50+
72.0		70.5-70.8' grades to ol. yel. harder siltstone/shale			
		B.H. @ 70.8'			

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DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/8/81 HOLE NO. WD-3

LOCATION Warner Draw Dam, ~sta. 15+45; 210' u/s GROUND SURFACE ELEV. ~2940' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS loose debris basin deposits; brushy WEATHER clear, warm, windy

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	ML	DEBRIS BASIN DEPOSITS (?) 0.0–5.0 GRAVELLY SILTY SAND:	B-1	ST-1 1.1/1.1	Pushed 3" shelby tube; end caved in, sample loose and disturbed we = wf = not weighed	
2.0	SM	reddish brn (2.5 YR 4/4); 25-50% low-non-plastic fines; 50-60% poorly graded f.-v.f. sand; 10-20% gravel, 1/4-1 1/2", prob. hd. sandst.; much disseminated $CaCO_3$ w/ strong reac. to HCl; prob. mod. dense; dry.	B-2	SPT-1 1.2/1.5	Drove standard split spoon 23/0.5 29/0.5 31/0.5	60
4.0		~0-1.0' siltier, less gravelly		RD	set up tub; casing to 1' RD w/ 4 7/8" tricone bit thru gravelly section	
		BEDROCK				
6.0	CL-ML	5.0–18.6 SHALE to SHALEY SILTSTONE/CLAYSTONE: grayish red (5R 4/2) where freshest to lt. olive brn. (2.5 YR 5/4) where most weathered; varies from v. crudely to fairly well developed shale fissility, so it's either a shale or claystone to siltstone; bedding not apparent from samples examined; fine hackly, angular blocky structure where fractured. Phy. Cond. — crushed to intensely fractured; soft to friable; friable to weak; deeply to moderately weathered.	B-3	PB-1 ?/2.0	Sample w/ 3" Pitcher Barrel end of tube badly bent saved disturbed sample in bag, didn't weigh tube	
			B-4	SPT-2 1.0/1.4	33/0.5 45/0.5 50/0.4 (hammering in rock)	95+
8.0	SHALE			RD	RD to clean hole	
				PB-2	end of tube bent we = 6.11 lb. wf = 21.30 lb.	
10.0			S-1	2.3/2.5		
		5.0-6.0' very deeply weath., decomposed rock; remolds easily to low plastic clay-silt	B-5	SPT-3	50/0.5; 0.5/0.5 (hammering in rock)	50+
12.0				RD	RD to clean hole	
				PB-3	end of tube o.k.	
14.0			S-2	2.52/2.5	we = 6.10 lb. wf = 22.56 lb.	
			B-6	SPT-4	50/0.5 - 0.5/0.5 (hammering in rock)	50+
16.0				RD	RD to 16.0' where rock seems slightly softer	
				PB-4	end of tube o.k.	
18.0		~17.0' grades hard enough that it can't be remolded (i.e. low hardness to mod. hard) B.H. @ 18.6'	S-3	2.38/2.5	we = 6.04 lb. wf = 22.78 lb	
			B-7	SPT-5	50/0.1; 0.1/0.1 (hammering on rock) Terminated hole @ 18.6' 13.6' into rock w/ sufficient	50+
20.0						

SHEET 1 OF 1

data acquired
Backfilled hole w/ cuttings

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DRILLING AND SAMPLING LOG

PROJECT 0118 - SCS Dams, Utah DATE DRILLED 10/8-9/81 HOLE NO. STK-1
LOCATION Stucki Dam · ~sta. 14+06 on ℄ GROUND SURFACE ELEV. ~2814' (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb, 30"
SURFACE CONDITIONS crest of earth embankment; gravelly cobbly WEATHER clear, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	GM-SM	EMBANKMENT FILL 0.0-4.0' SILTY GRAVELLY SAND - SANDY GRAVEL: as for 4.0-24.5' but w/40-60% hard sandst. gravel and small cobbles from 1/4-6" w/ most 1-1½ or 2".		AD	Auger w/6" flight auger easy augering in gravelly section to ~3½-4'	
2.0						
4.0	SM	4.0-24.5' SILTY SAND: reddish brn. (5YR4/4); 20-25% non-plastic fines; mod. quick dilatancy; no-v. low toughness; 75-80% poorly graded fine to v. fine sand, subang-sub rnd, iron-oxide stained gts prd.; 0-3% c. sand, fine gravel, 1/4-1" nodules sandst. and glassy volc., shale, all subrnd. to subang.; pervasive CaCO3 w/reac. to HCl; gyp. very common as v.f. clear crystals and irreg. nodules 1/16-1/2"; trace black carbonized organics; MnO staining; dense; slightly moist to moist.		RD	augers firmer @ ~4' set up mud tub; casing to 5' RD w/ tricone rock bit (4 7/8")	
6.0			S-1	PB-1 2.47/2.5	Sample w/ 3" Pitcher Barrel dent in end of tube we = 6.04 lb. wf = 20.48 lb	
8.0			B-1	SPT-1 1.2/1.5	Drove standard split spoon 22/0.5 22/0.5 25/0.5 (10-12% f. gravel)	47
10.0		8.5-10.0' grades slightly more gravelly	S-2	PB-2 2.19/2.2	two dents @ end of tube we = 6.12 lb. wf = 19.02 lb.	
12.0		12.2-13.7' grades siltier w/ 30-40% v. low plastic fines	B-2	SPT-2 1.4/1.5	18/0.5 20/0.5 24/0.5 (trace f. gravel)	44
14.0			S-3	PB-3 2.73/2.8	end of tube dented, sample loose we = 6.06 lb. wf = 22.64 lb.	
16.0		16.5-18.0' w/3" long conc. of gyp.; grades from silty sand to rel. clean sand to sandy silt w/ depth - layering probably reflects fill lifts	B-3	SPT-3 1.2/1.5	22/0.5 29/0.5 35/0.5 (locally gyp. cemented)	64
18.0			S-4	PB-4 2.44/2.5	end of tube o.k. we = 6.06 lb. wf = 21.01 lb	
20.0						

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/8-9/81 HOLE NO. STK-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SM	4.0-24.5' SILTY SAND: (con't.)	S-4 (con't.)	PB-4 (con't.)		
			B-4	SPT-4 1.4/1.5	11/0.5 16/0.5 28/0.5 (scattered f. gravel)	44
22.0			S-5	PB-5 2.40/2.5	end of tube curled over, void @ bottom of tube We = 6.07 lb. Wf = not weighed	
24.0						
	SC-SM	24.5-51.0' CLAYEY SILTY SAND: dk. red (2.5YR 3/6); 35-45% low plastic fines, slow-mod. quick dilatancy, low toughness; 55-60% poorly graded, f.-v.f. sand, prd. iron-oxide stained qtz; 5-5% c. sand - f. gravel to ~1" max, lithology as in prev. unit; pervasive $CaCO_3$; gyp. as f. crystals, small irreg. nodules. v. little carbonized org. debris; some w/crude planar fabric presumably due to fill compaction; dense; moist.	B-5	SPT-5 1.3/1.5	11/0.5 32/0.5 52/0.5 (maybe pounding into gravel below sample)	84
26.0			S-6	PB-6 2.50/2.5	end of tube dented, sample loose We = 6.08 lb. Wf = 20.80 lb.	
28.0			B-6	SPT-6 1.5/1.5	11/0.5 20/0.5 28/0.5 (scattered f. gravel)	48
30.0		27.0-32.5' grades slightly more plastic fines 28.5' grades locally to 10-15% c. sand, f. gravel	B-7	PB-7	sample slipped from tube while handling @ surface, tube not damaged	
32.0		Note: % fines vs. % sand varies somewhat throughout unit over a 1-1.0 commonly, presumably due to variations in fill lifts, as well as within a single lift. essentially all material observed in field is SC-SM	B-8	2.5/2.5		
			B-9	SPT-7 1.3/1.5	11/0.5 22/0.5 30/0.5 (scattered f. gravel)	52
34.0			S-7	PB-8 2.45/2.5	end of tube o.k. We = 5.97 lb. Wf = 21.43 lb	
36.0			B-10	SPT-8 1.5/1.5	15/0.5 21/0.5 29/0.5	50
38.0			S-8	PB-9 2.22/2.5	end of tube o.k. We = 6.02 lb. Wf = 20.25 lb	
40.0			B-11	SPT-9 1.4/1.5	18/0.5 26/0.5 24/0.5	50
42.0			S-9	PB-10 2.49/2.5	end of tube o.k. We = 6.00 lb. Wf = 21.62 lb.	
44.0						

PROJECT N18-SCS Dams, Utah DATE DRILLED 10/8-9/81 HOLE NO. STK-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
44.0	SC-SM	24.5-51.0' CLAYEY SILTY SAND (cont.)	S-9 (cont.)	PB-10 (cont.)		
				SPT-10	11/0.5 17/0.5 26/0.5	43
		44.5-46.0' contains several stringers to ½" of clean mod. plastic (CL) clay	B-12	1.4/1.5		
46.0				PB-11	end of tube o.k., thin annular space around sample	
			S-10	2.46/2.5	We = 6.03 lb. Wf = 21.61 lb	
48.0						
		48.5' grading slightly more plastic fines	B-13	SPT-11 1.3/1.5	15/0.5 20/0.5 25/0.5	45
50.0				PB-12	end of tube o.k.	
	SM	51.0-54.5' SILTY SAND: as described for 4.0-24.5'; w/some thin layers grading more plastic, more fines as for 24.5-51.0'; very dense; slightly moist.	S-11	2.60/2.5	We = 5.96 lb. Wf = 22.44 lb.	
52.0						
			B-14	SPT-12 1.4/1.5	32/0.5 42/0.5 45/0.5	87
		ALLUVIUM/COLLUVIUM			10/8 end shift @ 5:15	
54.0				PB-13	10/9 start shift @ 7:45	
	SM	54.5-63.0' SILTY SAND: reddish to dk. reddish brn. (2.5YR 3/2(4)); 20-30% v. low–non-plastic fines; 65-75% mod. poorly graded sand, most f. grained, some v.f. and m.; 0-5% f. gravel; abundant gyp. as distinct small crystals (same size as sand); pervasive $CaCO_3$ w/ v. strong reac. to HCl - w/ some carbonized black organics as pods to 1/4" and as small specks; thin bedding to 0.05-1.5" seen in SPT samples, defined by sand size and % fines; compactness uncertain due to gravel in SPT's; material uncemented, very friable; slightly moist to moist.	S-12	1.20/2.5	end of tube ok., slough on top of sample We = 6.11 lb. Wf = not weighed	
56.0						
			B-15	SPT-13 0.8/0.8	35/0.5 50/0.3 (lrg. gyp. nodule in shoe)	85+
	grades gravelly			RD	RD to clear cemented zone	
58.0				PB-14	end of tube slightly dented, small void @ bottom and loose	
			S-13	2.42/2.5	We = 6.08 lb. Wf = 20.32 lb	
60.0	SM					
		~57.0-63.0' unit grades more gravelly from 10-15% to as much as 30-35% locally; gravels to 1¼", sandst., shale pred.	B-16	SPT-14 0.6/0.8	45/0.5 50/0.3 (1/4" sandst. @ top, rest gravelly)	95+
				RD	RD to pass gravels	
62.0				PB-15	end of tube o.k.	
	SP-SM	63.0-73.0' SILTY SAND: reddish brn. to red (2.5YR 4/5); 20-25% v. low–non-plastic fines; 70-75% poorly graded, pred. iron-oxide coated qtz.; trace f. sandst., shale gravel to 3/4"; pervasive $CaCO_3$; gyp. as f. crystals, small nodules fairly common;	S-14	2.36/2.5	We = 6.12 lb. Wf = (forgot to weigh)	
64.0						
			B-17	SPT-15	50/0.5 (no gravel)	50+
				RD	RD in tight sand, slow drilling	
66.0	SM	~63.0-65.5' grades 10-15% non-plastic fines, little or no m.-c. sand or gravel		PB-16	end of tube o.k.	
			S-15	2.03/2.5	We = 6.08 lb. Wf = 17.72 lb.	
68.0						

to design drawings

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/8-9/81 HOLE NO. STK-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
68.0	SM	63.0-73.0' SILTY SAND: (con't)	S-15 (con't.)	PB-16 (con't.)		
			B-18	SPT-16 0.7/0.7	59/0.5 50/0.2	109+
				RD	RD to clear gravel slough	
70.0			S-16	PB-17 2.33/2.5	end of tube o.k. We = 6.09 lb. Wf = 19.44 lb	
72.0						
74.0	GM	73.0-75.0' SILTY SANDY GRAVEL: as for 54.5-63.0', but w/50-60% gravel common, fines ~20%; gravel is hd, subang., pred. sandst., slty to 1", most 1/4-1/2"	S-17	PB-18 2.47/2.5	end of tube o.k. We = 6.12 lb. Wf = 20.51 lb.	
	SM	75.0-75.8 SILTY SAND: as for 54.5-65.0' but slighty more gravelly.	B-19	SPT-17 0.7/0.8	44/0.5 50/0.3 (w/ gravels to 1/2")	94+
76.0		B.H. @ 75.8'			Terminated hole @ 75.8' >21' into foundation w/sufficient data acquired. Backfilled w/mud & cuttings	

SHEET 4 OF 4

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118, SCS Dams, Utah DATE DRILLED 10/9-10/81 HOLE NO. STK-2

LOCATION Stocki Dam, ~sta. 17+85 on ℄ GROUND SURFACE ELEV. ~2814' (topo)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS crest of earth embankment; gravelly, cobbly WEATHER clear, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	GM-SM	EMBANKMENT FILL 0.0-4.0' SILTY GRAVELLY SAND-SANDY GRAVEL: reddish brn. (5YR4/4); 20-25% non-plastic fines, 15-25% sand; 40-60% hard, pred. sandst. gravel & cobbles, most 1½-3", few cobbles to 6"; pervious; dry.		AD	Auger w/6" flight auger Hard augering in gravel, cobbles to ~4'	
2.0						
4.0	SM	4.0-14.0' SILTY SAND: reddish brown (5YR 4/4); 20-25% non-plastic fines, quick dilatancy, no-v. low toughness; 75-80% poorly graded sand, pred. qtz., iron-oxide stained, subang. to subrnd; pervasive $CaCO_3$ w/strong reac. to HCl; very common gyp. as stringers of sugary, crystalline gyp. and as small individual crystals; v. slight trace of MnO or carbonized black organics as small specks; dense, v. friable; slightly moist to moist. 6.5-7.5' w/a 3" hd. sandst. cobble		RD	Augering smooths @ ~4' set up tub, casing to 4' RD w/4 7/8" tricone bit	
			B-1	SPT-1 1.1/1.5	Drove standard splitspoon 6/0.5 15/0.5 23/0.5 (scattered f. gravel to ½")	38
6.0			B-2	PB-1 0.7/1.0	cobble in end of tube for 3" Pitcher Barrel sample ww	
8.0			S-1	PB-2 1.28/2.5	end of tube slightly dinged lower part of sample loose—slipped from tube and bagged We = 5.72 lb wf = 16.56 lb.	
			B-3			
10.0			B-4	SPT-2 1.3/1.5	17/0.5 22/0.5 32/0.5 (trace 1/4-3/8" gravel)	54
12.0			S-2	PB-3 2.42/2.5	end of tube badly bent, 2" clast removed from bottom end, sample loose We = 5.89 lb. wf = 20.25 lb	
14.0	SC-SM	14.0-26.5' CLAYEY SILTY SAND: dk. reddish brn. (5YR3/4); 35-45% low plastic fines; mod. slow dilat., low toughness; 50-60% mod. well graded sand, more f.-v.f. than m.-c.; 2-7% pred. f. gravel of sandst., shale; w/gyp. as for prev. unit, but less abundant; mod. reac. to HCl; grades more or less plastic in thin layers; med. dense; moist. ~17.0-22.0' grades w/5-10% gravel w/ clasts to 3/4"	B-5	SPT-3 1.3/1.5	11/0.5 9/0.5 11/0.5	20
16.0			S-3	PB-4 ?/2.5	end of tube caved in We = 5.72 lb. wf = not weighed	
18.0			B-6	SPT-4 1.4/1.5	20/0.5 15/0.5 23/0.5 (5-10% sandst. gravel to 3/4")	38
20.0			S-4	PB-5		

SHEET 1 OF 3

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/9-10/81 HOLE NO. STK-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SC-SM	14.0-26.5' CLAYEY SILTY SAND: (con't)	S-4 (con't)	PB-5 (con't) 2.48/2.5	end of tube badly dented; We = 5.71 lb.; Wf = 19.93 lb.	
22.0			B-7	SPT-5 1.3/1.5	11/0.5 13/0.5 16/0.5 (trace f. gravel)	29
24.0			S-5	PB-6 1.36/2.5	end of tube slightly bent, sample loose @ bottom end; We = 5.93 lb.; Wf = 13.83 lb.	
26.0	SC-SM to SC (grades clayer)	26.5-34.0' CLAYEY SILTY SAND to CLAYEY SAND: dk. red (2.5YR 3/6); fines 40-45%; very low-mod. plastic, mod. quick to slow dilat, low-mod. tough; 50-60% v. poorly graded v.f. sand, some f. sand; trace c. sand to f. gravel; mod. strong reac. to HCl; $CaCO_3$ dissem. & in small, 1/16-1/4" nodules; little visible gyp.; dense-very stiff; slightly moist.	B-8	SPT-6 1.4/1.5	13/0.5 13/0.5 23/0.5	36
28.0			S-6	PB-7 2.6/2.5	end of tube dented, sample grooved full length; We = 5.94 lb.; Wf = not weighed	
30.0			B-9	SPT-7 1.4/1.5	6/0.5 9/0.5 13/0.5	22
32.0			S-7	PB-8 2.57/2.5	end of tube o.k., thin annular space around bottom of sample; We = 5.90 lb.; Wf = 22.15 lb.	
34.0	SC-SM to SC	34.0-40.0' CLAYEY SILTY SAND to CLAYEY SAND: dk. reddish brown (5YR 3/4); similar to 14.0-26.5' but with slightly more fines, locally grading more plastic, slightly less m.-c. sand; dense to v. dense, very stiff to hard; slightly moist to moist.	B-10	SPT-8 1.4/1.5	11/0.5 19/0.5 23/0.5	42
36.0			S-8	PB-9 2.54/2.5	end of tube o.k., annulus as for PB-8, sample loose @ bottom; We = 5.91 lb.; Wf = 21.86 lb	
38.0		38.0' grades to only 50-55% sand, no gravel; sand f.-v.f. grained; fines mod. plastic	B-11	SPT-9 1.3/1.5	11/0.5 16/0.5 45/0.5 (bottom 0.3' w/ sandst. gravel)	61
		ALLUVIUM/COLLUVIUM				
40.0	SM	40.0-43.5' SILTY SAND: dk. reddish brown (5YR 3/4); 15-20% non-plastic fines; 75-85% v. poorly graded sand, pred. iron-oxide coated, subang.-subrnd. qtz. grains; trace to few % sandst., shale gravel to 1/2"; gyp. as sugary, crystalline nodules to 1/4" and individual crystals; $CaCO_3$ dissem.; dense; slightly moist.	S-9	PB-10 1.96/2.5	end of tube bent over last 0.5' gravelly; We = 5.89 lb.; Wf = not weighed	
42.0			B-12	SPT-10 1.4/1.5	19/0.5 31/0.5 42/0.5 (no gravel); 10/9 end shift 5:40; 10/10 start shift 7:45	73
44.0	SM	43.5-56.5' SILTY SAND: (see description on next sheet)	S-10	PB-11		

6' of [illegible] to design drawings

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/9-10/81 HOLE NO. STK-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
44.0	SM	43.5-56.5' SILTY SAND: reddish brn. (5YR 4/4) to dk. brn. (7.5 YR 4/4); 10-20% nonplastic fines, quick dilatancy, no toughness; 80-90% mod. poorly graded, pred. f. grained sand, some v.f., less m.-c. grains; 3-7% f.-m. gravel, locally more, sandst., shale; crude bedding evident in proportion of sand sizes and gravel content, beds 0.1-1+' thick; rel. slow reac. to HCL; exceptionally high gyp. content to 10-15% or more visible as sugary, small nodules and crystals in some intervals, less but still common throughout; compactness uncertain due to gravel in SPTs, unit is very friable, uncemented, slightly moist to moist.	S-10 (con't.)	PB-11 (con't.) 2.13/2.5	end of tube badly curled; we = 5.80 lb, wf = 17.93 lb	
46.0		46.0' w/10-15% gravel @ end of PB-11	B-13	SPT-11 1.1/1.3	22/0.5 45/0.5 50/0.5 (trace f. gravel)	95
				RD	RD to clear gravel	
48.0			S-11	PB-12 2.09/2.5	end slightly dinged, annulus as for PB-9; we = 5.72 lb, wf = 17.11 lb	
50.0			B-14	SPT-12 0.8/0.9	25/0.5 50/0.4 (1/2" gravel in shoe)	75+
				RD	RD to clear gravel	
52.0			S-12	PB-13 2.16/2.5	end of tube ok.; very small void @ end; we = 5.80 lb, wf = 17.49 lb	
54.0	grades coarser sand, more gravel	54.0' w/60% gravel @ end of PB-13; 54.0-55.0' coarser sand, more gravel	B-15	SPT-13 1.0/1.0	22/0.5 50/0.5 (gravel in bottom of spoon)	72
				RD	RD to clear gravel	
56.0	SM, ML	56.5-58.5' SANDY SILT to SILTY SAND: (2.5 YR 4/4) reddish brn.; 40-60% low plastic fines; 40-60% pred. f.-v.f. sand; no gravel; much gyp., inc. downward; very dense to hard; slightly moist.	S-13	PB-14 2.37/2.5	end of tube ok., small void @ end; we = 5.90 lb, wf = 18.38 lb	
58.0			B-16	SPT-14 1.1/1.3	22/0.5 37/0.5 50/0.3 (abundant gypsum)	87+
60.0	GM-SM	58.5-61.7' SILTY GRAVELLY SAND to SANDY GRAVEL: as for 43.5-56.5' but w/gravel varying 20-70%, 1/2-3+", sandst., shale; rock @ end of PB-15 and in SPT-15 could be in-situ bedrock - seems too shallow reviewing SCS foundation borings.		RD	RD to clear hole in gravel section	
	? (bedrock?)		S-14	PB-15 1.52/1.5	end of tube chewed up, cobble @ bottom end; we = 5.71 lb, wf = not weighed	
62.0		B.H. @ 61.7'	B-17	SPT-15	50/0.2 0.1/0.2 = refusal on sltst. cobble	50+
					Terminated hole @ 61.7' maybe into bedrock	
					Backfilled hole w/ mud, cuttings and embankment material	

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/10/81 HOLE NO. STK-3

LOCATION Stucki Dam, ~sta. 12+79; 97' d/s GROUND SURFACE ELEV. ~2782' (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS loose, brushy spoil downstream toe WEATHER clear, warm

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SM	ALLUVIUM / COLLUVIUM 0.0-6.5' SILTY SAND: reddish brn. (2.5YR 4/4); 15-25% non-plastic fines, quick dilatancy, v. low-no toughness; 75-80% poorly graded, f.-v.f. sand; 3-6% gravel, 1/4-3/4", prd sandst., shale; pervasive $CaCO_3$ and small (1/8") mod.-soft nodules of $CaCO_3$; trace gyp(?) as f. crystals; loose at surface to mod. dense (?); dry to v. slightly damp. 2.0-6.5' grades slightly more fines downward	B-1	SPT-1 1.0/1.5	Drove standard splitspoon 10/0.5 15/0.5 17/0.5	32
2.0			(S-1)	(ST-1 2.3/2.5)	Pushed 3" shelby tube adjacent to STK-3 from 0.0-2.5' We=8.0 lb Wf=17.45 lb	
				RD	Set up tub, casing to 4'	
4.0				PB-1	Sampled w/3" Pitcher Barrel end of tube slightly dinged We = 5.94 lb. Wf = 19.28 lb.	
6.0			S-2	2.22/2.5		
	SM	6.5-17.0 SILTY SAND: dk. reddish brn. (5YR 3/4); 15-25% non-plastic fines; 40-80% poorly graded, prd. f. sand, some m.-c. grains; 5-locally 25% gravel, 1/4-1", prd. sandst., shale; much pervasive $CaCO_3$ w/ v. strong reac. to HCl, small nodules of $CaCO_3$ locally; fairly common gyp. as individ. crystals and sugary to powdery mottling; crude, irregular layering/stratification w/ variation in % fines and gravel; med. dense to dense; slightly moist to moist.	B-2	SPT-2 1.3/1.5	22/0.5 24/0.5 25/0.5 (few % hd. to deeply weath. fine sandst. gravel)	49
8.0				PB-2	end of tube slightly dinged We = 6.00 lb Wf = 19.28 lb	
10.0			S-3	2.33/2.5		
		10.5-12.0' gravel to 5-10%	B-3	SPT-3 1.3/1.5	10/0.5 11/0.5 14/0.5 (5-10% c. sand f. gravel)	25
12.0				PB-3	end dinged, sample began slipping from tube We = 6.02 lb Wf = 20.59 lb	
14.0			S-4	2.34/2.5		
		14.5-16.0' w/ pervasive mottling of sugary gyp. throughout	B-4	SPT-4 1.1/1.5	33/0.5 44/0.5 50/0.5 (gravel in shoe)	94
16.0				PB-4	end of tube dinged in two places We = 6.01 lb Wf = 18.44 lb	
18.0	SM	17.0-25.0 (GRAVELLY) SILTY SAND: dk. reddish brn. to reddish brn (2.5YR 3/2/4); 20-25% non-plastic fines, locally grading v. low plastic; 55-60% mod. well graded to mod. poorly graded sand, prd. f.-m. grained; 15-20% gravel, 1/4-1 1/2", most 1/4-3/4", prd. sandst., some shale; pervasive $CaCO_3$; some gyp.;	S-5	2.23/2.5		
20.0			B-5	SPT-5 1.2/1.5	22/0.5 37/0.5 50/0.5 (15-20% gravel)	87

SHEET 1 OF 3

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/10/81 HOLE NO. STK-3

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SM	17.0-25.0' (GRAVELLY) SILTY SAND: (con't) trace black carbonized org. debris. Compactness uncertain, very friable, uncemented; slightly moist to moist.	S-6	PB-5 2.30/2.5	end of tube o.k. we = 6.03 lb wf = 18.74 lb	
22.0		~18.5' grades to silty sandy gravel, gravelly sand 21.0-25.0' grades less gravelly	B-6	SPT-6 0.9/1.0	39/0.5 71/0.5 (few f. gravels)	110
24.0				RD	RD to clear gravels	
			S-7	PB-6 2.43/2.5	end of tube o.k. we = 5.93 lb wf = 19.67 lb.	
26.0	SM	25.0-34.9' INTBDD. SILTY SAND: reddish brn. (5YR 4/3); fines vary 15-30%, non-plastic; sand varies 50-80%, pred. f. grained, some m.-c.; gravel varies 5% to locally 50-60%, usually 3-7%; pred. sandst., some sltst., 1/4-1"; pervasive $CaCO_3$; gyp. fl. common as single crystals and small nodules in some intervals;	B-7	SPT-7 1.2/1.5	14/0.5 28/0.5 45/0.5	73
28.0		26.5' very little fines to 5-8%; non-plastic	S-8	PB-7 2.34/2.5	end of tube badly dented we = 5.94 lb wf = 18.77 lb	
30.0		26.5'-28.0' four intbdd. units noted w/varying % fines and varying sand sizes, all SMs 34.5' grades to silty sandy gravel - gravelly sand w/ clasts to 1", most 1/8-3/8" grading c. sand	B-8	SPT-8 1.3/1.5	29/0.5 45/0.5 71/0.5 (gravels @ top to 1/2")	116
32.0			S-9	PB-8 2.33/2.5	end of tube o.k. we = 6.02 lb wf = 19.93 lb	
34.0			B-9	SPT-9 0.8/0.9	35/0.5 75/0.4	110
36.0	SM-SP	34.9-49.5' SILTY SAND-SAND: orange-red (2.5YR 4/6); 10-15% non-plastic fines, quick dilatancy, no toughness; 85-90% v. poorly graded f.-v.f. sand, pred. subang-sub-rnd. qtz, iron-oxide stained; 0-5% f. gravel; little $CaCO_3$ w/ v. slight rxn. to HCl;		RD	RD w/ 4 7/8" tricone rock bit searching for bedrock	
38.0						
40.0					Rattling hd @ 40' Smoother @ 40.5'	
42.0	grades siltier		S-10	PB-9 2.04/2.5	end of tube o.k. we = 6.03 lb wf = 17.92 lb	
44.0		~43.0' grades slightly siltier and w/ $CaCO_3$ mottling common	B-10	SPT-10 0.7/1.0	37/0.5 67/0.5 (no gravel, not cemented)	104

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/10/81 HOLE NO. STK-3

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
44.0	SM-SP, SM	34.9-49.5 SILTY SAND-SAND:		RD	RD w/4 7/8" tricone searching for bedrock
46.0					
48.0					
50.0	GM-SM	49.5-51.5' SILTY SANDY GRAVEL-GRAVELLY SAND: as for 17.0-35.0' but w/40-60% gravel, 1/4-1 1/2", pred. sandst., some shale, [illegible] silty sand matrix.			hard rattling 49.5-51.5' in gravel
52.0		B.H. @ 51.5'			Terminate hole @ 51.5' w/sufficient data, did not encounter bedrock. Backfill w/ mud and cuttings, surficial material

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/10-11/81 HOLE NO. GYP-1

LOCATION Gypsum Wash Dam, ~ sta. 33+65 on ℄ GROUND SURFACE ELEV. ~2740' (topo)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS crest of earth embankment WEATHER breezy, partly cloudy, mod. temp.

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SM	EMBANKMENT FILL 0.0-5.0 SILTY SAND: yellowish red (5YR4/6); 20-25% non-plastic fines, quick dilatancy, no toughness; 70% v. poorly graded f.-v.f. sand; 5-10% gravel, 1/4-3/4", prd. sandst.; mod. reac. to HCl in general, numerous 1/16-1/8" $CaCO_3$ nod.; gyp. not apparent; dense; dry to v. slightly moist. 1.5-3.0 w/ 15-20% gravel, few cobbles 5-6"	B-1	SPT-1 1.2/1.5	Drove standard split spoon 10/0.5 24/0.5 31/0.5	55
2.0				AD	Auger w/ 6" flight auger thru section w/ cobbles 10/10 end shift @ 5:15 10/11 start shift @ 7:30	
4.0			B-2	SPT-2 0.7/1.0	33/0.5 50/0.5 (refusal on cobble)	83
				RD	RD to 4.5' to clear cobble set up tub. casing to 4'	
	SC-SM	5.0-17.0 CLAYEY SILTY SAND: reddish to dk. reddish brown (5YR 3/2/4); 40-45% low plastic fines; mod. quick dilatancy, low toughness; 50-60% mod. well graded, prd. f.-m. sand, qtz, sandst., volc.(?), shale; 0-5% gravel, 1/4-3/4", mostly gray-green sltst./shale, sandst.; mod. strong reac. to HCl; nodules to 1/4" and individ. crystals of gyp. sel. common throughout; dense to very stiff-hard; slightly moist; contains occasional v. fine rootlets (appears to be cambic horizon material from borrow).		PB-1	sample w/ 3" Pitcher Barrel end of tube curled over	
6.0			S-1	2.46/2.5	We = 5.95 lb Wf = 19.71 lb.	
8.0			B-3	SPT-3 1.4/1.5	20/0.5 23/0.5 30/0.5 (trace sandst. gravel to 3/4")	53
				PB-2	end of tube slightly flared; sample v. loose in tube; some gravelly slough on top	
10.0			S-2	2.26/2.5	We = 5.97 lb Wf = 19.90 lb.	
12.0			B-4	SPT-4 1.2/1.5	10/0.5 14/0.5 22/0.5 (few gravels to 1/2-3/4")	36
				PB-3	end dented fairly badly	
14.0			S-3	2.26/2.5	We = 5.97 lb Wf = 18.90 lb	
		16.0' to 5-10% gravel				
16.0		16.5' grading redder color, more coarse sand, more plastic	B-5	SPT-5 1.3/1.5	11/0.5 11/0.5 22/0.5	33
	SC					
	GP-GC	17.0-19.5' CLAYEY SANDY GRAVEL as for 19.5-23.9' but w/ 60-70% gravel, sandst., sltst./shale; ~10% or more clayey, low-mod. plastic fines.		PB-4	one ding on end of tube	
18.0			S-4	2.03/2.5	We = 6.02 lb Wf = 18.33 lb.	
20.0	SC	19.5-23.0' CLAYEY SAND: (see description on next sheet)	B-6	SPT-6 1.3/1.5	13/0.5 20/0.5 21/0.5 (top 0.5' very gravelly)	41

SHEET 1 OF 2

PROJECT D118-SGS Dams, Utah DATE DRILLED 10/10-11/81 HOLE NO. GYP-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SC	19.5-23.0 CLAYEY SAND: (cont.) yellowish red (5YR 4/6) w/ buff tint; 30-35% low-mod. plastic fines; mod. slow dilatancy, low-mod. toughness; 65-70% mod. well graded sand, pred. f-m. grained; 0-5% gravel; pervasive $CaCO_3$ as mottling, nodules - also gyp. as small nodules, crystals, one vein @ 40° is 1/8" thick; dense; slightly moist.	8-6 (cont.)	SPT-6 (cont.)		
				PB-5	one large dent in end of tube We = 6.01 lb Wf = 21.41 lb	
22.0			S-5	2.58/2.5		
	SM to SC-SM			SPT-7	29/0.5 46/0.5 50/0.3	96+
24.0			B-7	1.2/1.5	(15-20% f. gravel)	
	SC-SM	23.0-33.2' CLAYEY SILTY SAND: reddish brown (5YR 4/3); 25-30% low plastic fines; slow-mod. quick dilatancy, low toughness; 55-65% mod. well graded sand, pred. f-m. grained, qtz, sandst, sltst, shale; 5-15% gravel, 1/4-3/4", lith. as for sand; pervasive $CaCO_3$ w/ strong reac. to HCl; gyp. common as small clear crystals and small (1/16") white nodules; dk. brown shale clasts are distinctive in this unit; dense; slightly moist to moist.		RD	RD thru gravelly slough to clean hole	
26.0				PB-6	end of tube rolled over on one side We = 6.03 lb Wf = 19.24 lb.	
			S-6	2.27/2.5		
28.0				SPT-8	12/0.5 17/0.5 30/0.5	47
			B-8	1.3/1.5	(few fine moist. gravel clasts)	
				PB-7	end of tube has one small ding	
30.0		23.0-23.9' less plastic, w/ f. gravel to 15-20%	S-7	2.45/2.5	We = 5.80 lb Wf = 20.61 lb.	
32.0				SPT-9	10/0.5 14/0.5 27/0.5	41
		ALLUVIUM/COLLUVIUM	B-9	1.3/1.5		
	GC-GM	33.2-37.0' CLAYEY SANDY GRAVEL: as for 23.0-33.2' but fines are less plastic locally; gravel to 50-60%, sandst, gray-grn sltst, brown shale, to 2-3", most 1/2-1"; 30-40% f.-c. sand; uncemented; friable.	B-10	PB-8 0.2/1.0	end of tube chewed up on cobble or gravel near start of run; not weighed	
34.0				RD	RD to 35 1/2 through coarse gravelly section, hard, rattling	
36.0		BEDROCK	B-11	PB-9 0.3/1.5	end of tube chewed up; sample bagged, not weighed	
	(CL-ML)	37.0-43.7 SILTSTONE/SHALE: dark reddish brn (5YR 3/3) shale where least weath, greenish gray (5G 6/1) sltst, dk. reddish brn. (5YR 3/4) shale where most weath; predominantly fissile shale w/ some inclusions, thin stringers of harder sltst; contains abundant thin gyp. mottles, veins along partings; v. slight reac. to $CaCO_3$		SPT-10	22/0.5 38/0.5 52/0.5	
38.0			B-12	0.7/1.5	(hammering in weath. rock)	90
	grades less weathered			PB-10	Mix w/sack of bentonite to lessen gravel caving end of tube dented	
			S-8	1.58/1.5	We = 5.92 lb Wf = 15.45 lb.	
40.0		Phys. Cond. - crushes (due to weath.); shale soft-friable, sltst. mod. hd-hd; shale plastic to friable, sltst. mod. strong; deeply weath shale, w/ fresh sltst.	B-13	SPT-11	76/0.5; 0.5/0.5 (hammering in rock)	76+
				RD	RD to 41' to clean hole	
				PB-11	end of tube slightly belled We = 5.98 lb. Wf = 20.71 lb.	
42.0	SILTSTONE SHALE	37.0-42.0' remolds to CL-ML	S-9	2.25/2.5	Terminated hole @ 43.7' 6.7' into rock Backfilled hole w/ mud and cuttings	
44.0		B.H. @ 43.7'	B-14		SHEET 2 OF 2	50+
		42.0-43.0' shale grades - friable to low hardness - friable to weak		SPT-12	50/0.2 0.2/0.2 (hammering in rock)	

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/11/81 HOLE NO. GYP-1A

LOCATION Gypsum Wash Dam, ~Sta. 33+55 on ℄ GROUND SURFACE ELEV. ~2740' (topo)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb. 30"

SURFACE CONDITIONS crest of earth embankment WEATHER breezy to windy, partly cloudy, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
0.0	SM	EMBANKMENT FILL Note: see log for boring GYP-1 for more complete description of units		AD	Auger w/6" flight auger
					set up tub, casing to 1'
2.0				RD	RD w/4 7/8" tricone bit
4.0					
	?				
6.0	SC-SM				
8.0			S-1	PB-1 1.73/1.8	sample w/3" Pitcher Barrel end of tube dinged we = 5.91 lb wf = 16.16 lb
		9.6' clayey silty sand; fines low plastic to 30-40%; sand to 60-70%, trace gravel w/ 1 clast to 1 1/4"; color is reddish to dk. red. brn. (5YR 3/2/4)			
10.0				RD	RD until drilling smooths somewhat @ 10.5'
			S-2	PB-2 1.48/1.5	end of tube chewed up we = 5.96 lb. wf = 14.87 lb
12.0		12.0' as above but less reddish color, trace c. sand, f. gravel		RD	RD until drilling smooths somewhat @ 13.5'
14.0			S-3	PB-3 2.17/2.0	end of tube o.k.; thin annular space around sample @ end of hole we = 5.98 lb. wf = 18.90 lb.
		15.5' as for 12.0' B.H. @ 15.5'			
16.0					Terminated hole @ 15.5' w/ two additional useable samples of embankment Backfilled hole w/mud and cuttings

SHEET 1 OF 1

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/11/81 HOLE NO. GYP-2

LOCATION Gypsum Wash Dam, ~sta. 20+01, 68' U/S GROUND SURFACE ELEV. ~2725 (Topo)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY AMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb, 30"

SURFACE CONDITIONS loose debris basin deposits; brush WEATHER cool; partly cloudy; windy

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft
0.0	SM-ML	DEBRIS BASIN DEPOSITS 0.0-3.5' SANDY SILT-SILTY SAND: reddish brn. (5YR 4/3-5/3); 40-60% v. low-non plastic fines; 40-60% v. poorly graded f-v.f. sand; 0-5% gravel; pervasive CaCO3; some gyp.; med. dense-very stiff; dry.	B-1	SPT-1 1.2/1.5	Drove standard split spoon 3/0.5 10/0.5 13/0.5	23
2.0				AD	Auger w/6" flight auger	
		ALLUVIUM/COLLUVIUM		RD	set up mud-tub, set surface casing to 3', RD w/ 4 7/8" tricone bit thru gravels to rock @ 6.5'	
4.0	SC-GM	3.5-6.5' CLAYEY to SILTY GRAVEL: as for 33.2-37.0' in GYP-1; clasts of [illegible], gray-green siltst, dk. brn. shale, 1/4-1 1/2", most 1/4-3/4".				
6.0		BEDROCK			Return fluid changes color to brown @ 6.5 sample w/3" Pitcher Barrel	
	(CL-ML)	6.5-33.5 SILTSTONE/SHALE: dark reddish brn. (5YR3/3) least weath. to dk. red. brn (5YR 4/4) w/grayish tint when fresh; generally fissile shale, locally grades to blocky siltstone; w/ gyp. crystalline nodules and gray green (gypsiferous?) veins, stringers on partings locally; v. slight to no reac. to HCl; grades harder w/depth, can be remolded to CL-ML to ~23-24' - ply. Cond. - crushed to intensely fractured (partly due to weath., driving SPT); grades from soft to low hardness w/ depth; grades from plastic to weak w/depth; grades deeply to mod. weathered w/depth.		PB-1	end of tube bent on one side	
8.0			S-1	2.1/2.5	w_e = 5.80 lb w_f = 18.73 lb	
	SILTSTONE/SHALE			SPT-2	38/0.5 45/0.5 58/0.5	103
10.0			B-2	1.2/1.5	(hammering in rock)	
				PB-2	end of tube o.k. w_e = 5.80 lb w_f = 18.93 lb	
12.0			S-2	2.13/2.5		
				SPT-3	16/0.5 38/0.5 41/0.5	79
14.0			B-3	1.2/1.5	(hammering in rock)	
				PB-3	end of tube caved in on one side w_e = 6.03 lb	
16.0			S-3	2.14/2.5	w_f = 18.82 lb	
				SPT-4	27/0.5 38/0.5 50/0.5	88
18.0			B-4	1.1/1.3	(hammering in rock)	
				RD	RD to clean hole	
				PB-4	end of tube o.k. w_e = 5.96 lb	
20.0			S-4	2.32/2.5	w_f = 19.75 lb.	

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/11/81 HOLE NO. GYP-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SILTSTONE/SHALE	6.5-33.5' SILTSTONE/SHALE: (con't.)	S-4 (con't.)	PB-4 (con't.)		
		21.0-22.2' several 1/8-1/10" thick, approx. horizontal layers of gray-green (gypsiferous?) clayey silt; may have resulted in rel. low blow count in SPT-5		SPT-5	4/0.5 9/0.5 16/0.5	25
22.0			B-5	1.2/1.5		
				PB-5	end has one bad ding, hit hard zone near end of run	
24.0			S-5	2.47/2.5	we = 6.03 lb wf = 21.10 lb	
			B-6	SPT-6 0.5/0.7	40/0.5 50/0.2 (refusal in rock)	90+
26.0				RD	RD to clear hole	
	grading harder			PB-6	end of tube dinged we = 5.79 lb wf = 18.79 lb	
28.0			S-6	2.06/2.5		
			B-7	SPT-7 0.6/0.6	39/0.5 50/0.1 (refusal in rock)	89+
30.0				RD	RD to slightly smoother, faster drilling @ 30.5'	
				PB-7	end of tube egg-shaped we = 6.01 lb wf = 21.63 lb	
32.0			S-7	2.43/2.5		
			B-8	SPT-8	87/0.5 (refusal in rock)	87+
34.0		B.H. @ 33.5'			Terminated hole @ 33.5' 27' into bedrock w/ sufficient data acquired Backfilled hole w/ cuttings and debris basin deposits	

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/12/81 HOLE NO. GYP-3
LOCATION Gypsum Wash Dam ~sta. 26+83 on ℄ GROUND SURFACE ELEV. ~2740' (topo)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS crest of earth embankment WEATHER breezy, partly cloudy, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	SM	EMBANKMENT FILL 0.0–2.0' SILTY SAND: yel. red. (5YR 4/3) 25–20% n.p. fines; 75–80% v.f.–f. sand; 0–5% gravel; pervasive $CaCO_3$; dense; dry to slightly moist.	B-1	SPT-1 1.2/1.5	Drove standard split spoon 10/0.5 29/0.5 30/0.5	59
2.0				AO	Auger w/6" flight auger	
	SM	2.0–5.0' SILTY SAND: reddish brn. (5YR 4/4); 25–35% non-plastic fines, 65–75% poorly graded, f.–v.f. sand; 0–5% gravel; pervasive $CaCO_3$ w/ strong reac. to HCl; gyp. as v. small white nodules to 1–2mm; dense; slightly moist–moist. 2.0' some 3–5" cobbles, c. gravel	B-2	SPT-2 1.2/1.5	13/0.5 14/0.5 26/0.5 (scattered f. gravel)	40
4.0				RD	RD to clear scattered gravels	
6.0	SC-SM	5.0–17.9' CLAYEY SILTY SAND: reddish to dk. reddish brown (5YR 3½/4); 35–45% low plastic fines; 50–60% mod. poorly graded sand, pred. f.–v.f. grained, less m.–c.; 0–5% gravel, 1/4–2", sandst., gray-green siltst., brn. shale; pervasive $CaCO_3$; gyp. fairly common as small (1/8–1/4") nodules some mottles, also as v. small clear crystals; contains some black carbonized organic debris, some rel. fresh to partly carbonized rootlets, stems (only trace amt. as small pieces); med. dense to dense; slightly moist to moist.	S-1	PB-1 2.48/2.5	Sample w/3" Pitcher barrel end of tube caved in on one side; small void @ bottom end of tube we = 5.78 lb wf = 19.45 lb	
	CL-CH					
8.0	SC-SM		B-3	SPT-3 1.4/1.5	20/0.5 37/0.5 45/0.5 (scattered f. gravel)	82
10.0			S-2	PB-2 2.34/2.5	end of tube curled in we = 6.01 lb wf = 20.02 lb.	
12.0			B-4	SPT-4 1.3/1.5	7/0.5 13/0.5 15/0.5 (10–15% c. sand, f. gravel)	28
14.0		7.5' a 0.1' thick CL-CH clay lens was noted in SPT-3, others may be present locally anywhere in unit		PB-3 0.0/2.5	sample slipped from tube while pulling rods; end of tube not damaged	
16.0			S-3	PB-4 2.19/2.5	one ding in end of tube we = 5.80 lb wf = 19.27 lb.	
18.0	SC (GC)	17.9–23.0' CLAYEY SAND: dk. reddish brn. (5YR 4/4); 25–35% low–mod. plastic fines; 60–70% mod. well graded sand, w/ larger clasts of sandst., gray-green siltst. and dk. brn shale; 5–10% gravel.	B-5	SPT-5 1.3/1.5	19/0.5 21/0.5 33/0.5 (bottom 0.9' is deeply weath. siltst. cobble)	54
20.0	SC		S-4	PB-3 2.5/2.5	end of tube caved in, small void @ end	

SHEET 1 OF 2

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/12/81 HOLE NO. GYP-3

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
20.0	SC	17.9-23.0' CLAYEY SAND: (con't) lith. as for c. sand; mod. strong reac. to HCl; some gyp as for 5.0-17.9', not as abundant; dense to v. stiff; slightly moist-moist.	S-4 (con't.)	PB-5 (con't.)	w_e = 5.80 lb. w_f = 18.72 lb.
22.0		17.9-18.8' soft, friable cobble of dk. yel. brn. (10YR 4/2) to lt. ol. gray (5Y5/2) clayey siltstone - shows ang. blocky structure; weak-friable; mod.-deeply weath.; remolds to CL-ML	B-6	SPT-6 1.3/1.5	11/0.5 20/0.5 23/0.5 (scattered f. gravel as deeply weath. sltst.) 43
24.0		B.H. @ 23.0'			Terminated hole w/ sufficient data acquired. Backfilled hole w/ cuttings, surficial embankment fill

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118 – SCS Dams Utah DATE DRILLED 10/12-13/81 HOLE NO. FH-1

LOCATION Frog Hollow Dam, ~ sta. 11+26 on ℄ GROUND SURFACE ELEV. ~119' * (topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30 in.

SURFACE CONDITIONS top of embankment WEATHER clear, cool, breezy

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
0.0	CL-ML (grades sandier)	EMBANKMENT FILL 0.0–5.0 CLAY-SILT: reddish brn (5YR4/4); 95+% low plastic fines; slow–mod. quick	B-1	SPT-1 1.1/1.5	Drove standard split spoon (scattered f. gravel) 6/0.5 19/0.5 23/0.5	42
2.0		dilat., low toughness; 3–5% f.-v.f. sand; trace c. sand,		AD	Advance hole w/6" flight auger to 2½'	
		f. gravel; strong reac. to HCl throughout; trace visible gyp. as white specs, small (<1/32")	B-2	SPT-2 1.1/1.5	27/0.5 24/0.5 24/0.5 (scattered fine gravel)	48
4.0		soft nodules; hard; dry to slightly moist w/depth.			set tub; surface casing to 1½'	
	CL-ML	2.0–5.0' grades sandier to 5–15% f.-v.f. sand; more visible gyp; moist; trace carbonized organic debris	S-1	PB-1 2.43/2.5	Sample w/3" Pitcher Barrel. One side caved in on end. We = 5.96 lb, Wf = 19.50 lb.	
6.0	SM	5.0–32.5' SANDY CLAY-SILT:				
	CL-ML	dk. reddish brn (5YR3/4); 65–75% low plastic fines, mod.	B-3	SPT-3 1.4/1.5	11/0.5 19/0.5 28/0.5 (scattered gravel)	47
8.0		quick to slow dilatancy, low–mod. toughness; 25–35% poorly graded, f.-v.f. sand, w/ % m.-c. sand variable; 0–15–20%	S-2	PB-2 2.34/2.5	end tube caved in on one side We = 6.07 lb Wf = 18.12 lb.	
10.0	CL-CH	gravel locally, usually <3–5% scattered randomly; unit is interlayered as indicated on				
	CL-ML	log; trace to 1–2% locally of carbonized organic material as mottles, flecks, small chips to	B-4	SPT-4 0.75/1.5	11/0.5 13/0.5 15/0.5 (used spoon w/ split inner liner)	28
12.0		1/8", some rel. fresh twig, root? fragments noted; mod. to strong reaction to HCl throughout; gyp as white, sugary, irreg.		PB-3 0.0/2.5	PB-3 cut smooth, even; sample slipped from tube while pulling rods	
14.0		nodules from 1/32–1/2" rel. common, some harder nodules also (gyp. or gypsiferous sltst.?); very stiff to hard; slightly moist to moist.	S-3	PB-4 2.51/2.5	One ding in end of tube; part of sample pulled off bottom, leaving ~1 in³ void We = 6.06 lb. Wf = 20.67 lb.	
16.0	CL-CH	6.5–7.1' grades to silty f. sand w/some fine basalt gravel clasts 10.5–11.2' contains a 0.05' thick CL-CH clay lens	B-5	SPT-5 1.3/1.5	13/0.5 18/0.5 20/0.5	38
18.0	CL-ML	17.0–18.3' contains several 1/8–1/2" CL-CH clay seams	S-4	PB-5 2.35/2.5	end of tube ok. We = 6.03 lb. Wf = 20.25 lb.	
20.0						

SHEET 1 OF 3

* arbitrary datum

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/12-13/81 HOLE NO. FH-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	CL-ML	5.0-32.5' SANDY CLAY-SILT:	S-4 (con't)	PB-5 (con't)		
			B-6	SPT-6 1.3/1.5	8/0.5 11/0.5 19/0.5 (3/4" gravel in shoe)	30
22.0		22.0' grades more sandy, fine gravel locally w/ common black clayey organic debris as mottles, irregular, small pods to 1/16-1/4"				
				PB-6	end of tube o.k. w_e = 6.07 lb. w_f = 19.75 lb.	
24.0			S-5	2.30/2.5		
	SM-ML	~24.0-25.5' grades to silty v.f. sand to v.f. sandy silt w/non-plastic fines; some gyp.(?) visible				
	CL-ML		B-7	SPT-7 1.3/1.5	17/0.5 15/0.5 19/0.5	34
26.0		25.0-26.5' gyp. as soft to mod hd. nodes 1/8-1/3" rel. common				
				PB-7	end of tube o.k. w_e = 6.04 lb. w_f = (forgot to weigh)	
			S-6	1.88/2.0		
28.0					cuts gravelly @ ~28½'	
	CL-ML w/gravel	28.5-29.6' grades to gravelly sandy clay-silt w/cbsts of basalt, sltst. to ½" in non-low plastic fines matrix	B-8	SPT-8 1.4/1.5	11/0.5 14/0.5 20/0.5 (top 0.6' w/gravel to ½")	34
30.0	CL-ML					
				PB-8	end of tube o.k. w_e = 6.03 lb w_f = 21.66 lb	
		29.0-30.4' contains thin stringers of silty f. sand and CL-CH clay	S-7	2.64/2.5	(driller over-cut by 0.14' depth not adjusted on log)	
32.0		32.5 w/some c.sand, f.gravel				
	CL	32.5-48.5' SILTY CLAY: reddish brown (5YR 4/3); 95+% low-mod. plastic fines, slow dilatancy, mod toughness; 0-5% v.f. sand; black organic clay to carbonized organic debris rel. common throughout as irregular patches, specks to 1/4" max. dimen.; mod. strong reac. to HCl throughout due to $CaCO_3$; occasional rel. fresh fine root or twig remnant to 1/4" long (only saw two); gyp. as f.-v. fine off-white specks rel. common; very stiff to hard; slightly moist to moist.	B-9	SPT-9 1.5/1.5	8/0.5 13/0.5 18/0.5	31
34.0				PB-9	end of tube o.k. w_e = 5.98 lb w_f = 19.85 lb	
			S-8	2.39/2.5		
36.0						
			B-10	SPT-10 1.5/1.5	8/0.5 13/0.5 17/0.5	30
38.0				PB-10	end of tube o.k. w_e = 5.97 lb w_f = 21.00 lb	
			S-9	2.47/2.5		
40.0						
			B-11	SPT-11 1.3/1.5	8/0.5 16/0.5 22/0.5	38
42.0	CL	41.4-41.8' grades to sandy silty clay w/ 10-20% f.-v.f. sand		PB-11	end dinged on one side cut gravelly @ ~43'	
	CL		S-10	2.57/2.5		
44.0						

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/12-13/81 HOLE NO. FH-1

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
44.0	CL	32.5-48.5' SILTY CLAY: (con't)	S-10 (con't)	PB-11 (con't)	We = 5.99 lb. Wf = (forgot to weigh)	
		44.5-46.0' grades w/ trace of coarse sand size grains, trace v. fine gyp.	B-12	SPT-12 1.5/1.5	7/0.5 13/0.5 20/0.5	33
46.0			S-11	PB-12 2.25/2.5	end of tube o.k. We = 5.98 lb. Wf = 20.35 lb.	
48.0	CL-ML	48.5' grades slightly less plastic and slightly more fine sand and scattered coarse grains ALLUVIUM/COLLUVIUM	B-13	SPT-13 1.2/1.5	10/0.5 12/0.5 14/0.5	26
		48.5-58.0' SANDY CLAY-SILT: reddish brown (5YR 4/3); 80-90% low-mod. plastic fines; slow-mod. quick dilatancy, low-mod toughness; 10-20% skip-graded sand, pred. v.f. grained w/ ~3-5% as m.-c. grained subrnd smoky to clear qtz. and basalt; trace f. gravel pred. basalt; small off-white specks, nodules to 1/16" of gyp(?), rel. common - some irridescent black 'MnO(?) coatings on grains, blocky small soil peds; some black carbonized organic debris; occassional fine, rel. fresh rootlets; pervasive $CaCO_3$ as indicated by strong reac. to HCl; crude angular blocky structure (soil ped development?); very stiff; slightly moist to moist.				
50.0				RD(?)	10/12/81 end shift @ 6:05; 10/13/81 start shift @ 10:10	
52.0	void or very soft material			PB-13 0.2(?)/4.5	Encounter slough/cave at ~45', no drill fluid in hole; clean hole to 50.5' w/no return fluid; put PB into hole for run #13, encounter very little to no resistance lowering sampler until ~55', no return during sampling run; recovered 0.2'-may be sidewall or from bottom of run; ran PB-14 w/ no return fluid; total fluid loss > 250 gals.	
54.0						
56.0	CL-ML grades gravelly		S-12	PB-14 1.43/1.8	PB-14 - end of tube o.k. We = 6.00 lb. Wf = (not weighed)	
			B-14	SPT-14 1.0/1.2	10/0.5 35/0.5 50/0.5 (gravel clast in shoe)	85
58.0		B.H. @ 58.0'				

50.5-54.8'	void or very soft material - see remarks column for description of behavior during drilling/sampling
56.8-58.0	grades increasing gravel downward to ~10-20% @ 57.4'; clasts 1/4-3/4" pred. basalt, also slightly calcareous qtz. sandstone, lt. gray-green (gypsiferous?) siltstone; large (1/4") charcoal fragment @ top of sample; 0.15' basalt clast at bottom of sample, grades deeply weathered to rel. fresh downward; top of bedrock(?)

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT 0118, SCS Dams, Utah DATE DRILLED 10/13,14/81 HOLE NO. FH-2
LOCATION Frog Hollow Dam, ~sta. 10+52, 106' U/S GROUND SURFACE ELEV. ~89'* (topo)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb, 30"
SURFACE CONDITIONS soft, loose sediment in reservoir WEATHER partly cloudy, windy, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
0.0	CL-ML	DEBRIS BASIN DEPOSITS 0.0-15.3' CLAY-SILT: dk. reddish brown (5YR 3/4); 95+% low-mod. plastic fines; mod. quick dilatancy, low-mod. toughness; <5% v.f. sand; no gravel; trace of gyp. as c. sand-size soft to mod. hd. nodules; occassional rel. fresh rootlets, twigs, trace black carbonized debris; some intervals varied w/ subtle grain size changes; pervasive $CaCO_3$ disseminated throughout indicated by strong reac. to HCl; stiff-v. stiff; med. dense; dry to moist w/ depth.	B-1	SPT-1 1.3/1.5	2.0" OD standard split spoon 10/0.5 14/0.5 19/0.5	33
2.0				RD	set tub; surface casing to 1', RD w/ rock bit to 2½'	
			B-2	SPT-2 1.3/1.5	7/0.5 8/0.5 10/0.5	18
4.0				PB-1	Sample w/ 3" Pitcher Barrel end of tube o.k. We = 6.02 lb. Wf = 17.72 lb.	
6.0			S-1	2.35/2.5		
			B-3	SPT-3 1.2/1.5	7/0.5 8/0.5 14/0.5	22
8.0				PB-2	Losing drill fluid to formation, but maintain circulation @ ~6-8'	
10.0			B-4	0.3/2.5	All but 0.3' of sample in PB-2 slipped from tube while coming out of hole (may be due to collapse of sample upon wetting?)	
	SM	10.5-11.2' lens of silty fine quartz sand	B-5	SPT-4		
12.0	CL-ML	12.0-14.5' contains a few v. thin (1-2mm) silty f. sand lenses	B-6	1.4/1.5	3/0.5 7/0.5 8/0.5	15
			B-7	PB-3	Portion of PB-3 slipped from tube at surface - remainder loose in tube - kept in plastic bags	
14.0			B-8	1.8/2.5		
	w/ SM	14.5-15.3' contains common thin beds, lenses of silty f. sand	B-9	SPT-5 1.3/1.5	2/0.5 4/0.5 5/0.5	9
16.0	CL-CH	15.3-16.0' CLAY: v. dk. gray to black (N3-N2); mod.-high plastic fines; no sand or gravel; spongy feel, burnt-organic odor (may be OL-OH?); contains few rel. fresh rootlets, twigs, lense of partially decayed org. debris; firm; moist.	B-10			
	SM	ALLUVIUM/KOLLUVIUM 16.0-17.0' SILTY SAND: mod. brn. (5YR 4/4); 35-40% low-non-plastic fines; 60-65% f.-m. grained sand, some c. grains; no gravel; compactness uncertain; in-situ moisture uncertain.	S-2	PB-4 ~1/1.0	end of tube slightly dinged We = Wf = (slough on top, not weighed)	
	CL-ML			SPT-6	stop PB-4 @ 17' on rock or gravel	
18.0	GC		B-11	1.0/1.5	3/0.5 16/0.5 16/0.5 (w/ gravel to 1½")	32
				RD	RD to 19' to clean gravel out of hole; still losing fluid (have lost ~500 gal)	
20.0			S-3	PB-5		

SHEET 1 OF 2

* arbitrary datum

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/13,14/81 HOLE NO. FH-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	GC SM	17.0-20.5' GRAVELLY, SANDY CLAY-SILT to CLAYEY-SILTY GRAVEL: multi-colored clasts in dk. reddish brn. (5YR3/4) matrix; matrix of low plastic fines varies 30-80%; sand varies 10-40%, mod. well graded gravel varies 10-60%, incl. sandst., sltst., basalt 1/4-1 1/2", all mod.-deeply weathered; w/CaCO3; some gyp. (?); some carbonized org. debris; rel. low compactness; in-situ moisture uncertain.	S-3 (con't)	PB-5 (con't)	end badly caved one side We = 5.72 lb Wf = 15.50 lb.	
22.0	CL-ML		B-12	SPT-7 1-1/1.5	6/0.5 16/0.5 21/0.5 (w/10-15% f. gravel locally)	37
24.0			S-4	PB-6 1.17/2.5	end of tube o.k.; sample is notably soft @ end; some slough on top of sample We = 5.54 lb Wf = 12.65 lb	
26.0		20.5-21.5' SILTY SAND: similar to 16.0-17.0' but w/several % c. sand, f. gravel; fines non-plastic.	B-13	SPT-8 .9/1.5	6/0.5 7/0.5 10/0.5 (w/some f. gravel)	23
28.0		21.5-32.0' SANDY CLAY-SILT: (same as 48.5-58.0' in FH-1); reddish brown (5YR4/3); 80-90% low-mod. plastic fines; 10-20% pred. f.-m. grained sand, locally less; locally trace f. gravel; some black carbonized organics, trace rel. fresh rootlets, twigs; some MnO (?) coatings on grains; trace gyp. as white nodules to 1/32", pervasive CaCO3; some thin black org. clay seams; v. crude arg. blocky structure; grades hard to stiff w/depth; grades slightly moist to moist, locally wet.	S-5	PB-7 2.28/2.5	end of tube badly caved in; small void at end of tube We = 5.54 lb Wf = 18.67 lb	
30.0			B-14	SPT-9 1.0/1.5	6/0.5 6/0.5 7/0.5	13
32.0	? CL		S-6	PB-8 2.62/2.5	end of tube o.k. We = 5.62 lb Wf = 20.76 lb. still losing fluid; have used another 500 gals	
34.0		21.5-25.0' locally to 10-15% sandst., sltst. gravel 29.5' wet, soft @ end of PB-7 29.5-31.0' contains irreg. black org. clay seams	B-15	SPT-10 1.5/1.5	6/0.5 10/0.5 12/0.5 10/13/81 end shift @ 4:15 10/14/81 start shift @ 8:30	22
36.0		32.0-37.0' SILTY CLAY: dk. reddish brn (5YR3/4); 95+% low-mod. plastic fines, slow dilatancy, mod. toughness; <5% v.f. sand; very stiff; moist.	S-7	PB-9 ~1.45/2.2	Drill fluid standing @ ~20', encounter slough @ ~27.5'; mix 3/4 sack mud, 2-3 lb salt-gel; drove casing to 29'; RD to 35' to clean hole, mud up walls.	
38.0	? GC		B-16	SPT-11 0.4/0.4		100+
	GC-CL	37.0-39.4' CLAYEY GRAVEL: black volc. gravel, cobbles in dk. red. brn. silty clay, clayey silt matrix; matrix rel. free of sand; basalt clasts mod.-little weathered, clasts 1/4-2 1/2". 38.9-39.4' grades more clay		RD	PB-9 - end of tube bent over, chewed up We = 5.67 lb Wf = (not weighed)	
40.0	BASALT				SPT-11 100/0.4 (pounding on gravel or rock)	
42.0		39.4-43.0' BASALT - rel. fresh, hd. basalt cuttings, no clay noted.			RD 37.6-38.8' rough drilling, gravelly 38.8-39.4' smoother 39.4-43.0' rocky Losing some fluid during RD Terminate hole @ 43' w/ sufficient data acquired Backfill w/cuttings, mud	
44.0		B.H. @ 43.0'				

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-3

LOCATION Frog Hollow Dam ~ sta. 11+19 on ℄ GROUND SURFACE ELEV. ~ 119' *(topo.)

DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered

TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"

SURFACE CONDITIONS top of earth embankment WEATHER clear, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
0.0	CL-ML	EMBANKMENT FILL 0.0-5.0' CLAY-SILT: see same interval in FH-1 for detailed description		AD	Begin set-up @ 11:30 Auger to 4' w/5" flight auger
2.0					
4.0					set mud tub, set surface casing to 1'
	CL-ML	5.0-32.0' SANDY CLAY-SILT: see interval 6.0-32.5' in FH-1, for detailed description; note variations below.		RD	start RD w/4 7/8" tricone bit @ 11:54
6.0		6.5' w/some gravel, some gypsum			slight chatter @6½'
8.0		8.5' grades siltier w/some fine sand and black organic clay			
10.0		9.5-10.0' grades back more plastic 10.5' less stiff			drills faster @ ~10½'
12.0					
14.0					
16.0		16.0' w/gypsum; trace of coarse sand			
18.0		18.0-19.0' grades siltier, a little more stiff			drills slower 18-19'
20.0					SHEET 1 OF 3

* arbitrary datum

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-3

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
20.0	CL-ML	5.0-32.0' SANDY CLAY-SILT: (con't.)		RD	
		~20' grades up to 5-7% med.-coarse sand			
22.0					
		23' gray-black clay lens			
24.0		24' grades gravel, coarse sand in clayey silt, low plasticity matrix; clasts of yel. brown weath. sandst.			rattling and slower drilling @ 24'
26.0		24.5-27.0' grades less c. sand, f. gravel and more f.-v.f. sand			
		27.0' grades sandier w/ scattered f. gravel of green-gray sltst., brown sandst.			
28.0					
30.0		30.5' grades more plastic w/ trace f.-c. sand grains			
32.0	CL	32.0-46.0' SILTY CLAY: see interval 32.0-48.5' in FH-1 for detailed description; see below for local variations.			drill rate slows @ 33½'
34.0		32.0' grades mod. plastic w/ olive-black organic clay mottling or lenses			bit balled-up w/ clay - dislodge @ 34'
		33.5' grades stiffer			
36.0		36.0' cuttings d. gray w/ black charcoal fragments			
		37.0' some fibrous black organic debris in cuttings			drill rate increases slightly @ 37'
38.0		38.0' as @ 36.0'			
40.0					
42.0					
44.0		43.5' grading slightly sandier w/ trace m.-c. sand			

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-3

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/Ft.
44.0	CL	32.0-46.0' SILTY CLAY: (con't.) ALLUVIUM/COLLUVIUM		RD	complete RD to 45' @	
				PB-1 1.49/1.6	Sample @ 3" 50 pitcher barrel, end tube slightly dinged, slight chatter @ 46' We = Wf = 14.90 lb.	
46.0	CL-ML	46.0-56.5' SANDY CLAY-SILT: reddish brn. (5YR4/3); 80-90% low-mod. plastic fines, slow to mod. quick dilatancy, low-mod. toughness; 10-20% sand, pred. f.-v.f. grained, variable % of m.-c. sand; trace f. gravel as basalt, sltst., some sandst., some clear to smoky quartz(?) grains, small clasts; locally w/specks, small nodules of gypsum(?); some MnO(?) coatings, veins; trace of black carbonized organic debris, locally trace of rel. fresh rootlets; pervasive $CaCO_3$ w/ strong reaction to HCl; crude ang. blocky structure suggesting soil ped development; very stiff; slightly moist-moist.	S-1			
			B-1	SPT-1 1.4/1.5	mod. chatter @ 46.6', stop run Drive standard split spoon 9/0.5 23/0.5 30/0.5 (w/coarse sand, f. gravel)	53
48.0	?	46.6-48.1' several zones to 0.1' w/ >50% c. sand, f. gravel, w/white agate notable		PB-2 2.56/2.4	smoother @ 48' when chasing SPT-1 w/ RD one bad dent end of PB-2 We = 5.63 lb. Wf = 20.70 lb.	
	CL-ML		S-2			
50.0	leached interval	~49.0-51.1' color to lt. red. brown (2.5YR 5½/4) w/ leached appearance; v. strong reaction to HCl	B-2	SPT-2 1.3/1.5	9/0.5 13/0.5 13/0.5	26
	CL-ML	51.1' color grades to reddish brn. (5YR 3/4), thus more brown than previously	B-3			
52.0		51.1-51.8' w/20-25% v.f. to f. sand	S-3	PB-3 2.21/2.5	end badly caved in on one side (large gravel clast on top of sample) We = 5.59 lb. Wf = 18.49 lb.	
54.0		54.8' grades more plastic, w/ a 3/4-1" basalt clast, some green, sltst. fragments	B-4	SPT-3 0.7/1.5	8/0.5 12/0.5 13/0.5 (few gravels, one 3/4-1")	25
56.0	CL w/ gravel	56.5-57.9' SILTY CLAY: similar to above but less sand, more plastic; w/scattered basalt gravel and cobbles.		PB-4 0.0/2.0	end mushroomed-probably pushed cobble and washed formation in front of tube-run came to abrupt halt @ 57.9' on basalt	
58.0	Basalt	B.H. @ 60.0'		RD	RD 57.9-60.0 in hard rock; no fluid loss	
60.0		BEDROCK 57.9-60.0' BASALT: gray to black; rel. fresh to unweathered cuttings; hd; drills uniformly suggesting rel. unfractured(?); no clay binder noted.			Terminate hole @ 60' 2.1' into rock w/ sufficient data acquired Backfill hole w/mud & cuttings	

SHEET 3 OF 3

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-4
LOCATION Frog Hollow Dam, ~sta. 11+33 on ℄ GROUND SURFACE ELEV. 119'* (topo)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS top of earth embankment WEATHER clear, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
0.0	CL-ML	EMBANKMENT FILL 0.0-5.0' CLAY-SILT: see same interval in FH-1 for detailed description.		AD	Auger drill w/6" flight auger to 4' where c. gravel or cobble is encountered
2.0					
4.0		4.0' gravel or small cobble of hd. basalt		RD	set-up to 6; surface casing to 1'; no mud mixed
	CL-ML	5.0-32.0' SANDY CLAY-SILT: see interval 5-32' in FH-1 for detailed description; note local variations below.			RD w/ 4 7/8" tricone bit
6.0		6.0' grades more plastic, red-brn. color locally			
8.0		7.8' large gravel clast			hd. rattle @ ~7.8'
		8.5' note black organic clay streaks in cuttings			
10.0		9.5' gravel clast, stringer of silty f. sand w/ med.-coarse sand common			brief rattle, faster drilling @ 9.5'
12.0		12.0' grades locally to mod. yel. brn. silty clay			
14.0		14.0' some med.-c. sand in cuttings			
16.0		15.8' locally gravelly			rattling @ 15.8'
18.0					
20.0		19.0' w/ black, probably carbonized organics (trace amount), trace m.-c. sand grains			

SHEET 1 OF 3

* arbitrary datum

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-4

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS
20.0	CL-ML	5.0-32.0' SANDY CLAY-SILT: (con't.)		RD	
22.0		22.0' w/few coarse sand size white agates			
24.0		23.5-24.0' grades w/f.-v.f. sand, siltier (less plastic), little m.-c. sand			
		25.0' grades w/more m.-c. sand			
26.0		26.0' w/some gray-green sltst. frags			
28.0					
30.0		29.5' w/more c.-m. sand size grains of sltst., basalt, trace f. gravel size clasts			
		31.0' gravel clast			rattle @ 31'
32.0	CL	32.0-47.5' SILTY CLAY: see interval 32.0-48.5' in FH-1 for detailed description; see local variations described below.			
34.0		32.0' grades mod. plastic, dk. brn-gray color w/blk. org. clay mottling			
36.0					
38.0					
40.0		39.0' w/common black, partially carbonized org. debris (some identifiable as small twigs, shoots)			
42.0					
44.0					SHEET 2 OF 3

PROJECT 0118- SCS Dams, Utah DATE DRILLED 10/14/81 HOLE NO. FH-4

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ Ft.
44.0	CL	32.0-47.5' SILTY CLAY (con't.)		RD	sample w/ 3" Pitcher Barrel 45.0-47.5'	
46.0		ALLUVIUM/COLLUVIUM	S-1	PB-1 2.57/2.5	end of tube bent on one side, ~0.25' of sample pulled off bottom of sample at surface; we = 5.60 lb; wf = 20.69 lb	
48.0	CL-ML	47.5-57.0' SANDY CLAY-SILT: detailed description as for FH-1 and FH-3 in similar intervals w/ local variations as noted below.	B-1	SPT-1 1.3/1.5	Drive standard split spoon 47.5-49.0; 18/0.5 32/0.5 30/0.5 (some basalt gravel to 3/4-1")	62
50.0		47.5-49.0' several basalt gravel clasts to max. of 3/4-1"; 49.0' w/ appreciable f.-v.f. sand (stringer or lens?)	S-2	PB-2 2.65/2.5	end of tube badly caved in; small void @ bottom of sample; encountered gravel @ ~0.5' into run; we = 5.60 lb; wf = 19.18 lb	
52.0		51.5' color grades to dk. red. brn (5YR 3/4); w/ buff colored gyp. mottles to 1/8"; w/ moisture content grading moist to damp	B-2	SPT-2 1.1/1.5	5/0.5 8/0.5 9/0.5 (2 3/4" basalt clasts)	17
54.0		51.5-53.0 w/ 2 3/4" basalt clasts; some pale-brn. inclusions to 3/4" w/ high $CaCO_3$ content (similar to leached interval from 49.0-51.1' in FH-3)	S-3	PB-3 1.88/2.5	end of tube ok.; some slough (?) on top of sample; we = 5.62 lb; wf = 17.47 lb	
56.0		54.5' some v.f., pl. fresh rootlets noted	B-3	SPT-3 1.0/1.5	5/0.5 13/0.5 27/0.5 (3/4-1" basalt clast in shoe)	40
58.0	CL (GC)	55.5-57.0' grades 20-25% f.-v.f. sand, trace of white gyp. w/ specks to 1/4"		RD	Hard drilling @ 57' w/ tricone rock bit, grades less hard to 57.7', hd. rattling 57.7-58.1', then smoother to 58.5'.	
60.0	grades more basalt	57.0-61.0' (GRAVELLY) SILTY CLAY: mod. to reddish brn (5YR 4/3); 70-90% mod. plastic fines; 5-10% f.-c. sand, pred. basalt; 5-25% pred. basalt gravel; w/ buff gyp. locally common; density and in-situ moisture content uncertain. 60.0-61.0' grades to weathered basalt w/ clay binder	S-4	PB-4 1.19/1.5	one ding in end of tube for PB-4 run; basalt at top of tube; we = 5.99 lb; wf = not weighed	
62.0	BASALT	BEDROCK		RD	RD is slow, rattling from 61.0-63.0'; no fluid loss	
64.0		61.0-63.0' BASALT: little weath. to fresh, hard, no fluid loss. B.H. @ 63.0'			Terminate hole @ 63', 2' into hard bedrock. Backfilled hole w/ mud & cuttings	

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DRILLING AND SAMPLING LOG

PROJECT 0118 - SCS Dams, Utah DATE DRILLED 10/15/81 HOLE NO. IV-1
LOCATION Diversion Dam #5, ~ sta. 12+48 on ℄ GROUND SURFACE ELEV. ~3189 (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY OMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS top of dirt embankment WEATHER partly cloudy, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
0.0	SM	EMBANKMENT FILL 0.0-19.2' SILTY SAND: red (10R4/6); 30-40% non-plastic coarse silt fines; 60-70% poorly graded, pred. f.-v.f. sand, w/ few % m.-c. sand grains; trace f. gravel; $CaCO_3$ disseminated throughout; some gyp. as fine specks; dense to v. dense; dry to v. slightly moist (may be due to drill fluid); some intervals lightly cemented w/ $CaCO_3$	B-1	SPT-1 1.2/1.5	Drove standard split spoon 10/0.5 30/0.5 37/0.5 (trace gravel)	67
2.0				AD		
			B-2	SPT-2 1.4/1.5	40/0.5 40/0.5 37/0.5 (trace sltst. gravel clasts) set up mud tub; casing to	77
4.0				PB-1	Sample w/ 3" Pitcher Barrel end o.k.	
			S-1	2.54/2.5	w_e = 5.62 lb w_f = 20.24 lb.	
6.0						
			B-3	SPT-3 1.2/1.5	13/0.5 19/0.5 22/0.5	41
8.0		7.8-8.0' very abundant gyp. as white mottling		PB-2	end of tube o.k.	
			S-2	2.34/2.5	w_e = 6.59 lb. w_f = 19.43 lb.	
10.0		10.3' 3 f. sltst. clasts to 3/8"				
		11.0-11.6' much gyp. evident	B-4	SPT-4 1.2/1.5	10/0.5 17/0.5 35/0.5	52
12.0				PB-3	one side of end caved in sample v. loose in tube	
		13.0' grades slightly more sandy, more gravel and m.-c. grained sand (~5%)	S-3	2.17/2.5	w_e = 5.51 lb. w_f = 16.63 lb	
14.0						
			B-5	SPT-5 1.1/1.5	14/0.5 30/0.5 21/0.5 (~5% m.-c. sand, trace f. gravel)	51
16.0				PB-4	sample slipped out of tube while pulling rods; end of tube not damaged	
18.0				0.0/2.5		
		18.5-19.2' grades to med. dense COLLUVIUM			Losing a little water to hole starting ~16-17'	
	ML	19.2-21.0' SANDY SILT: as above but 50-60% non-v. low plastic fines; med. dense.	B-6	SPT-6 1.2/1.5	3/0.5 6/0.5 12/0.5	18
20.0						

SHEET 1 OF 2

PROJECT 0118-SCS Dams, Utah DATE DRILLED 10/15/81 HOLE NO. IV-1

DEPTH	CLASS.		FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0		ML w/ gravel	19.2-21.0' SANDY SILT: (con't.) 20.0' grades 10-20% c. sand, f. gravel	S-4	PB-5 1.34/1.5	end of tube dinged; sample loose in tube We = 5.59 lb Wf = 7.30 lb	
			BEDROCK 21.0-27.0 SILTSTONE: dk. reddish brown (2.5YR 3/4); sltst. breaks down to low-mod. plastic silty clay-clayey silt; gyp. very prevalent as crystals and pervasive stringers, mottles; slight to mod. reaction to HCl; crude angular blocky structure.		RD	RD to 22.0' to clear gravel	
22.0		SILTSTONE		B-8	SPT-7 1.2/1.5	10/0.5 25/0.5 27/0.5 (granular sltst. @ bottom of spoon)	52
24.0			Phy. Cond. - crushed; soft to friable; plastic to friable; deeply weathered (hard in soils terms) 26.0' ang. blocky structure, 27.0' gyp. crystals 1/4-1/2"	S-5	PB-6 1.83/2.5	tube mod. badly dinged on end We = 5.69 lb Wf = 16.39 lb	
26.0			B.H. @ 27.0'	B-9	SPT-8 0.9/1.0	13/0.5, 71/0.5 (0.5' slough on top; mod. hard sltst. w/gyp @ end of spoon)	84
28.0						Terminate hole @ 27' w/sufficient data, ~6' into bedrock. Backfill hole w/cuttings, embankment fill	

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DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/15-16/81 HOLE NO. IV-2
LOCATION Diversion Dam #5, ~sta. 20+00 on ℄ GROUND SURFACE ELEV. ~3189 (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS top of dirt embankment WEATHER scattered clouds, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
0.0	ML-SM	EMBANKMENT 0.0–10.5' SANDY SILT to SILTY SAND: red (10R 4/6); fines 45-55%, non-plastic, quick dilatancy, no toughness; sand, 45-55%, very poorly graded, f.-v.f. grained, iron-oxide stained, subang. to subrounded qtz.; trace of c. sand to f. gravel size siltst. clasts; trace gyp.; very strong reac. to HCl in disseminated $CaCO_3$; dense to v. dense (may be due to light cementing by $CaCO_3$), dry to slightly moist (drill fluid invades sample relatively easily).	B-1	SPT-1 1.3/1.5	Drove standard split spoon 4/0.5 13/0.5 20/0.5	33
2.0				AO		
			B-2	SPT-2 1.2/1.5	26/0.5 28/0.5 40/0.5 (trace sltst. gravel)	68
4.0			B-3	PB-1 1.0/2.5	10/15 end shift @ 5:30 10/16 start shift @ 7:15, set up, tub. casing to 1', sampled w/ 3" Pitcher barrel. Part of sample slipped from tube pulling rods, remainder bagged	
6.0		6.5-10.5' gyp., < 1-2% visible, several sm. (1/8-1/4") nodules	B-4	SPT-3 1.5/1.5	22/0.5 31/0.5 32/0.5 (scattered sltst. frags)	63
8.0	grades? ↓		S-1	PB-2 2.18/2.5	end of tube o.k. We = 5.67 lb. Wf = 18.72 lb	
10.0		ALLUVIUM/COLLUVIUM (?) 10.5–22.0' SILTY SAND: as above, but with 40-45% fines and 55-60% sand; grades to medium dense to dense.	B-5	SPT-4 1.4/1.5	18/0.5 21/0.5 27/0.5 (scattered f. sltst. gravel)	48
12.0	SM		S-2	PB-3 1.45/2.5	end of tube o.k. probably washed part of sample during PB run We = 5.72 lb Wf = 14.13 lb	
14.0		14.0-18.0' mottled gyp. conc. fairly common 14.8' thin lens w/ ~15% coarse sand as siltst. chips	B-6	SPT-5 1.0/1.5	6/0.5 9/0.5 11/0.5 (coarse sand to 15%)	20
16.0			S-3	PB-4 2.26/2.5	end of tube o.k. We = 5.62 lb. Wf = 18.13 lb. (0.2' slough on top removed — w/ c. sand size sltst. chips common)	
18.0		18.5-21.5' stratification apparent with thin lenses from 1/4" to sev. inches alternating more or less sand	B-7	SPT-6 1.2/1.5	2/0.5 4/0.5 10/0.5	14
20.0						

SHEET 1 OF 2

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/15-16/81 HOLE NO. IV-2

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SM	10.5-22.0' SILTY SAND: (con't)	B-8	SPT-7 1.0/1.5	8/0.5 12/0.5 17/0.5 (c. sand siltst frags to 1/8" common)	29
22.0	GP-GM	22.0-24.1' SILTY SANDY GRAVEL: red (10R 4/6) with brownish tint; 10-15% non-plastic fines; 15-20% mod. well graded sand; 65-75% red. fine gravel from 1/4-1/2", mostly flat shale and subrounded to rounded sandst; very pervious.	S-4 (B-9)	PB-5 1.80/2.5	end of tube o.k.; ~0.3' of sample slipped from tube saved in B-9; gravel or gravelly slough on top of sample? w_i = 5.57 lb w_f = 16.22 lb	
24.0	SM / SM-SP / ML-SM	24.1-25.5' SILTY SAND: as for 10.5-22.0; medium dense; stratification apparent in variations shown in CLASS. column on log.	B-10	SPT-8 1.8/1.5	9/0.5 9/0.5 15/0.5 (c. sand as for SPT-7)	24
26.0		B.H. @ 25.5'			Terminate hole @ 25.5' w/sufficient info. Backfill w/cuttings. See logs of IV-4 and IV-5 for more info. on foundation near this boring	
28.0						

SHEET 2 OF 2

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DRILLING AND SAMPLING LOG

PROJECT D118 - SCS Dams, Utah DATE DRILLED 10/16/81 HOLE NO. IV-3
LOCATION Diversion Dam #5, ~ sta. 36+11 GROUND SURFACE ELEV. ~3189' (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS top of dirt embankment WEATHER partly cloudy, cool, breezy

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	N blows/ft.
					Drove standard split spoon	
0.0	ML-SM	EMBANKMENT 0.0-10.8' SANDY SILT to SILTY SAND: rd (10R 4/6); 45-55% non-plastic fines; 45-55% v. poorly graded, f.-v.f. grained, iron-oxide stained qtz. sand; 1-3% c. sand to f. gravel size sltst./shale fragments; gyp. common as finely disseminated crystals to irreg. mottled veins; strong reac. to HCl w/ abundant disseminated $CaCO_3$; lightly cemented due to $CaCO_3$; very dense; dry to very slightly moist.	B-1	SPT-1 1.2/1.5	8/0.5 16/0.5 36/0.5 (c. sand to f. gravel sltst. to 1-3%; abund. gyp. in shoe)	52
2.0				AD		
			B-2	SPT-2 1.4/1.5	30/0.5 30/0.5 37/0.5	67
4.0			S-1	PB-1 2.50/2.5	Sample w/ 3" Pitcher Barrel; end of tube dinged on one side; w_e = 5.70 lb, w_f = 20.13 lb	
6.0		3.0-10.8' gyp. as soft to low hd. nodules from 1/16-1/2" fairly common, have white-gray color, sugary texture	B-3	SPT-3 1.4/1.5	18/0.5 37/0.5 53/0.5 (few 1/4" sltst/shale gravels)	90
8.0			S-2	PB-2 2.10/2.5	end caved in; sample cut gravelly; w_e = 5.51 lb; w_f = not weighed (top 0.5' of sample is loose in tube)	
10.0	soft sltst. in SM	COLLUVIUM (?) 10.8-17.0' SILTY SAND and SILTSTONE: rd (10R 4/6) matrix w/ weak rd (10R 4/3) deeply weathered clasts; matrix is silty sand w/ 20-30% non-plastic fines, otherwise as above; ~50-70% of unit is deeply weathered sltst. clasts w/ abundant v.f. gyp. crystals, clasts are soft, weak, sltst. clasts rounded to irreg. w/ indistinct borders, range 1/4-1 1/2"; contains gyp. nodules and mottling; matrix reacts to HCl; very dense to hard; v. slightly moist.	B-4	SPT-4 0.9/1.0	33/0.5 53/0.5 (deeply weath. sltst. clasts to 1/2" in middle 0.3')	86
12.0			S-3	PB-3 2.15/2.5	end of tube badly caved in; top looks ok; w_e = 5.65 lb; w_f = 18.44 lb	
14.0			B-5	SPT-5 1.3/1.5	27/0.5 30/0.5 52/0.5 (as for SPT-4)	82
16.0		BEDROCK	S-4	PB-4 1.75/2.5	end of tube ok; sample cuts v. slowly; w_e = 5.57 lb; w_f = 15.96 lb. (tube has a little slough on top)	
18.0	SILTSTONE	17.0-19.5' SILTSTONE: rd (10R 4/6) w/ purplish-black tint; rel. clean sltst. w/o sand or gravel clasts; abund. gyp. veining, mottling, small crystals; mod. reac. to HCl; crude, ang. blocky structure; some mod. hd. cores. Phy. Cond. - crushed, weak to friable, plastic to friable; v. deeply weath.	B-6	SPT-6 1.2/1.5	12/0.5 24/0.5 29/0.5 (few hd. ang. sltst blocks to 1/2"); Terminate hole @ 19.5' w/ soft. into. 7 1/2" into bedrock	53
20.0		B.H. @ 19.5'				

SHEET 1 OF 1

Backfill hole w/ cuttings and embankment fill

EARTH SCIENCES ASSOCIATES
DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/16/81 HOLE NO. IV-4
LOCATION Diversion Dam #5, ~ sta. 19+62, 43' u/s GROUND SURFACE ELEV. ~3179' (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY NMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS loose debris basin deposits WEATHER scattered clouds, cool

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS (Drove standard split spoon)	N blows Ft.
0.0	SM-ML	DEBRIS BASIN DEPOSITS 0.0-2.0 SILTY SAND to SANDY SILT: red (10R4/6); 45-55% non-plastic fines; 45-55% v. poorly graded f.-v.f. sand; trace c. sand to f. gravel; gyp. mottling; much disseminated $CaCO_3$; med. dense; dry. ALLUVIUM/COLLUVIUM	B-1	SPT-1 0.9/1.5	1/0.5 5/0.5 7/0.5	12
2.0				AD	Auger w/6" flight auger	
	SP-SM	2.0-30.0 SAND to SILTY SAND: red (10R4/6); 5-15% non-plastic fines; 85-95% v. poorly graded f.-v.f. qtz. sand; trace to 1-3% widely scattered c. sand to f. gravel sized siltst, sandst. clasts; subtle stratification locally due to variations in % fines and sand size; generally little visible gyp.; strong reac. to HCl throughout; varies loose to mostly med. dense; v. slightly moist (easily penetrated by drill fluid). 3.0-4.0' abund. mottled gyp. 7.0-8.0' grades siltier	B-2	SPT-2 1.2/1.5	3/0.5 6/0.5 8/0.5	14
4.0				PB-1 0.0/2.5	set up tub. casing to 1'; add 1/2 sk. bentonite - losing water to surficial units; 3" Pitcher Barrel sample slipped from tube while pulling rods	
6.0			B-3	SPT-3 1.1/1.5	5/0.5 6/0.5 7/0.5	13
8.0			S-1	PB-2 2.5/2.5	end of tube slightly dented on one side We = 6.07 lb. Wf = 20.48 lb.	
10.0			B-4	SPT-4 0.7/1.5	2/0.5 3/0.5 4/0.5	7
12.0			S-2	PB-3 1.55/2.5	one dent in end of tube; flushed c. sand, f. gravel during run; ~1/4-1/2" of slough on top of sample We = 5.50 lb Wf = 14.22 lb	
14.0		14.5' some soft gyp. noted @ bottom of PB-3	B-5	SPT-5 0.7/1.5	5/0.5 8/0.5 11/0.5	19
16.0			B-6	PB-4 0.8/2.5	end of tube dinged; most of sample slipped from tube or washed away sampling; recovered sample bagged We = Wf = not weighed	
18.0			B-7	SPT-6 1.5/1.5	6/0.5 7/0.5 12/0.5	19
20.0						

SHEET 1 OF 2

PROJECT D118-SGS Dams, Utah DATE DRILLED 10/16/81 HOLE NO. IV-4

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SP-SM	2.0-30.0' SAND to SILTY SAND: (con't.)		PB-5	end of tube o.k.; a little slough on top of sample; either washed formation or part slipped from tube pulling rods	
			S-3	1.08/2.5	We = 5.51 lb. Wf = 12.07 lb	
22.0			B-8	SPT-7 1.1/1.5	5/0.5 9/0.5 11/0.5	20
24.0				RD	~1' of in-situ sand was jetted away while RDing to clean hole	
26.0				PB-6 0.0/2.5	Sample from PB-6 either washed away and/or slipped from tube while pulling rods We = Wf = nothing to weigh	
28.0			B-9	SPT-8 0.8/1.5	9/0.5 14/0.5 23/0.5 (sample recovered as liquefied slurry - see B-9)	37
				PB-7	end of tube o.k.; may be some slough on top	
30.0	CL	30.0-32.5' SANDY SILTY CLAY: red (10 R 4/6) w/ brownish tint; 80% low-mod. plastic fines, slow dilatancy, mod. toughness; 20% v. f. sand; scattered sltst. frags. to 1/4"; gyp. mottling common; little to no reac. to HCl; hard; slightly moist.	S-4	~1.55/2.0	We = 5.99 lb. Wf = 15.77 lb	
32.0			B-10	SPT-9 0.8/1.5	8/0.5 11/0.5 25/0.5 (w/ scattered sltst. frags)	36
		B.H. @ 32.5'			Terminated hole @ 32.5' w/ hole through sand unit - sufficient data acquired	
34.0					Backfilled hole w/ mud, cuttings	

SHEET 2 OF 2

EARTH SCIENCES ASSOCIATES

DRILLING AND SAMPLING LOG

PROJECT D118-SCS Dams, Utah DATE DRILLED 10/16/81 HOLE NO. IV-5
LOCATION Diversion Dam #5 @ sta. 20+02; 42'd/s GROUND SURFACE ELEV. ~3175' (topo.)
DRILLING CONTRACTOR Pitcher Drilling Co. LOGGED BY DMY DEPTH TO GROUND WATER not encountered
TYPE OF RIG Failing 1500 HOLE DIAMETER 4 7/8" HAMMER WEIGHT AND FALL 140 lb., 30"
SURFACE CONDITIONS dirt access road; brushy WEATHER scattered clouds, cool, brief lt. shower to overcast

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS (Over standard split spoon)	N blows/ft.
0.0	SM-ML	AEOLIAN DEPOSITS 0.0–5.0' SILTY SAND-SANDY SILT: red (10R 4/6); 45-55% non-plastic fines; 45-50% poorly graded, f.-v.f. sand; 0-5% scattered f. gravel to m.-c. sand; trace gyp. as v.f. soft spots, nodules; strong reac. to HCl throughout; loose to med. dense; dry.	B-1	SPT-1 1.1/1.5	3/0.5 4/0.5 5/0.5	9
2.0				AD	Auger w/ 6" flight auger; material caves badly	
			B-2	SPT-2 1.3/1.5	2/0.5 6/0.5 8/0.5	14
4.0		COLLUVIAL DEPOSITS		RD	set up tob. casing to 4' RD to 5.0' to clean hole	
	SP, SM	5.0–20.0' INTERBEDDED SAND and SILTY SAND: red (10R 4/6); fines vary 10-15% in SP sand, to 25-50% in less common SM, non-plastic; sand varies 85-90% in SP to 70-75% in SM, pred. sa-sr qtz., iron-oxide stained; most is f.-v.f.; locally 5% m.-c. sand, f. gravel as sandst. and sltst. frags; gyp. variable from none visible to several % as mottling, small nodules, mod.-strong reac. to HCl throughout; some irreg. zones, fragments are lightly $CaCO_3$ cemented; grades from med. dense to very dense with inc. depth; v. slightly moist (drill fluid penetrates fairly easily).	S-1	PB-1 1.18/2.5	sample w/ 3" Pitcher Barrel end of tube egg-shaped, otherwise o.k. w_e = 5.48 lb. w_f = 12.02 lb	
6.0						
8.0	SM		B-3	SPT-3 1.0/1.5	10/0.5 11/0.5 12/0.5	23
10.0	SP, SM			PB-2 0.0/2.5	end of tube not damaged; drilled smooth, quiet — sample presumably slipped from tube pulling rods w_e = 6.00 lb. w_f = no recovery	
12.0	SP SP w/ gravel		B-4	SPT-4 0.8/1.5	9/0.5 16/0.5 21/0.5 (w/ common sltst./ss gravels, 0.3-1.0' into sample)	37
	SP, SM	7.5-9.0' evenly bedded SM 11.5-11.8' clean SP sand 11.8-12.3' grades to slightly silty gravelly sand		PB-3 0.0/2.5	end of tube o.k., assume sample slipped from tube pulling rods w_e = 5.46 lb w_f = no recovery	
14.0						
		15.5-16.1' clean SP sand				
16.0	SP SM	16.1-16.4' silty fine sand	B-5	SPT-5 0.9/1.5	7/0.5 16/0.5 21/0.5 (no c. sand or gravel)	37
	SP, SM	Note: bedding, stratification identified in SPT samples; PB samples and intervals not successfully sampled are probably similarly stratified		RD	RD to 17.5' to clean, some gravels sloughed into hole	
18.0			B-6	SPT-6 0.8/1.5	13/0.5 25/0.5 30/0.5 (few lightly cemented nodules of sand to silty sand)	55
20.0			S-2	PB-4 1.44/2.0	end of tube o.k.	

SHEET 1 OF 2

PROJECT 0118 - SCS Dams, Utah DATE DRILLED 10/16/81 HOLE NO. IV-5

DEPTH	CLASS.	FIELD DESCRIPTION	SAMPLE	MODE	REMARKS	
20.0	SP	20.0-28.5 SAND: orangey red (10R4/6) to (10R4/8); < 5 % non-plastic fines; >95% v. poorly graded, iron-oxide stained qtz; trace of scattered sub-rounded sandst. clasts from 1/4-1 "; mod. reac. to HCl throughout; occassional trace of gyp; dense to very dense (seems lightly cemented in some zones w/(CaCO3); slightly moist (penetrated easily by drill fluid).	S-2 (con't.)	PB-4 (con't)	We = 5.50 lb Wf = 13.53 lb	
22.0			B-7	SPT-7 1.1/1.5	12/0.5 30/0.5 36/0.5 (as for SPT-8)	66
				RD	RD to 23' to ensure clean hole for SPT	
24.0			B-8	SPT-8 1.0/1.5	14/0.5 25/0.5 36/0.5 (as for SPT-7)	61
				RD	RD to 25' to ensure clean hole for SPT	
26.0			B-9	SPT-9 1.2/1.5	14/0.5 21/0.5 26/0.5 (cemented nodule @ top of sample)	47
				RD	RD to 27' to ensure clean hole for SPT	
28.0		B.H. @ 28.5'	B-10	SPT-10 0.6/1.5	15/0.5 33/0.5 43/0.5 (as for SPT-8)	76
30.0					Terminate hole @ 28.5' into high blow-count sand; 7:30 p.m. - too dark to continue drilling safely Backfilled hole w/ cuttings, surficial deposits	

SHEET 2 OF 2

APPENDIX C

TEST PIT EXCAVATIONS

Appendix C

TEST PIT EXCAVATIONS

A total of 32 test pits were excavated on the dam embankments and in their foundations to investigate the following:

1. To provide information on the type, zoning and classification of embankment and foundation materials.

2. To perform in situ density tests.

The test pit excavations were performed at the same time as the drilling operations. Excavation of test pits was subcontracted to Ziegler's Backhoe Service of Cedar City, Utah. Logging of the test pit excavations and in situ density tests were performed by Richard Morris of Earth Sciences Associates.

Three to five test pits were excavated at each dam, using a Case 580C backhoe with a 24-inch bucket. The locations of test pits are shown in Figures B-1 through B-8 and are summarized in Table C-1. Logs of the test pits are given in Figures C-1 through C-18 along with the locations of the in situ sand cone density tests. In many cases, attempts were also made to obtain undisturbed Shelby tube samples by pushing with the backhoe bucket. All such samples were sealed and shipped to the ESA laboratories in Palo Alto, California.

Pit locations were chosen so as to provide information on embankment conditions at both the crest and the toe of each dam, usually on the upstream side. This was the case at all three Green's Lake dams and at Stucki, Gypsum Wash, and Frog Hollow dams. At Warner Draw and Ivins dams, the crest pit was dug on the downstream face of the embankment; at Green's Lake Dam No. 2, Green's Lake Dam No. 3, and Stucki Dam, crest pits were dug on both the upstream and downstream faces. Toe pits were also dug on the downstream face at Gypsum Wash and Frog Hollow dams. All pits were located to be at or near points of maximum section or of embankment curvature. Those pits excavated at the embankment toe were stepped so that one level of the pit was in the embankment and a second level was in the foundation.

Large bag samples of material excavated from the pits were collected from all crest pits, and two bag samples--one from each level--were collected from the toe pits. These samples were used for laboratory compaction testing and material classification purposes.

Sand cone density tests were performed in about three-fourths of the test pits. Although not all pits were tested, the density tests were disturbed among the pits to provide a sampling of both embankment and foundation densities at each dam. Testing was done in general accordance with ASTM method D1556-64 and in specific accordance with U.S. Bureau of Reclamation method E-24. Deviations from the standard methods included the use of preweighed sand volumes to avoid complications associated with the field weighing. Most tests were performed using an ASTM standard six-inch cone apparatus; a twelve-inch cone was used in two pits where very large rock particles were encountered in the fill. To improve the accuracy of the density determinations replicate tests were made in all cases. Typically, three density tests were performed when using the six-inch cone, and two tests were performed when using the twelve-inch cone. Moisture contents were obtained either by ESA personnel in the field or by the Civil/Earth Consulting Group of Fort Collins, Colorado. All samples obtained during the density testing were retained and shipped to the ESA laboratories in Palo Alto, California.

Table C-2 presents information on the sampling and testing for the test pits at each dam site.

Table C-1

Locations of Test Pit Excavations

Dam	Pit No.	Crest Station	Offset from Dam Centerline	Approx. Bottom Elevation	Material in Trench
Green's Lake No. 2	GL2-TP1	12+75	15' upstream	6064'	Shell
	GL2-TP2	11+30	40' "	6053'	Shell
	"	"	48' "	6050'	Foundation
	GL2-TP3	9+05	14' downstream	6063'	Shell
	GL2-TP4	4+00	15' upstream	6063'	Shell
	GL2-TP5	2+80	21' "	6059'	Shell
			29' "	6056'	Foundation
Green's Lake No. 3	GL3-TP1	17+65	15' upstream	6058'	Shell
	GL3-TP2	17+15	31' upstream	6053'	Shell/Found.
	"	"	38' "	6049'	Foundation
	GL3-TP3	14+40	33' "	6052'	Shell/Found.
	"	"	40' "	6048'	Foundation
	GL3-TP4	5+70	18' "	6057'	Shell
	"	"	25' "	6053'	Foundation
	GL5-TP5	6+40	13' downstream	6060'	Shell
Green's Lake No. 5	GL5-TP1	2+07	15' upstream	5933'	Shell
	GL5-TP2	1+98	62' "	5923'	Shell/Found.
	"	"	67' "	5920'	Foundation
	GL5-TP3	1+19	61' "	5922'	Shell/Found.
	"	"	68' "	5919'	Foundation
Warner Draw	WD-TP1	13+67	15' downstream	2979'	Shell
	WD-TP2	13+25	128' upstream	2945'	Shell
	"	"	136' "	2942'	Foundation
	WD-TP3	18+92	143' "	2940'	Shell
	"	"	150' "	2937'	Foundation
Stucki	STK-TP1	16+43	15' upstream	2807'	Shell
	STK-TP2	18+90	14' downstream	2805'	Shell
	STK-TP3	16+03	88' upstream	2783'	Shell
	"	"	94' "	2780'	Foundation
	STK-TP4	18+96	39' "	2799'	Shell
	"	"	44' "	2796'	Foundation
Gypsum Wash	GW-TP1	21+56	36' downstream	2720'	Shell
	"	"	42' "	2715'	Foundation
	GW-TP2	15+48	37' upstream	2725'	Shell
	"	"	43' "	2722'	Foundation
	GW-TP3	25+86	14' "	2733'	Shell
	GW-TP4	35+99	43' "	2724'	Shell
	"	"	50' "	2720'	Foundation

Table C-1 (Continued)

Locations of Test Pit Excavations

Dam	Pit No.	Crest Station	Offset from Dam Centerline	Approx. Bottom Elevation	Material in Trench
Frog Hollow	FH-TP1	12+97	17' upstream	111'	Shell
	FH-TP2	11+48	28' downstream	106'	Shell
	"	"	35' "	103'	Found./Old fill
	FH-TP3	12+49	88' upstream	93'	Shell
	"	"	95' "	89'	Foundation
	FH-TP4	16+10	87' "	93'	Shell
	"	"	94' "	90'	Foundation
Ivins Diversion No. 5	IV-TP1	42+35	22' upstream	3179'	Shell
	"	"	29' "	3176'	Foundation
	IV-TP2	21+53	19' "	3180'	Shell
	"	"	25' "	3176'	Foundation
	IV-TP3	8+46	41' "	3172'	Shell
	"	"	47' "	3169'	Foundation
	IV-TP4	15+31	15' downstream	3181'	Shell

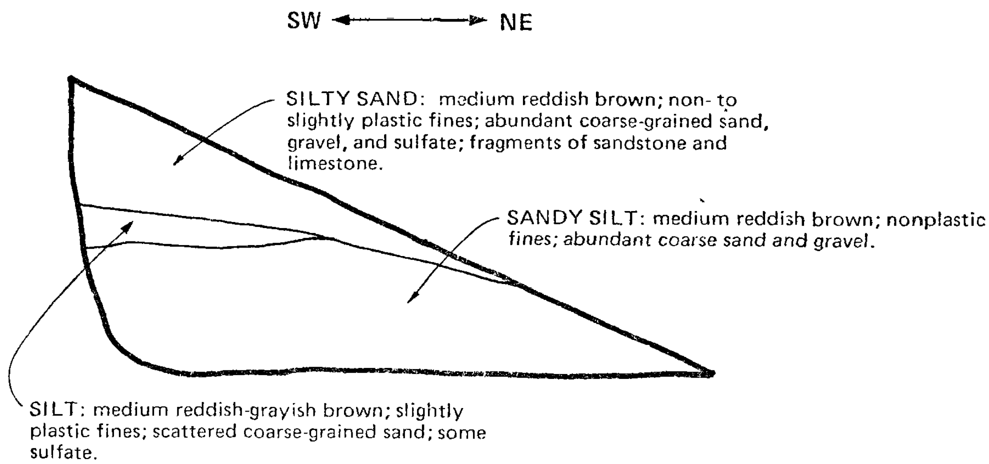
Notes: Stations and offsets refer to approximate center of pit. Elevation refers to pit floor. Two values for a pit indicate data for both benches in pits. In general, tests were run one or more days after excavation of test pits.

Table C-2

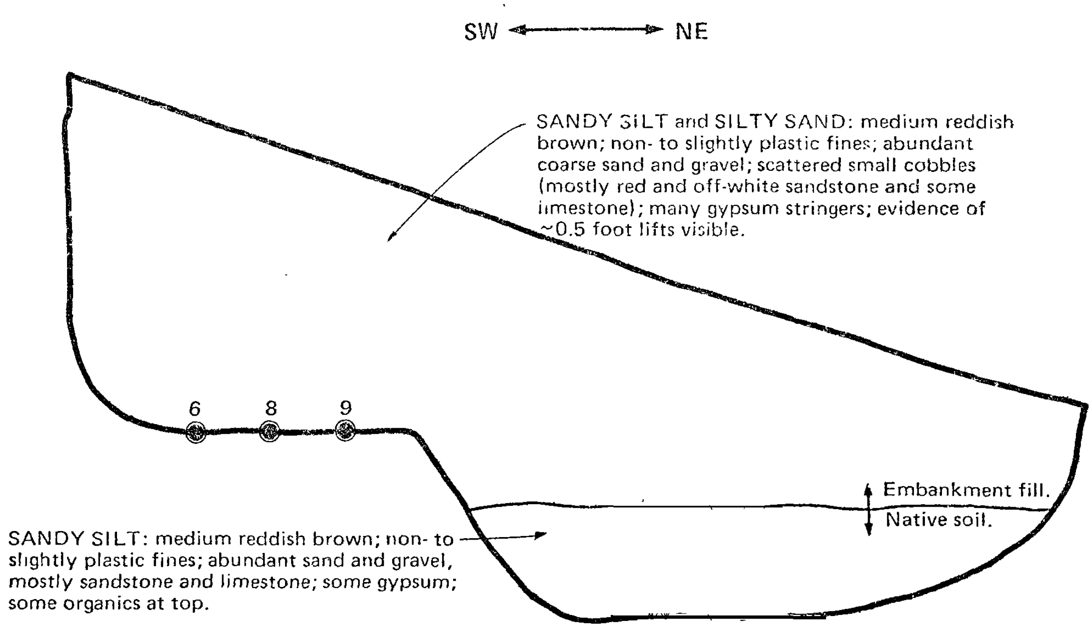
Sampling and Testing of Test Pit Excavation

Dam	Number of Test Pits	Number of Pits Tested	Number of Bulk Samples	Number of Sand Cone Tests	Number of Shelby Tube Samples
Green's Lake No. 2	5	3	7	8	5
Green's Lake No. 3	5	5	8	15	4
Green's Lake No. 5	3	3	5	9	2
Warner Draw	3	2	5	6	2
Stucki	4	3	6	9	2
Gypsum Wash	4	3	7	7	3
Frog Hollow	4	3	7	7	2
Ivins Diversion No. 5	4	3	7	9	3
TOTALS	32	25	52	70	25

GL2-TP1



GL2-TP2



Notes

1. All materials in test pit excavation GL2-TP1 are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

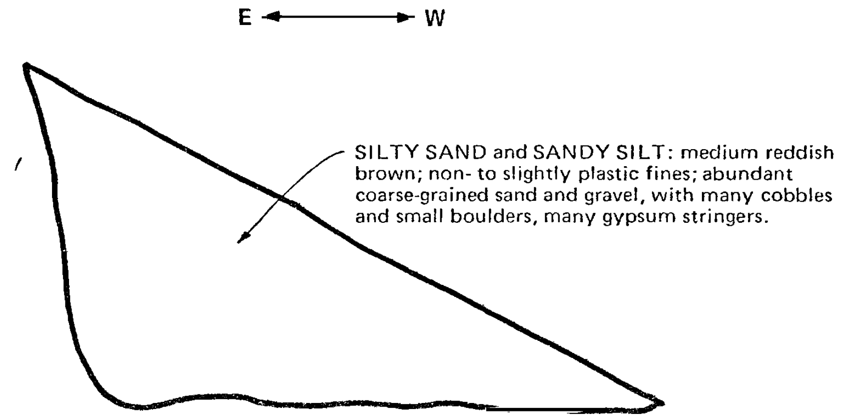
Horizontal = Vertical

Earth Sciences Associates
Palo Alto, California

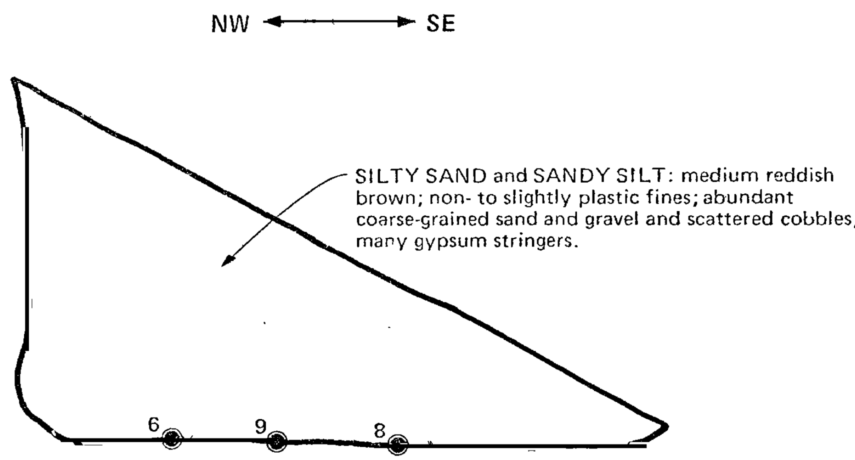
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
GREEN'S LAKE NO. 2

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. C-1
Approved by [illegible]	Date 27 MAY 82		

GL2-TP3



GL2-TP4



Notes

1. All materials in test pit excavations are embankment fill.
2. ● indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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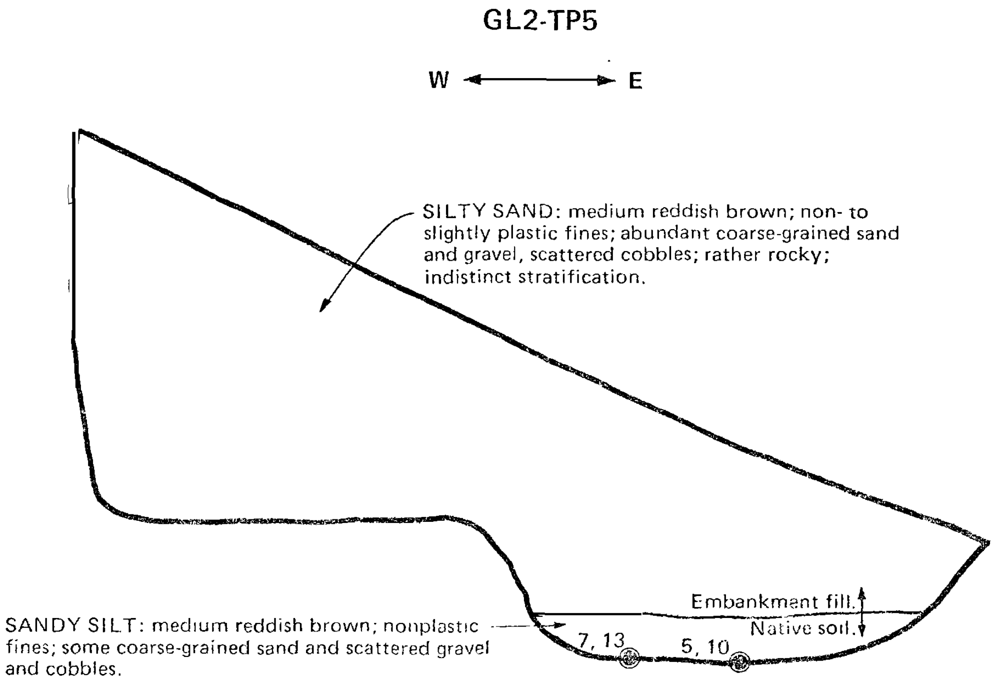
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

LOGS OF TEST PIT EXCAVATIONS
GREEN'S LAKE NO. 2

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. C-2
Approved by CA Nelson	Date 27 MAY 82		



Note

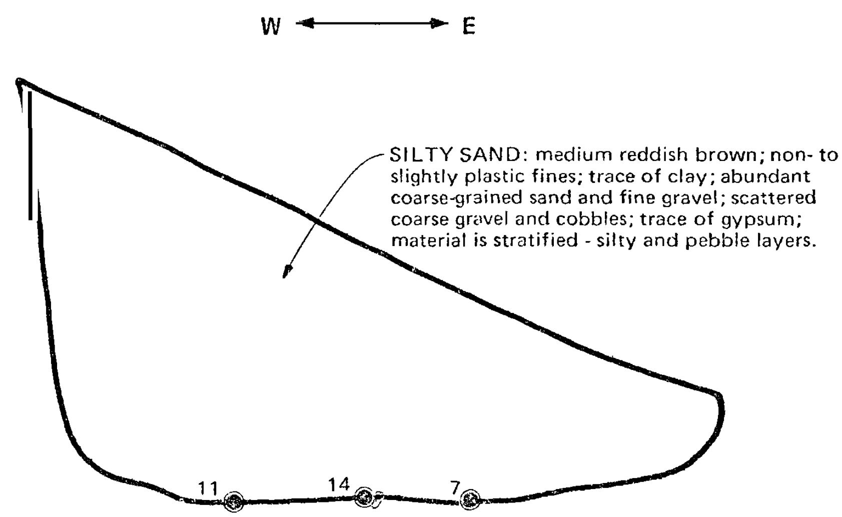
● indicates location of sand cone density test.

0 1 2 feet

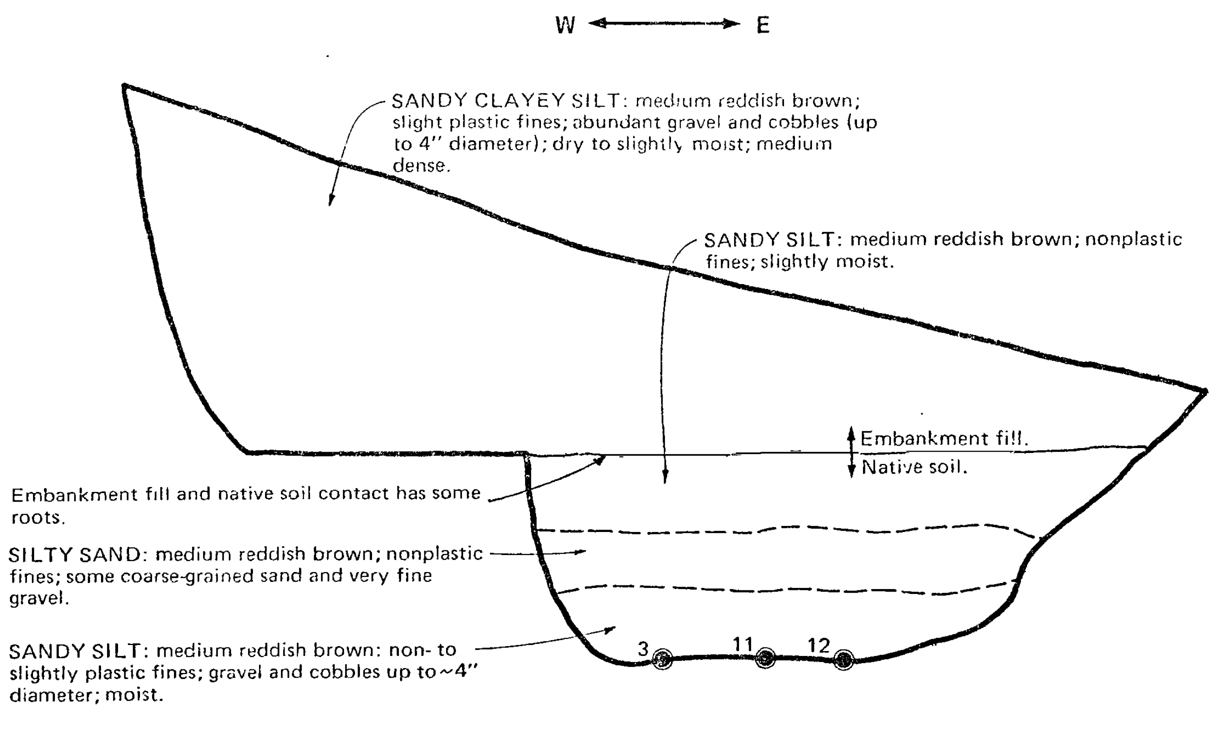
Horizontal = Vertical

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOG OF TEST PIT EXCAVATION** **GREEN'S LAKE NO. 2**		
Checked by MYT Date 5/27/82 Approved by EA Nelson Date 27 MAY 82	Project No. D118	Figure No. C-3

GL3-TP1



GL3-TP2



Notes

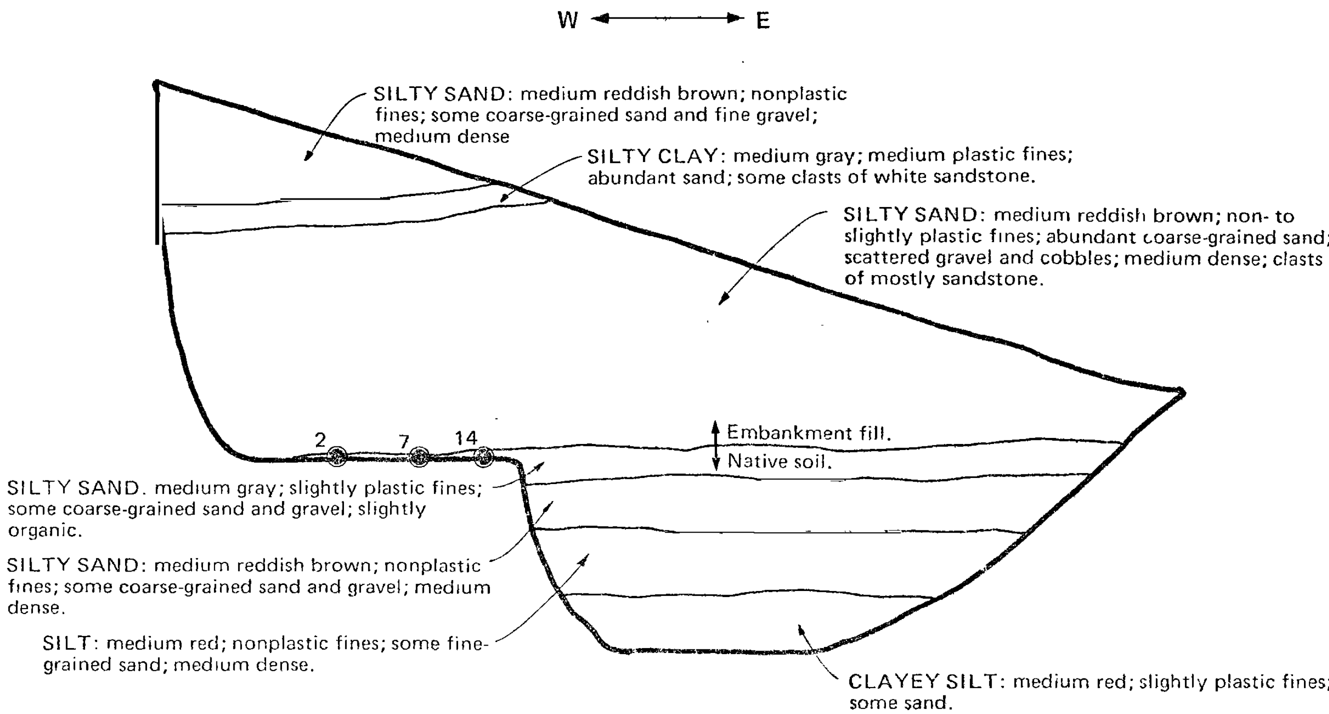
1. All materials in test pit excavation GL3-TP1 are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

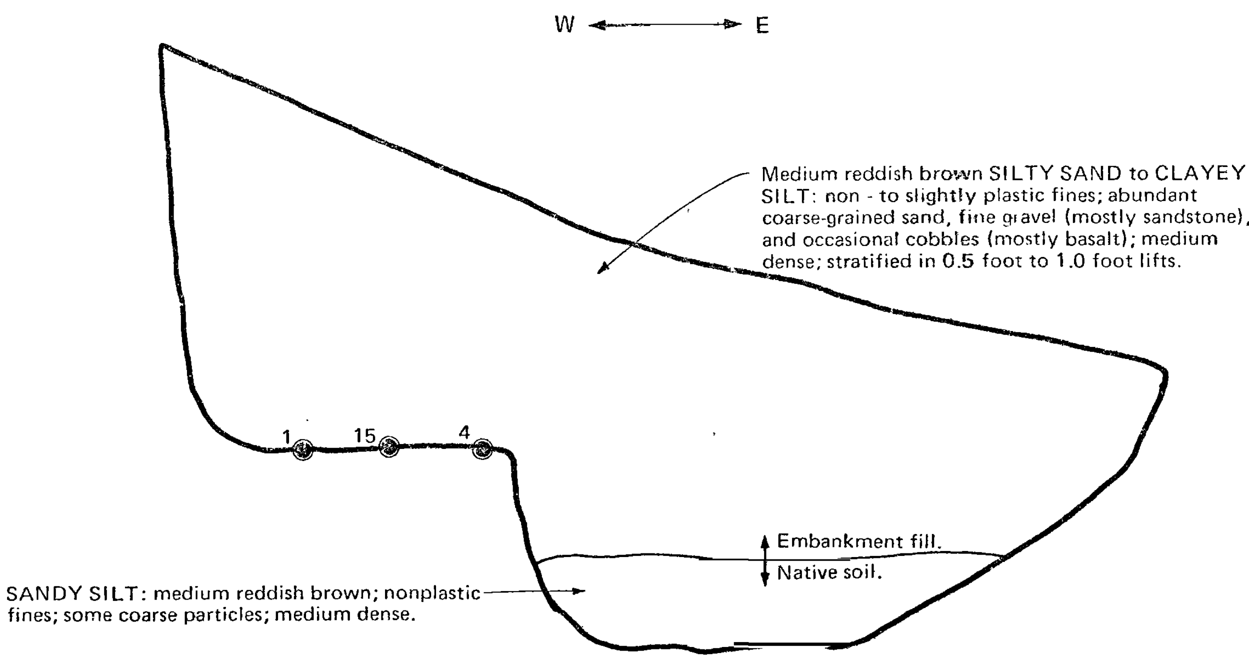
Horizontal = Vertical

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOGS OF TEST PIT EXCAVATIONS** **GREEN'S LAKE NO. 3**		
Checked by MLT Date 5/27/82 Approved by EA Wilson Date 27 May 82	Project No. D118	Figure No. C-4

GL3-TP3



GL3-TP4



Note

◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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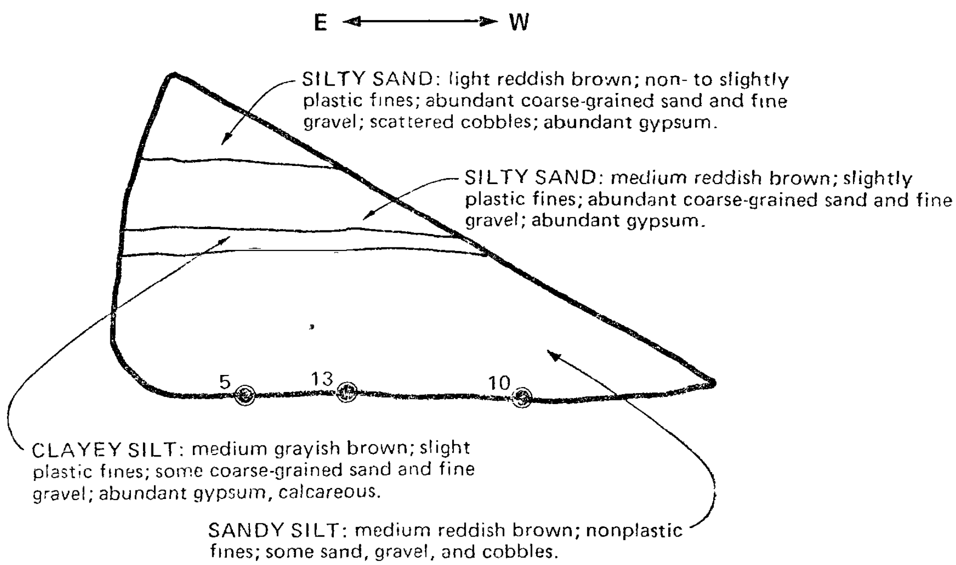
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
GREEN'S LAKE NO. 3

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. C-5
Approved by EA Wilson	Date 27 MAY 82		

GL3-TP5



Notes

1. All materials in test pit excavation are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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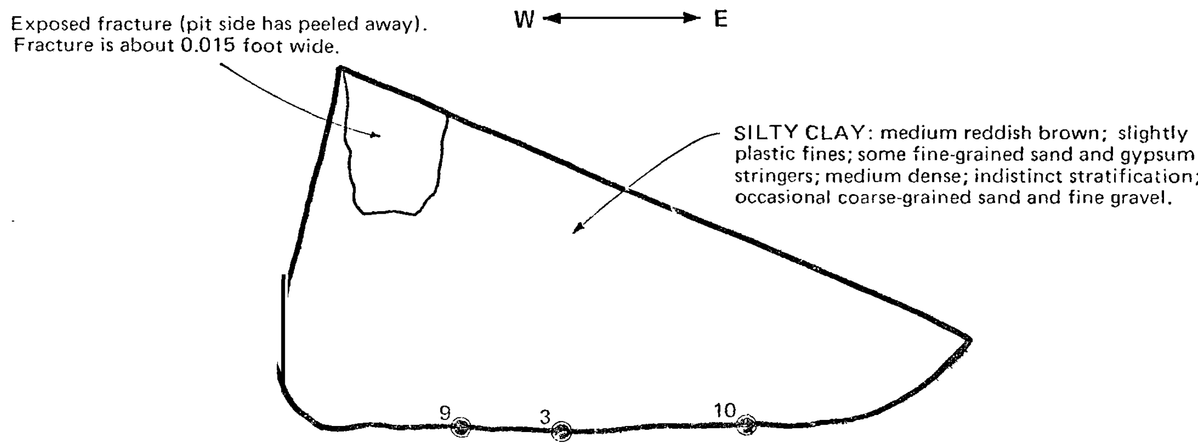
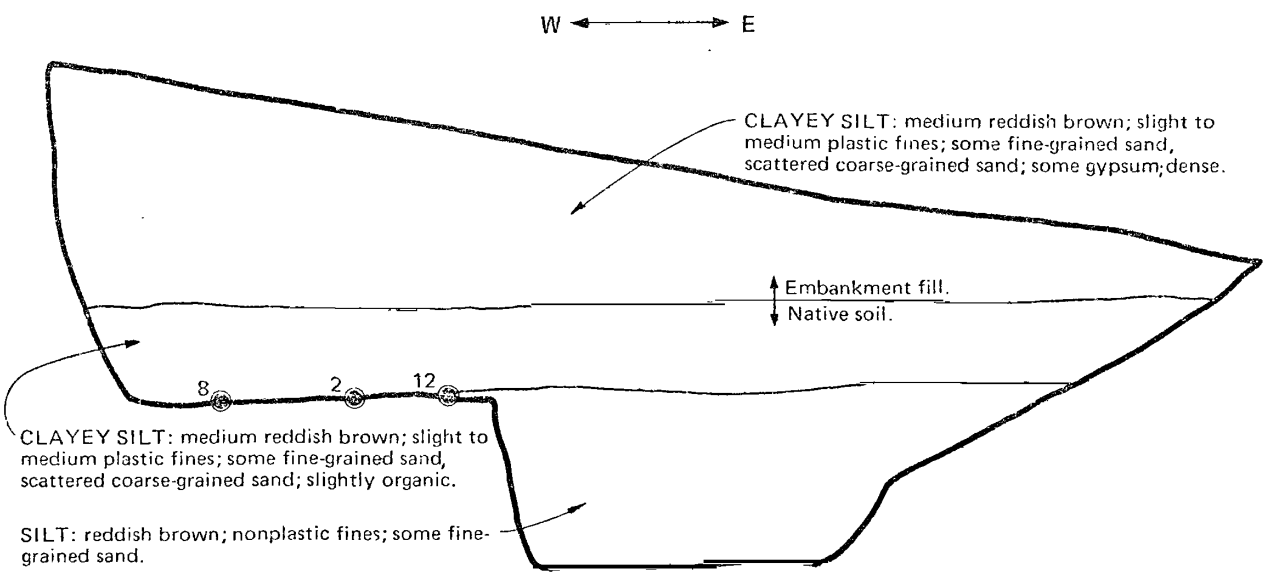
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOG OF TEST PIT EXCAVATION
GREEN'S LAKE NO. 3 .

Checked by MLT	Date 5/21/82	Project No. D118	Figure No. C-6
Approved by EA Nelson	Date 27 May 82		

GL5-TP1



GL5-TP2



Notes

1. All materials in test pit exacavation GL5-TP1 are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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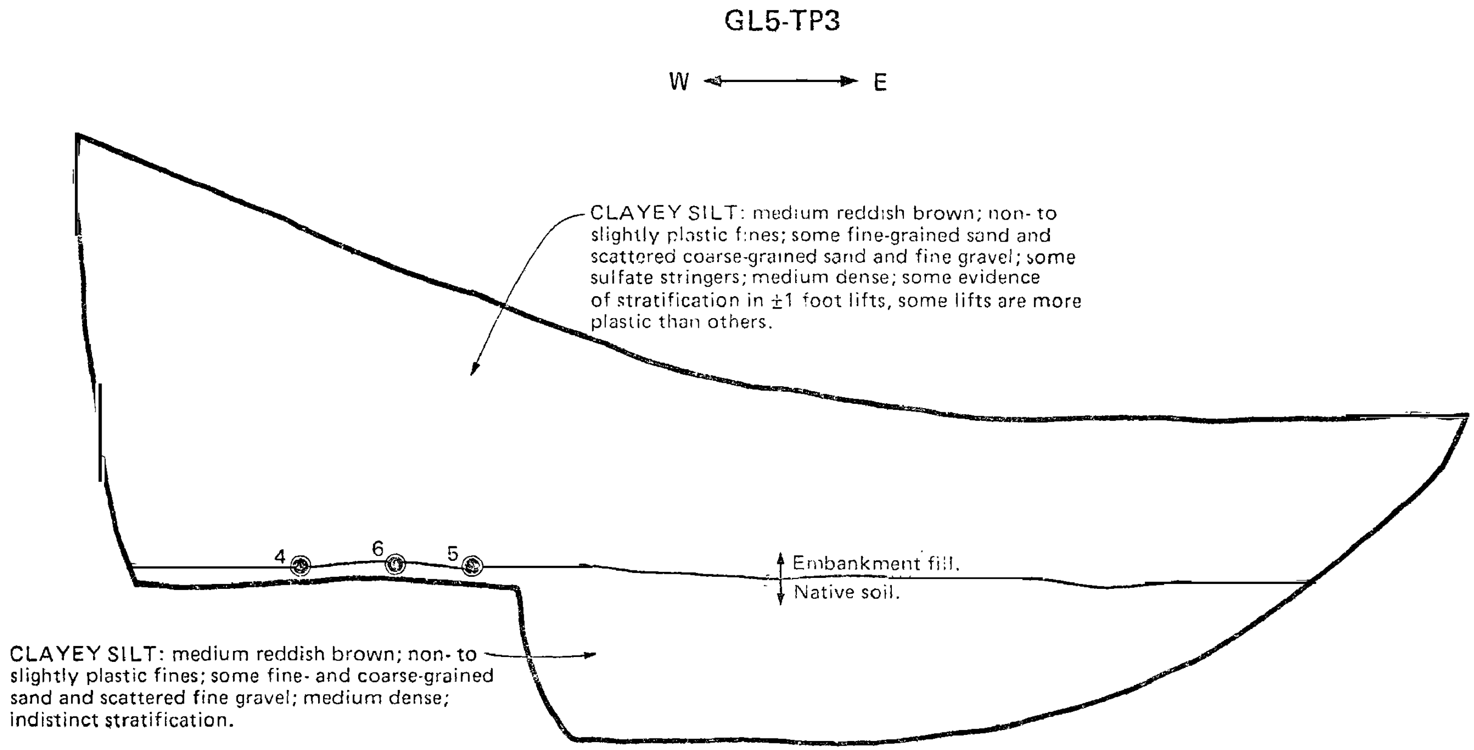
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
GREEN'S LAKE NO. 5

Checked by MLT	Date 5/21/82	Project No. D118	Figure No. C-7
Approved by EANelson	Date 27 MAY 82		



Note

◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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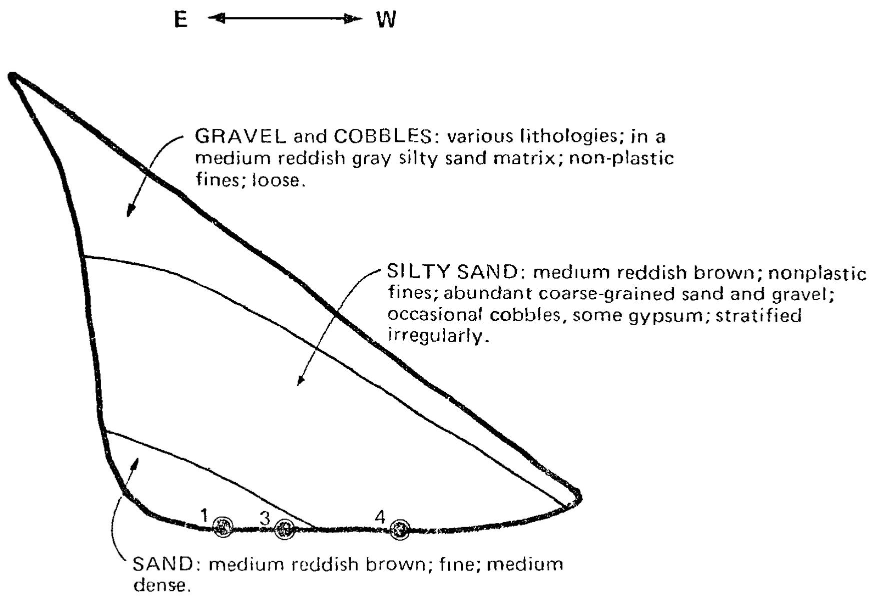
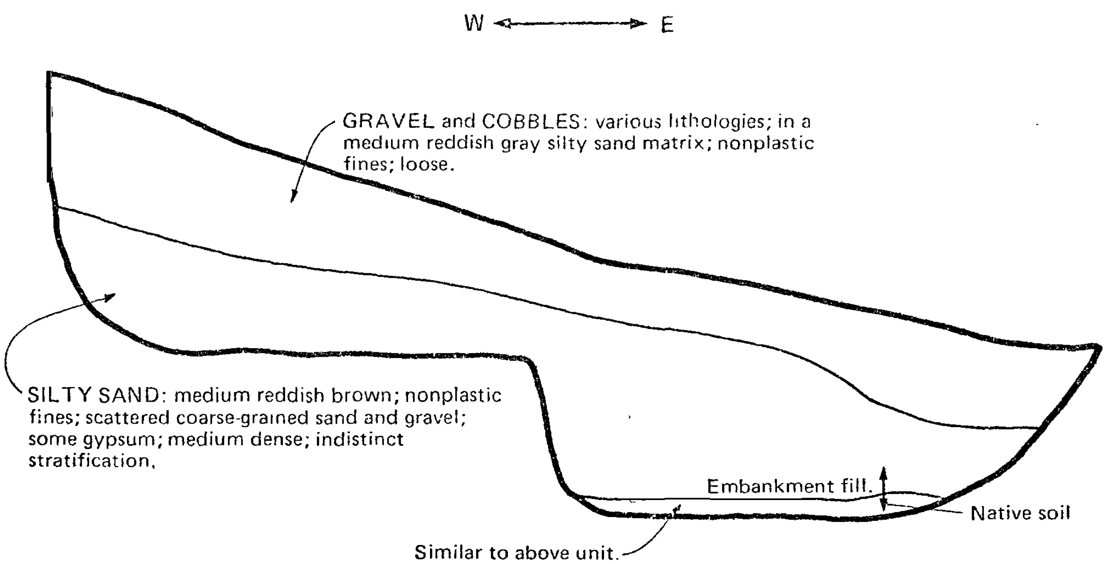
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOG OF TEST PIT EXCAVATION
GREEN'S LAKE NO. 5

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by E.A. Nelson	Date 27 MAY 82	D118	C-8

WD-TP1



WD-TP2



Notes

1. All materials in test pit excavation WD-TP1 are embankment fill.
2. ● indicates location of sand cone density test.

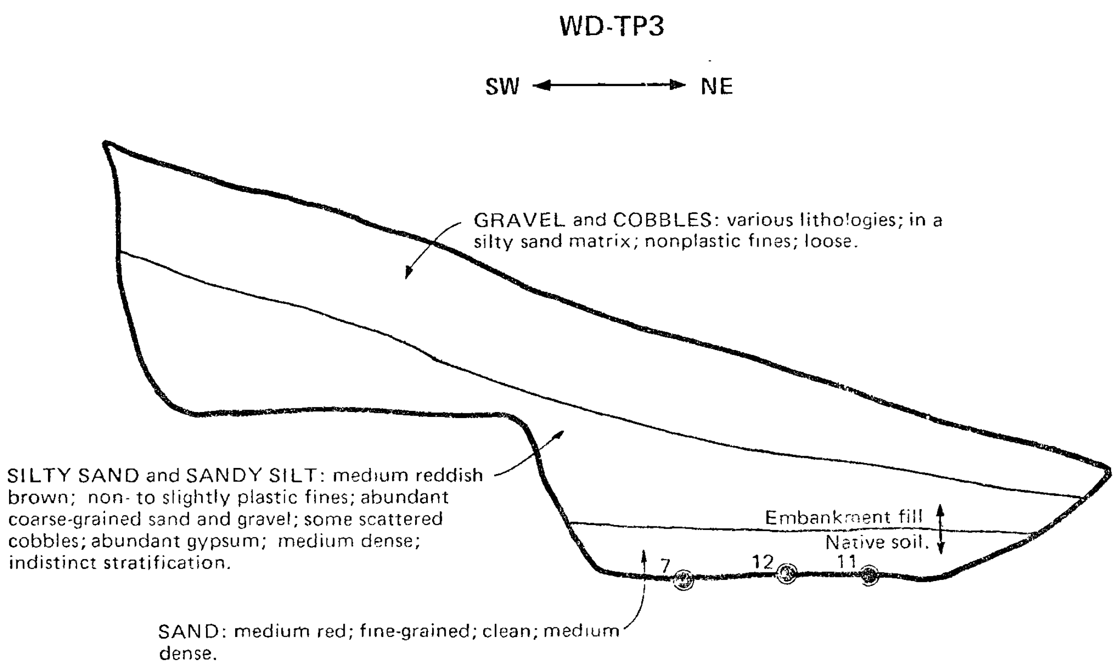
0 1 2 feet

Horizontal = Vertical

Earth Sciences Associates
Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
WARNER DRAW DAM

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. C-9
Approved by [signature]	Date 27 MAY 82		



Notes

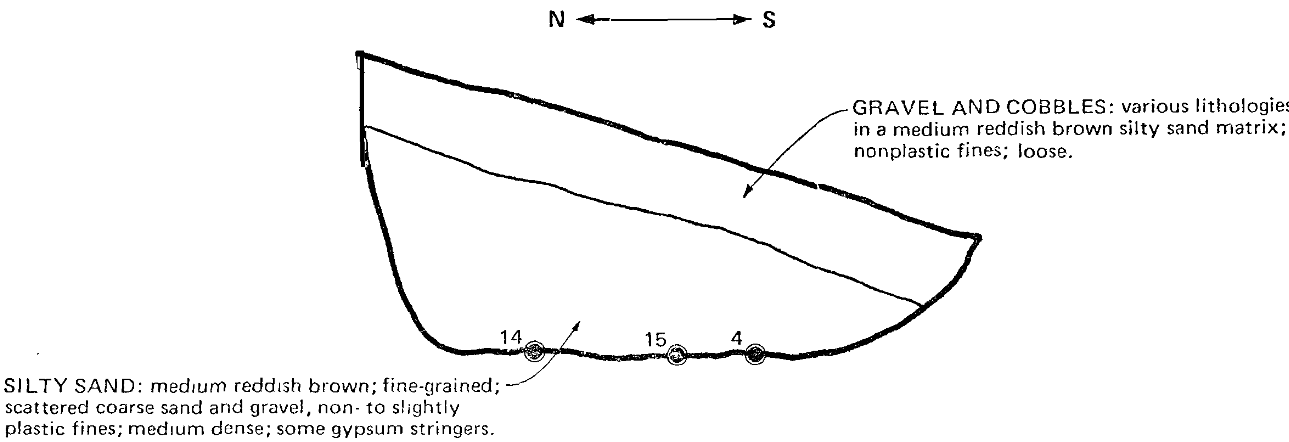
1. All materials in test pit excavation are embankment fill.
2. ● indicates location of sand cone density test.

0 1 2 feet

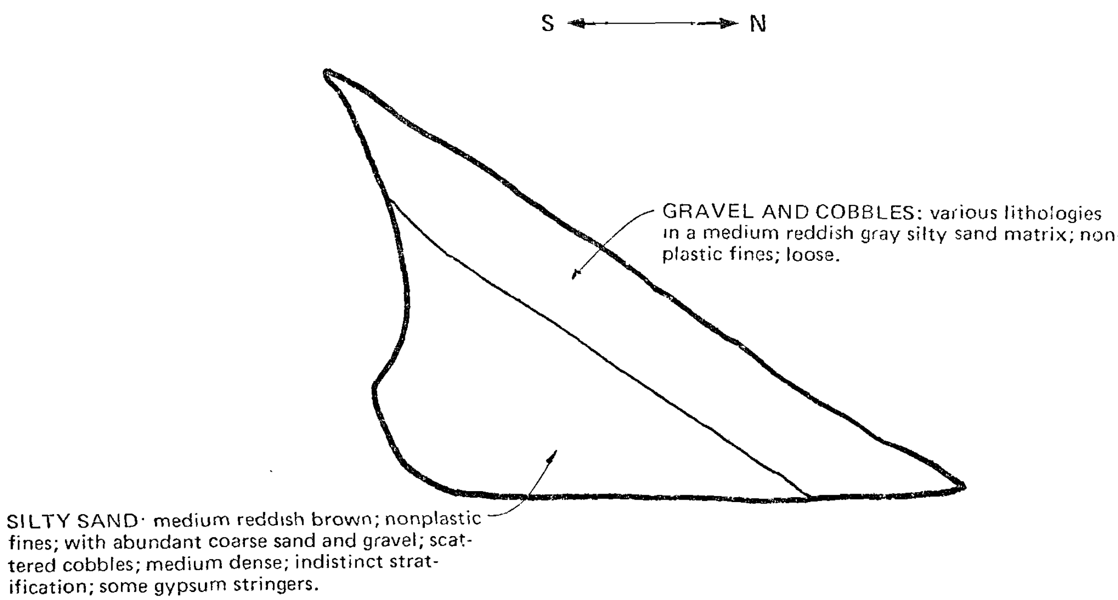
Horizontal = Vertical

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOG OF TEST PIT EXCAVATION** **WARNER DRAW DAM**		
Checked by MLT Date 5/27/82 Approved by EA Wilson Date 27 MAY 82	Project No. D118	Figure No. C-10

STK-TP1



STK-TP2



Notes

1. All materials in test pit excavations are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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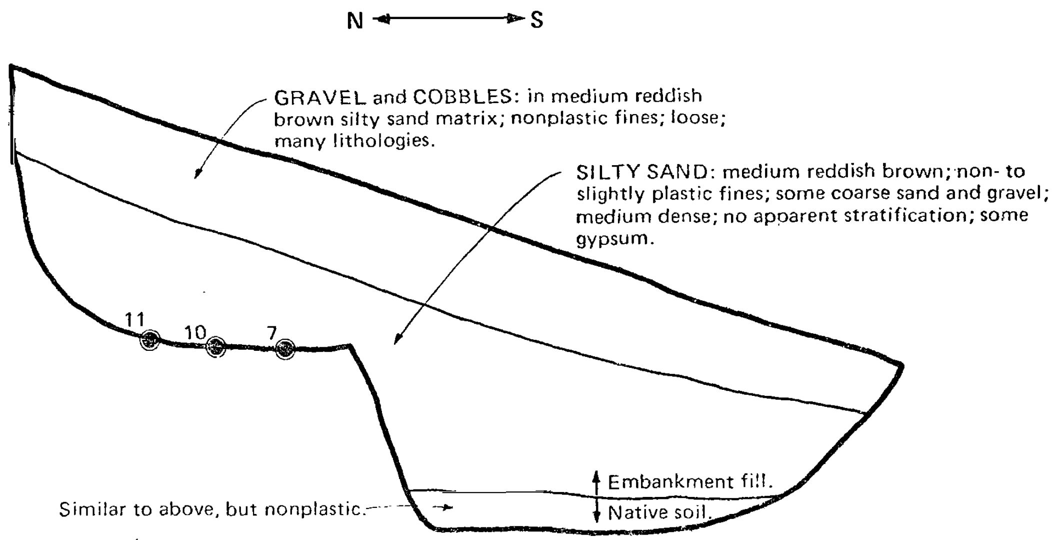
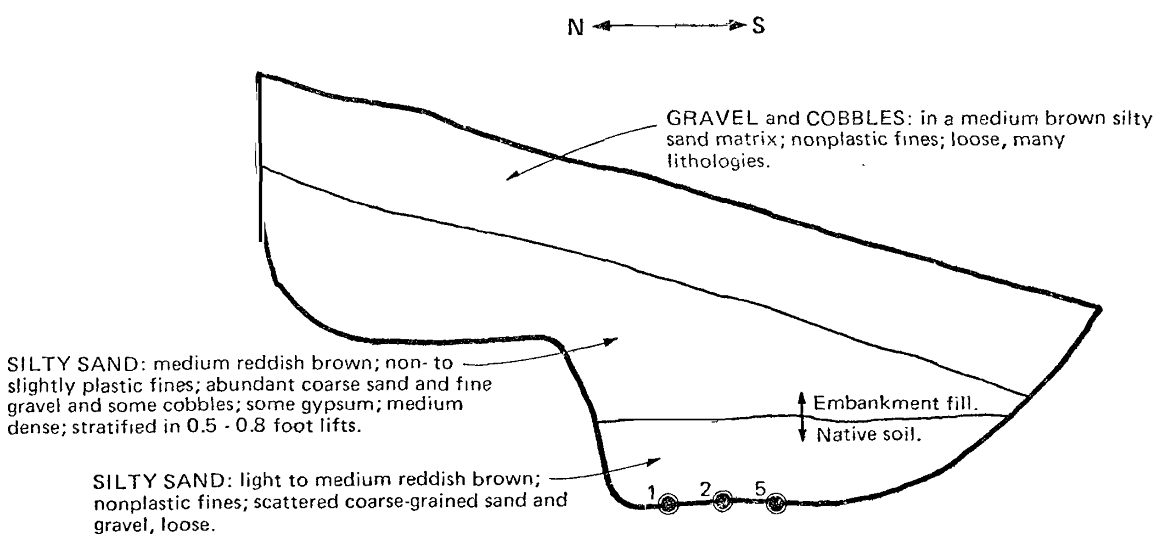
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
STUCKI DAM

		Project No.	Figure No.
Checked by MGT	Date 5/27/82	D118	C-11
Approved by [signature]	Date 27 May 82		

STK-TP-3



STK-TP-4



Note

● indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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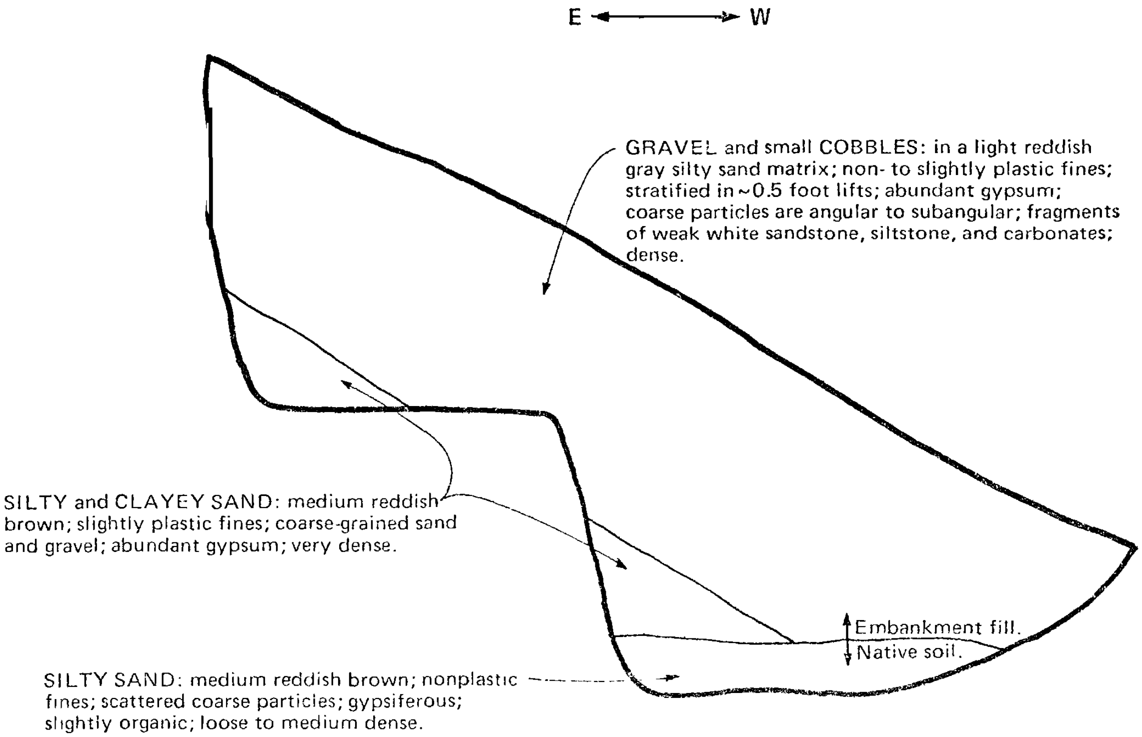
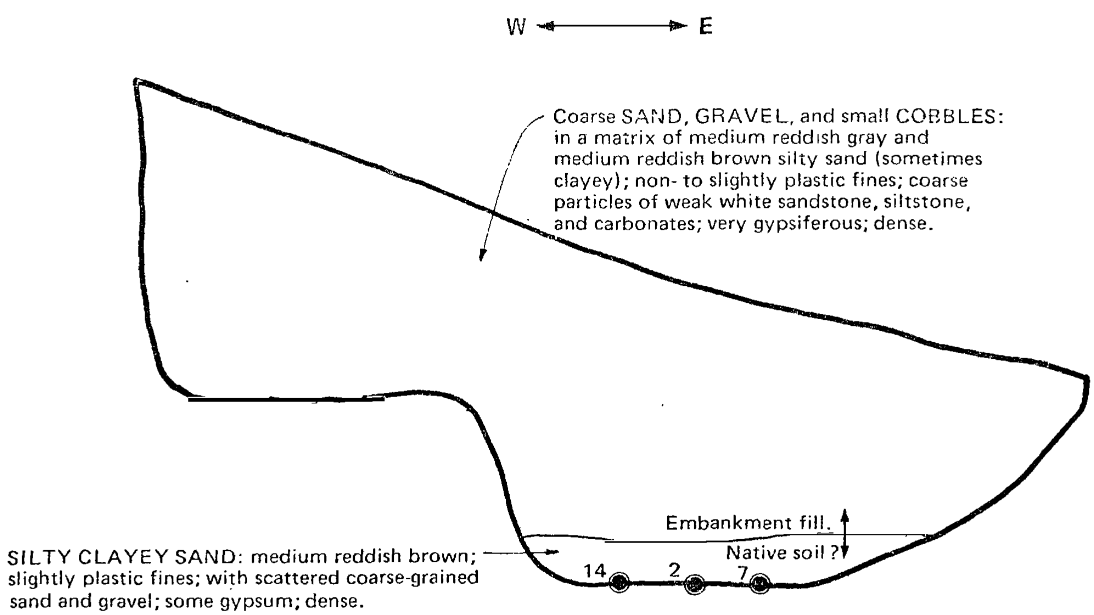
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
STUCKI DAM

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson Date 27 May 82	D118	C-12

GW-TP1



GW-TP2



Note

● indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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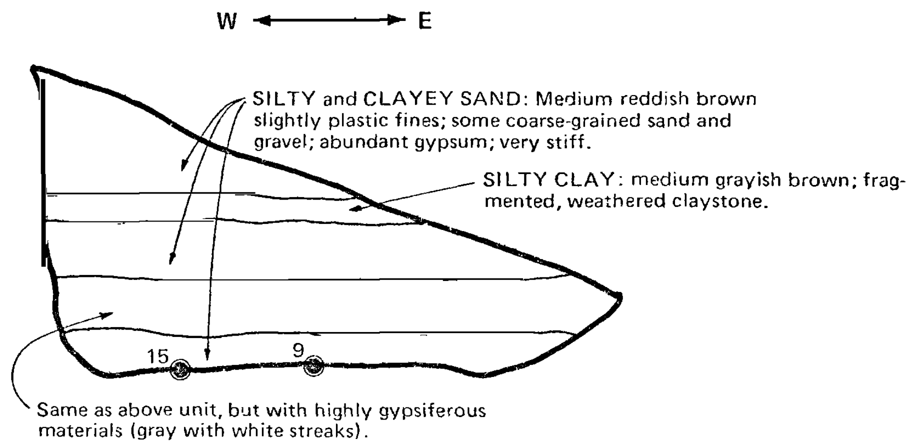
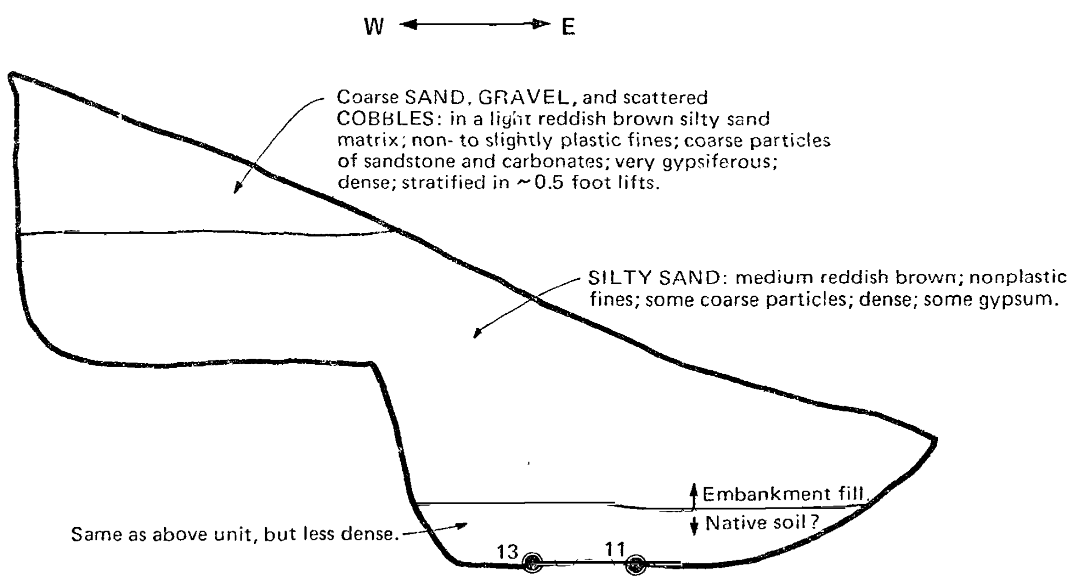
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOGS OF TEST PIT EXCAVATIONS** **GYPSUM WASH DAM**		
Checked by M4T Date 5/27/82 Approved by EA Nelson Date 27 MAY 82	Project No. D118	Figure No. C-13

GW-TP3



GW-TP4



Notes

1. All materials in test pit excavation GW-TP3 are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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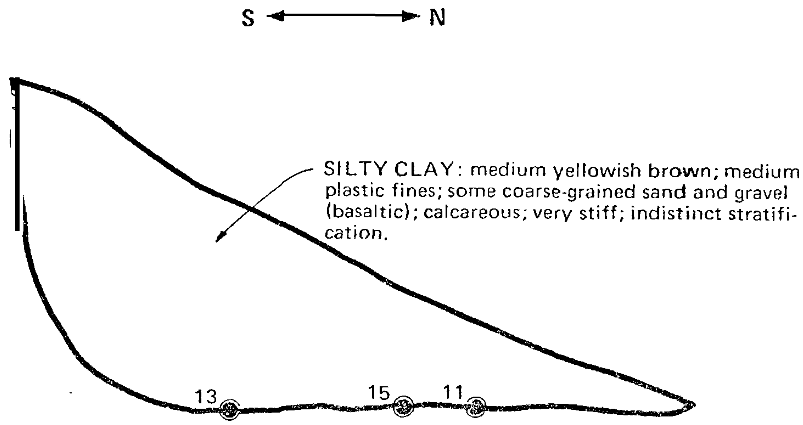
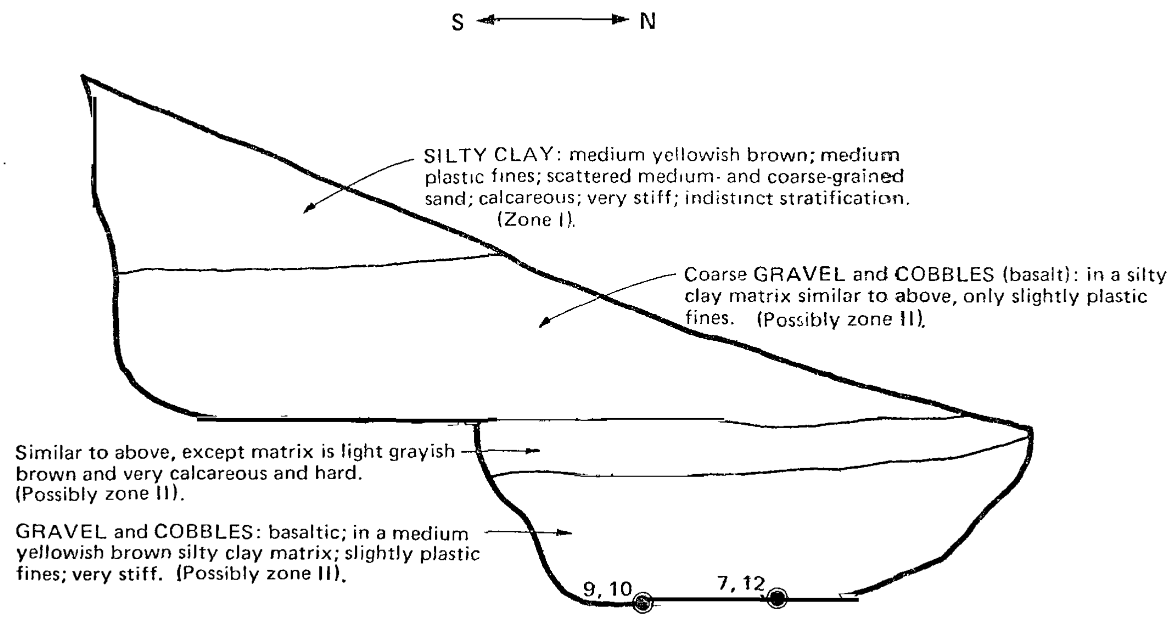
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOGS OF TEST PIT EXCAVATIONS** **GYPSUM WASH DAM**			
Checked by MLT Date 5/27/82		Project No. D118	Figure No. C-14
Approved by EA Nelson Date 27 May 82			

FH-TP1



FH-TP2



Notes

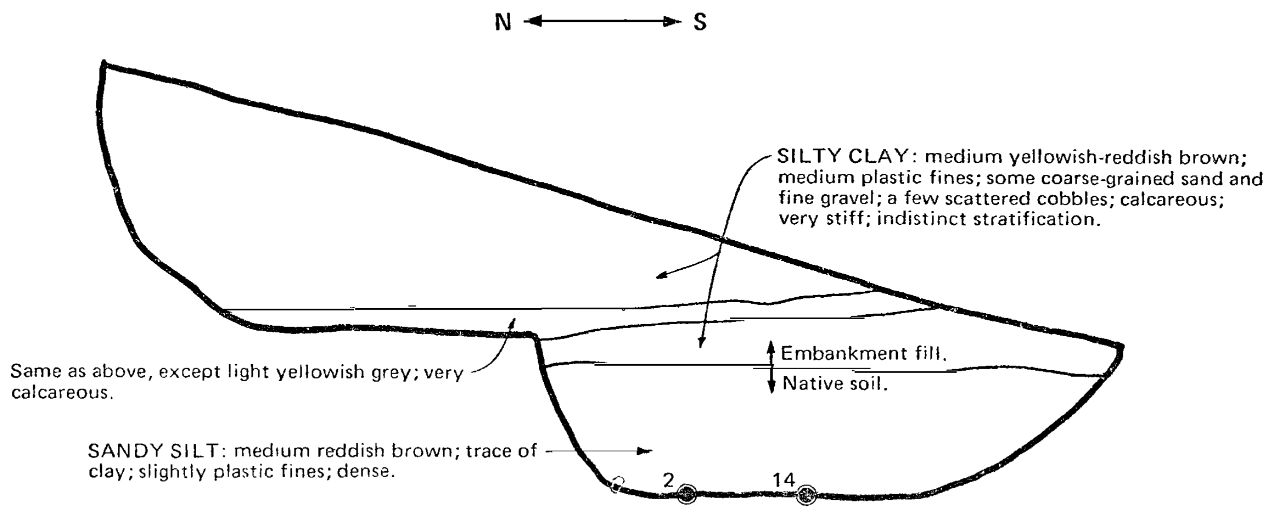
1. All materials in test pit excavations are embankment fill.
2. ● indicates location of sand cone density test.

0 1 2 feet

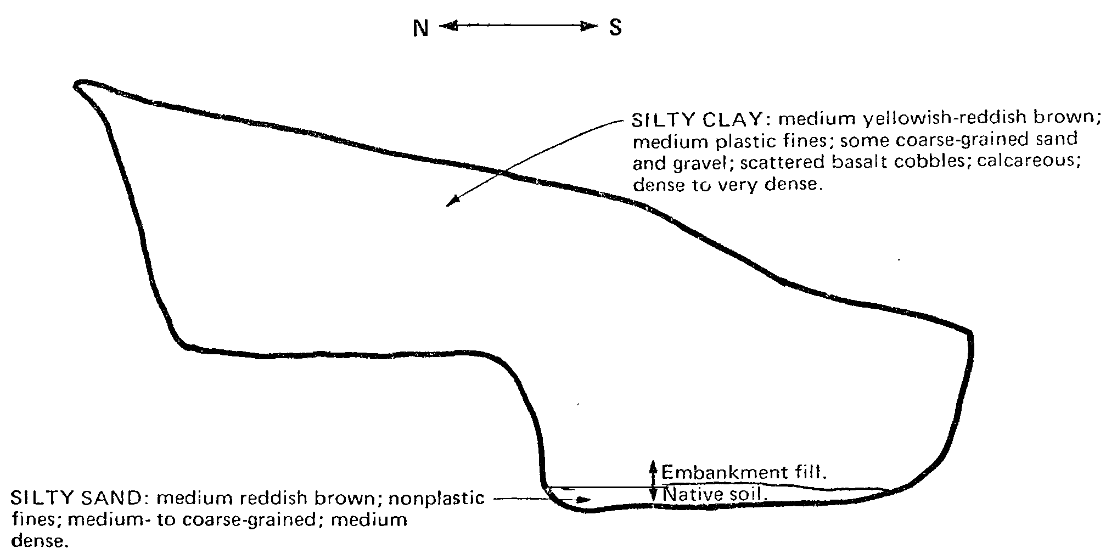
Horizontal = Vertical

Earth Sciences Associates Palo Alto, California		
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOGS OF TEST PIT EXCAVATIONS** **FROM HOLLOW DAM**		
Checked by MGT Date 5/27/82 Approved by EA Nelson Date 27 MAY 82	Project No. D118	Figure No. C-15

FH-TP3



FH-TP4



Note

● indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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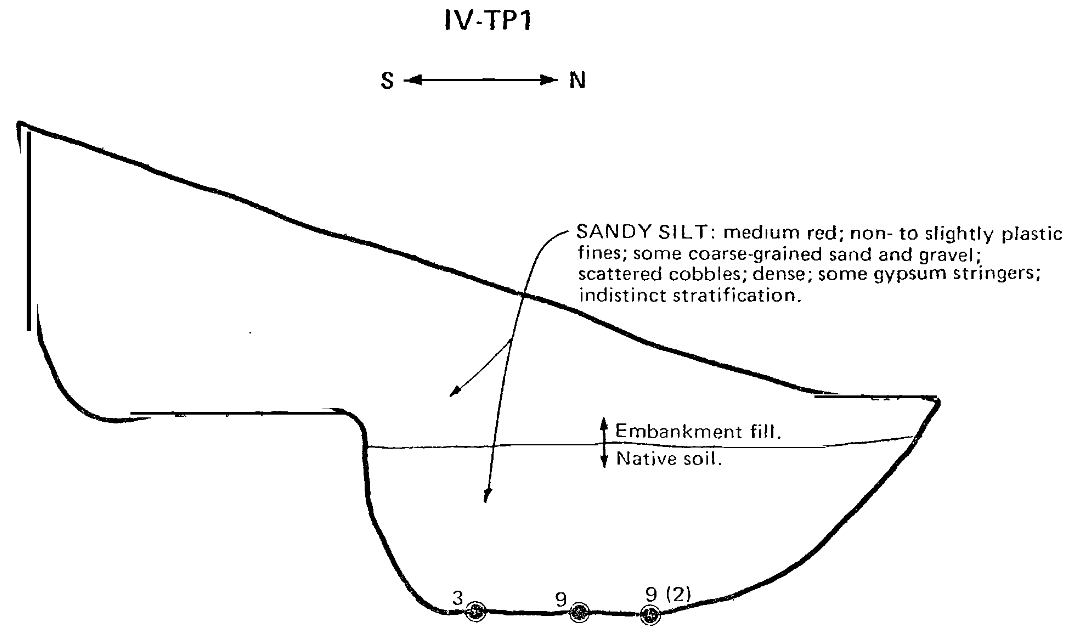
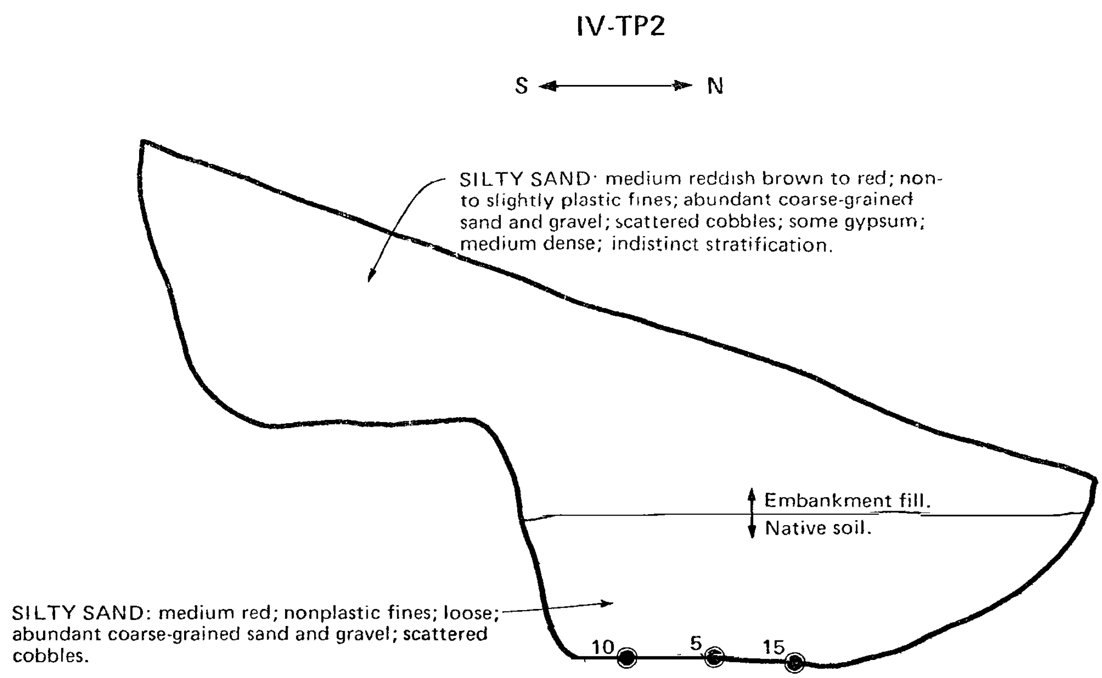
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
FROG HOLLOW DAM

Checked by MLT Date 5/27/82 Approved by EA Nelson Date 27 MAY 82	Project No. D118	Figure No. C-16





Note

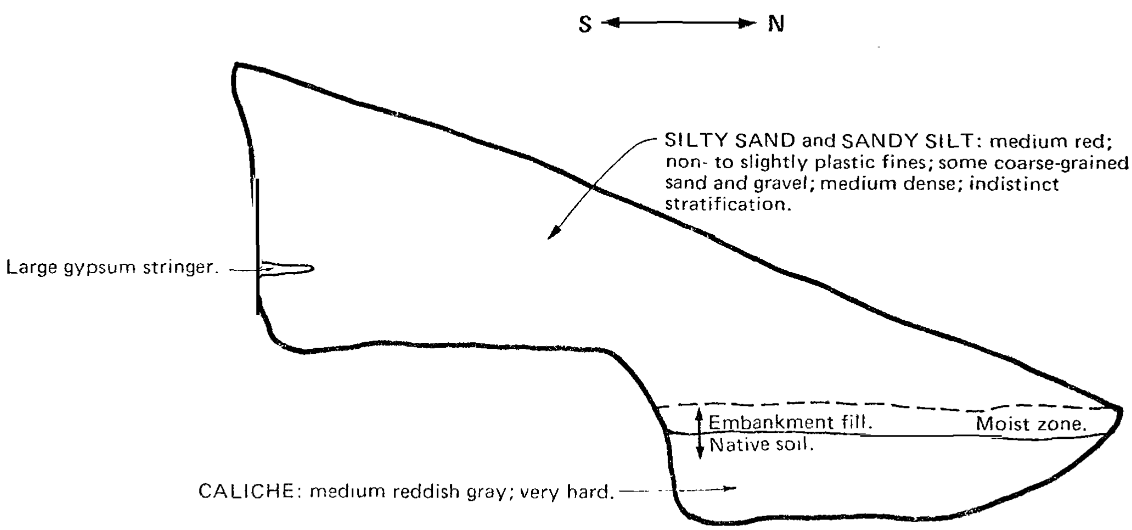
● indicates location of sand cone density test.

0 1 2 feet

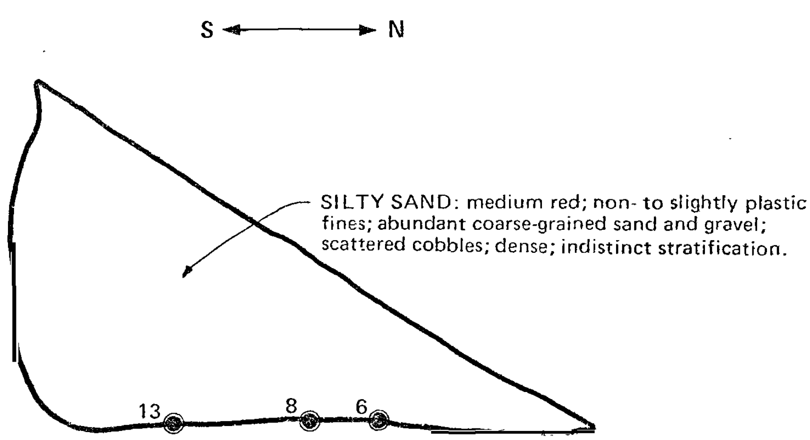
Horizontal = Vertical

Earth Sciences Associates Palo Alto, California			
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **LOGS OF TEST PIT EXCAVATIONS** **IVINS DIVERSION DAM NO. 5**			
Checked by MLV	Date 5/27/82	Project No. D118	Figure No. C-17
Approved by EA Wilson	Date 27 May 82		

IV-TP3



IV-TP4



Notes

1. All materials in test pit excavation IV-TP4 are embankment fill.
2. ◉ indicates location of sand cone density test.

0 1 2 feet

Horizontal = Vertical

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
LOGS OF TEST PIT EXCAVATIONS
IVINS DIVERSION DAM NO. 5

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. C-18
Approved by EA Nelson	Date 27 May 82		

APPENDIX D

LABORATORY TESTING

Appendix D
LABORATORY TESTING

Laboratory tests consisting of grain-size determination and compaction tests were performed to establish the relative compaction of the embankment and foundation materials. In addition, Atterberg limit tests were performed to help facilitate the classification of the various materials encountered. Results of Atterberg limit tests are shown in Figures D-1 and D-2. Sieve analyses and compaction tests were run on all of the bag samples obtained from the test pits. Sieve analyses were also performed on some of the sand cone test samples to establish their similarity with the corresponding bulk sample. Gradation curves for all of the samples tested are shown in Figures D-3 through D-10 for each of the dam embankments. Compaction curves for the materials tested are shown in Figures D-11 through D-18 for the various materials tested along with the corresponding maximum dry densities and optimum moisture contents. The compaction tests were performed using a 4-inch diameter mold in accordance with ASTM procedure D698-70 method C (standard Proctor and 3/4 inch maximum particle size).

The degree of relative compaction at each sand cone test location was computed using the appropriate value of maximum dry density established in the laboratory for the corresponding bulk sample. These results are tabulated in Tables D-1 through D-8 for each test performed at each dam location.

Table D-1

Relative Compaction Evaluation

Green's Lake Dam #2

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γd (pcf)	Field Test w/c (%)	Laboratory $\gamma dmax$ (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
GL2-TP2	#6	Shell	SM-ML w/gravel, cobbles	SM-SC	111.3	10.1			90.4	
GL2-TP2	#8	"	"	"	106.5	7.9	123.1	10.7	86.5	
GL2-TP2	#9	"	"	"	110.4	8.5			89.7	
GL2-TP4	#6	Shell	SM-ML w/gravel	SM-SC	101.7	5.7			85.8	
GL2-TP4	#9	"	"	"	101.0	6.0	118.5	13.2	85.2	
GL2-TP4	#8	"	"	"	101.6	8.4			85.7	
GL2-TP5	#7,13	Foundation	SM w/gravel, cobbles	SM-SC	116.4	6.9	121.8	11.0	95.6	12" sandcone
GL2-TP5	#5,10	"	"	"	106.7	7.0			87.6	"

Table D-2

Relative Compaction Evaluation

Green's Lake Dam #3

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification: Field	Unified Soil Classification: Lab	Field Test: γd (pcf)	Field Test: w/c (%)	Laboratory: $\gamma dmax$ (pcf)	Laboratory: Opt w/c (%)	Relative Compaction (%)	Remarks
GL3-TP1	#11	Shell	SM w/gravel, cobbles	ML	102.1	9.6			82.5	Sandcone sample
GL3-TP1	#14	"	"	"	117.6	7.6	123.7	9.9	95.1	has finer sand
GL3-TP1	#7	"	"	"	116.2	6.5			93.9	than bulk sample.
GL3-TP2	#3	Foundation	ML w/sand, gravel,	SM	106.3	11.6			86.6	
GL3-TP2	#11	"	"	"	107.3	10.8	122.8	9.7	87.4	
GL3-TP2	#12	"	"	"	108.7	11.5			88.5	
GL3-TP3	#2	Foundation	SM w/gravel	SM-ML	111.3	9.5			88.5	
GL3-TP3	#7	"	"	"	117.3	8.4	125.7	10.6	93.3	
GL3-TP3	#14	"	"	"	115.9	10.6			92.2	
GL3-TP4	#1	Shell	SM-ML w/gravel,	SM-ML	112.1	7.6			89.0	
GL3-TP4	#15		cobbles	"	105.2	7.9	126.0	11.6	83.5	
GL3-TP4	#4			"	109.9	7.3			87.2	
GL3-TP5	#5	Shell	SM w/gravel, cobbles	SM-ML	98.8	8.6			80.2	
GL3-TP5	#13	"	"	"	103.9	9.6	123.2	10.9	84.3	
GL3-TP5	#10	"	"	"	97.2	11.7			79.3	

Table D-3

Relative Compaction Evaluation

Green's Lake Dam #5

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification: Field	Unified Soil Classification: Lab	Field Test: γ_d (pcf)	Field Test: w/c (%)	Laboratory: γ_{dmax} (pcf)	Laboratory: Opt w/c (%)	Relative Compaction (%)	Remarks
GL5-TP1	#9	Shell	CL w/sand gravel	CL	79.3	10.8			70.2	Field test water contents are not in situ values due to time between opening of pits and testing (rain).
GL5-TP1	#3	"	"	"	86.8	10.6	113.0	13.5	76.8	
GL5-TP1	#10	"	"	"	92.5	11.6			81.9	
GL5-TP2	#3	Foundation	ML w/sand	SM-SC	98.7	12.3			82.9	
GL5-TP2	#2	"	"	"	99.4	11.3	119.1	11.0	83.5	
GL5-TP2	#12	"	"	"	108.6	10.3			91.2	
GL5-TP3	#4	Foundation	ML w/sand, gravel	CL-ML	98.5	11.4			88.3	
GL5-TP3	#6	"	"	"	97.0	11.6	111.6	15.5	86.9	
GL5-TP3	#5	"	"	"	96.3	10.2			86.3	

Table D-4

Relative Compaction Evaluation

Warner Draw

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γ_d (pcf)	Field Test w/c (%)	Laboratory γ_{dmax} (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
WD-TP1	#1	Shell	SP-SM w/gravel, cobbles	SM	120.3	7.1			103.0	
WD-TP1	#3	"	"	"	120.2	5.6	117.8	7.0	104.0	
WD-TP1	#4	"	"	"	108.8	3.6			92.4	
WD-TP3	#7	Foundation	SP	SM	127.5	9.6			106.0	
WD-TP3	#12	"	"	"	124.1	6.5	119.8	9.0	104.0	
WD-TP3	#11	"	"	"	114.7	5.3			95.7	

Table D-5

Relative Compaction Evaluation

Stucki

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γ_d (pcf)	Field Test w/c (%)	Laboratory γ_{dmax} (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
STK-TP1	#14	Shell	SM w/gravel	SM	126.8	9.0			102.6	
STK-TP1	#15	"	"	"	119.9	9.2	123.6	9.4	97.0	
STK-TP1	#4	"	"	"	114.4	8.9			92.6	
STK-TP3	#11	Shell	SM w/gravel	SM	125.5	6.4			98.3	
STK-TP3	#10	"	"	"	120.8	7.1	127.7	9.7	94.6	
STK-TP3	#7	"	"	"	135.2	7.4			105.9	
STK-TP4	#1	Foundation	SM w/gravel	SM	113.6	7.9			92.0	
STK-TP4	#2	"	"	"	113.2	7.2	123.5	10.8	91.7	
STK-TP4	#5	"	"	"	120.3	6.4			97.4	

Table D-6

Relative Compaction Evaluation

Gypsum Wash

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γ_d (pcf)	Field Test w/c (%)	Laboratory γ_{dmax} (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
GW-TP2	#14	Foundation	SC-SM w/gravel	SM	+95.9	8.9			76.4	Water contents not in situ
GW-TP2	#2	"	"	"	114.4	7.5	125.6	10.1	91.1	
GW-TP2	#7	"	"		97.4	6.3			77.5	"
GW-TP3	#15	Shell	CL w/silt, sand, gravel	SM	103.1	16.7	122.0	11.0	84.5	"
GW-TP3	#9	"	"	"	107.6	13.3			88.2	"
GW-TP4	#13	Foundation	SM w/gravel	SM	125.3	5.2	120.4	7.3	104.1	"
GW-TP4	#11	"	"	"	127.9	4.6			106.2	"

Note: + Field tests required rock correction.

Table D-7

Relative Compaction Evaluation

Frog Hollow

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γ_d (pcf)	Field Test w/c (%)	Laboratory γ_{dmax} (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
FH-TP1	#13	Shell (Zone I)	CL w/silt, sand, gravel	CL-ML	111.6	13.3			95.1	
FH-TP1	#15	"	"	"	116.8	12.8	117.4	13.5	99.5	
FH-TP1	#11	"	"	"	115.5	12.0			98.4	
FH-TP2	#9,10	Shell (Zone II)	GC-GM w/cobbles	GC-GM	72.2+	14.4			79.3	12" sandcone.
							116.2	15.4		
FH-TP2	#7,12		"	"	106.8+	10.0			91.9	12" sandcone.
FH-TP3	#2	Foundation	ML w/clay, sand	ML-CL	90.2	12.5			80.5	
							112.1	16.2		
FH-TP3	#14	"	"	"	99.9	11.8			89.1	

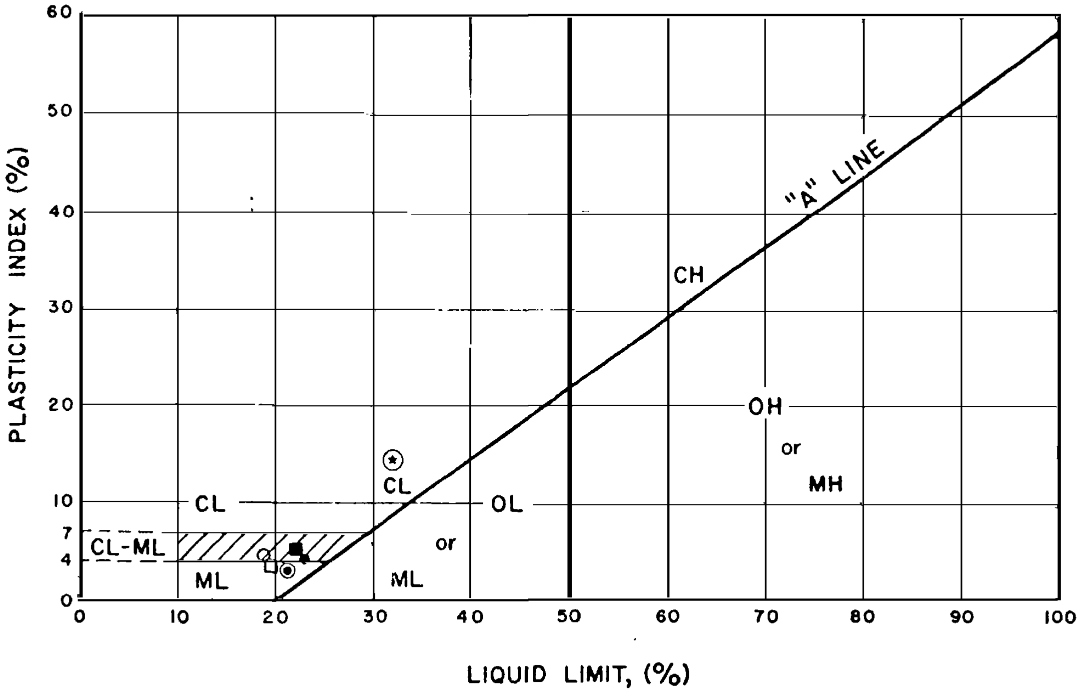
Note: + Field test required rock correction.

Table D-8

Relative Compaction Evaluation

Ivins Diversion No. 5

Dam/Test Pit	Can #	Zone Tested	Unified Soil Classification Field	Unified Soil Classification Lab	Field Test γ_d (pcf)	Field Test w/c (%)	Laboratory γ_{dmax} (pcf)	Laboratory Opt w/c (%)	Relative Compaction (%)	Remarks
IV-TP1	#3	Foundation	ML w/gravel, cobbles	SM	113.1	10.2			95.4	
IV-TP1	#9	"	"	"	102.8	10.9	118.6	13.1	86.7	
IV-TP1	#9(2)	"	"	"	106.2	10.5			89.5	Sandcone sample is coarser than corresponding, bulk sample.
IV-TP2	#10	Foundation	SM w/gravel, cobbles	SM	92.1	8.9			83.3	
IV-TP2	#5	"	"	"	91.0	9.3	110.5	11.5	82.4	
IV-TP2	#15	"	"	"	93.8	8.6			84.9	
IV-TP4	#13	Shell	SM w/gravel	SM	116.3	6.1			95.7	
IV-TP4	#8	"	"	"	110.7	5.6	121.5	10.2	91.1	
IV-TP4	#6	"	"	"	128.1	4.5			105.4	



SYMBOL	BORING NO.	MATERIAL	LIQUID LIMIT, %	PLASTICITY INDEX, %	USC SYMBOL
□	GL3 - TP1	SHELL	19.3	3.7	ML
◉	GL3 - TP4	SHELL	21.0	3.3	SM - ML
○	GL2 - TP2	SHELL	18.8	4.2	SM - SC
●	GL2 - TP5	FOUND	23.4	4.6	SM - SC
⊛	GL5 - TP1	SHELL	32.1	14.4	CL
■	GL5 - TP2	FOUND	21.9	4.7	SM - SC

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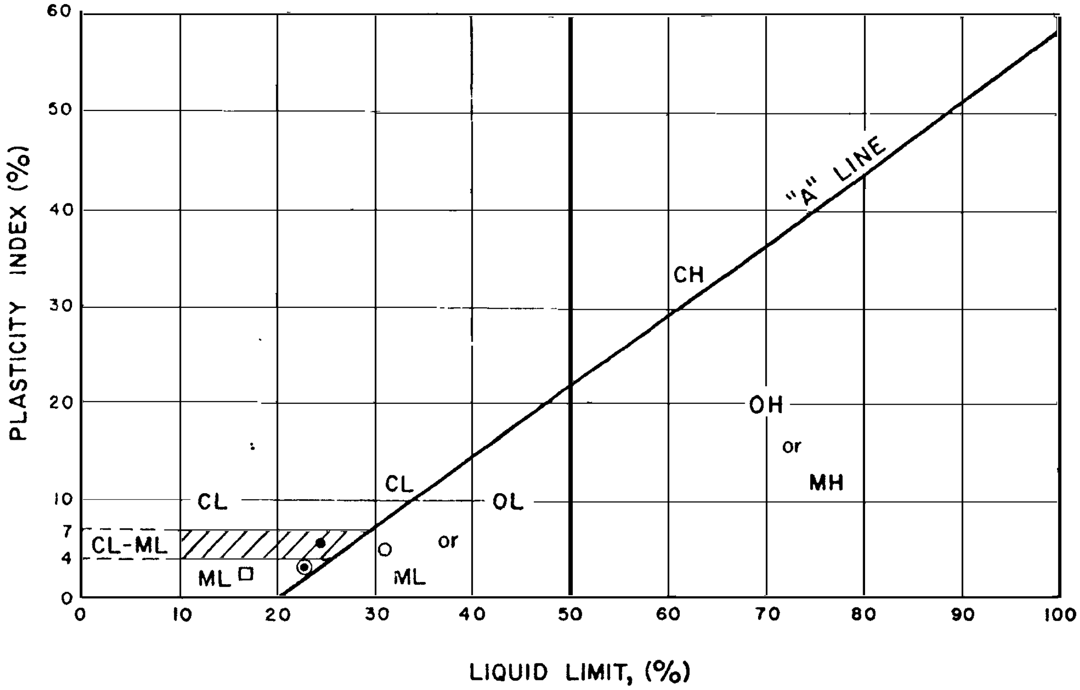
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SUMMARY OF ATTERBERG LIMITS

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. D-1
Approved by EA Wilson	Date 27 Mar 82		



SYMBOL	BORING NO.	MATERIAL	LIQUID LIMIT, %	PLASTICITY INDEX, %	USC SYMBOL
•	FH - TP1	SHELL	24.4	5.5	CL - ML
○	FH - TP2	FOUND	32.1	5.3	GC - GM
□	STK - TP3	SHELL	16.4	2.5	SM
◉	GW - TP3	SHELL	22.3	3.1	SM

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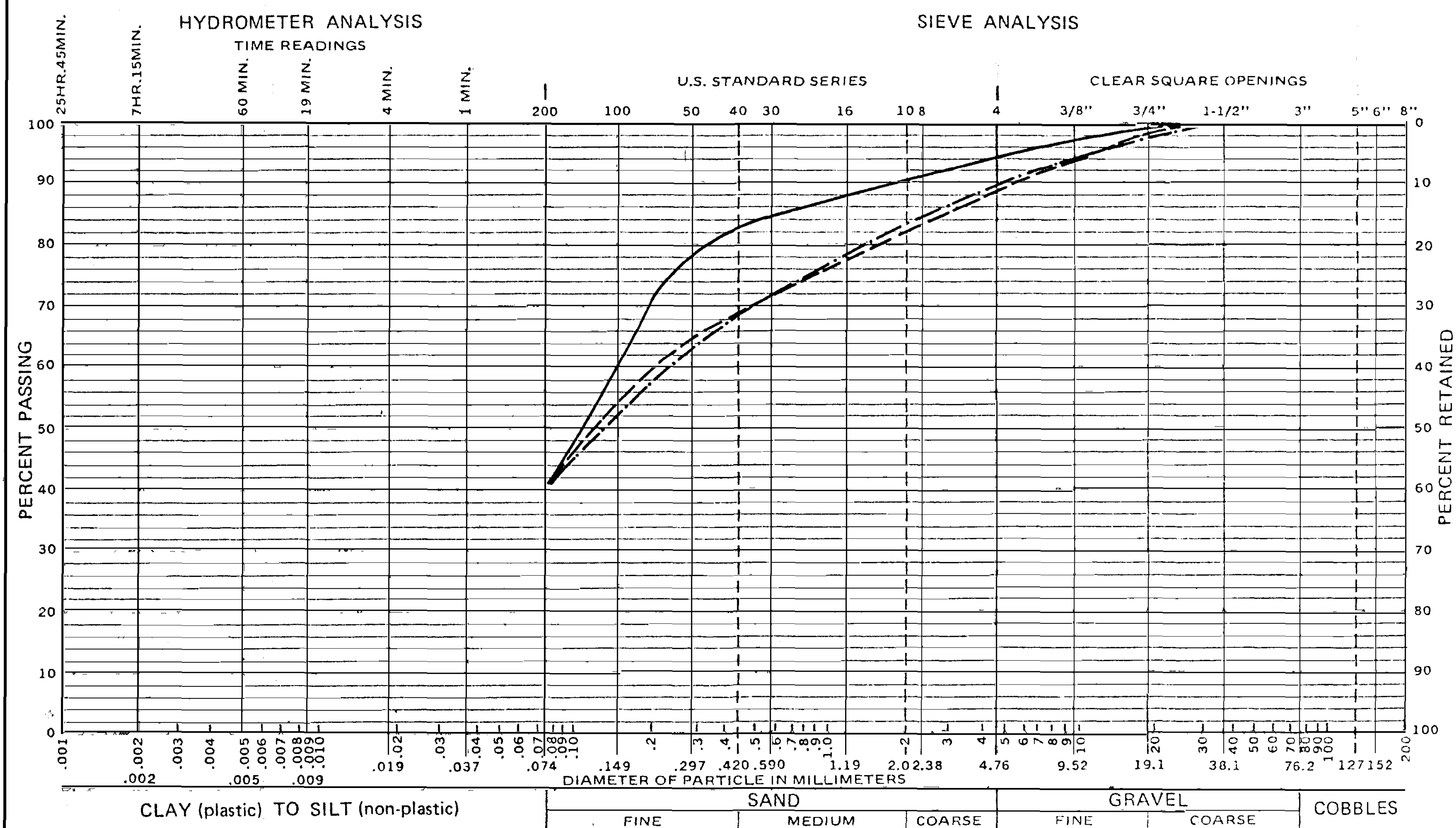
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
SUMMARY OF ATTERBERG LIMITS

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	D-2



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
———— (solid)	GL2 - TP2	SHELL	123.1	10.7	SM - SC
—·—·—· (dash-dot)	GL2 - TP4	SHELL	118.5	13.2	SM - SC
— — — (dashed)	GL2 - TP5	FOUND	121.8	11.0	SM - SC

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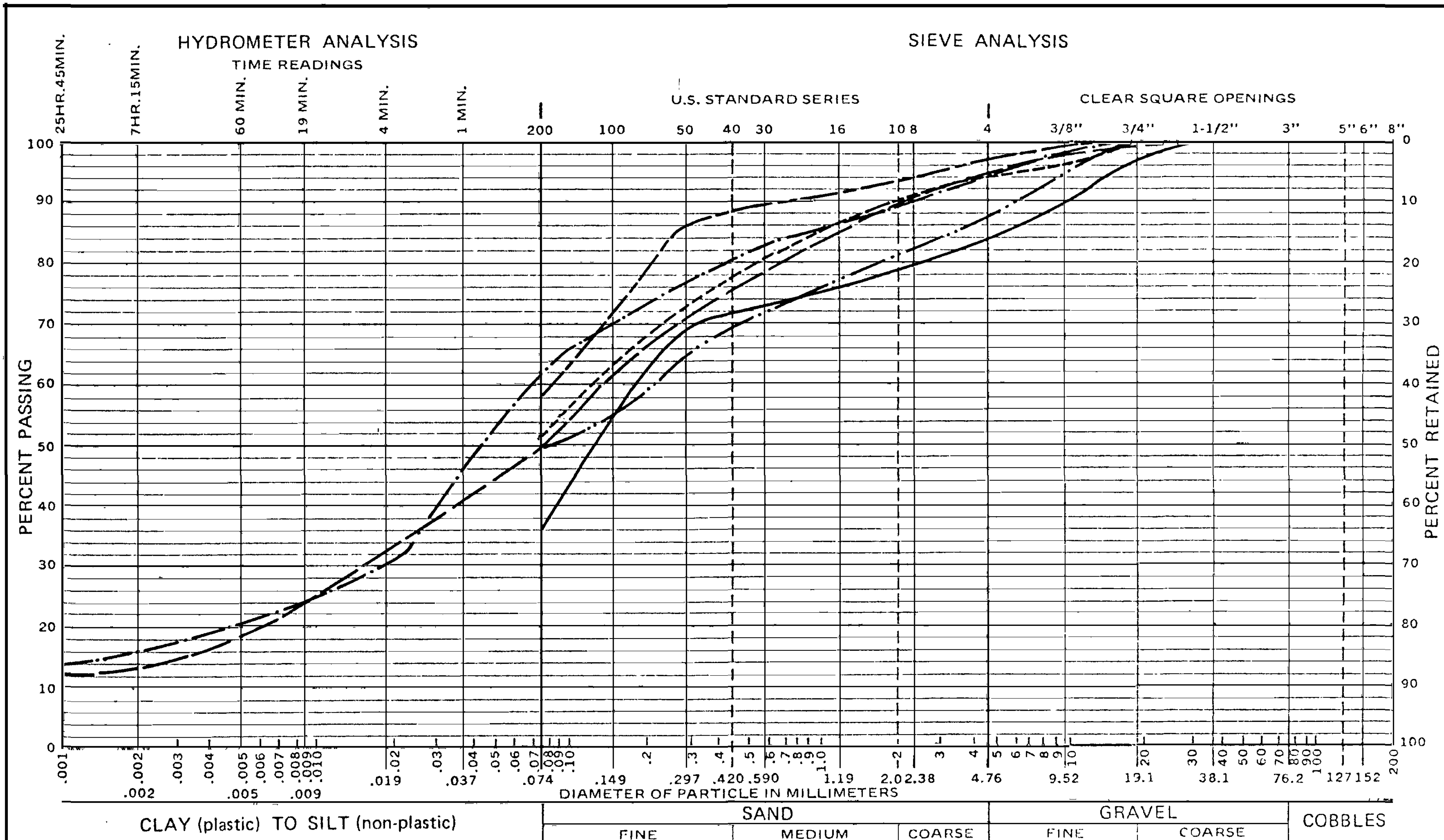
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
GREEN'S LAKE NO. 2

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May '82	D118	D-3



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
	GL3 - TP1	SHELL	123.7	9.9	ML
	GL3 - TP2	FOUND	122.8	9.7	SM with gravel.
	GL3 - TP3	FOUND	125.7	10.6	SM - ML
	GL3 - TP4	SHELL	126.0	11.6	SM - ML
	GL3 - TP5	SHELL	123.2	10.9	SM - ML
	GL3 - TP1	SHELL	—Sand cone test No. 11—		ML

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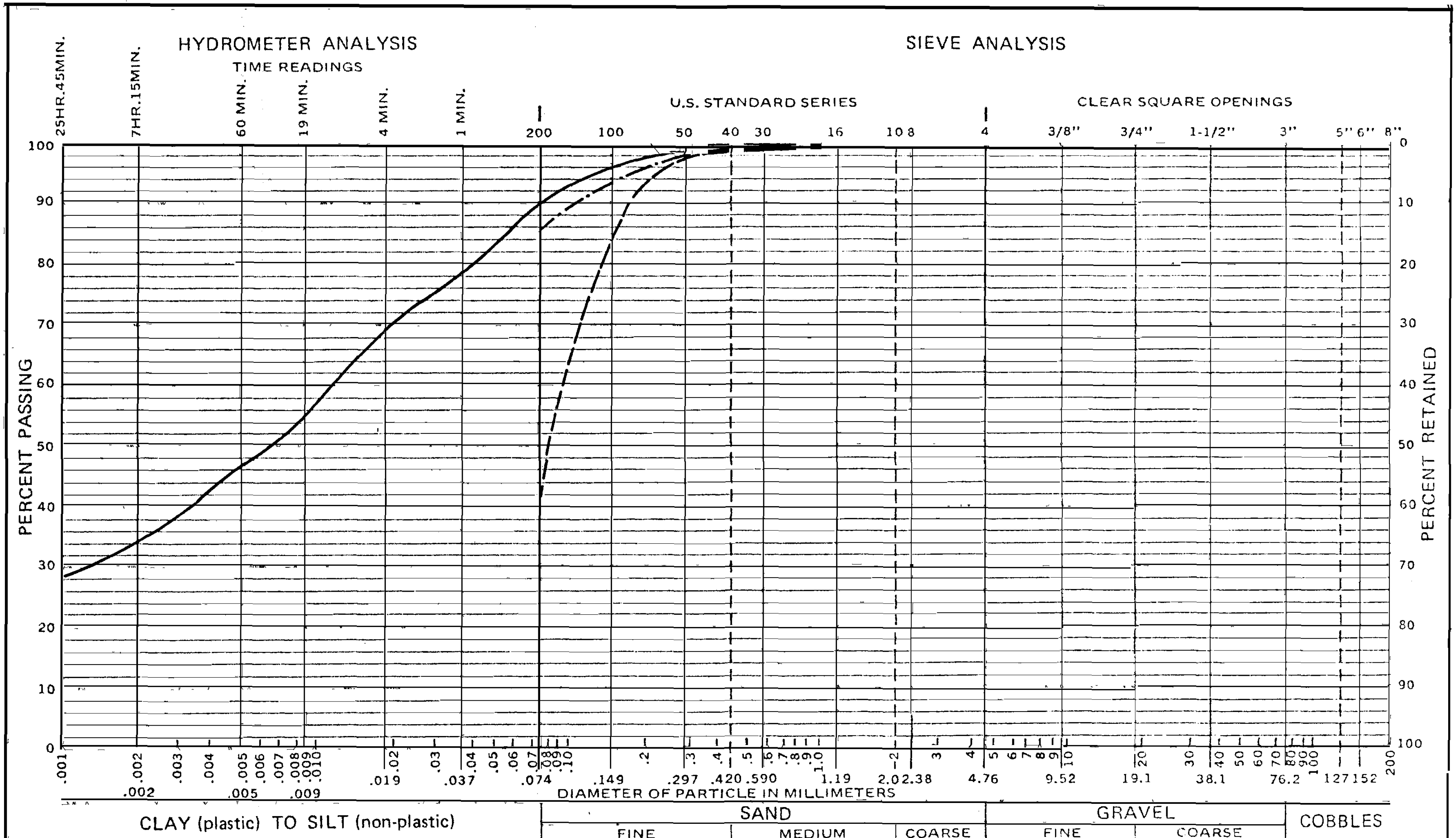
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
GREEN'S LAKE NO. 3

Checked by MLT Date 5/27/82
Approved by EA Nelson Date 27 MAY 82

Project No. D118

Figure No. D-4



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
———— (solid)	GL5 - TP1	SHELL	113.0	13.5	CL
— — — — (dashed)	GL5 - TP2	FOUND	119.1	11.0	SM - SC
—·—·— (dash-dot)	GL5 - TP3	FOUND	111.6	15.5	CL - ML

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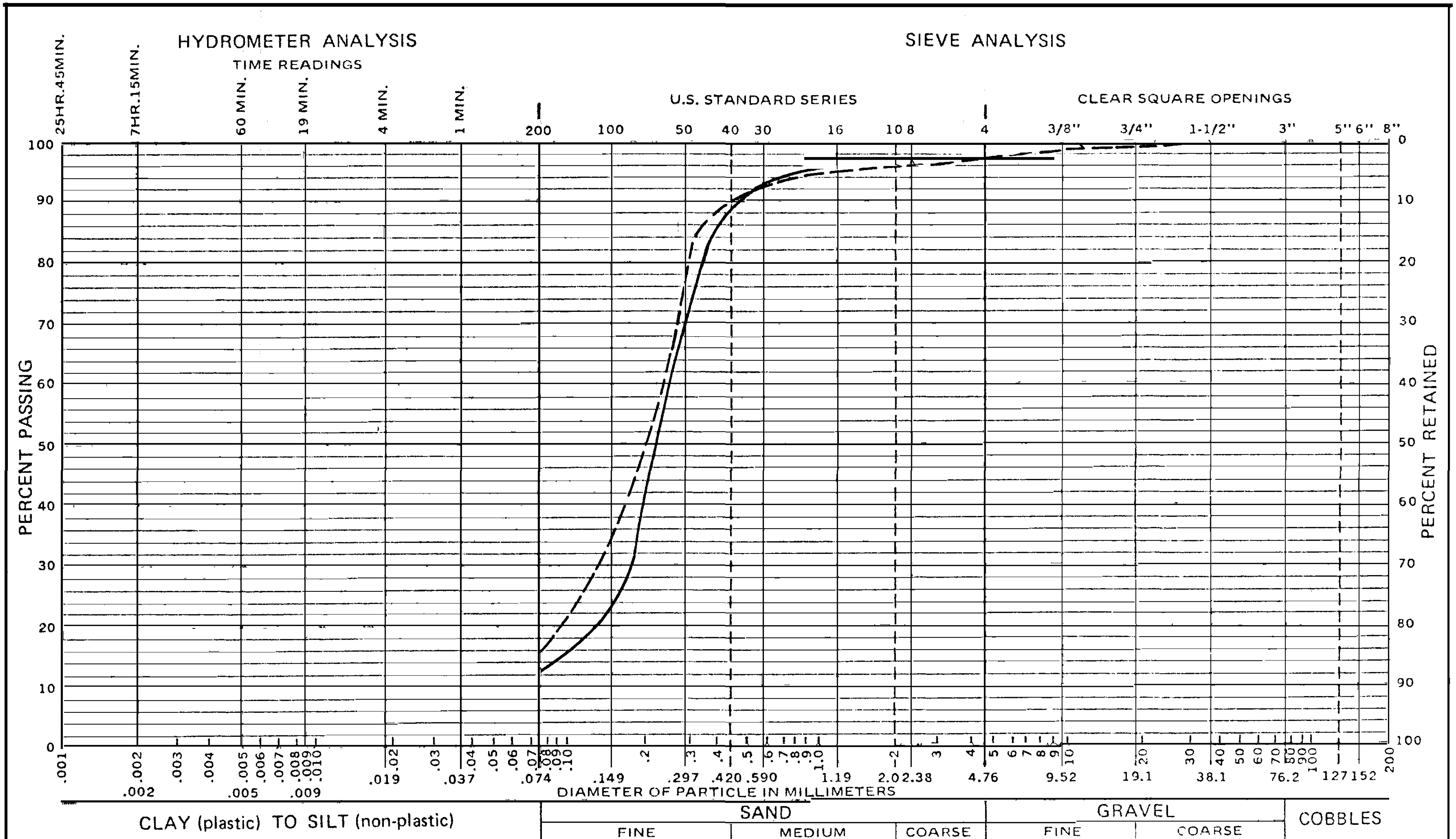
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
GREEN'S LAKE NO. 5

Checked by MLT Date 5/27/82 | Project No. D118 | Figure No. D-5
Approved by EA Nelson Date 27 May 82



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
———————	WD - TP1	SHELL	117.8	7.0	SM
— — — — — —	WD - TP3	FOUND	119.8	9.0	SM

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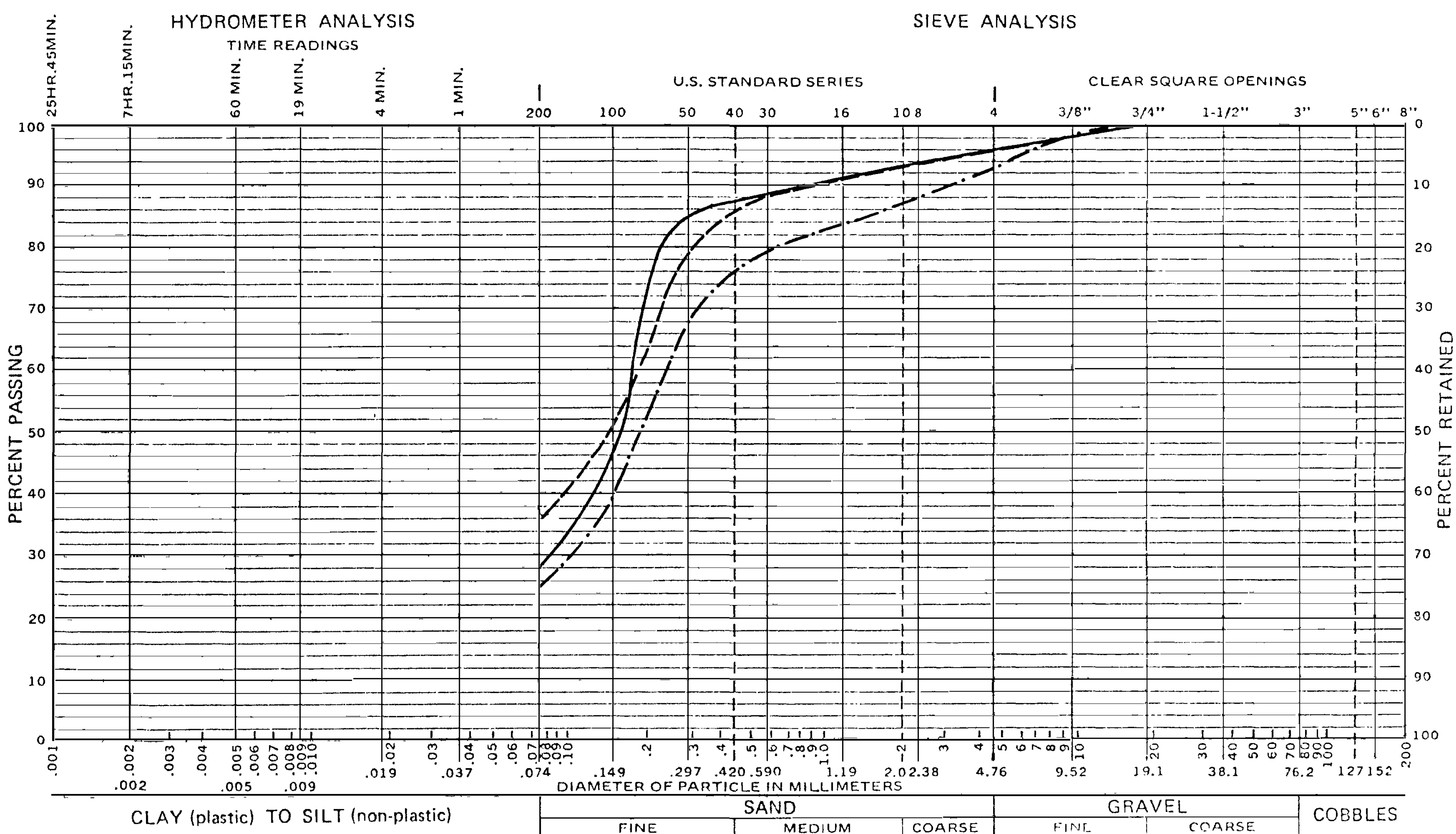
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
WARNER DRAW DAM

Checked by MLT Date 5/27/82
Approved by EA Wilson Date 27 MAY 82

Project No. D118
Figure No. D-6



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
————————	STK - TP1	SHELL	123.6	9.4	SM
— — — — — —	STK - TP3	SHELL	127.7	9.7	SM
—·—·—·—	STK - TP4	FOUND	123.5	10.8	SM

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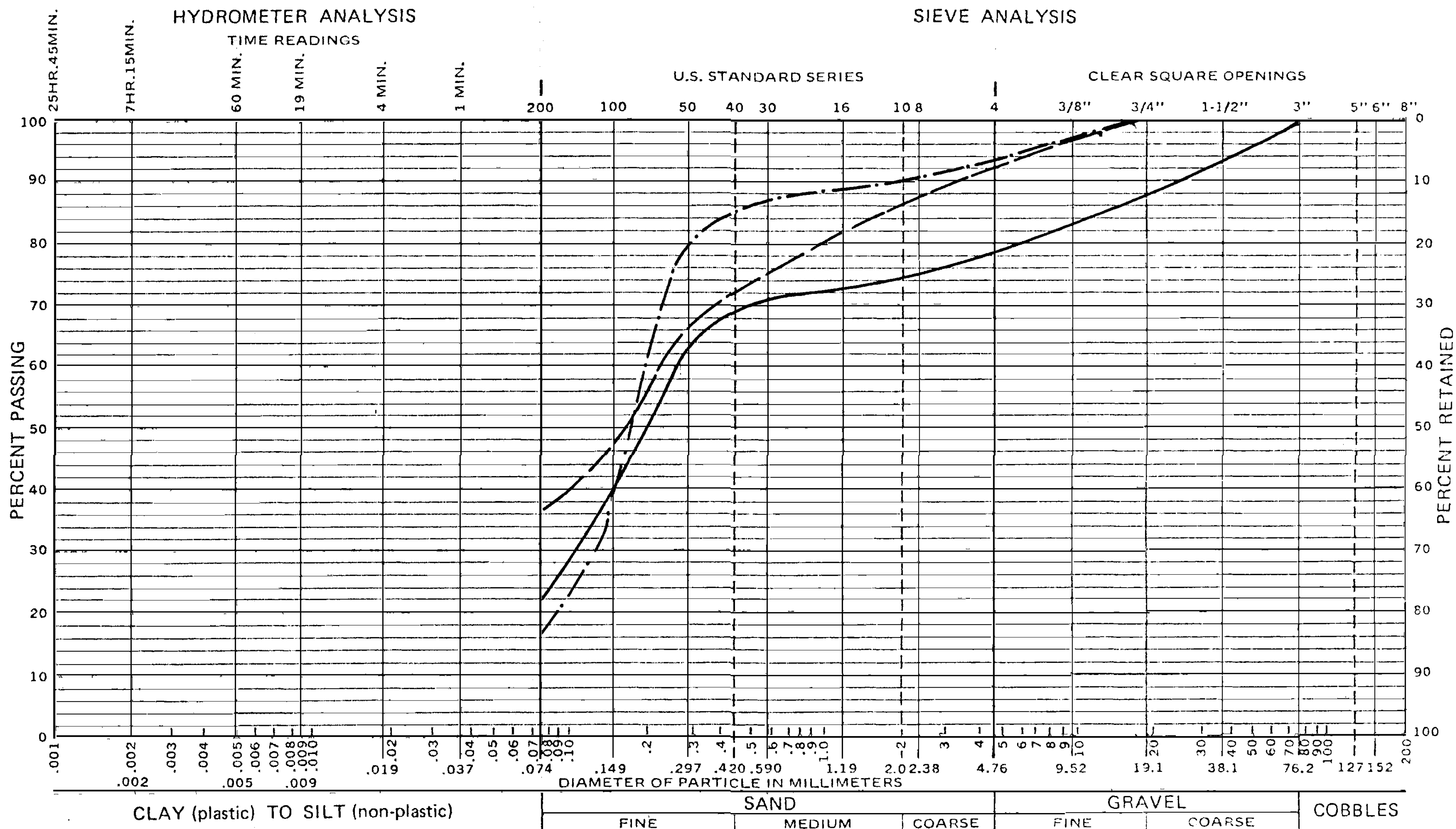
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
STUCKI DAM

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. D-7
Approved by EA Nelson	Dated 27 MAY 82		



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
———————	GW - TP2	FOUND	125.6	10.1	SM w/gravel
— — — —	GW - TP3	SHELL	122.0	11.0	SM
—·—·—·—	GW - TP4	FOUND	120.4	7.3	SM

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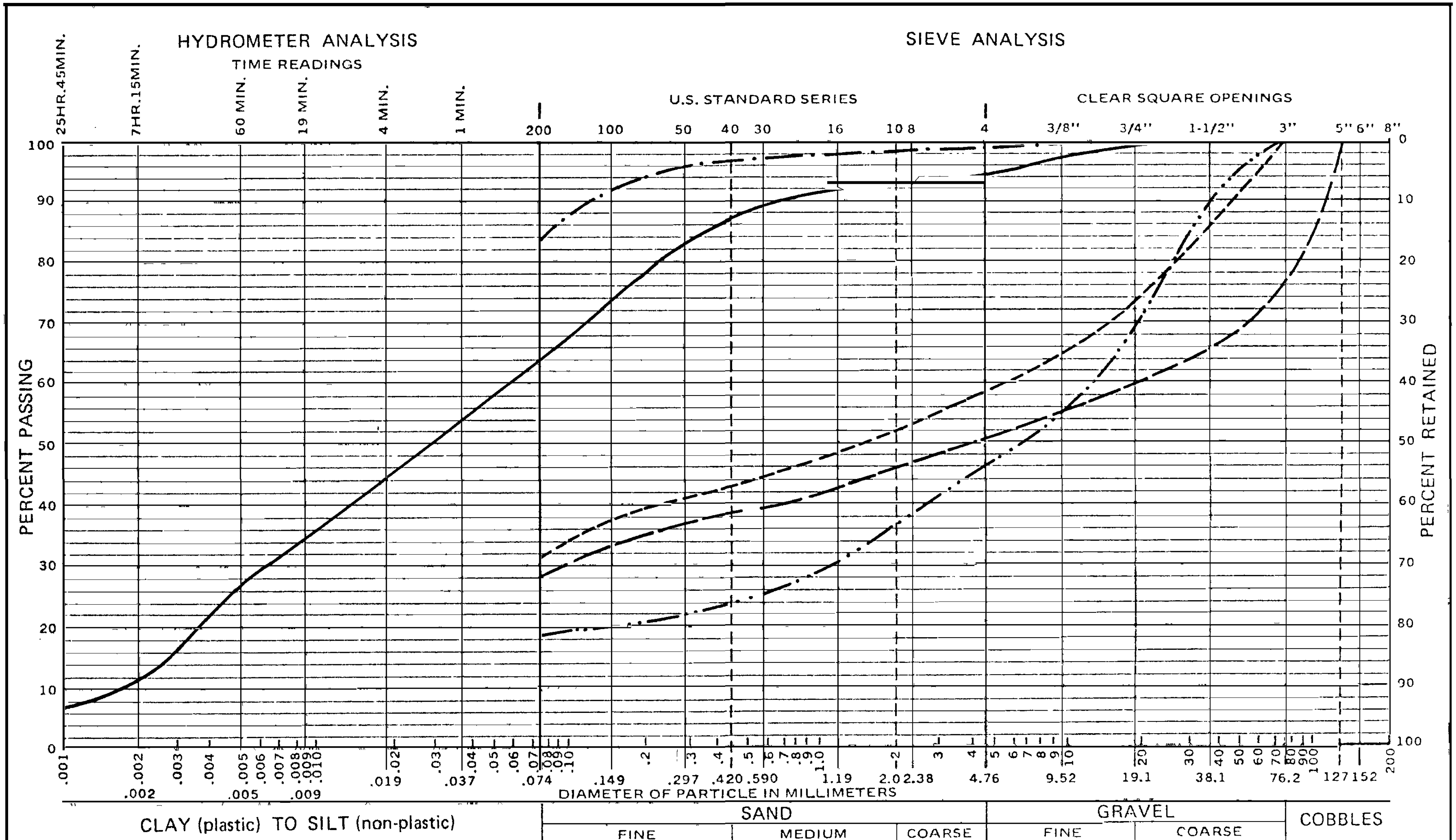
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
GYPSUM WASH DAM

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY 82	D118	D-8



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
	FH - TP1	SHELL (I)	117.4	13.5	CL - ML
	FH - TP2	SHELL (II)	116.2	15.4	GC - GM
	FH - TP3	FOUND	112.1	16.2	ML - CL
	FH - TP2	SHELL (II)	—Sand cone test No. 7,12—		GC - GM
	FH - TP2	SHELL (II)	—Sand cone test No. 9,10—		GC - GM

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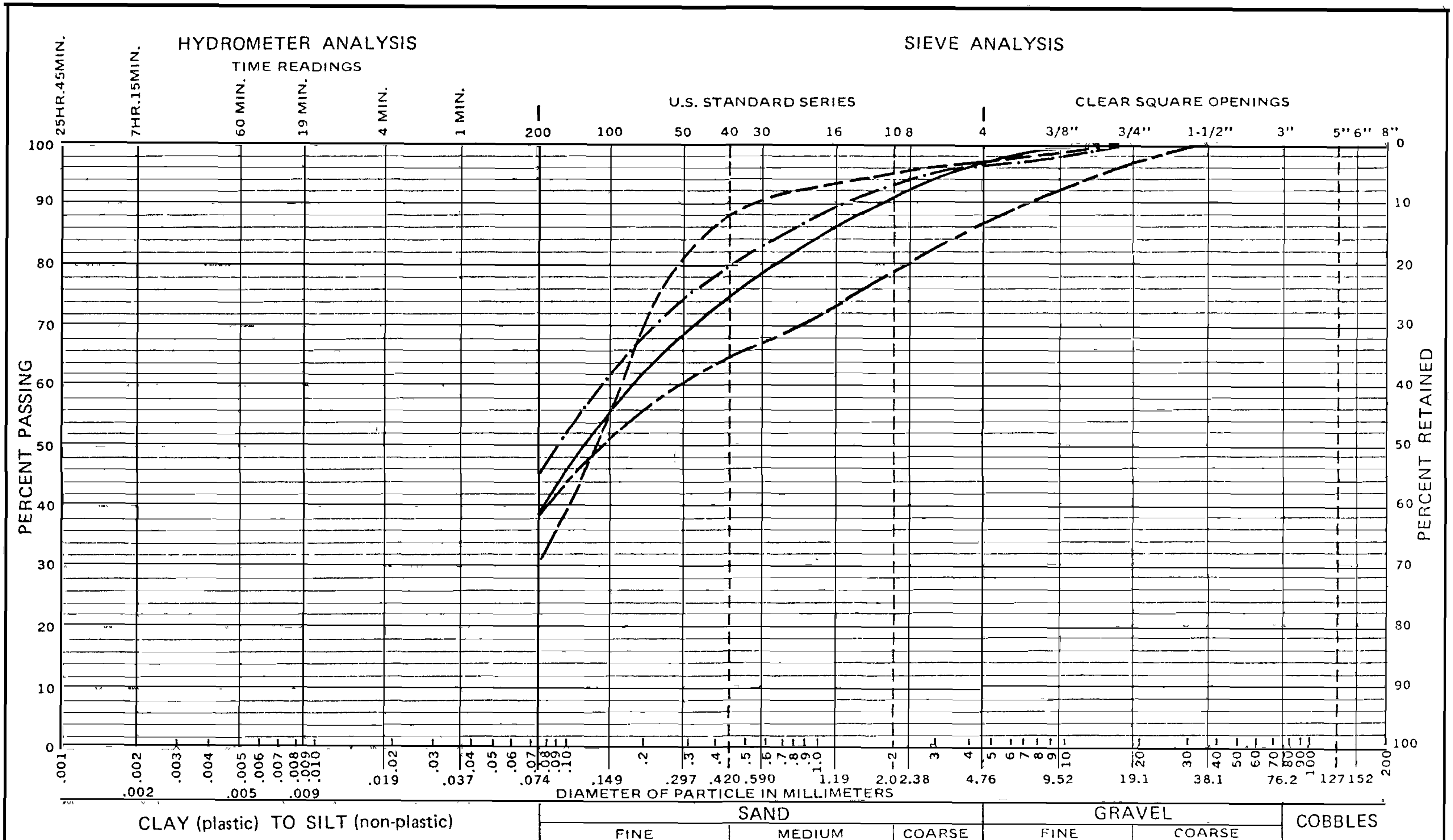
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
FROG HOLLOW DAM

Checked by MLT Date 5/27/82
Approved by EA [signature] Date 27 MAY 82

Project No. D118

Figure No. D-9



SYMBOL	TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
————	IV - TP1	FOUND	118.6	13.1	SM
—·—·—	IV - TP2	FOUND	110.6	11.3	SM
— — —	IV - TP4	SHELL	121.5	10.2	SM with gravel.
—— - —— -	IV - TP1	FOUND	–Sand cone test No. 9(2)–		SM

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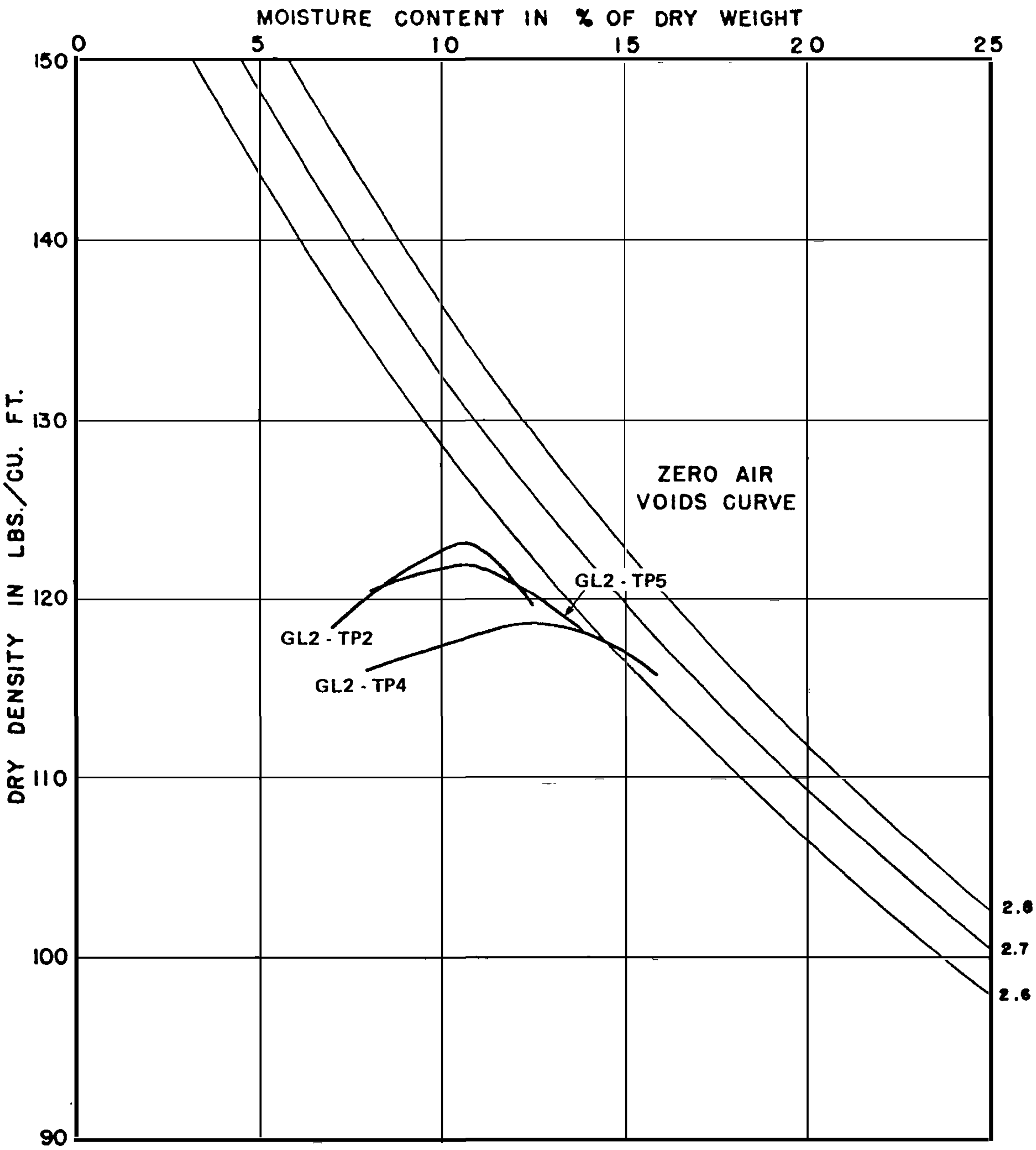
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRAIN SIZE DISTRIBUTION
IVINS DIVERSION DAM NO.5

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. D-10
Approved by EA Wilson	Date 27 MAY 82		



TEST PIT	MATERIAL	MAX DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
GL2 - TP2	SHELL	123.1	10.7	SM - SC
GL2 - TP4	SHELL	118.5	13.2	SM - SC
GL2 - TP5	FOUND	121.8	11.0	SM - SC

Test procedure: ASTM D698-70
METHOD C.

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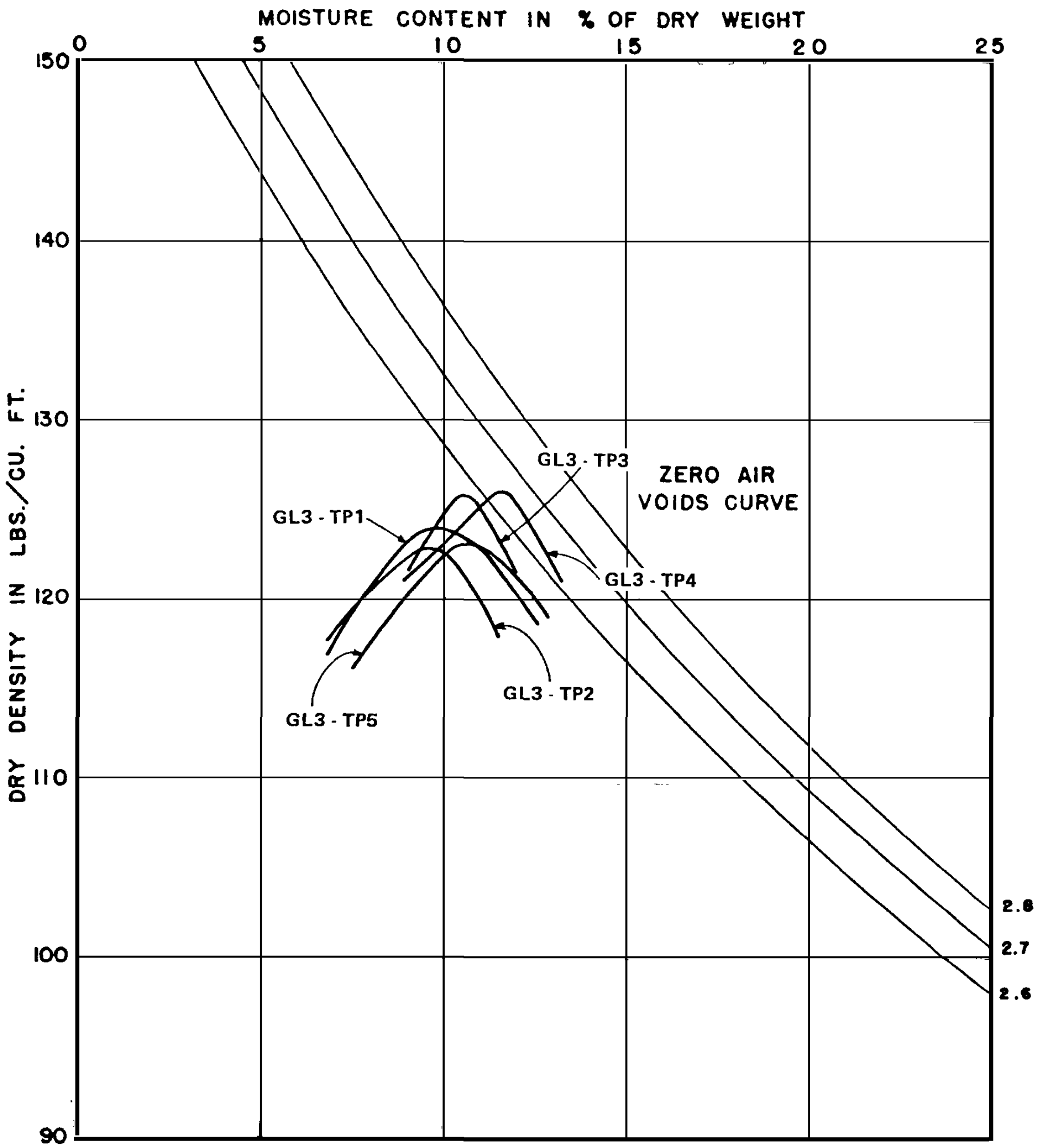
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
GREEN'S LAKE NO. 2

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 May 82	D118	D-11



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
GL3 - TP1	SHELL	123.7	9.9	ML
GL3 - TP2	FOUND	122.8	9.7	SM with gravel.
GL3 - TP3	FOUND	125.7	10.6	SM - ML
GL3 - TP4	SHELL	126.0	11.6	SM - ML
GL3 - TP5	SHELL	123.2	10.9	SM - ML

Test procedure: ASTM D698-70
METHOD C.

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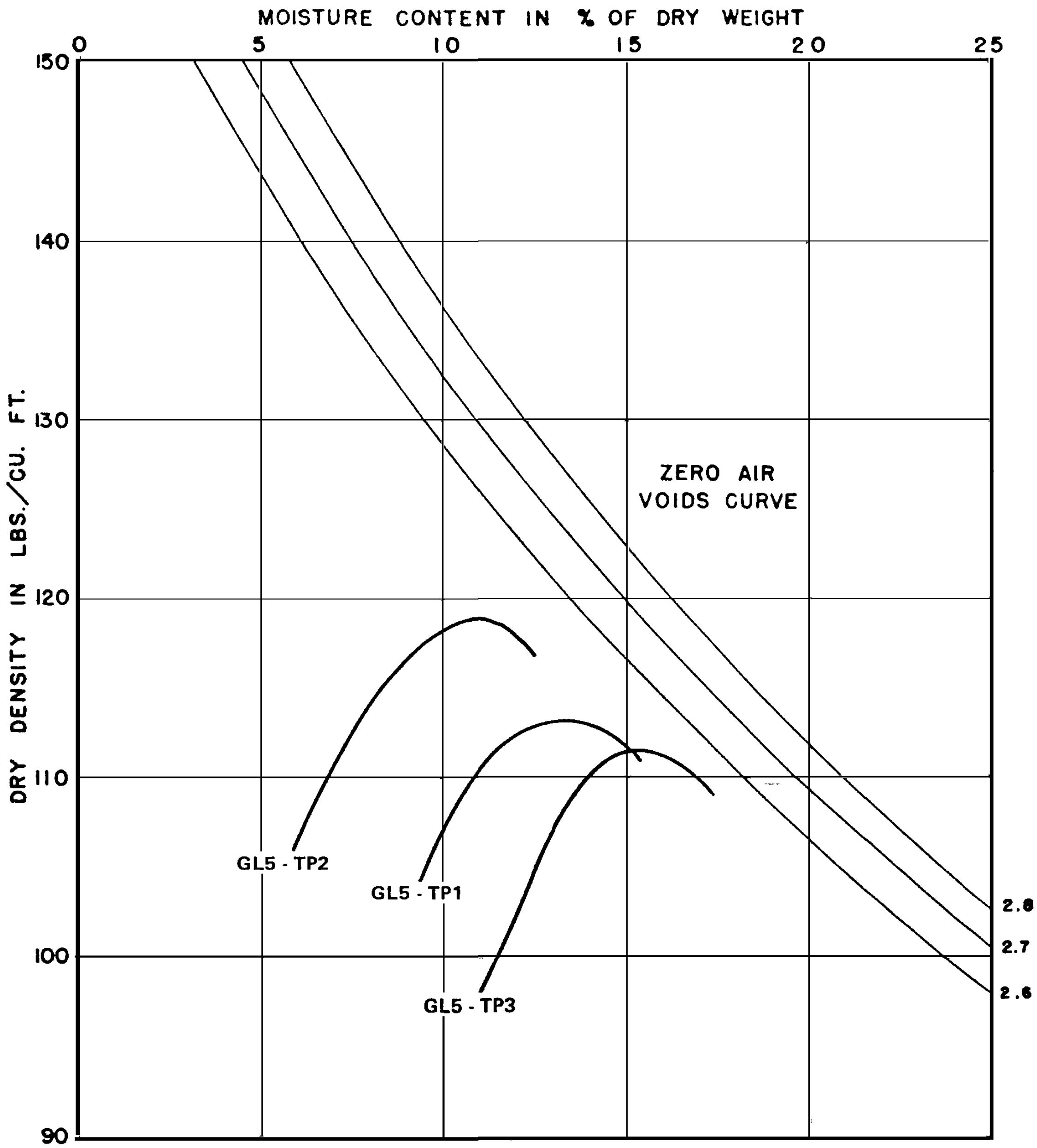
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
GREEN'S LAKE NO. 3

Checked by MLT Date 5/27/82	Project No. D118	Figure No. D-12
Approved by EA Wilson Date 7 May 82		



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
GL5 - TP1	SHELL	113.0	13.5	CL
GL5 - TP2	FOUND	119.1	11.0	SM - SC
GL5 - TP3	FOUND	111.6	15.5	CL - ML

Test procedure: ASTM D698-70
METHOD C.

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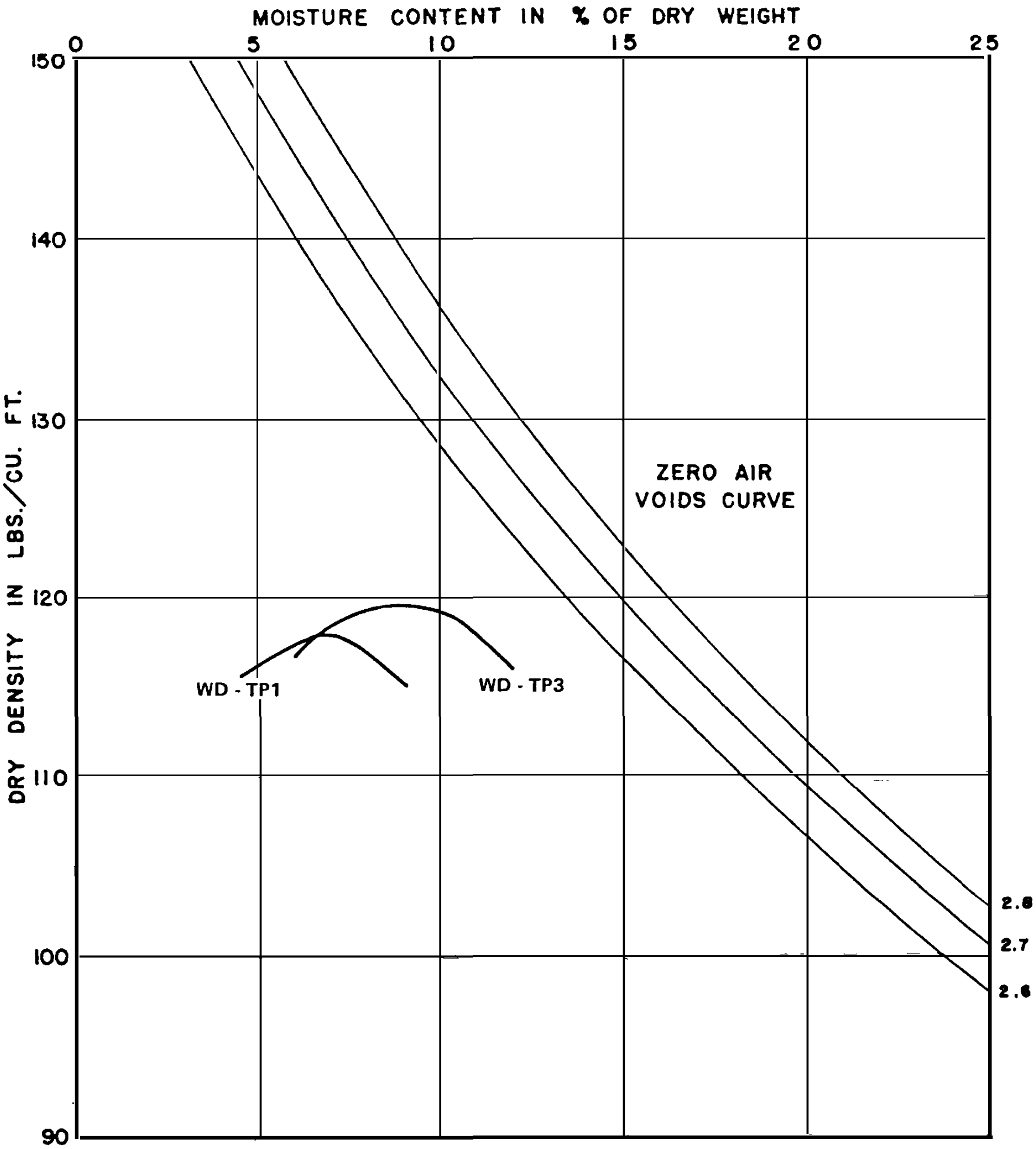
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
GREEN'S LAKE NO. 5

Checked by MGT Date 5/27/82 | Project No. D118 | Figure No. D-13
Approved by [signature] Date 27 MAY 82



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
WD - TP1	SHELL	117.8	7.0	SM
WD - TP3	FOUND	119.8	9.0	SM

Test procedure: ASTM D698-70
METHOD C.

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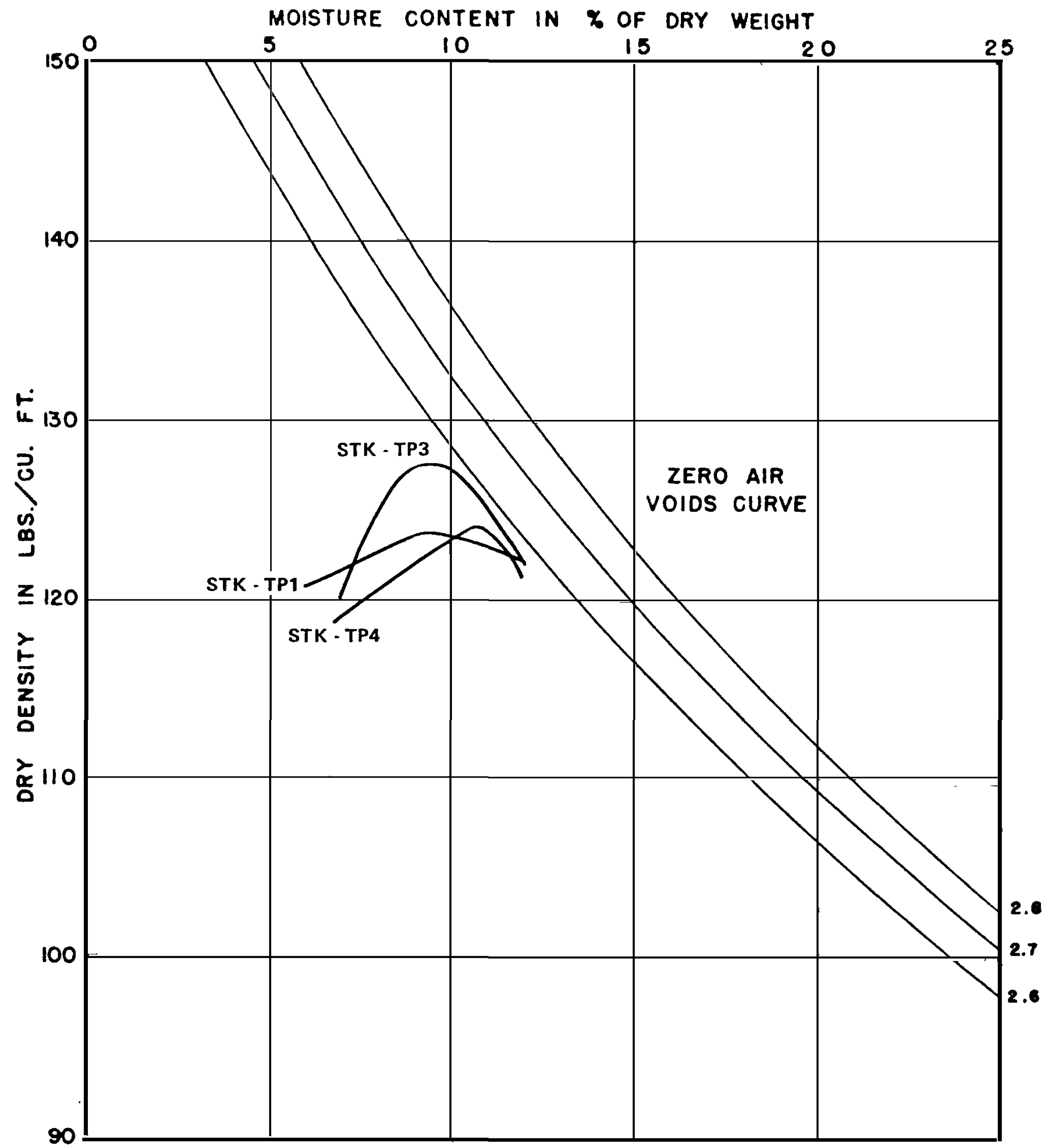
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

MAXIMUM DENSITY CURVES

WARNER DRAW DAM

Checked by MWT	Date 5/27/82	Project No. D118	Figure No. D-14
Approved by EA Wilson	Date 27 May 82		



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
STK - TP1	SHELL	123.6	9.4	SM
STK - TP3	SHELL	127.7	9.7	SM
STK - TP4	FOUND	123.5	10.8	SM

Test procedure: ASTM D698-70
METHOD C.

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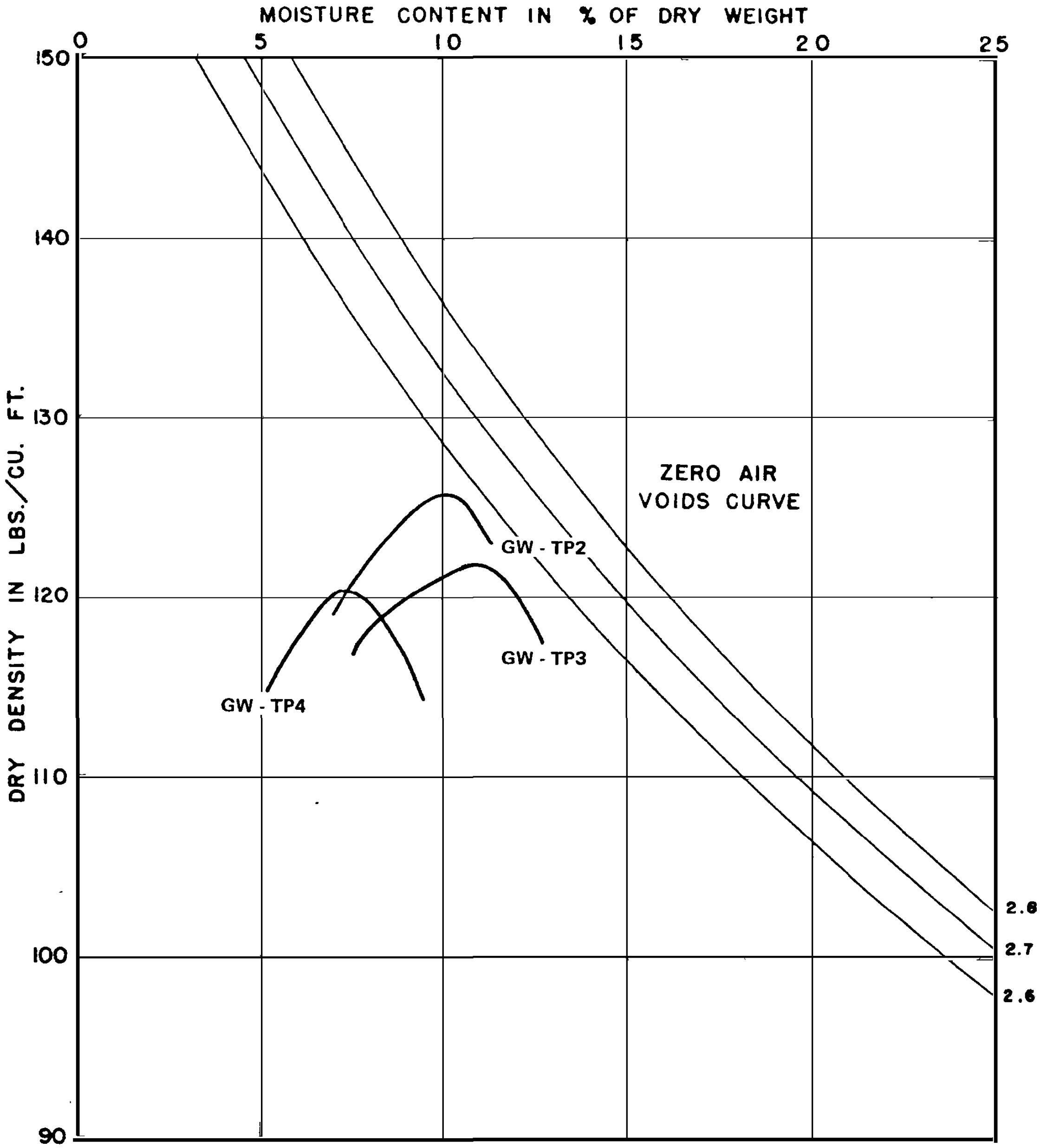
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

MAXIMUM DENSITY CURVES
STUCKI DAM

Checked by MLT	Date 5/27/82	Project No. D118	Figure No. D-15
Approved by EA Wilson	Date 27 MAY 82		



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
GW - TP2	FOUND	125.6	10.1	SM w/gravel
GW - TP3	SHELL	122.0	11.0	SM
GW - TP4	FOUND	120.4	7.3	SM

Test procedure: ASTM D698-70
METHOD C.

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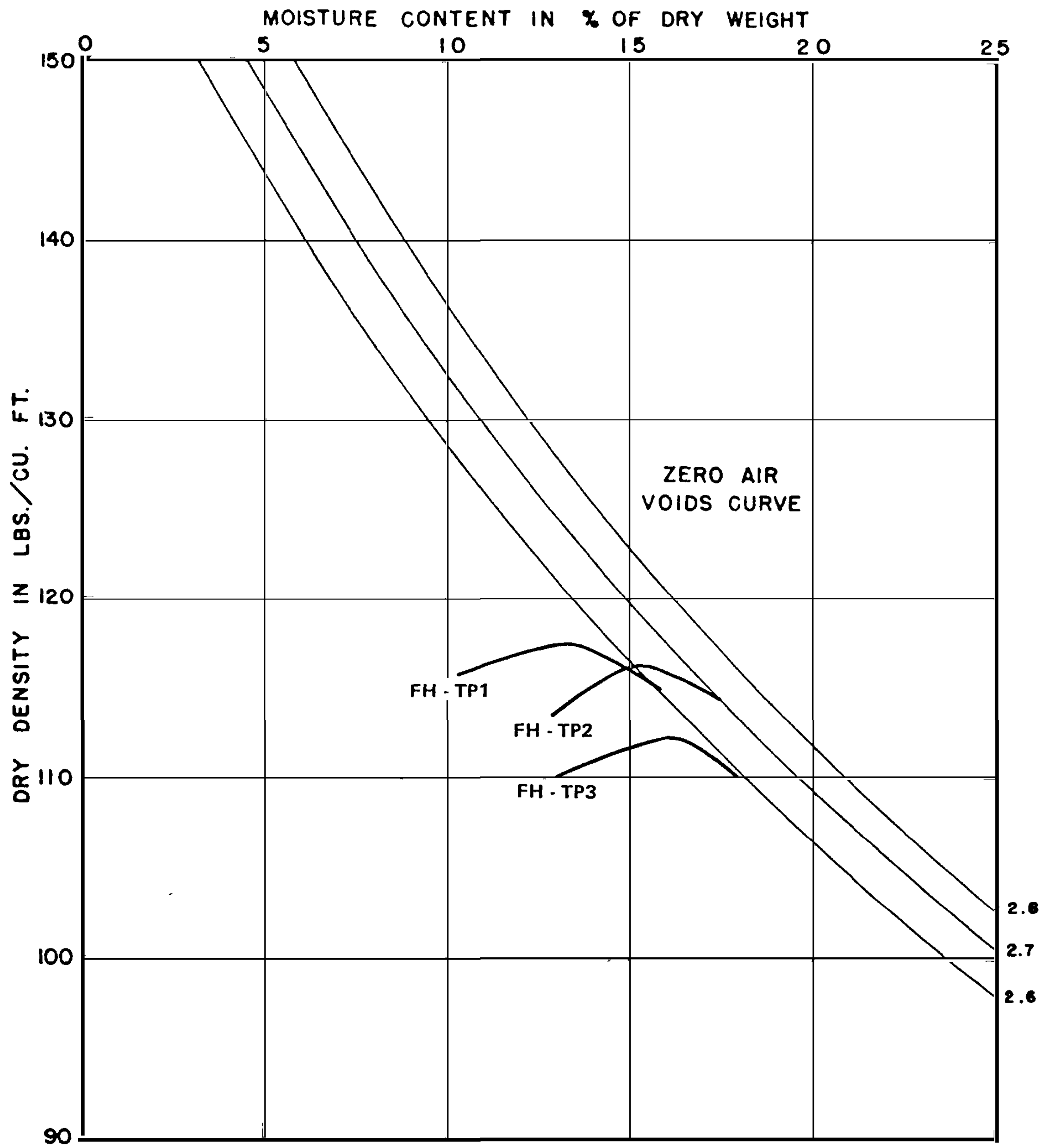
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
GYPSUM WASH DAM

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by RA Wilson Date 27 MAY 82	D118	D-16



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
FH - TP1	SHELL (I)	117.4	13.5	CL - ML
FH - TP2	SHELL (II)	116.2	15.4	GC - GM
FH - TP3	SHELL (II)	112.1	16.2	ML - CL

Test procedure: ASTM D698-70 METHOD C.

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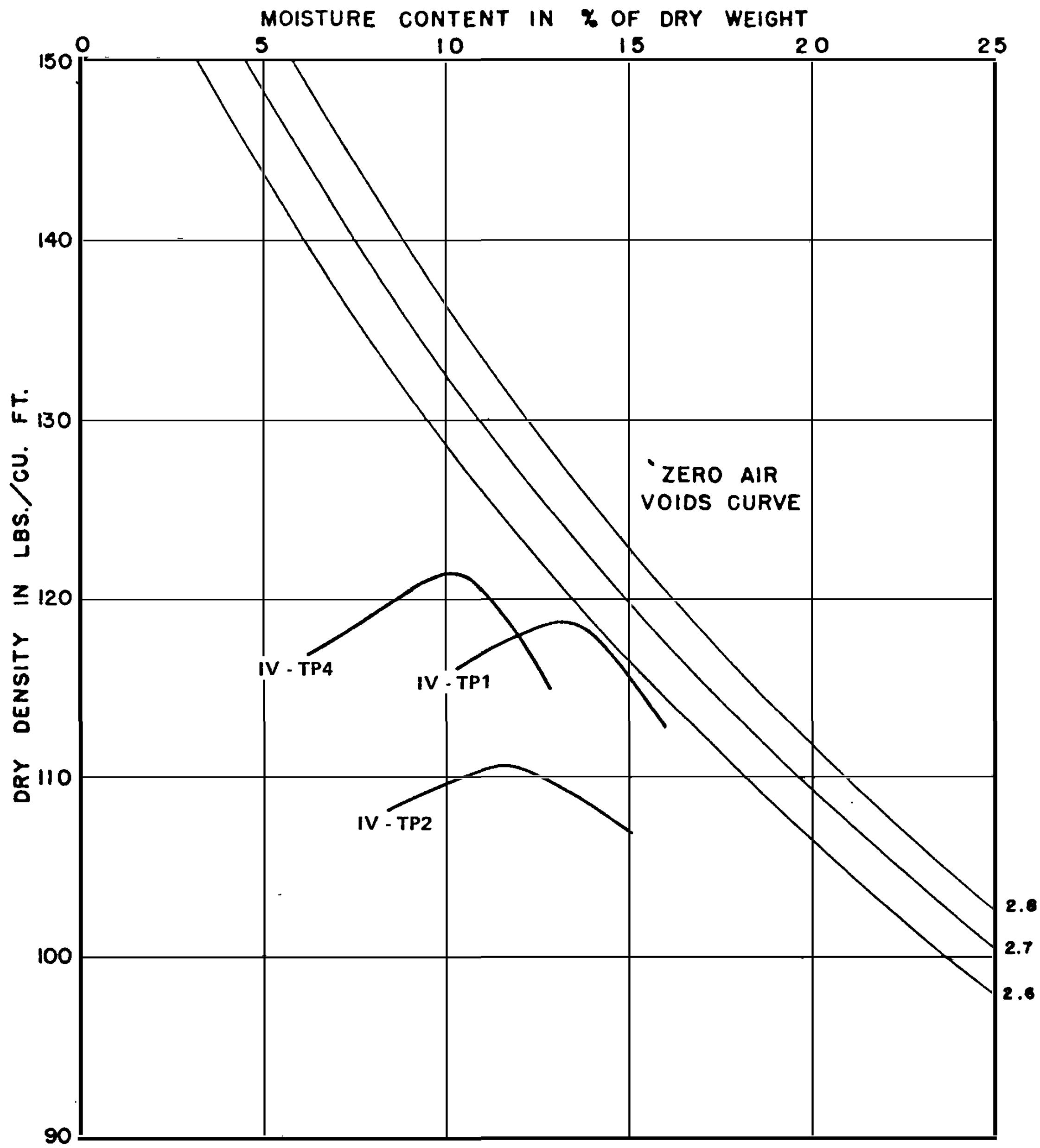
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
FROG HOLLOW DAM

Checked by MDT Date 5/27/82 Approved by [signature] Date 27 MAY 82	Project No. D118	Figure No. D-17



TEST PIT	MATERIAL	MAX. DRY DENSITY (pcf)	OPT. WATER CONTENT (%)	CLASSIFICATION
IV - TP1	FOUND	118.6	13.1	SM
IV - TP2	FOUND	110.6	11.3	SM
IV - TP4	SHELL	121.5	10.2	SM with gravel.

Test procedure: ASTM D698-70 METHOD C.

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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
MAXIMUM DENSITY CURVES
IVINS DIVERSION DAM NO.5

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Wilson	Date 7 MAY 82	D118	D-18

APPENDIX E

REGIONAL GEOLOGY AND TECTONICS

APPENDIX E

REGIONAL GEOLOGY AND TECTONICS

FIGURES

E. REGIONAL GEOLOGY AND TECTONICS

E.1. TECTONIC FRAMEWORK

E.1.1 General Setting

The Cedar City-St. George area, located in the southwestern corner of Utah, lies along the boundary (more properly, within a transition zone) between the Basin and Range and Colorado Plateau physiographic-geologic provinces (fig E-1). The area is in a tectonically active intraplate setting about 400 km northeast of the San Andreas transform fault, which forms the boundary between the Pacific and North American plates (fig.E-1.

The eastern margin of the Great Basin, or northern portion of the Basin and Range province,is well known to be tectonically active. It coincides spatially with a lengthy segment of the Intermountain seismic belt (Smith and Sbar, 1974; Smith, 1978; Arabasz and Smith, 1981)--schematically depicted in figure E-1--a major zone of intraplate seismicity within western North America that follows the boundary between thin weak crust and lithosphere of the eastern Basin and Range province and thicker more stable crust and lithopshere of the Middle Rocky Mountains and the Colorado Plateau. The Intermountain seismic belt is characterized by extensive late Quaternary normal faulting, diffuse shallow seismicity, and episodic scarp-forming earthquakes ($6\frac{1}{2} \leq M \leq 7\frac{1}{2}$) (Arabasz and Smith, 1981).

In considering the tectonic setting of the Cedar City-St. George area along the eastern margin of the Basin and Range province, it should be noted that the area is situated close to an important boundary at roughly lat 37°N that separates the northern, or Great Basin, section of the Basin and Range province from the southern, or Sonoran Desert, section (see fig.E-1). The boundary, whose deep-seated origin is not fully understood, is marked by a change in Bouguer gravity of nearly 100 mgal (Eaton and others, 1978).

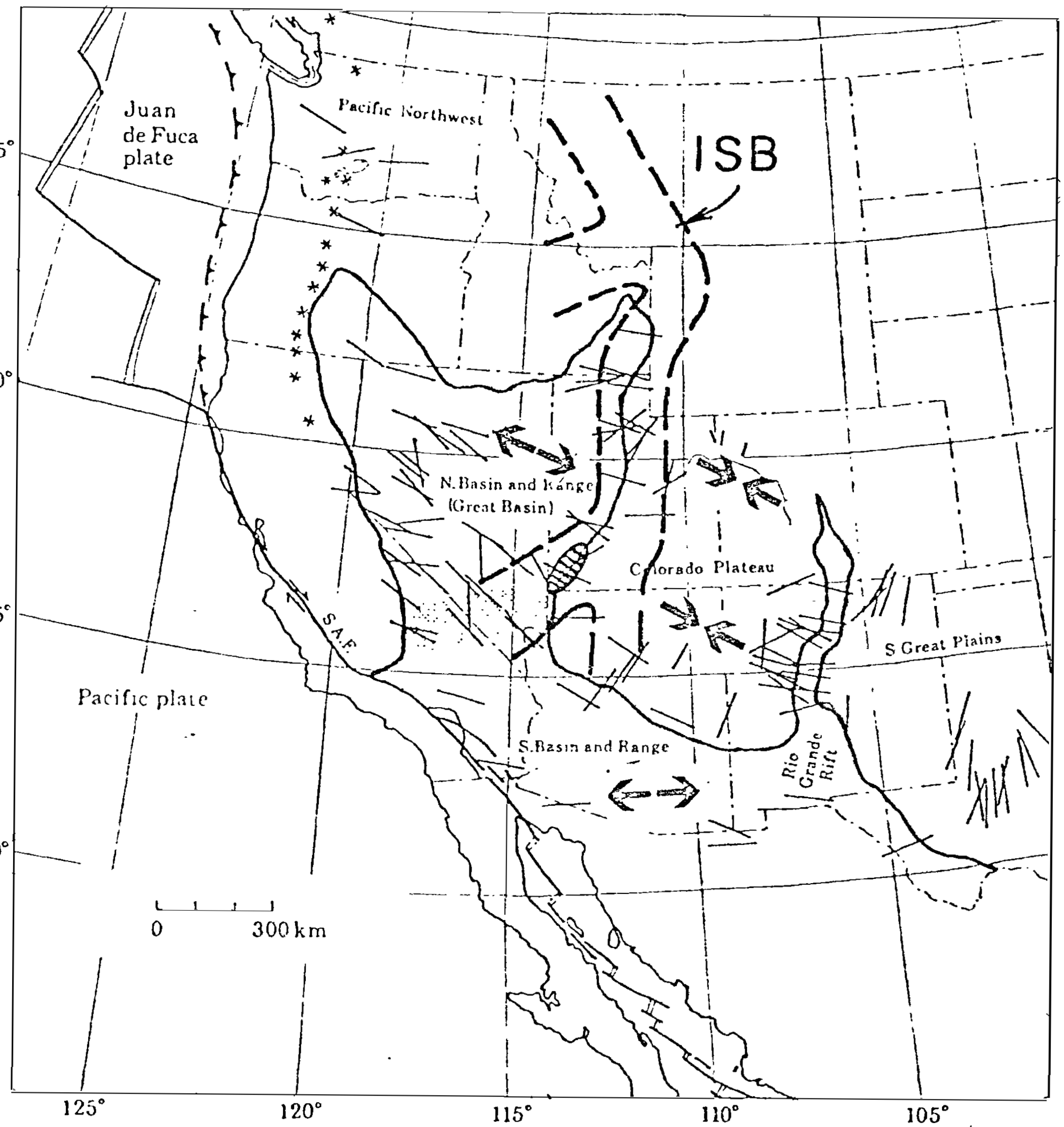


FIGURE E-1-Tectonic sketch map (adapted from Zoback and others, 1981) showing setting of the Cedar City-St. George area (dashed ellipse) in southwestern Utah. Heavy dashed lines outline Intermountain seismic belt, ISB (after Arabasz and Smith, 1981); heavy arrows, generalized stress directions: either least (outward directed) or greatest (inward directed) principal horizontal compression (from Zoback and Zoback, 1980). Shaded region in southern Nevada and Utah marks transitional boundary between northern and southern Basin and Range provinces.

Importantly, the two sections of the Basin and Range province, which are physiographically different, have had significantly different late Cenozoic histories (Eaton and others, 1978; Eaton, 1979; Zoback and others, 1981), a point we return to later.

The Cenozoic history of the Cedar City-St. George area is closely associated with tectonism along the Great Basin-Colorado Plateau boundary. However, proximity of the area to the Great Basin-Sonoran Desert transition must be emphasized. Generalizations applicable to the contemporary seismotectonics of southwestern Utah will not generally be applicable to northwestern Arizona--to the south of the area of interest.

E. 1.2 Tectonic Processes and Crust-Mantle Framework

A host of hypotheses have been proposed to explain the late Cenozoic tectonics of the Basin and Range province, the Colorado Plateau, and the Intermountain West in general. Abundant information has recently been summarized in Memoir 152 of the Geological Society of America (Smith and Eaton, eds., 1978) and in subsequent papers by Thompson and Zoback (1979), Eaton (1979, 1980), Zoback and Zoback (1980), and Zoback and others (1981). Stewart (1978) and Davis (1980) review the chief categories of models that may pertain: (1) oblique intraplate fragmentation caused by differential motion along the North American-Pacific plate boundary; (2) backarc extension and mantle upwelling, typically above a subducting plate; (3) major changes in dip or configuration of a subjacent subducted plate (or plates); (4) subduction of the East Pacific rise; and (5) mantle plumes.

For the present site-specific study, postulated tectonic models become chiefly academic (in the face of continuing debate and on-going evolutionary studies), so we emphasize some fundamental observations. (Appendix J includes a selected bibliography relevant to the "big picture" tectonics of western North America). Later, however, we describe aspects of some tectonic models for which there seems to be good academic agreement, and which provide a useful conceptual framework for discussion. Ultimately, the record of late Quaternary faulting and observed seismicity--discussed in Appendix F--provide the basis for evaluating contemporary tectonics within a time frame of engineering relevance.

The eastern margin of the Great Basin has been interpreted to define a subplate boundary between the Great Basin and the Colorado Plateau-Middle Rocky Mountains (e.g., Smith, 1978); in any case, it clearly is a locus of tectonic instability reflected, in part, by thin crust (~25 km, see fig. E-2a), anomalous upper mantle ($7.4 \leq P_n \leq 7.9$ km/sec), high heat flow (>120 mW/m^2; 1 HFU = 41.9 mW/m^2), high regional elevation (>1,500 m), and a crustal low-velocity layer in the 5-15 km depth interval (see fig. E-2b) (Smith, 1978; Eaton and others, 1978; Blackwell, 1978).

Figure E-2c illustrates the anomalous nature of crust-upper mantle structure along the eastern Great Basin; it also depicts transitional change from the Basin and Range province to the Colorado Plateau. The boundary between the Basin and Range province and the Colorado Plateau province in central and southwest Utah is well known to be a transitional one--not only physiographically (e.g., Stokes, 1977), but also in terms of surficial geology (Burchfiel and Hickcox, 1972; Anderson and Mehnert, 1979), crustal velocity structure (Smith and others, 1975), heat flow (Bodell and Chapman, 1982), lithospheric thickness (Thompson and Zoback, 1979), and other geophysical parameters (see reviews by Thompson and Zoback, 1979; Smith, 1978; Keller and others, 1979). Typically, the geophysical parameters tend to

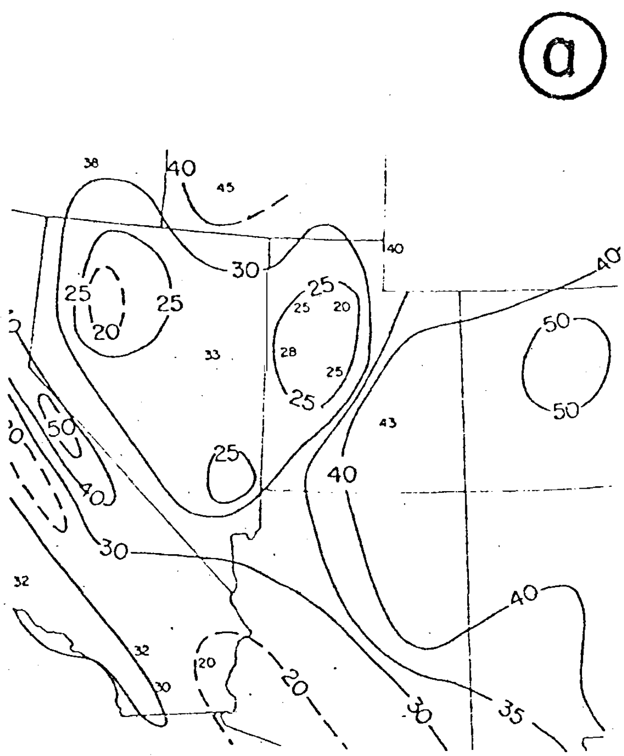


FIGURE E-2a-Crustal thickness (km)
(from Smith, 1978)

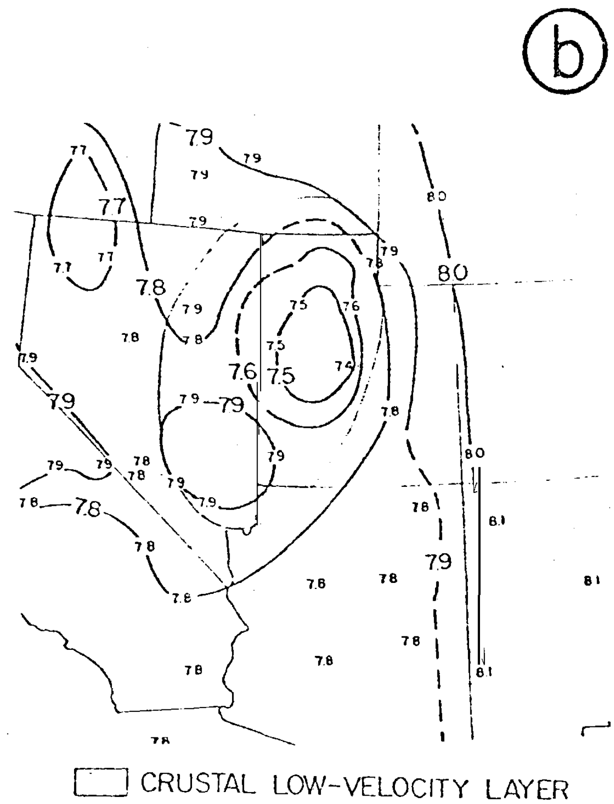


FIGURE E-2b--P_n velocities (km/sec)
(from Smith, 1978)

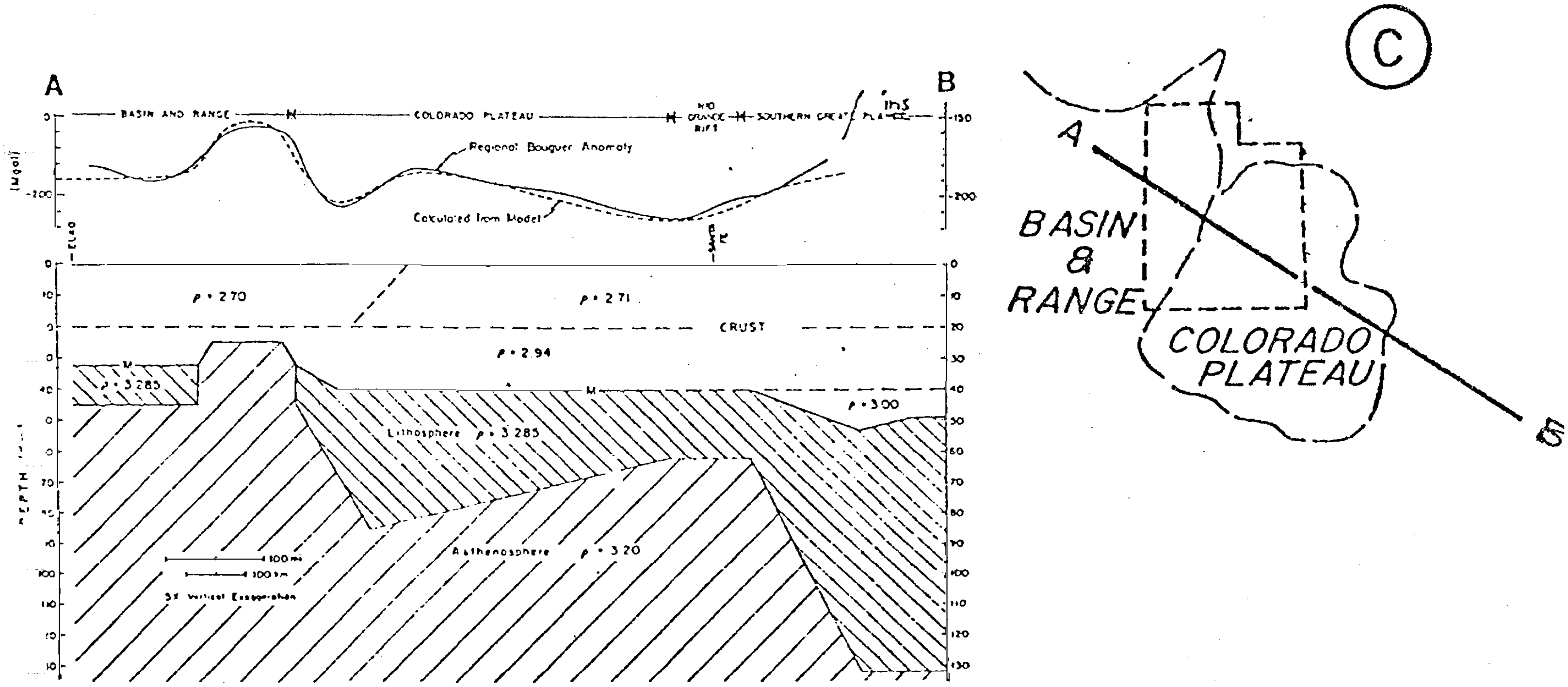


FIGURE E-2c-Crust-upper mantle structure along NW-SE profile that crosses Basin and Range-Colorado Plateau transition (see location map on right) (from Thompson and Zoback, 1979).

have transitional values that extend several tens of kilometers east of the classical physiographic boundary between the two provinces.

In the Cedar City-St. George area, crustal thickness is ~30 km and subcrustal P_n velocity is ~7.9 km/sec (fig. E-2a, b). Smith and others (1975) and Smith (1978) summarize evidence for anomalous teleseismic P-wave residuals in southwestern Utah (see also Anderson, 1978, p. 3), supportive of relatively thin crust and anomalous upper mantle. It should be emphasized that the observed P-wave anomalies were not unique to southwest Utah--because of limited spatial sampling--but rather they would presumably typify a more extensive belt along the eastern Great Basin margin.

Contemporary stress is predominantly extensional in a WNW-ESE direction along the eastern Great Basin (fig. E-1), but there are spatially rapid changes in stress orientation in local areas, and there is a notable change to a compressional stress regime (with roughly a WNW-ESE maximum principal horizontal stress direction) within the interior of the Colorado Plateau (Zoback and Zoback, 1980). The source of the observed stress field in the Intermountain West is not completely understood, but it likely involves contributions both from differential motion along the San Andreas margin and sublithospheric tractions (Zoback and Zoback, 1980; Thompson and Zoback, 1979; Smith, 1978).

Residual effects of early Cenozoic subduction along the western margin of the North American plate are thought to be of great importance to understanding the stress and thermal fields (and hence the contemporary tectonics) of the Intermountain West (Thompson and Zoback, 1979; Zoback and Zoback, 1980; Bodell and Chapman, 1982). Bodell and Chapman (1982), for example, discuss how transitional changes in observed heat flow across the Basin and Range-

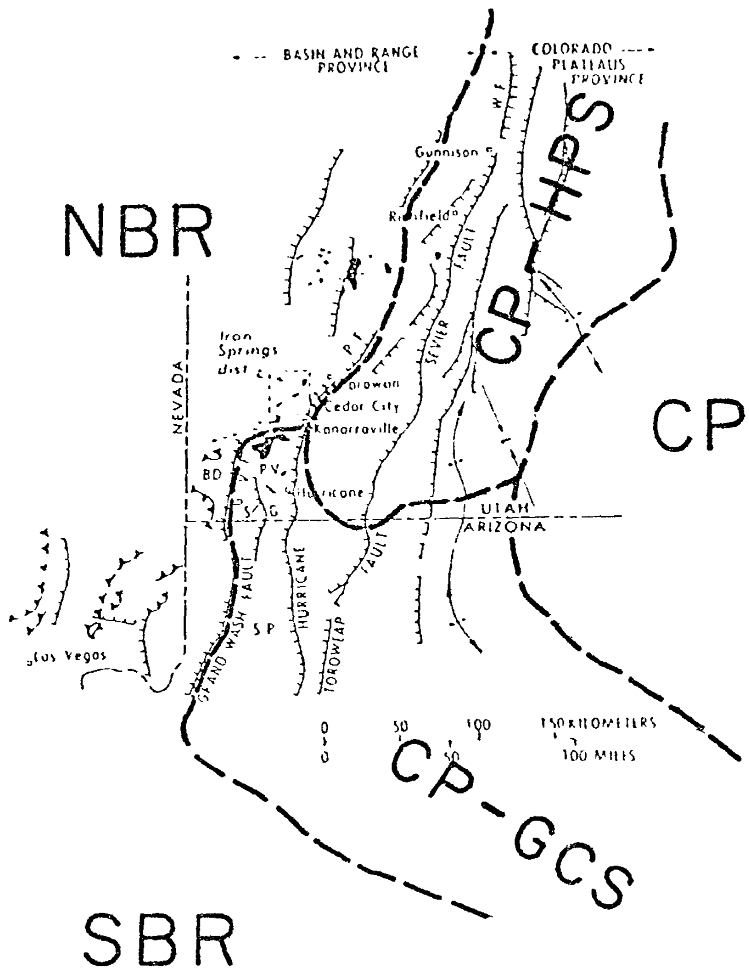
Colorado Plateau boundary (ranging from >100 mW/m^2 in the eastern Great Basin to >50 mW/m^2 within the interior of the Colorado Plateau) may be a significant clue to understanding the late Cenozoic tectonics along the province boundary. Their thermal modeling suggests that lateral warming and weakening of the Colorado Plateau lithosphere began at the Basin and Range boundary some 20 m.y. ago. Lithospheric thinning under the Plateau would have quickly resulted in surface uplift, but corresponding surface heat flux would predictably lag in time by as much as 15-20 m.y.--in agreement with current observations (Bodell and Chapman, 1982). Long-continued thermal weakening apparently had earlier resulted in anomalously thin crust and lithosphere beneath the Basin and Range province as seen in figure E-2d (see Eaton, 1979).

To adequately describe the active tectonic processes in southwest Utah, we need to consider the complicated Cenozoic history of the region, as well as its contemporary seismotectonics, seismic flux, and strain rate--all of which are elaborated in later sections. From what we have seen so far, we can anticipate that (1) because of its intraplate setting, southwest Utah will expectedly be associated with lower rates of secular deformation than along the San Andreas plate margin, (2) crustal extension and thermal processes will have a fundamental influence on earthquake generation, and (3) normal faulting associated with deformation of the Great Basin-Colorado Plateau boundary will be of primary importance.

E.1.3 Tectonic Provinces

In figure E-3, tectonic provinces are outlined in the region surrounding the Cedar City-St. George area. This figure and the following brief descriptions are intended to place the study area in regional perspective on a scale of a few hundreds of kilometers. Various workers differ in their delineation of some of the province boundaries, or perhaps in their outline of subprovinces--depending upon their emphasis of physiography, geologic structure, or geophysical attributes (see Eaton, 1979). We have attempted to follow well-established usage, allowing for updating by more recent geological work. Also, we portray and depict two transitional regions that do not have precisely determined boundaries, but whose general location has important tectonophysical implications. The tectonic provinces outlined in figure E-3 are chiefly based on geological structure and physiography. They are not uniform seismogenic zones; we discuss such zones separately in Appendix F.

E.1.3.1 Northern Basin and Range (Great Basin) Province (NBR). The northern Basin and Range province encompasses a broad region of Nevada and western Utah characterized by basin-range physiography--i.e., elongate ranges with a length-to-width radio of ∿4-8 and crest-to-crest spacing of ∿25-35 km, separated by basins filled with Tertiary-Quaternary fluvial-lacustrine sediments (Zoback and others, 1981). Mention has already been made of separation of the Basin and Range province into northern and southern sections. The northern or Great Basin section stands mostly above about 1,500 m (5,000 ft), is marked by interior drainage, and has predominant NNE-trending physiography that has chiefly developed within the past 10 m.y. (Eaton 1979; Zoback and others, 1981). Basin-range structure, which has led to the development of



TECTONIC PROVINCES AND SUBPROVINCES

NBR	Northern Basin and Range (Great Basin) Province
SBR	Southern Basin and Range (Sonoran Desert) Province
CP	Colorado Plateau Province
CP-HPS	High Plateaus Section of the Colorado Plateau Province
CP-GCS	Grand Canyon Section of the Colorado Plateau Province
	Basin and Range-Colorado Plateau Transition*
	Great Basin-Sonoran Desert Transition*

*not shown on this figure

FIGURE E-3.

normal-fault-controlled alluviated basins and mountain blocks by crustal extension, "is commonly inferred to represent either (1) blocks tilted along downward-flattening (listric) faults in which the upslope part of an individual rotated block forms a mountain and the downslope part a valley or (2) alternating downdropped blocks (grabens) that form valleys and relatively upthrown blocks (horsts) that form mountains" (Stewart, 1978, p. 1).

E.1.3.2. Southern Basin and Range (Sonoran Desert) Province (SBR). In contrast to the Great Basin, the Sonoran Desert section of the Basin and Range province lies mostly below about 900 m (3,000 ft) and has a general NW-trending physiography that developed by block faulting, chiefly in the period 13-10 m.y. ago (Zoback and others, 1981; Eaton, 1979). Earlier timing (and a different stress field) for the development of basin-range structure in the southern Basin and Range province, compared to that in the Great Basin section, accounts for its present low elevation, extensively eroded ranges with broad range-bounding pediments, paucity of active faulting, and relatively low seismicity (Eaton, 1979; Zoback and others, 1981).

E.1.3.3 Colorado Plateau Province (CP). The Colorado Plateau, sometimes referred to as the Colorado Plateaus province, defines a crudely circular region covering adjoining regions of Utah, Arizona, New Mexico, and Colorado. The province coincides with a relatively coherent block surrounded on three sides by the extensional regimes of the Basin and Range province and the Rio Grande rift (see fig. E-1) that has experienced nearly two kilometers of vertical uplift during the last 20 m.y. while remaining relatively undeformed (Thompson and Zoback, 1979; Hunt, 1956). Cenozoic uplift of the Plateau is generally ascribed to upper-mantle thermal processes (see McGetchin, 1979; Bodell and Chapman, 1982). The interior of the Colorado Plateau is characterized by a 40 km-thick crust, a P_n velocity of about 7.85 km/sec, a compressive stress field, and an average elevation of about 1,500-2,000 m (Thompson and Zoback, 1979); its average heat flow is about 50 mW/m^2 (milliwatts/square meter) (Bodell and Chapman, 1982). The pre-Tertiary geology of the Colorado Plateau is dominated by stable shelf deposits; on the other hand, early Tertiary fluvial-lacustrine sediments, late Tertiary intrusive and extrusive rocks (particularly around the margin of the Plateau), and a scarcity of late Cenozoic sedimentary rocks all relate to instability during the Cenozoic (Hunt, 1956). Peripheral regions of the Colorado Plateau province generally are deformed as a result of monoclinal warping and block faulting. We next describe two of these peripheral subprovinces, delineated by Hunt (1956), which form the western and southwestern part of the Colorado Plateau province.

E.1.3.3.1 High Plateaus Section of the Colorado Plateau Province (CP-HPS):
The High Plateaus of central and southwest Utah form a series of high-standing (2,700-3,300 m), NNE-trending mountain blocks that abruptly rise above the eastern Great Basin, separating it from the interior of the Colorado Plateau (fig. E-4). The mountain blocks are generally flat-topped (capped by lower Tertiary formations or volcanic rocks) with typically steep sides and intervening valleys defined by en echelon normal faults of late Tertiary and Quaternary age (Anderson and Rowley, 1975; Hunt, 1956). Extensive volcanism occurred during much of the Cenozoic in the southwestern High Plateaus and adjoining Great Basin (Rowley and others, 1979; Anderson and Rowley, 1975). The distribution of regional ash-flow tuffs leads Rowley and others (1978) to conclude that differential uplift of the High Plateaus

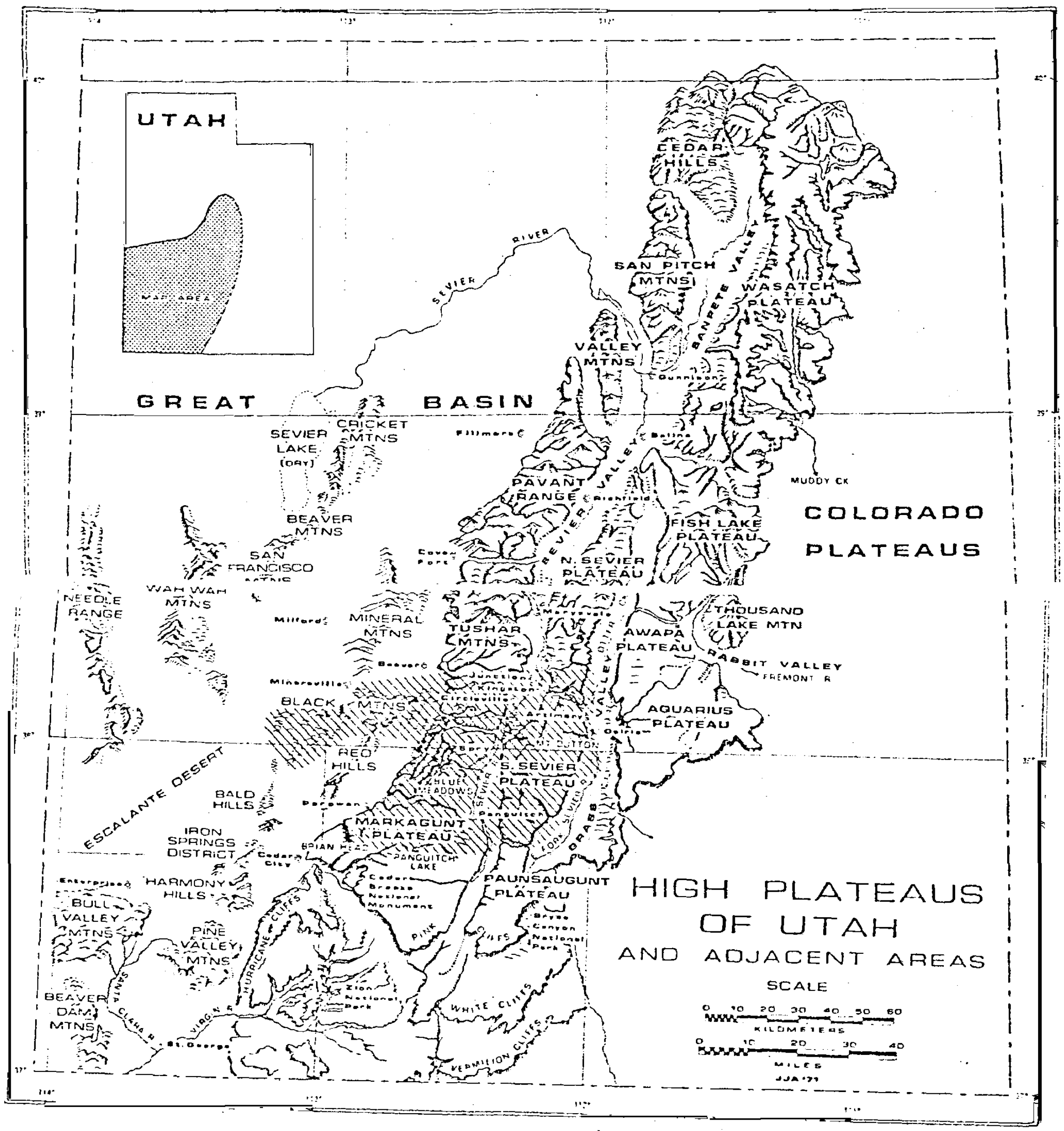


FIGURE E-4.-Physiographic map of southwestern Utah showing relation of Cedar City-St. George area to High Plateaus section of the Colorado Plateau province (from Anderson and Rowley, 1975).

to form the Great Basin-Colorado Plateau boundary occurred some time after 29 m.y. ago; structural differentiation was apparently underway by 26 m.y. ago and had produced significant topographic contrasts by 24 m.y. ago. Complexity of the Great Basin-Colorado Plateau boundary in the Cedar City-St. George area is discussed in a later section on structural geology.

E.1.3.3.2 Grand Canyon Section of the Colorado Plateau Province (CP-GCS):
The Grand Canyon section of the Colorado Plateau in Arizona, as delineated by Hunt (1956), encompasses relatively high-standing blocks of nearly horizontal strata that form the southwestern rim of the Plateau. Maximum elevations are less than 2,000 m, significantly lower than in the High Plateaus section. The northern part of the Grand Canyon section is dominated by NNE-trending, down -to-the-west normal faults (Grand Wash, Hurricane, and Toroweap faults) that continue northward into Utah (Hunt, 1956; Hamblin, 1970). Evidence for Quaternary displacements on NNE-trending faults in this area is discussed by Huntoon (1977, 1979; see also Anderson, 1979). Southward, the structural grain and province boundary of the Grand Canyon section become parallel to NW-trending structure of the Sonoran Desert section of the Basin and Range province.

E.1.3.4 Basin and Range-Colorado Plateau Transition (BR-CP Trans.). Because the boundary between the Basin and Range and Colorado Plateau provinces in central and southwest Utah is transitional (see Section E.1.2), demarcation of the two provinces is not straightforward. Features of both provinces overlap: Cenozoic normal faulting extends, with diminishing displacements, approximately 50 km into the High Plateaus section of the Colorado Plateau--while many of the easternmost basin-range mountain blocks have a general plateau structure (e.g., Stokes, 1977; Anderson and Rowley, 1975; Spieker, 1949). The Basin and Range-Colorado Plateau transition zone depicted in figure 3 for central and southwest Utah is based on Stokes (1977). Extrapolation of this transition zone outside of Utah is uncertain. West of the Utah-Nevada border the transition zone becomes mixed with the Great Basin-Sonoran Desert transition; in northwestern Arizona, the boundary between the Basin and Range and Colorado Plateau provinces is more clearly demarcated by the Grand Wash fault (Lucchitta, 1979).

E.1.3.5 Great Basin-Sonoran Desert Transition (GB-SD Trans.). Division of the Basin and Range province into northern and southern sections was discussed in Section E.1.1. A transition zone between the two sections of the province, following Zoback and others (1981) and Eaton (1979), is sketched in figure E-3. Comparison with figure 1 shows that the Great Basin-Sonoran Desert transition roughly coincides with a NE-SW trending branch of the Intermountain seismic belt that extends across southern Nevada--following a major structural corridor of late Tertiary deformation that transects a northerly-trending structural grain (Anderson, 1978). The transition zone defined a relatively amagmatic corridor during late Cenozoic time (Anderson, 1981). Also, the zone displays complex structural ties between the northern and southern sections of the

Basin and Range province relating to an episode of thin-skinned extensional tectonics about 15 m.y. ago (Anderson, 1981), although modern basin-range structure in the Great Basin is distinctly younger (<10 m.y.) than in the Sonoran Desert section (13-10 m.y.) (Zoback and others, 1981).

E.2 Geologic History of Southwest Utah

E.2.1 Pre-Cenozoic Geologic History

The post-Archean, pre-Cenozoic geologic history of southwest Utah (i.e., its history between 2,400 m.y. and 65 m.y. ago) is dominated by (1) marine sedimentation and a westward-facing, passive continental plate margin during Late Precambrian-Paleozoic time, and (2) intraplate, eastward-directed, compressive orogenic activity during the Mesozoic resulting from convergent plate tectonics farther west. Figure E-5, adapted from Stokes and Heylmun (1963) provides a useful framework for discussion.

Of fundamental importance is the concept of the Wasatch-Las Vegas Line (see Stokes and Heylmun, 1963; Stokes, 1976, 1979), also referred to as the Cordilleran Hingeline (e.g., Hill, 1976, p. 6)--the term we adopt here for simplicity. This feature marks a persistent zone of weakness in the North American plate, apparently inherited from late Precambrian continental rifting. It defines an axis of differential crustal movement that controlled late Precambrian to Mesozoic-age stratigraphy in the Cordilleran geosyncline, and also defined where eastward-moving thrust plates broke to the surface during Cretaceous-early Tertiary time (Stokes, 1976). Because of its important control on Mesozoic and Cenozoic tectonism, the Cordilleran Hingeline separates regions of contrasting geologic history.

E.2.1.1 Precambrian-Paleozoic Geology. The Transcontinental Arch, shown in figure E-5, is a major northeast-trending element of the North American Precambrian craton that formed an important positive feature in the early Paleozoic (see Hintze, 1973, p. 99). The oldest stratified rocks in the western United States--including the Vishnu Schist, which crops out in the Grand Canyon region and in the Beaver Dam Mountains west of St. George (Cook, 1960; Hintze, 1973, p. 10)--form part of the crystalline terrain of this belt.

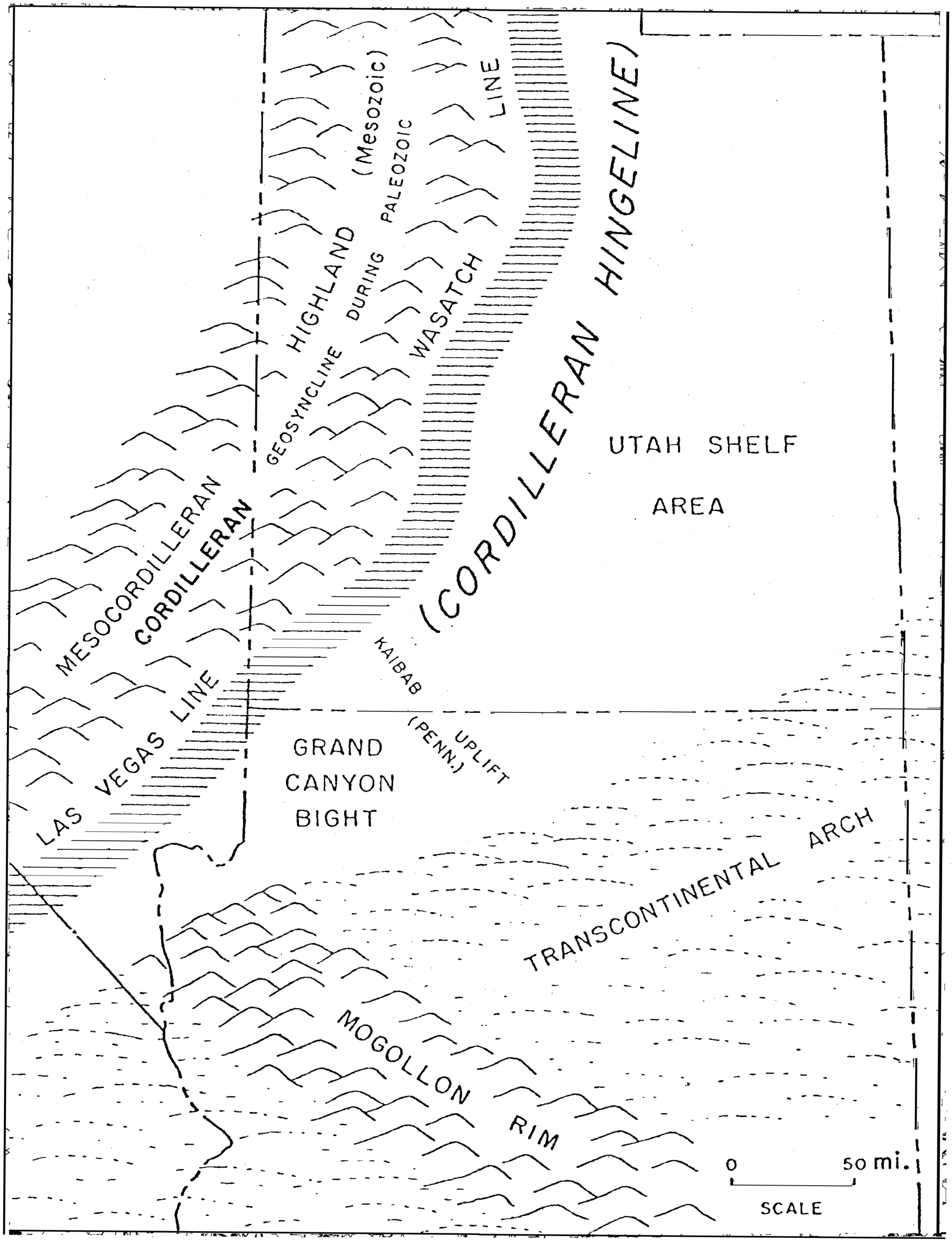


FIGURE E-5. Sketch map of some major pre-Cenozoic tectonic features affecting southwestern Utah (adapted from Stokes and Heylmun, 1963).

According to extensive radiometric dating and field studies by Silver and others (1977), these rocks represent marine strata, deposited in a major eugeosyncline 1,730-1,770 m.y. ago, that were subseqeuently metamorphosed, intruded by orogenic batholithic rocks 1,700-1,740 m.y. ago, and later intruded by anorogenic granites 1,410-1,465 m.y. ago.

In late Precambrian time, miogeoclinal deposition (i.e., sedimentation along a passively subsiding plate margin) began along the western margin of the North American craton. Deposition of a thick sequence (up to 7,600 m [25,000 ft]) of upper Precambrian and Lower Cambrian diamictites (conglomeratic mudstones), tholeiitic basalts, and marine sedimentary strata has been interpreted by Stewart (1972) as resulting from rifting of the North American protocontinent (<850 m.y. ago). Creation of a new westward-facing continental margin marked the beginning of the Cordilleran geosyncline. Isopachs of upper Precambrian-Lower Cambrian strata indicate abrupt downwarping and probable continental separation roughly along the Cordilleran Hingeline (see Stewart, 1972; Stokes, 1979). Aeromagnetic data are consistent with such framentation of the Precambrian craton; an order-of-magnitude difference in the amplitude of magnetic anomalies in eastern Utah, as opposed to "quiet" magnetic data over the Basin and Range province, appears to be related to the regional distribution of buried Precambrian rocks (Zietz, 1980).

Figure E-6 (from Hintze, 1973), which summarizes the general stratigraphy of the Cedar City-St. George area, indicates the predominance of shallow-water marine sedimentation throughout the Paleozoic, reflecting deposition in the vicinity of the Cordilleran Hingeline--with facies associated with either the continental shelf or adjoining, mildly negative, platform (see Stokes, 1979, and Hintze, 1973, for details of paleogeography and paleo-plate tec-

SOUTHWESTERN UTAH
CEDAR CITY - ZION PARK - ST. GEORGE - IRON MINES

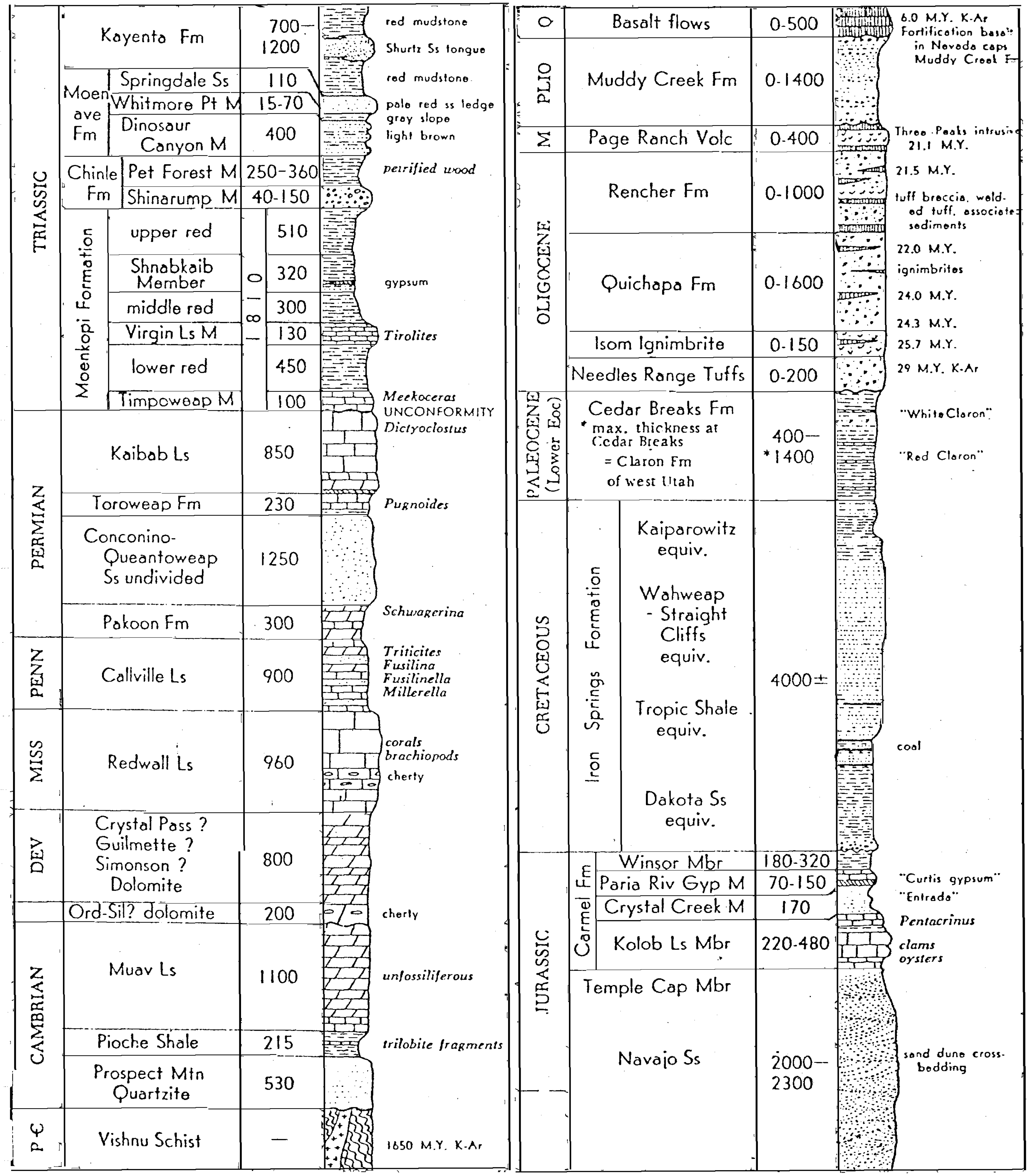


FIGURE E-6. Representative stratigraphic column for the Cedar City-St. George area (from Hintze, 1973).

tonics). For example, Lower Paleozoic rocks (Prospect Mountain quartzite, Pioche shale, and overlying carbonates) exposed in the Beaver Dam Mountains west of St. George, which are important exposures because of their isolation from correlative rocks by considerable distances, represent a transgressive assemblage along the miogeocline-craton hingeline (Hintze, 1963).

During Late Devonian and Mississippian time, the Antler orogeny produced compression, uplift, and eastward thrusting in the western part of the Cordilleran geosyncline, chiefly affecting the area of western and central Nevada; only mild folding occurred in western Utah and parts of the Colorado Plateau (Shawe and others, 1978; Stokes, 1979). During the Pennsylvanian period and continuing into the Permian, areas of the eastern Great Basin were affected by the development of northwest-trending downwarps and uplifts that accompanied the Ancestral Rocky Mountains orogeny, the effects of which were most intense to the east and southeast of the Utah region (Stokes, 1979; Hintze, 1973). The Pennsylvanian Kaibab uplift (fig. E-5) formed in northern Arizona and southern Utah at this time (Stokes and Heylmun, 1963).

E.2.1.2 Mesozoic History. The unconformity (or more correctly, the disconformity) shown in fig. E-6 at the base of the Triassic Moenkopi Formation reflects a major change from marine deposition, which persisted in Utah into Early Triassic time, to chiefly continental deposition by Late Triassic time. Profound change accompanied reversal of relief of the Cordilleran geosyncline into the Sevier orogenic belt during the Mesozoic era, with most pronounced orogenic effects in Utah during the latest Jurassic and Cretaceous periods (Armstrong, 1968; Hintze, 1973). Thus areas to the west of the Cordilleran Hingeline became positive while those to the east became negative, receiving sediments. In fig. E-5 the uplifted area is identified as the Mesocordilleran Highland (also referred to as the Sevier Geanticline, e.g., Hintze, 1973). A companion uplifted area, the Mogollon Rim, appears to have originated in the middle Triassic at about the same time as the Mesocordilleran Highland; the Mogollan Rim became the southwestern margin of Triassic, Jurassic, and Cretaceous sedimentary basins--while a relatively low area between the Mogollan Rim and the Mesocordilleran Highland (the Grand Canyon Bight in fig. E-5) received thick accumulations of Upper Triassic, Jurassic, and Cretaceous sediments (Stokes and Heylmun, 1963).

Continental deposition in southwest Utah in Late Triassic time involved both eastward-spreading detritus from orogenic highlands in western Nevada and California, as well as detritus from uplifts to the east and southwest (Shawe and others, 1978; Hintze, 1973, p. 57). Aridity in the lee of the Mesocordilleran Highland, combined with a surrounding of the Colorado Plateau region by uplifts, resulted in deposition of Late Triassic fluvial-lacustrine red beds (Stokes, 1979).

The dominance of continued continental deposition in southwest Utah through most of the early Jurassic is reflected by the Navajo sandstone (fig. E-6) with its large-scale cross-bedding of sand-dune origin. Middle and Upper Jurassic marine strata of the Carmel Formation are interpreted to be related to marine invasion by a southerly extending tongue of a shallow epicontinental sea that was connected to a Pacific Ocean through Canada or Alaska; the extensive Upper Jurassic Morrison Formation, of continental origin, did not extend into southwest Utah (see Hintze, 1973, p. 59-67).

During the Cretaceous, the last epicontinental sea in Utah, which had spread northwestward from the Texas coastal plain, was bounded on the west by the Mesocordilleran Highland. Cretaceous strata in southwest Utah reflect typical marginal-marine, coastal-plain conditions immediately east of the Sevier orogenic belt. The thick Cretaceous stratigraphic section (fig. E-6), for example, includes marine sandstones and shales, coal-bearing strata, and occasional intercalations of locally coarse deposits derived from the Sevier orogenic highlands to the west.

The Mesocordilleran Highland depicted in fig. E-5 resulted from strong folding and large-scale eastward thrusting during the Sevier orogeny, probably involving foreshortening of several tens of kilometers (Armstrong, 1968). According to Armstrong (1968) the Sevier orogeny occurred throughout the Cretaceous period. Sevier thrusting in southwestern Utah had probably terminated by latest Cretaceous time (Shawe and others, 1978; Armstrong, 1968; Stokes and Heylmun, 1963), although elsewhere in the so-called Idaho-Wyoming-Utah foreland thrust belt there is overlap with compressional tectonics generally ascribed to the Laramide orogeny during latest Cretaceous-Paleocene-Eocene time (Burchfiel, 1980). Effects of the Laramide orogeny extended well inland (eastward) of the fold and thrust belt.

E.2.2 Cenozoic Geologic History

Chief elements of the Cenozoic history of southwestern Utah, i.e., its history from 65 m.y. ago to the present, include (e.g., Shawe and others, 1978, p.3): "extensive volcanism, plutonism, and continental sedimentation in local basins, and in later stages regional uplift, block faulting, and attendant continental sedimentation." Another important element is the structural differentiation between the Colorado Plateau and Basin and Range provinces. Fortuitously, some excellent detailed summaries of these various aspects of the Cenozoic geology of southwestern Utah have been recently published. These notably include: (1) a comprehensive summary of the stratigraphic and structural framework of southwestern Utah by Rowley and others (1978); (2) a guidebook edited by Shawe and Rowley (1978) that focuses on economic mineral deposits in southwestern Utah, but which includes an informative geologic overview; and (3) various publications by R.E. Anderson and colleagues that focus on the Quaternary tectonics of southwestern Utah, particularly as relevant to problems of active faulting and earthquake hazards (e.g., Anderson, 1981,1979, 1978; Anderson and Mehnert, 1979; Anderson and Bucknam, 1979; Zoback and others, 1981).

Figure E-7 from Zoback and others (1981), provides an up-to-date synthesis of Cenozoic plate tectonic elements and magmatic patterns in the western U.S. that is useful for placing the history of southwestern Utah in a regional perspective. One introductory comment is required. During the Laramide orogeny (ca. 80-40 m.y. ago), there was a prominent absence of calc-alkaline volcanism throughout most of the western U.S. landward of a west-coast subduction zone; this absence of magmatism, together with the great inland extent of compressional Laramide tectonism, have been attributed to long-continued, very low-angle subduction along the western plate boundary (see Zoback and others, 1981).

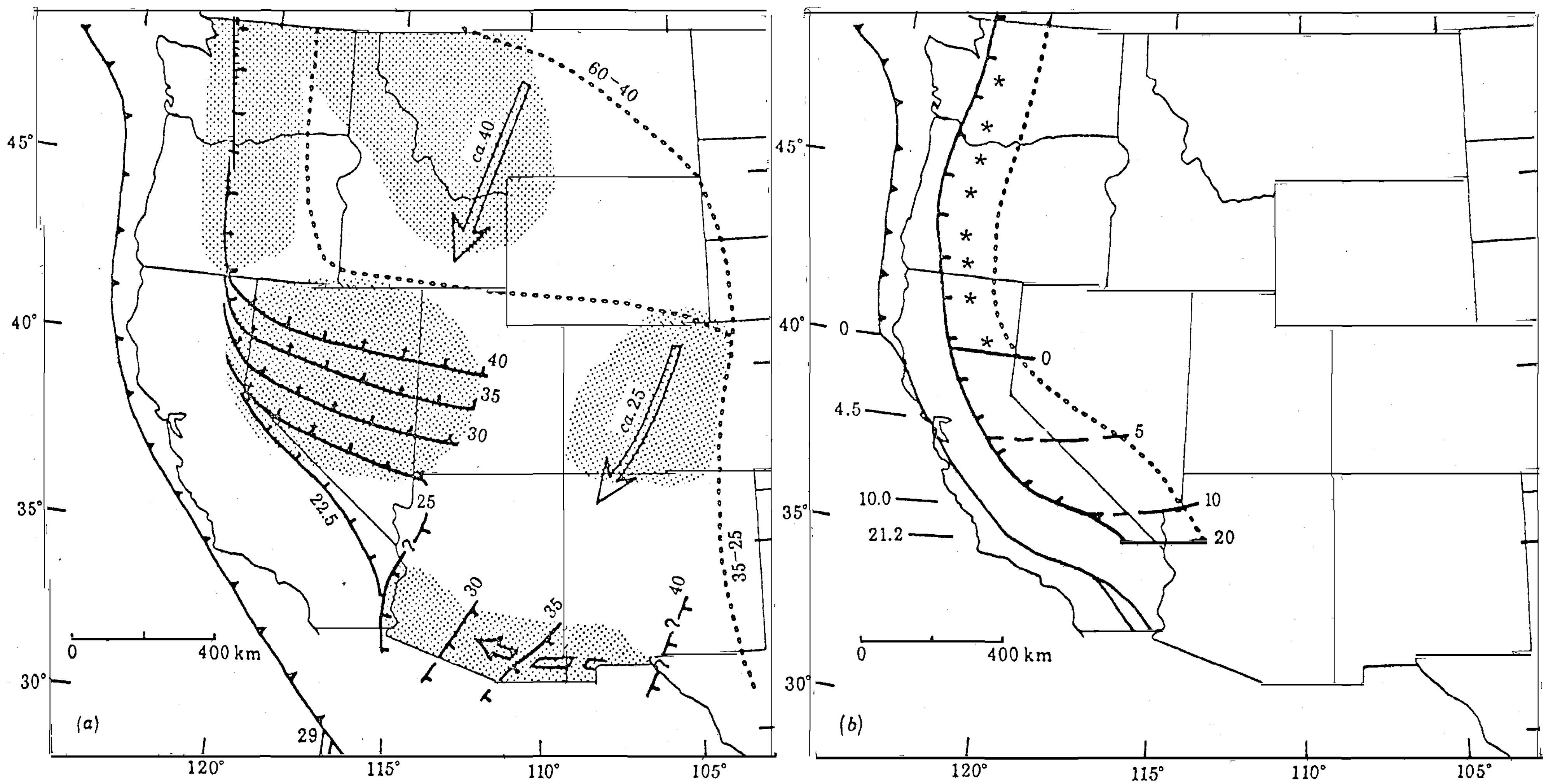


FIGURE E-7. Synthesis of Cenozoic tectonic patterns in western U.S. (from Zoback and others (1981) involving (a) migration of calc-alkaline volcanism across the Laramide magmatic gap, and (b) northward migration of a triple junction along the western North American plate. Hachured lines indicate westernmost extent of calc-alkalic volcanism; small circles, the easternmost extent. Numbers identify time stages (in megayears).

Between about 40 and 20 m.y. ago after cessation of the Laramide orogeny--coinciding with changes in world-wide plate motions (Coney, 1978)--calc-alkaline volcanism systematically swept west to southwestward across the Laramide magmatic gap (fig. E-7a) Zoback and others (1981) present evidence for early extensional tectonism concurrent with the cala-alkaline volcanism in an "intra-arc" or back-arc" setting.

Between about 20 and 30 m.y. ago, a ridge-trench collision along the western North American plate caused major tectonic changes in the western U.S., including formation of the San Andreas transform boundary (Atwater, 1970). Northward migration of a triple junction along the San Andreas boundary after about 20 m.y. ago (fig. E-7b) produced the following important changes in the Basin and Range region (Zoback and others, 1981; Eaton, 1979): (1) replacement of calc-alkaline volcanism by basaltic volcanism in the southern Basin and Range region by about 20 m.y. ago; (2) initiation of significant extension in the southern Basin and Range region by about 20 m.y. ago, with intensive NW-trending basin-range block faulting in that region 13-10 m.y. ago; (3) widespread initiation of basaltic volcanism throughout the northern Basin and Range region at about 17 m.y. ago; and (4) development of modern NNE-trending basin-range block faulting in the northern Basin and Range region after 10 m.y. ago.

With the above-outlined scenario in mind, much of the complex Cenozoic geology of southwestern Utah can be related to three general stages: (1) early Tertiary (ca. 65-35 m.y. ago) sedimentation in broad basins formed by local warping east of the Sevier orogenic highlands during Laramide time, (2) middle Tertiary (ca. 35-20 m.y. ago) calc-alkaline magmatism along ENE-trending igneous belts, and (3) late Cenozoic (<20 m.y. ago) bimodal basalt-rhyolite volcanism and extensional tectonism.

Figure E-8, from Rowley and others (1979), provides a simplified overview of some elements of the Cenozoic geology of southwestern Utah. More than 300 m of fluvial-lacustrine strata accumulated in a broad easterly-trending depositional basin in southwest Utah during latest Cretaceous(?) to perhaps middle Oligocene time (Rowley and others, 1979). The Paleocene-Eocene Cedar Breaks Formation (fig. E-6) exposed near Cedar City was deposited in this basin, which did not extend as far south as St. George.

In middle Tertiary time, the southward migration of calc-alkaline magmatism that swept through Nevada and western Utah (fig. E-7a) produced extensive andesitic and rhyolitic volcanism (accompanied by granitoid intrusions) in roughly east-trending belts, each successively younger to the south (Stewart and others, 1977). Calc-alkaline igneous rocks in southwest Utah, which nearly all range in age from about 35 m.y. to 19 m.y. (Rowley and others, 1979; see also fig. E-6) define one of these belts--a broad zone of Oligocene-Miocene magmatism between roughly 37°N and 39°N latitude (see Shawe and others, 1977). Within this broad zone in southwest Utah, two distinct ENE-trending belts of mineralization are recognized (see fig. E-8): the Pioche-Marysvale belt and the Delamar-Iron Springs belt (Shawe and others, 1978).

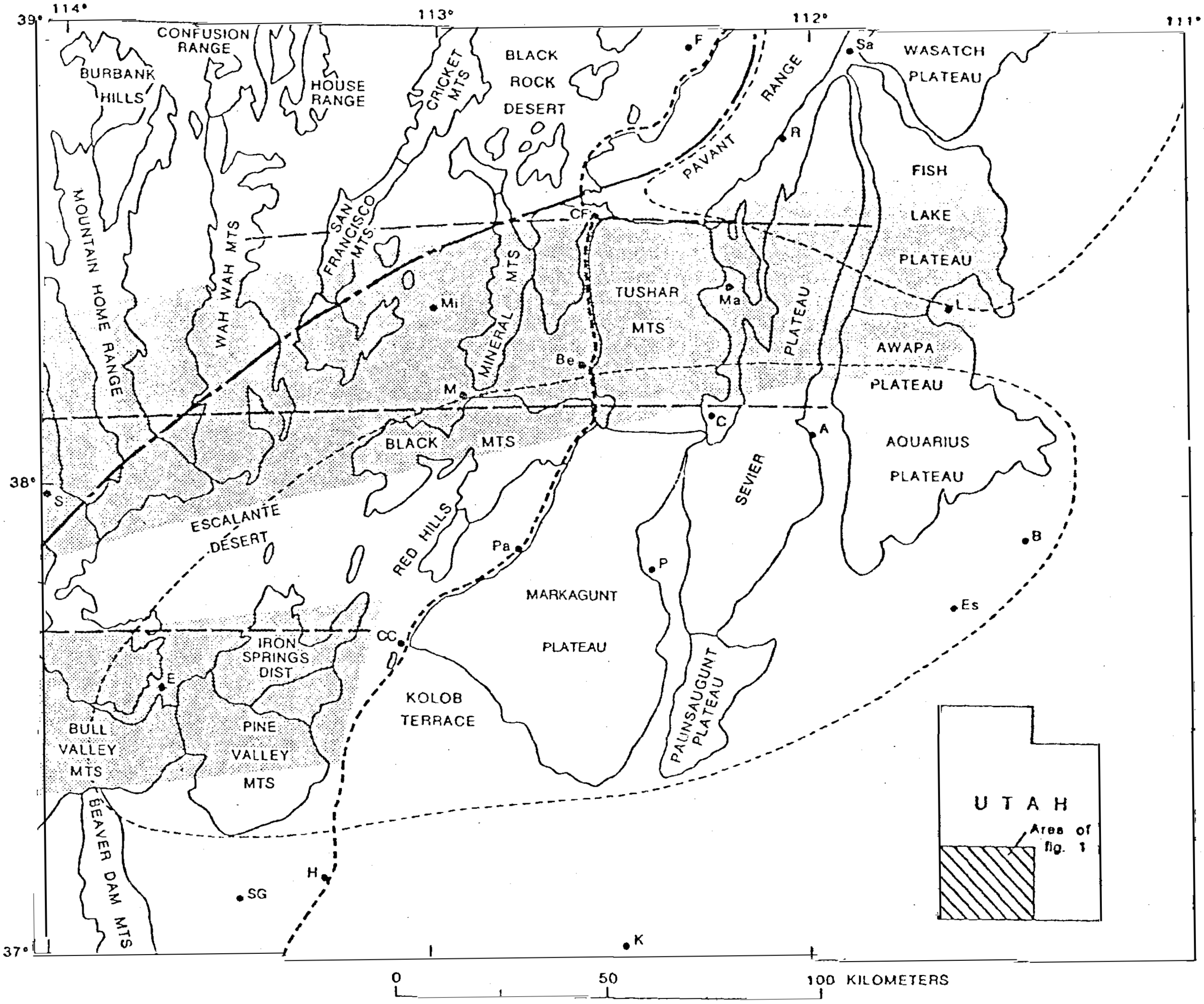


FIGURE E-8.

Physiographic features and major structural features of southwestern Utah. Basin and Range — Colorado Plateaus boundary shown by heavy short-dashed line; Pavant Range, Tushar Mountains, and named plateaus belong to the High Plateaus subprovince. Central part of Pioche-Marysvale igneous belt on north, and of Delamar-Iron Springs igneous belt on south, patterned. Dot-dash line, east edge of major Sevier thrust faults, modified from Crosby (1973). Heavy long-dashed lines, axes of lineaments, consisting from north to south of the Black Rock, Blue Ribbon, and Timpahute lineaments. Fine dashed line on the north, approximate minimum boundaries of depositional basins of the North Horn to Crazy Hollow Formations; to the south, the Claron Formation and related rocks. Tushar highland is between them. A, Antimony; B, Boulder; Be, Beaver; C, Circleville; CC, Cedar City; CF, Cove Fort; E, Enterprise; Es, Escalante; F, Fillmore; H, Hurricane; K, Kanab; L, Loa; M, Minersville; Ma, Marysvale; Mi, Milford; P, Panguitch; Pa, Parowan; R, Richfield; S, Stateline mining district; Sa, Salina; SG, St. George. (From Rowley and others, 1979)

Ash-flow tuff sheets originating from volcanic centers in the Pioche-Marysvale and Delamar-Iron Springs igneous belts were widespread in southwest Utah during middle Tertiary time. Indeed, their distribution provides critical evidence for timing the structural differentiation between the Colorado Plateau and Basin and Range provinces. Regional dating of ash-flow tuffs suggests that the provinces became structurally separate some time after 29 m.y. ago, and that vertical movements on boundary faults along the west side of the Colorado Plateau began about 26-18 m.y. ago in late Oligocene-early Miocene time (Rowley and others, 1978, 1979; Best and Hamblin, 1978). Movement on the Hurricane fault may not have been so early. Although Rowley and others (1979) associated the Hurricane fault with the Basin and Range-Colorado Plateau boundary (see fig. E-8) Andreson and Mehnert (1979) argue otherwise and suggest that major movement on the Hurricane fault was probably post-Miocene.

During late Cenozoic time (<20 m.y. ago), basaltic volcanism, regional uplift, and extensional tectonism dominate the geology of southwestern Utah. Some important aspects of basaltic volcanism in the general region surrounding the Cedar City-St. George area include (Best and Hamblin, 1978; Rowley and others, 1979): (1) a hiatus of several million years between the end of mid-Tertiary calc-alkaline volcanism and the inception of basaltic volcanism; (2) the occurrence of relatively isolated, low-volume basaltic fields, particularly in the boundary region between the Basin and Range and Colorado Plateau provinces, without large central volcanic complexes; (3) representative ages ranging from about 13 m.y. to 0.5 m.y. for basaltic volcanic fields in the eastern Basin and Range province to be tholeiitic, whereas basalts on the Colorado Plateau are more alkalic and undersaturated--possibly reflecting differing regimes of upper-mantle magma generation. Basaltic fields in the immediate vicinity of St. George are discussed by Hambin and others (1981) and by Hamblin (1970b).

The history of extensional faulting and basin-fill sedimentation in southwestern Utah is clearly complex. There seems to be agreement that the present-day topography of the northern Basin and Range province did not develop before 10 m.y. ago (Zoback and others, 1981; Stewart, 1978). However, pre-basin-range extension (now recognized by faulted and tilted strata exposed in uplifted range blocks) was under way locally in the Basin and Range province by at least 30 m.y. ago (Zoback and others, 1981). A major episode of pre-basin-range, thin-skinned extensional normal faulting affected rocks now exposed in the Beaver Dam and Bull Valley Mountains west of St. George between about 15 and 11 m.y. ago (Anderson, 1981).

In the High Plateaus subprovince of the Colorado Plateau, major block faulting was under way by 20 m.y. ago, and from about 20 m.y. ago to 7 m.y. ago the High Plateaus were characterized by both faulting and broad warping (Rowley and others, 1979). Basin-fill from erosion of fault blocks has been dated to be at least as old as 14 m.y. in the High Plateaus, and as old as 10 m.y. in the northern Basin and Range province--although the oldest ages of basin-fill might be about 20 m.y. and 15 m.y., respectively, in the two regions (Rowley and others, 1979; Zoback and others, 1981). Pliocene basin-fill in the Cedar City-St. George area is identified in the stratigraphic column of fig. E-6 as the Muddy Creek Formation.

Relative vertical motions between the eastern Basin and Range province and the Colorado Plateau introduce additional complexity. Observed uplift and northeastward tilting of the western margin of the Colorado Plateau may relate to a broad upwarping that involved the entire Basin and Range province during late Cenozoic time; if so, then relative down-dropping of the eastern Basin and Range province must have accompanied collapse of the upwarp by fault fragmentation (see Best and Hamblin, 1978). In any case, both provinces are now rising, but the western Colorado Plateau is rising at a significantly faster rate (Hamblin and others, 1981).

E.3 STRUCTURAL GEOLOGY

E.3.1 General Structure of Study Area

Figure E-9 gives an overview of the general structure of the Cedar City-St. George area, which is dominated by N- to NNE-trending faults that deform a complex boundary region between the eastern Great Basin and the higher-standing western Colorado Plateau to the east. East-west structural sections in figure E-10 (from Best and Hamblin, 1978) illustrate differences across the province boundary in northwestern Arizona (section B-B') compared to southwestern Utah (section A-A'), as one passes from the Grand Canyon section to the High Plateaus section of the Colorado Plateau. Section B-B', 50-60 km south of the Utah-Arizona border, shows the relatively simple structure of the Grand Staircase--a series of northeastward-tilted fault blocks bounded by major down-to-the-west normal faults. Northward into Utah, section A-A' (about 30 km north of Cedar City) shows more "ragged" faulting across the province boundary involving horsts, grabens, and ramp structures with scissor-like displacement (Best and Hamblin, 1978).

In northwestern Arizona, the Grand Wash fault forms the boundary between the Basin and Range and Colorado Plateau provinces (section B-B', fig. E-10). To the north of the Utah border, the province boundary is less well defined. Anderson and Mehnert (1979) interpret that it follows the Cedar Pocket Canyon-Gunlock-Veyo fault (the northern continuation of the Grand Wash fault), then passes north of the Pine Valley Mountains to join the Hurricane-Parowan-Paragonah monocline-fault system near Cedar City (see fig. E-9). Thus en echelon stepping of the province boundary from the Cedar Pocket Canyon-Gunlock-Veyo fault to the Hurricane-Parowan-Paragonah structure at roughly lat 37.5^{o}N forms a structural block encompassing the Pine Valley Mountains and the St. George Basin. This structural block (fig. E-9) is mildly warped, cut

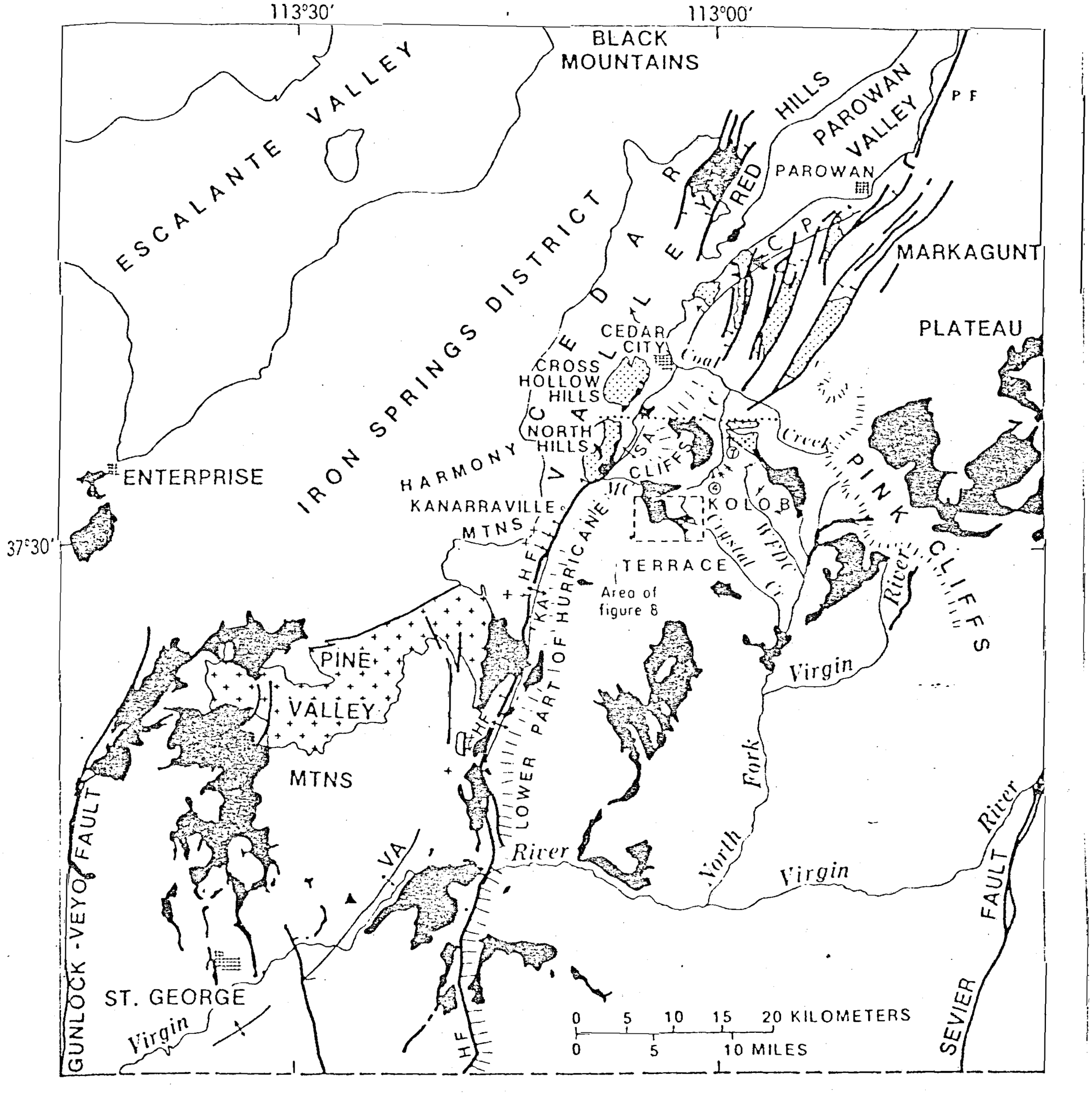


FIGURE E-9. Geologic sketch map showing structural overview of Cedar City-St. George study area (from Anderson and Mehnert, 1979). HF indicates Hurricane fault; PF, Paragonah fault; VA, Virgin anticline; KA, Kanarra anticline; SA, Shurtz Creek anticline; CP, Cedar City-Parowan monocline. Distribution of upper Cenozoic basaltic lava flows shown in black.

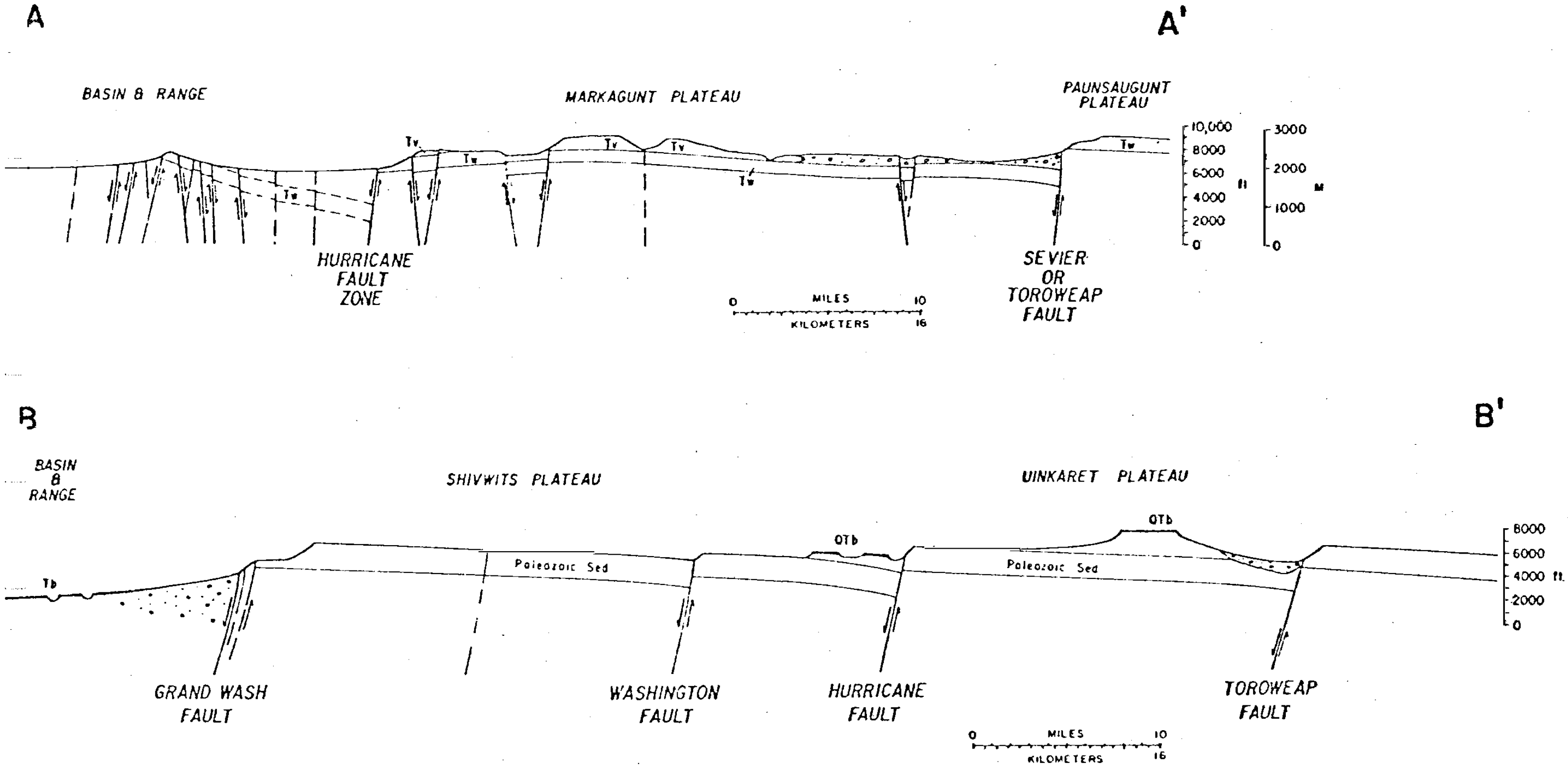


FIGURE E-10. East-west structural sections (from Best and Hamblin, 1978) illustrating changing structural style across the Basin and Range-Colorado Plateau province boundary along strike in southwestern Utah (A-A') and northwestern Arizona (B-B'). Section A-A' located 30 km north of Cedar City, Utah; B-B', 50-60 km south of Utah-Arizona border. QTb, Tb, basaltic flows; Tv undifferentiated Oligocene andesitic volcanic fields; Tw, Eocene Wasatch Formation.

by faults of relatively small dispacement, and is marked by the absence of any prominent basin-range graben structure--suggesting affinity with the Colorado Plateau province (Anderson and Mehnert, 1979).

The Hurricane fault is the most prominent structure in the study area. Anderson and Mehnert (1979) provide an extensive review of geological data relevant to the Utah segment of the fault. Their interpretation, however, that the total normal displacement on the fault in Utah is only 600-850 m has been modified (R.E. Anderson, personal communication to W.J. Arabasz, January 1982) after access to confidential oil-company data that require the total displacement to be at least 2,000 m. Given current displacement rates of the order of 300-500 m/m.y. along the northern Hurricane fault (Appendix F.3.4), such total displacement can still be accommodated chiefly in Quaternary and Pliocene time.

Eastward-directed thrust faults and related folds of Cretaceous age associated with the Sevier orogeny have affected pre-Cenozoic rocks in southwestern Utah. The eastern limit of major thrusting (see Rowley and others, 1979) passes near the northwestern extremity of fig. E-9. The leading edge of the Sevier disturbed belt, however, directly affected the study area where NE- or NNE-striking overturned and open folds, some locally thrust faulted, were formed in a belt parallel to the front of major thrusting (Rowley and others, 1979). These include the Virgin and Kanarra anticlines (fig. E-9) Anderson (1980) and Anderson and Mehnert (1979) review the influence of pre-Quaternary structure on the NE-trending fault fabric of the study area.

E.3.2 Structure in the Cedar City Area

SCS dams Greens Lake Numbers 2, 3, and 5, located south of Cedar City, lie within a complicated structural region bridging the northernmost, well defined segment of the Hurricane fault, 15 km south-southwest of Cedar City, with the Parawon-Paragonah fault, about 35 km northeast of Cedar City (see fig. E-9) (Threet, 1963; Anderson and Bucknam, 1979; Anderson and Mehnert, 1979; Averitt, 1964; Averitt and Threet, 1973). Threet (1963) describes the situation:

> ".....the Neogene Hurricane fault cannot be extended properly along the plateau margin between Cedar City and Paragonah; instead, a Neogene monocline controls the plateau margin geomorphology in that segment. The northwestward-throwing monocline intersects the east flank of the Laramide Kanarra fold, a few miles north of Cedar City, in a remarkably well documented case of oblique unfolding....." (Threet, 1963, p. 110).

Figure E-11, combining illustrations from Threet (1963) and Anderson and Bucknam (1979) shows the combination fault-monocline structure.

A detailed geologic map (scale 1:24,000) of the area of interest surrounding Cedar City has been published by Averitt and Threet (1973). As part of this study, detailed photointerpretation and field mapping and exploration were conducted in the immediate Cedar City area. The results of the photointerpretation, part of a larger study of the Hurricane fault in southwestern Utah conducted as part of this study, is discussed in detail in ChapterIV of the report and shown on figure IV-2 (scale 1:62,500). The results of the field mapping and exploration in the Cedar City area is discussed in detail in ChapterVIII-A and B of the report and shown on figure VIII-1 (scale 1:24,000).

In summary, the results of detailed photointerpretation and field mapping and exploration in the immediate Cedar City area indicate the structure described above is further complicated along the Hurricane Cliffs below Lone Tree Mountain by large scale, complex landsliding, and possibly some basalt flows, which underlie the escarpment in this area. As shown on figure VI-1, recent traces of the Hurricane fault apparently cut the landslide deposits and lie somewhat upslope from the present topographic break-in-slope at the base of the Hurricane Cliffs south of Cedar City. These traces apparently exit the escarpment in the vicinity of Greens Lake Dams Numbers 2 and 3, but cannot be traced on air photos to the north across the recent alluvial fan deposits that underlie the dams.

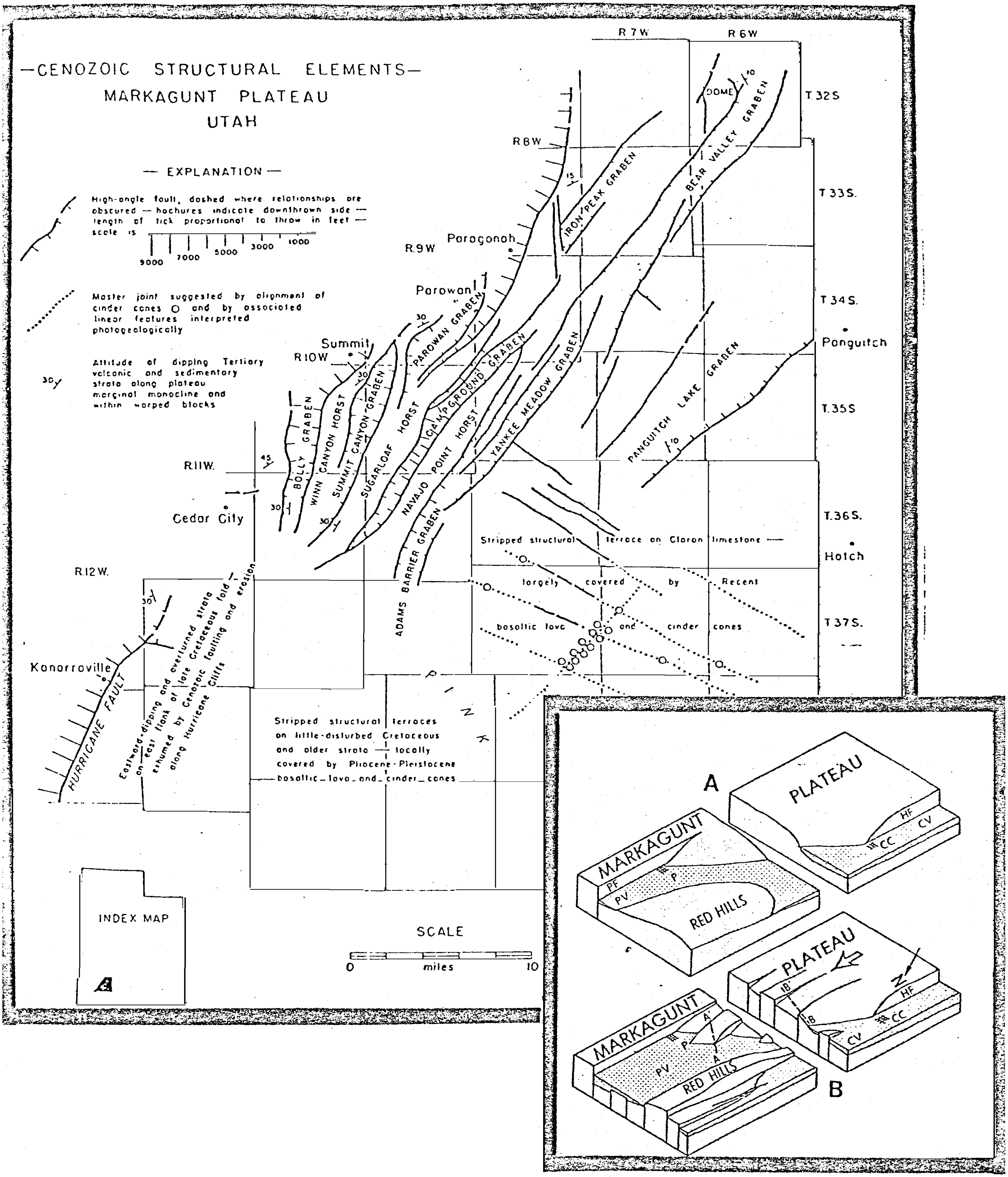


FIGURE E-11. Map of Cenozoic structural elements of the Markagunt Plateau near Cedar City (from Threet, 1963). Inset (from Anderson and Bucknam, 1979) illustrates NE-trending monoclinal flexure that serves as a structural bridge between the Paragonah fault (PF) and the Hurricane fault (HF). CC = Cedar City; P, Parowan.

Southwest of Cedar City, fault traces cut Pleistocene alluvium and locally overlying basalt, and may cut late Pleistocene colluvium along the east side of Cross Hollow Hills (see figure VIII-1). These fault traces and associated air photo lineaments can be mapped discontinuously to the southwest along the east side of North Hills to a projected intersection with the main Hurricane fault near Murie Creek (see figure IV-2). This relationship suggests that the alluvial valley(s) southwest of Cedar City between the Hurricane Cliffs and Cross Hollow - North Hills may be a late Pleistocene graben, herein called the Shurtz Creek Graben (see figure IV-2), similar to those located northeast of Cedar City along the southern part of the Paragonah fault (figure E-11).

E.3.3 Structure in the Hurricane-Frog Hollow Area

The SCS Frog Hollow Dam is located southeast of Hurricane in the relatively flat upland area of the Grand Canyon Section subprovince of the Colorado Plateau Provine, east of the Hurricane Cliffs. The structure of interest in this area is the Hurricane fault which passes approximately 3 km west of the dam. Localized Quaternary basaltic volcanism has occurred west and southwest of the dam.

As part of this study, detailed photointerpretation and field mapping were conducted in the immediate Frog Hollow area. The results of these investigations are discussed in detail in Chapter VIII-F of the report and shown in Figure VIII-3 (scale 1:24,000).

E.3.4 Structure in the St. George Area

SCS dams Gypsum Wash, Warner Draw, and Stucki are located southeast of St. George along the southeast side of the alluviated Washington Fields adjoining the western edge of Warner Ridge. The structure of primary interest in this area is the Washington fault, a NNW-trending, down-to-the-west normal fault that crosses the eastern part of the St. George basin (fig. E-12) passing within 0 to 1225 m of one or more of the dams. The Washington fault extends approximately 68 km from just north of the town of Washington, southward with increasing displacement into northwest Arizona (Dobbin, 1939; Cook, 1960; Cook and Hardman, 1967; Hamblin, 1970a, b) Best and Hamblin, 1978; Wilson and others, 1969). Vertical displacement on the Washington fault has been estimated to range from several hundred feet (a few hundred meters) near the Virgin River, where the fault breaches the northeast-trending pre-Quaternary Virgin anticline, to 2,500 feet (760 m) at the Arizona state line (Dobbin, 1939; Cook and Hardman, 1967).

As part of this study, detailed photointerpretation and field mapping and exploration were conducted in the immediate area of the SCS Dams. The results of these investigations are discussed in detail in Chapter VIII C, D, and E of the report and shown on Figure VIII-2 (scale 1:24,000). In summary, the results of the detailed photointerpretation and field mapping and exploration in the Gypsum Wash - Warner Draw - Stucki area indicate that the Washington fault displays probable early Holocene, normal, east-side-up displacement in the vicinity of Gypsum Wash Dam.

E.3.5 Structure in the Ivins Area

The Ivins area, which includes the Ivins Bench Diversions, lies in the St. George Basin within a structural block bounded on the west by the northern extension of the Grand Wash fault (designated the Cedar Pocket Canyon - Gunlock fault in fig. E-13 and the Gunlock-Veyo fault in fig. E-9) (Cook, 1960; Dobbin, 1939; Anderson and Mehnert, 1979; Best and Hamblin, 1978) is part of a major fault zone which is mapped as extending to the vicinity of Grapevine Wash in northwestern Arizona (Wilson and others, 1969).

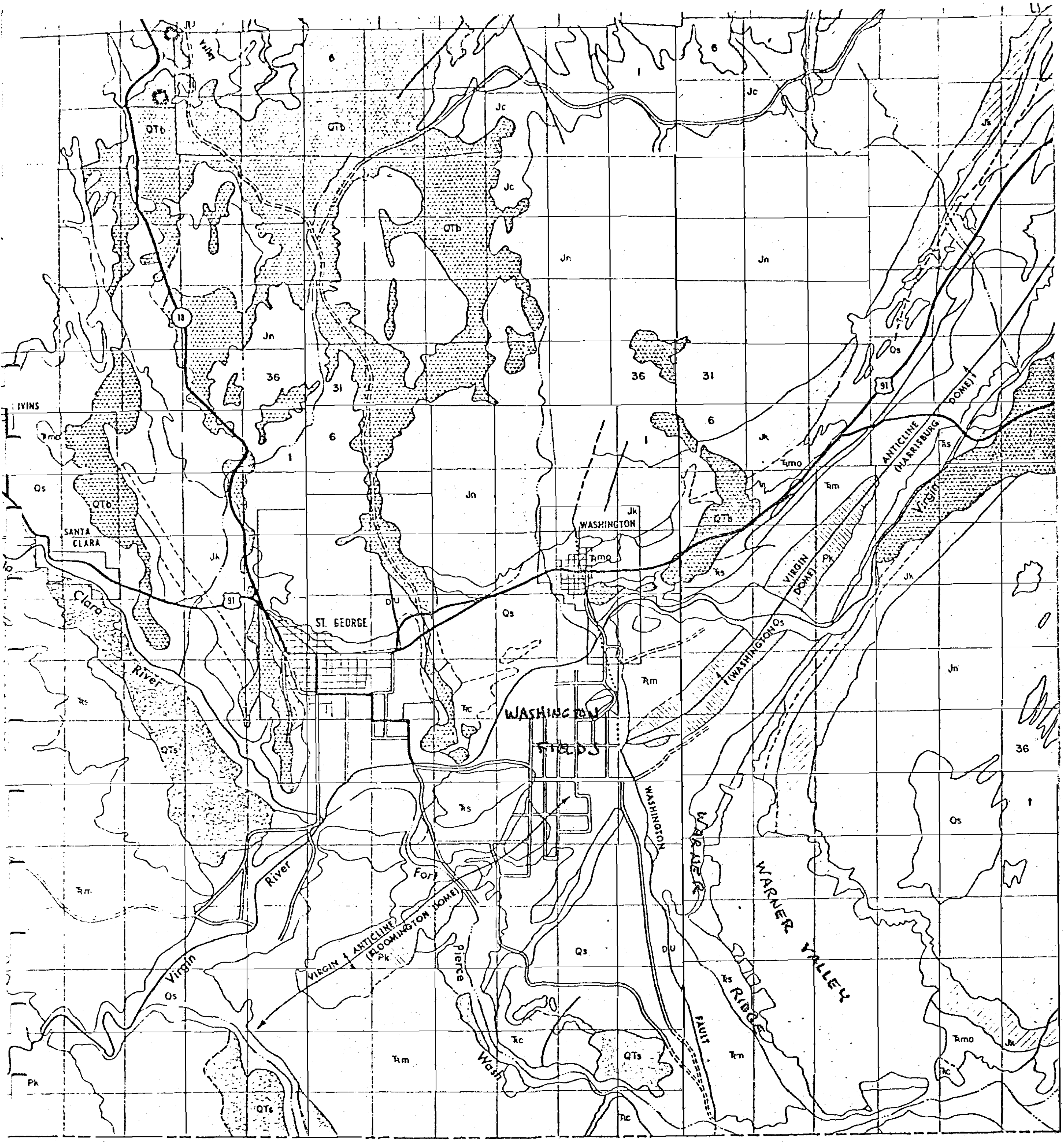
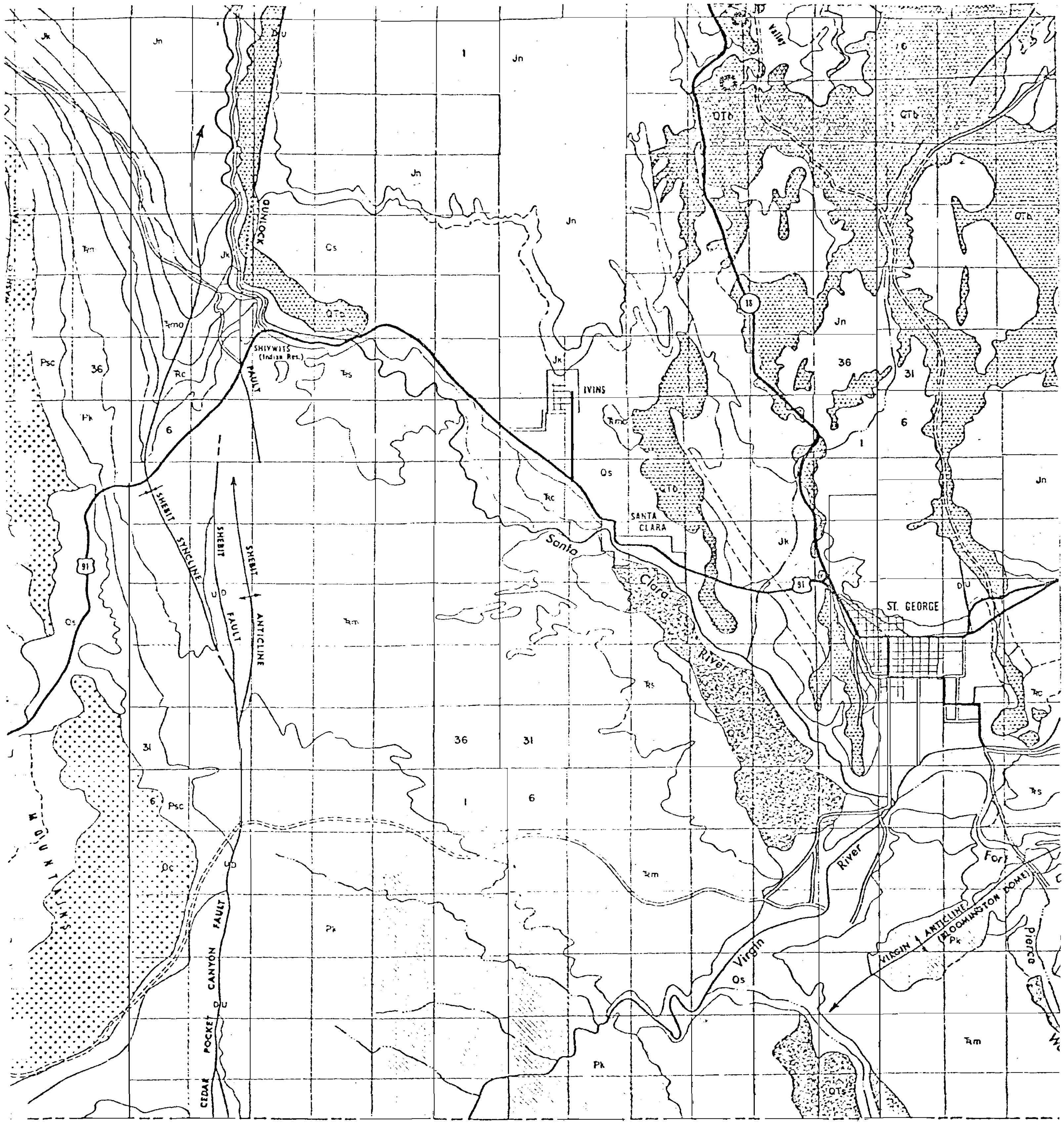


FIGURE E-12. Geological map of the area of the Washington fault east of St. George, Utah (from Cook, 1960). Section lines define scale.

The total mapped length of the Grand Wash - Cedar Pocket Canyon - Gunlock fault zone is approximately 159 km. The structural block between the Hurricane and Grand Wash faults in the St. George area has been uplifted at least 64 m/m.y. in late Cenozoic time (Hamblin and others, 1981). In addition to the Grand Wash and Hurricane faults, other faults of interest in the Ivins area include the Washington fault, located approximately 16 km east-southeast and a 20 km long zone of suspected Quaternary faulting (see Appendix F, figure F-7) traced by Anderson and Miller (1979) on the basis of unpublished mapping made available to them by W. K. Hamblin, located approximately 10 km east-northeast.

As part of this study, detailed photointerpretation and field mapping and exploration were conducted in the immediate Ivins area. The results of these investigations are discussed in detail in Chapter VIII G of the report and shown on figure VIII-4 (scale 1:24,000).



ARIZONA

FIGURE E-13. Geological map of the Ivins area northwest of St. George, Utah (from Cook, 1960). Section lines define scale.

APPENDIX F

HISTORIC SEISMICITY AND LATE QUATERNARY FAULT ACTIVITY

APPENDIX F

HISTORIC SEISMICITY AND LATE QUATERNARY FAULT ACTIVITY

FIGURES

F. HISTORIC SEISMICITY AND LATE QUATERNARY FAULT ACTIVITY

F.1 REGIONAL SEISMICITY

F.1.1 General Features

The Cedar City-St. George area lies directly within the Intermountain seismic belt (ISB) (fig. F-1), an extensive linear zone of current intraplate deformation in the western United States that is characterized by late Quaternary normal faulting, diffuse shallow seismicity, and episodic scarp-forming earthquakes ($6\frac{1}{2} \leq M \leq 7\frac{1}{2}$) (Arabasz and Smith, 1981; Smith, 1978; Smith and Sbar, 1974).

As summarized by Arabasz and Smith (1981), the notable features of the ISB are: (1) its length (>1300 km) and breadth (100-200 km); (2) its segmentation into several sectors with divergent trends; (3) the diffuseness of seismicity, with focal depths almost exclusively shallower than 15-20 km, and weak correlation with major active faults (based on dense-network monitoring with both portable and fixed microearthquake networks); (4) a general predominance of normal faulting reflecting an extensional stress regime, but with spatially rapid changes in stress orientation in some areas; (5) the common occurrence of swarm sequences at various localities throughout the ISB; (6) relatively low rates of crustal strain ($\sim 10^{-8}$ mm/mm/yr or less) compared to those at active plate boundaries; (7) moderate background seismic flux, which, for comparison is lower by a factor of 4-6 than that in the California-Nevada seismic zone (Algermissen, 1969); (8) apparent stresses that are within the range of values (0.01-100 bar) computed similarly for intraplate earthquakes elsewhere (Doser, 1980); (9) relatively long (>1000 yr) recurrence intervals for surface faulting (excepting parts of the Wasatch fault) (Swan et al., 1980; Wallace, 1980);

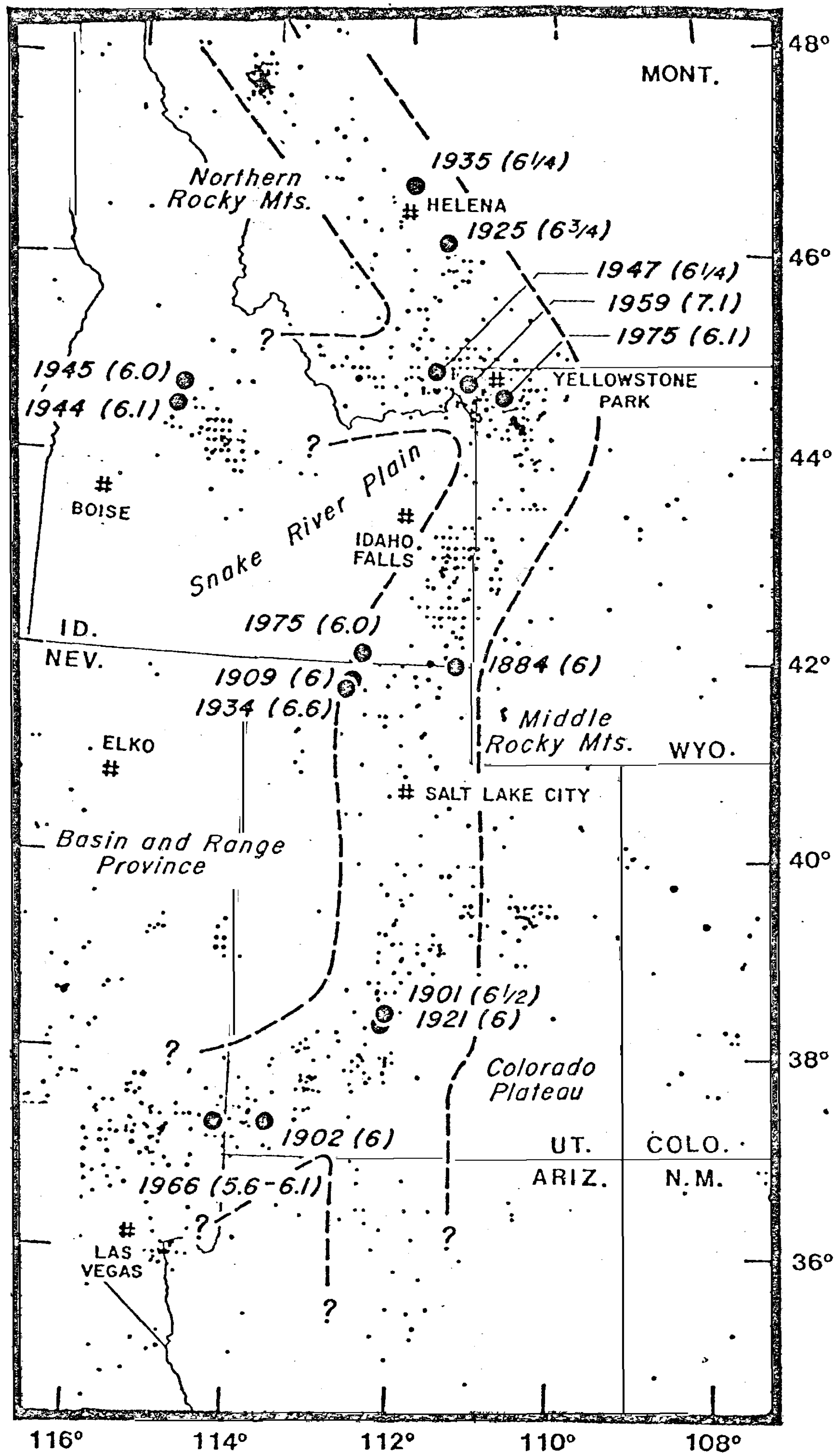


FIGURE F-1.--Map of Intermountain seismic belt (from Arabasz and Smith, 1981). Epicenters of historical mainshocks (M 6.0) shown as large circles, NOAA epicenters through 1974 as smaller circles. Schematic dashed outline of seismic belt based on various seismotectonic studies as well as depicted seismicity. Magnitudes (in parentheses) are estimated or measured values of M_L, except values for 1925-1959 (attributed to Pasadena), which are either m_b or M_s. Epicenter of 1966 shock (M_L 5.6, m_b 6.1) added for reference.

and (10) a historical paucity of large (M>7.0) surface-faulting earthquakes--despite abundant late Quaternary and Holocene fault scarps throughout the ISB (e.g., Bucknam et al., 1980; Swan et al., 1980; Witkind, 1975).

In southern Utah at about lat 38°N, there is an apparent southward bifurcation of the ISB (fig.F-1). The most active belt of seismicity extends southwestward into southern Nevada, but there is a weak continuation of seismicity southward into northern Arizona (fig.F-1). Smith and Sbar (1974) originally considered that the main ISB continued southward into Arizona, with the ENE-trending zone that passes through southern Nevada and southwest Utah as distinct. However, Smith (1978) more recently has identified the weak seismicity continuing into Arizona as part of a zone surrounding the entire Colorado Plateau, and he traces the main ISB into southern Nevada.

The branch of the ISB diverging southwestward into southern Nevada--herein referred to as the SW Utah-S. Nevada seismic zone, is without question far more seismically active than the zone continuing southward into Arizona. Earlier (Section C.1.3.5) we discussed how the SW Utah-S. Nevada seismic zone correlates with a major structural corridor (see also Anderson, 1978, p. 3)--perhaps reflecting a profound upper-mantle discontinuity (Eaton and others, 1978).

One important observation that should be emphasized with regard to figure F-1 is the absence of any historical earthquake in the southwest Utah region larger than about magnitude 6½. Here, as throughout much of the ISB, the historical paucity of scarp-forming earthquakes contrasts with abundant geologic evidence for late Quaternary faulting.

F.1.2. Historical Earthquake Record for SW Utah

To evaluate historical and instrumental seismicity in the general vicinity of the Cedar City-St. George study area, we have placed fundamental reliance on earthquake data from the University of Utah. The University of Utah Seismograph Stations has compiled the most authoritative information on the seismicity of the Utah region dating from 1850, and also carries out the most comprehensive instrumental monitoring of current seismicity in the Intermountain area (Arabasz and others, 1979, 1980; Richins and others, 1981).

The following systematic approach was taken to document seismicity in the area of interest (see figure F-2):

1. Compilation and plotting of regional seismicity, including all earthquakes of magnitude 3.0 or greater within 200 km of the study area. (For convenience, the 200-km radial distance was measured from a point half-way between Cedar City and St. George at lat 37°25'N, long 113°15'W.) These are tabulated in Appendix H.

2. Listing of seismicity ($M \geq 3.0$) within 150-km radial distance of four specific points, representative of the various dam sites (see Appendix I for partial listing):

Cedar City:	37°39.00'N,	113°04.30'W
Frog Hollow:	37°07.00'N,	113°15.30'W
St. George:	37°03.30'N,	113°29.00'W
Ivins:	37°10.30'N,	113°40.00'W

3. Compilation and plotting of the entire University of Utah earthquake catalog for the period: 1850-December 31, 1981 within a rectangular

area encompassing St. George and Cedar City (lat 36.75°N-38.00°N, long 112.00°W-114.25°W) for detailed evaluation of local seismicity (see Appendix J).

The catalog of documented earthquakes in the Utah region, as elsewhere in the western United States is a mixed one variously relying upon early reports and newspaper accounts, and later upon seismographic recordings during several stages of evolving coverage. The documentation of earthquakes pre-dating July 1962--the beginning of the University of Utah's instrumental catalog--combines both historical (i.e., based on felt reports) and early instrumental seismicity--determined for example by the U.S. Coast and Geodetic Survey or by the Seismological Laboratory in Pasadena. Arabasz and McKee (1979) outline with extensive annotations the 1850-1962 catalog for the Utah region, whose compilation involved the careful checking and correlation of numerous sources. The term "Utah region" as used by the University of Utah, signifies the rectangular area extending from lattitude 36°45'N to 42°30'N, and from longitude 108°45'W to 114°45'W--which defines the areal bounds of the University of Utah earthquake catalogs, unless specified otherwise.

The University of Utah master catalog for the Utah region comprises three parts (e.g., Arabasz and others, 1979, 1980): (1) the 1850-June 1962 historical catalog; (2) a catalog for the period July 1962-September 1974, consisting of systematically revised, instrumental earthquake locations and magnitudes; and (3) a catalog of instrumental seismicity since October 1974 based upon data from an extensive network of telemetered seismic stations. Data from the various time blocks have differing levels of uncertainty.

It should be noted that local magnitudes (M_L) for all earthquakes located in the Utah region since July 1, 1962, have been systematically estimated by either direct or indirect relation to Wood-Anderson-type torsion seismographs at three (currently two) widely spaced sites within Utah. The importance here is that a uniform earthquake catalog is essential for meaningful estimates of earthquake recurrence.

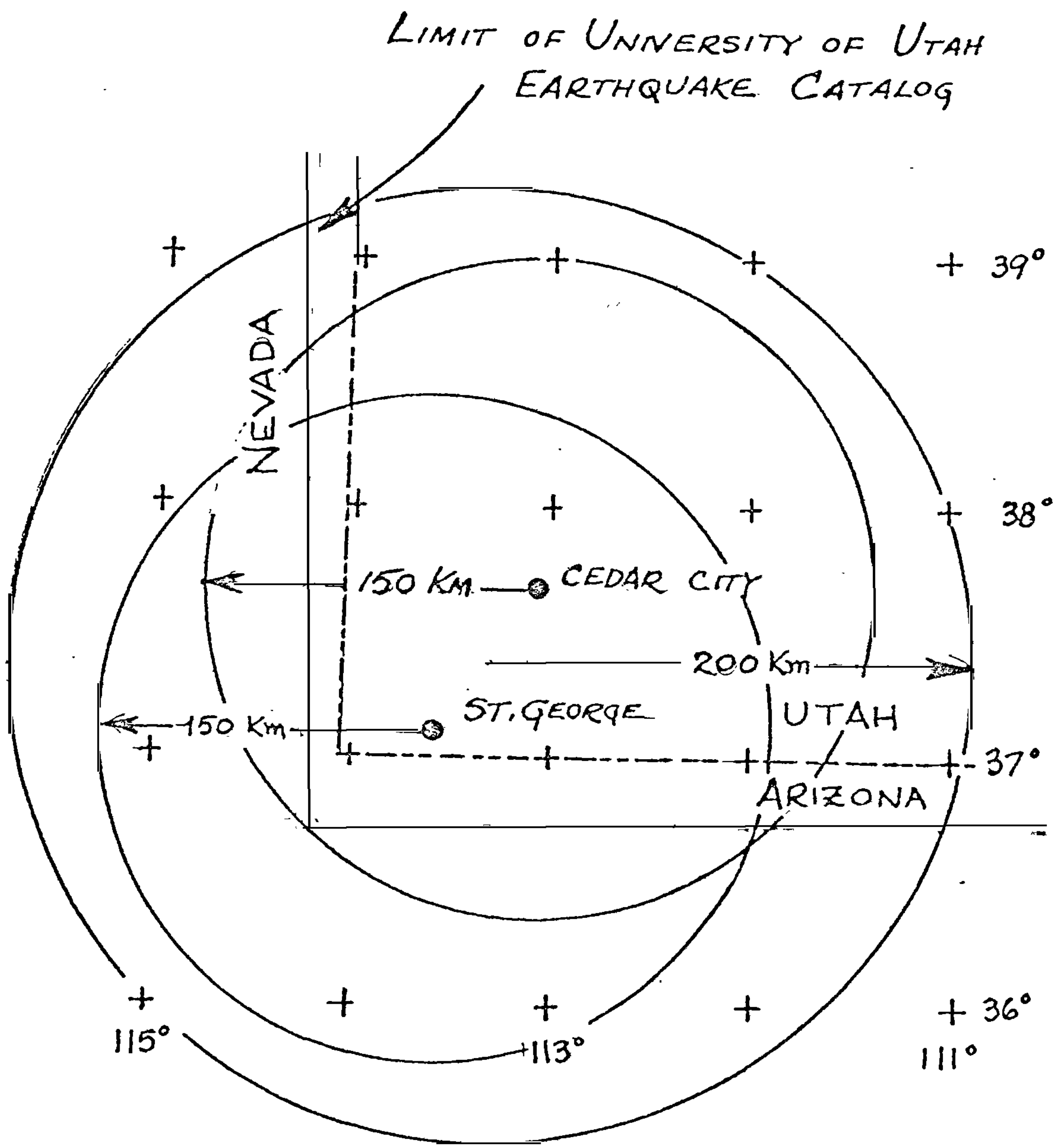


FIGURE F-2.--Schematic outline of seismicity domains related to compilations of regional seismicity in vicinity of various study areas.

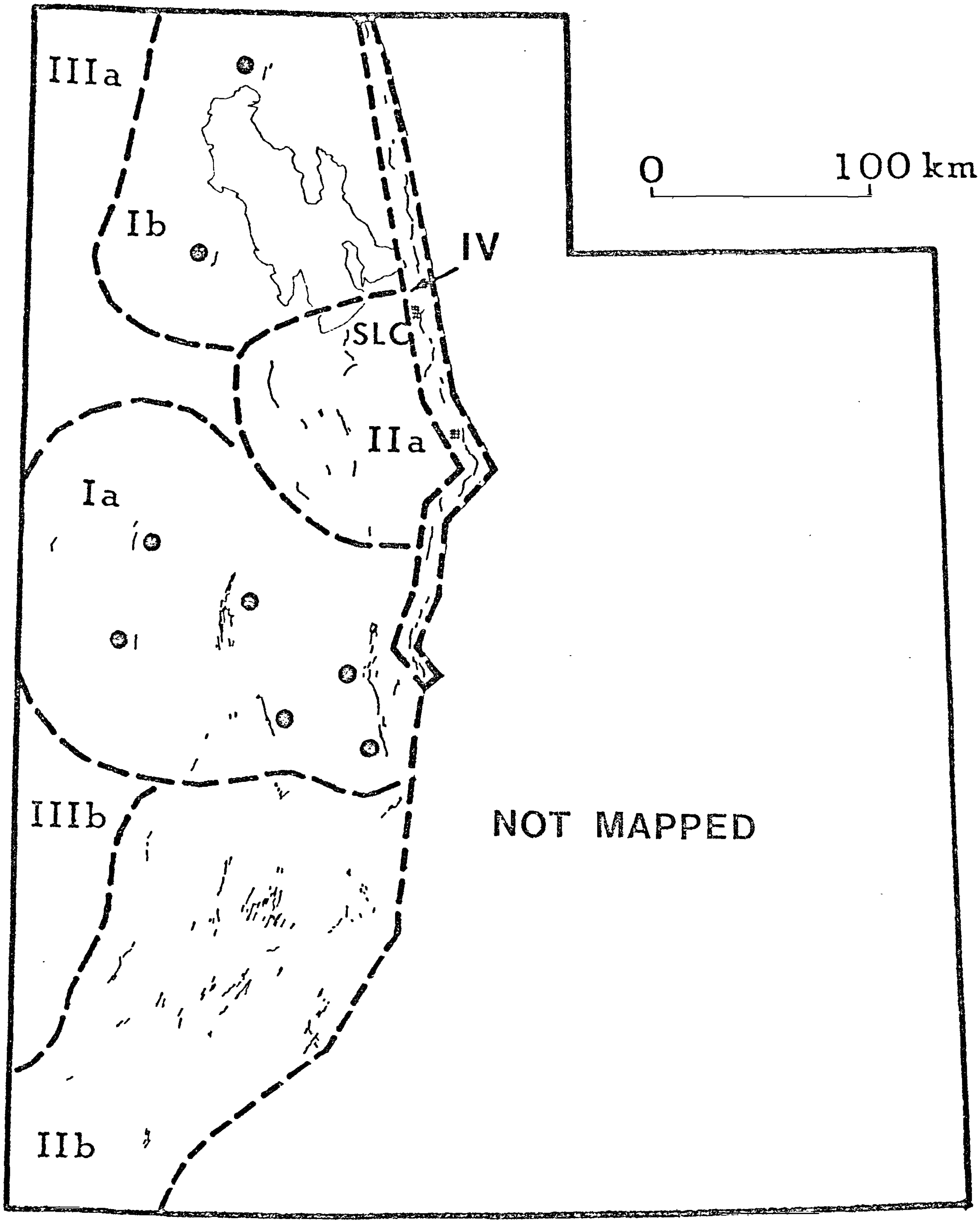


FIGURE F-8.--Map from Bucknam and others (1980) showing late Quaternary fault scarps in unconsolidated sediments (fine lines), Holocene fault scarps in unconsolidated sediments (fine lines with adjacent dot), and seismic source regions I, II, III, IV (heavy dashed lines).

TABLE F-1. LARGEST EARTHQUAKES WITHIN 200 KM OF STUDY AREA, 1850 THROUGH 1981[1]

Date (GMT)	Lat. (°N)	Long. (°W)	I_o	Magnitude (M_L)	Location	Distance (km)
1887 Dec 05	37.1	112.5	7	(5½)	Kanab, Ut.	77
1891 Apr 20	37.1	113.6	6	(5)	Washington Co., Ut. (St. George)	34
1901 Nov 14	38.8	112.1	8-9	(6½+)	Richfield, Ut.	182
1902 Nov 17	37.4	113.5	8	(6)	Pine Valley, Ut.	24
1902 Dec 05	37.4	113.5	6	(5)	Pine Valley, Ut.	24
1908 Apr 15	38.4	113.0	6	(5)	Milford, Ut.	110
1910 Jan 10	38.7	112.1	6-7	(5-5½)	Elsinore, Ut.	171
1910 Jan 12	38.7	112.1	6	(5)	Elsinore, Ut.	171
1912 Aug 18	36.5	111.5	6-7	(5½)	Williams, Ariz.	186
1921 Sep 29	38.7	112.1	8	(6)	Elsinore, Ut.	171
1921 Sep 30	38.7	112.1	7	(5½)	Elsinore, Ut.	171
1921 Oct 01	38.7	112.1	8	(6)	Elsinore, Ut.	171
1933 Jan 20	37.8	112.8	6	(5)	Parowan, Ut.	60
1934 Apr 15	38.0	115.0	-	5.0	SE Nevada	167
1942 Aug 30	37.7	113.1	6	(5)	Cedar City, Ut.	34
1942 Sep 26	37.7	113.1	6	(5)	Cedar City, Ut.	34
1945 Nov 18	38.8	112.0	6	(5)	Glenwood, Ut.	186
1952 May 24	36.1	114.7	6	5.0	Ariz.-Nev. border	195
1959 Feb 27	38.0	112.5	6	(5)	Panguitch, Ut.	93
1959 Jul 21	37.0	112.5	6	5½-5 3/4	Kanab, Ut.	81
1966 Aug 16	37.5	114.2	6	5.6	Nev.-Ut. border	80
1967 Oct 04	38.5	112.2	7	5.2	Marysvale, Ut.	158

[1]Summarized from compilation of regional seismicity ($M \geq 3.0$) within 200-km radial distance of study area. Table includes earthquakes of estimated Richter magnitude 5 or greater. I_o = maximum Modified Mercalli intensity. Magnitudes in parentheses estimated from I_o($M=1+2/3\ I_o$). Distance measured from a point half-way between Cedar City and St. George.

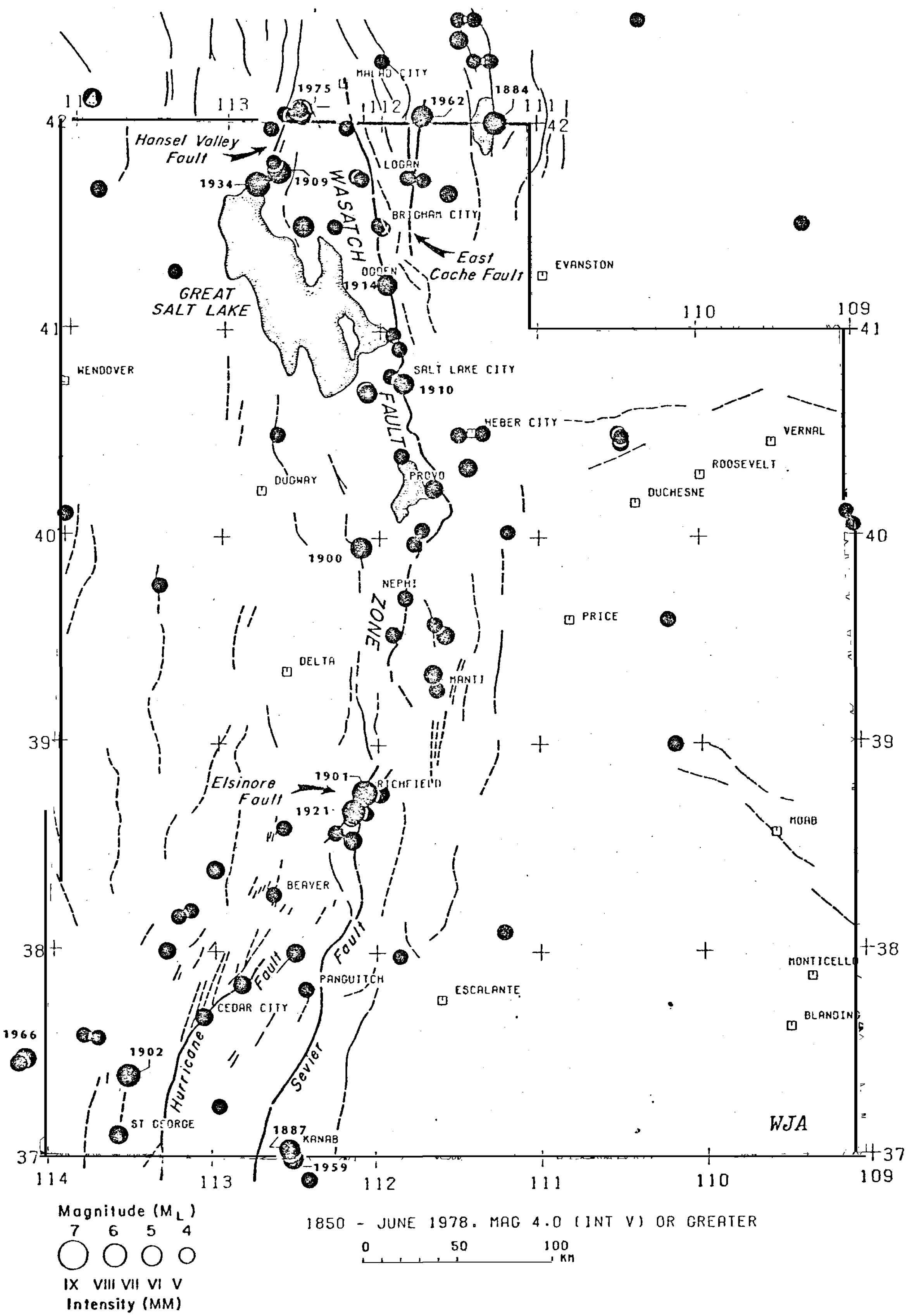


FIGURE F-3.--Epicenter map of the largest historical earthquakes in the Utah region, 1850-1978. For coincident epicenters, only the largest event is shown. Earthquakes of magnitude 5½ or greater are dated by year (see table F-1) (from Arabasz and Smith, 1979).

(3) An aftershock of the 1902 Pine Valley earthquake that occurred on December 5, 1902 (I_o=6, M_L∿5).

(4) An earthquake of January 20, 1933 (I_o=6, M_L∿5) near Parowan, 30 km northeast of Cedar City. Minor damage occurred in Parowan and Minersville (Williams and Tapper, 1953).

(5) Two earthquakes, apparently as part of a swarm sequence, near Cedar City on August 30, 1942, and September 26, 1942 (each with I_o=6, M_L∿5). Minor damage occurred in Cedar City during both of these shocks (Williams and Tapper, 1953).

F.1.2.2 Swarm Seismicity in SW Utah. Episodic earthquake swarms have been observed since the 1920's in southwestern Utah and appear to be characteristic of the area (e.g., Arabasz, 1979, p. 425; Richins and others, 1981). Earthquake swarms are a general type of earthquake sequence characterized by many events of nearly the same size without a distinct main shock, and they are common worldwide in areas of recent volcanism (e.g., Sykes, 1970).

Smith and Sbar (1974) discuss the occurrence of several earthquake swarms throughout the ISB, but they do not convey the relative abundance of swarm seismicity in southwestern Utah. As outlined in table F-2, at least seven swarm sequences with maximum magnitudes in the range of 3 to 5 have been documented in southwestern Utah since 1926.

The distribution of observed swarms in southwestern Utah is shown in figure F-4. There appears to be clustering in the vicinity of the Hurricane and Sevier fault zones; however, direct association with

TABLE F-2. SWARM SEISMICITY IN SOUTHWESTERN UTAH

Approx. Date	Location	Max. Magnitude (M_L)	References
1926-1927	Orderville	~3	(Williams and Tapper, 1953; Arabasz and McKee, 1979)
Feb-Apr 1937	Panguitch	~4-4½	(Williams and Tapper, 1953; Arabasz and McKee, 1979)
Aug-Sep 1942	Cedar City	~5	(Williams and Taper, 1953; Arabasz and McKee, 1979)
Dec '63-Feb '64	Nev.-Ut. border	3.2 (m_b 4.0)	(Smith and Sbar, 1974; Arabasz and others, 1979; "United States Earthquakes", 1963,1964)
Nov 1971	Cedar City	3.7 (m_b 4.5)	(Arabasz, 1979)
Dec 1978	Cove Fort	3.3	(Olson, 1976; Richins and others, 1981)
Dec '80-May '81	Kanarraville	4.5	(Richins and others, 1981)
Mar 1981	Panguitch	2.3	(Richins and others, 1981; Univ. of Utah unpub. data)
Jun-Aug 1981	Mineral Mts.	1.5-2.0 (>1,000 shocks)	(G. Zandt, Univ. of Utah, unpub. data)

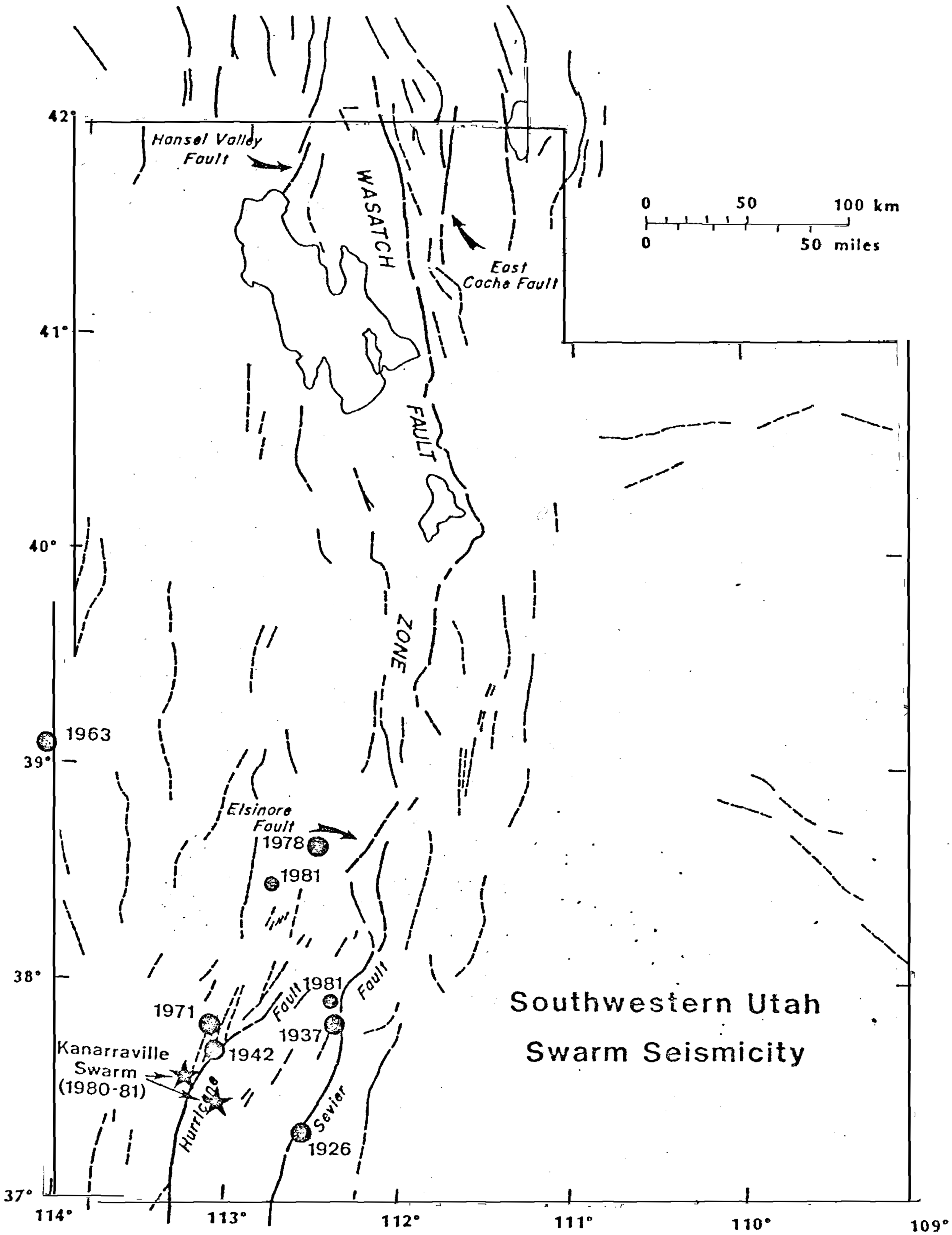


FIGURE F-4.--Location map of documented earthquake swarms in southwest Utah (see table F-2) (from Richins and others, 1981).

these faults has yet to be established (see Section F.2.2). A more general association of most of the swarm seismicity might be made with a broad zone of late Cenozoic volcanism in southwestern Utah, along the Basin and Range-Colorado Plateau transition zone (cf. Best and Hamblin, 1978, fig. 14-7).

F.1.3 Detailed Instrumental Seismicity in SW Utah

Figure F-5, from Arabasz and others (1979) gives an overview of the instrumental seismicity of the Utah region since 1962. A larger scale epicentral plot, complete through December 31, 1981, is presented in figure F-6 for a rectangular region encompassing the Cedar City-St. George study area.

A persistent feature of the seismicity of southwestern Utah (fig. F-5) is a broad band of diffuse, but locally intense, seismicity trending to the southwest below about lat 38.5°-39°N and extending into southern Nevada to form the SW Utah-S. Nevada seismic zone (Smith and Arabasz, 1979; Richins and others, 1981). Cedar City lies within the central, most seismically active part of this belt, whereas St. George lies along its southern fringe. Diffuse seismicity and problematic correlation of seismicity with the traces of major active faults is typical throughout the ISB (Arabasz and Smith, 1981). Perhaps the most striking example of this in the Utah region is the persistent low level of earthquake activity along most of the trace of the major Wasatch fault zone in central and north-central Utah (fig. F-5; Arabasz and others, 1980). In southwest Utah, the scattered occurrence of earthquake swarms contributes to the regionally diffuse epicentral pattern. Significantly, the general NE-SW trend defined by the diffuse seismicity transects the NNE-trending structural grain of the region.

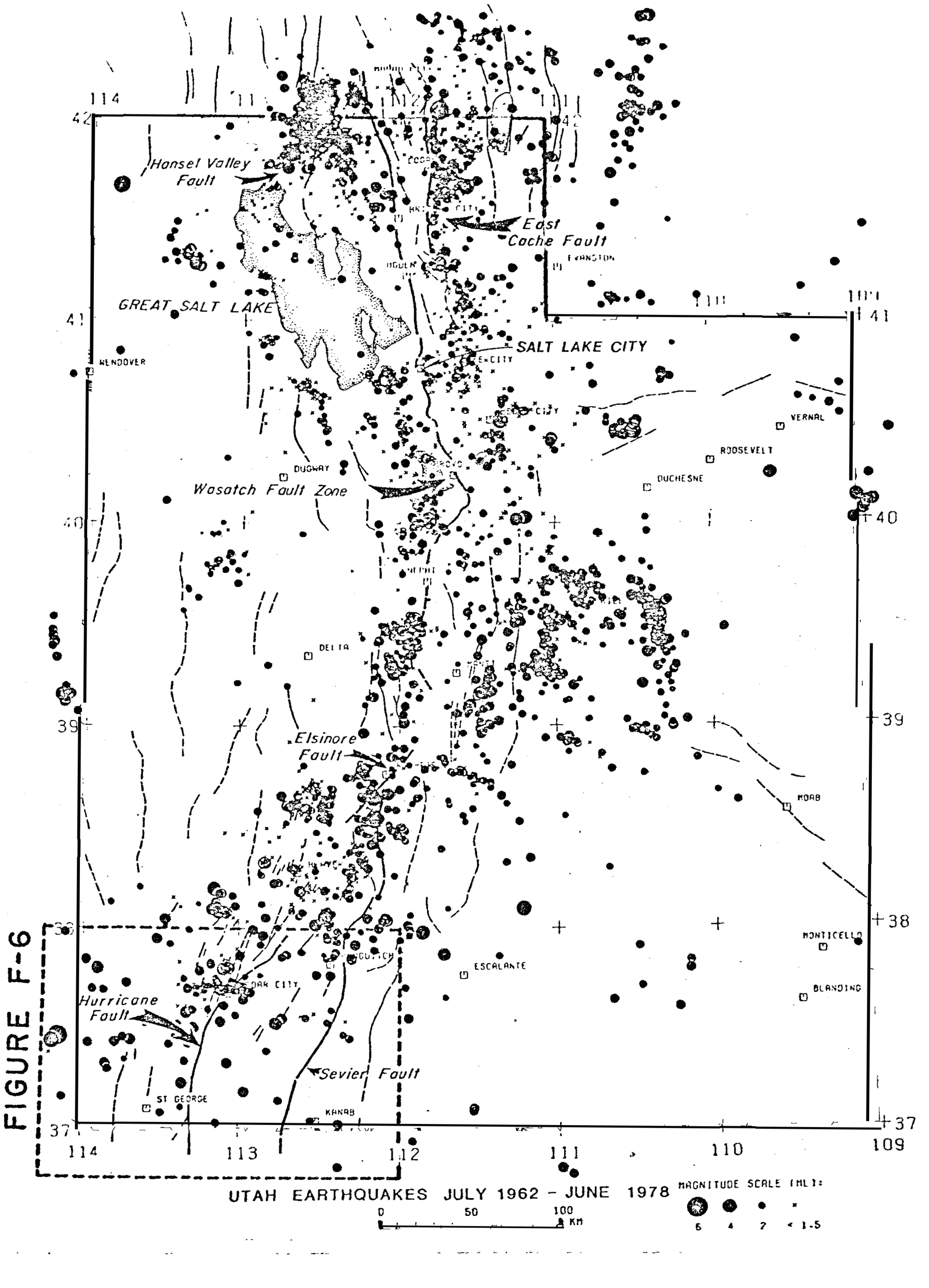
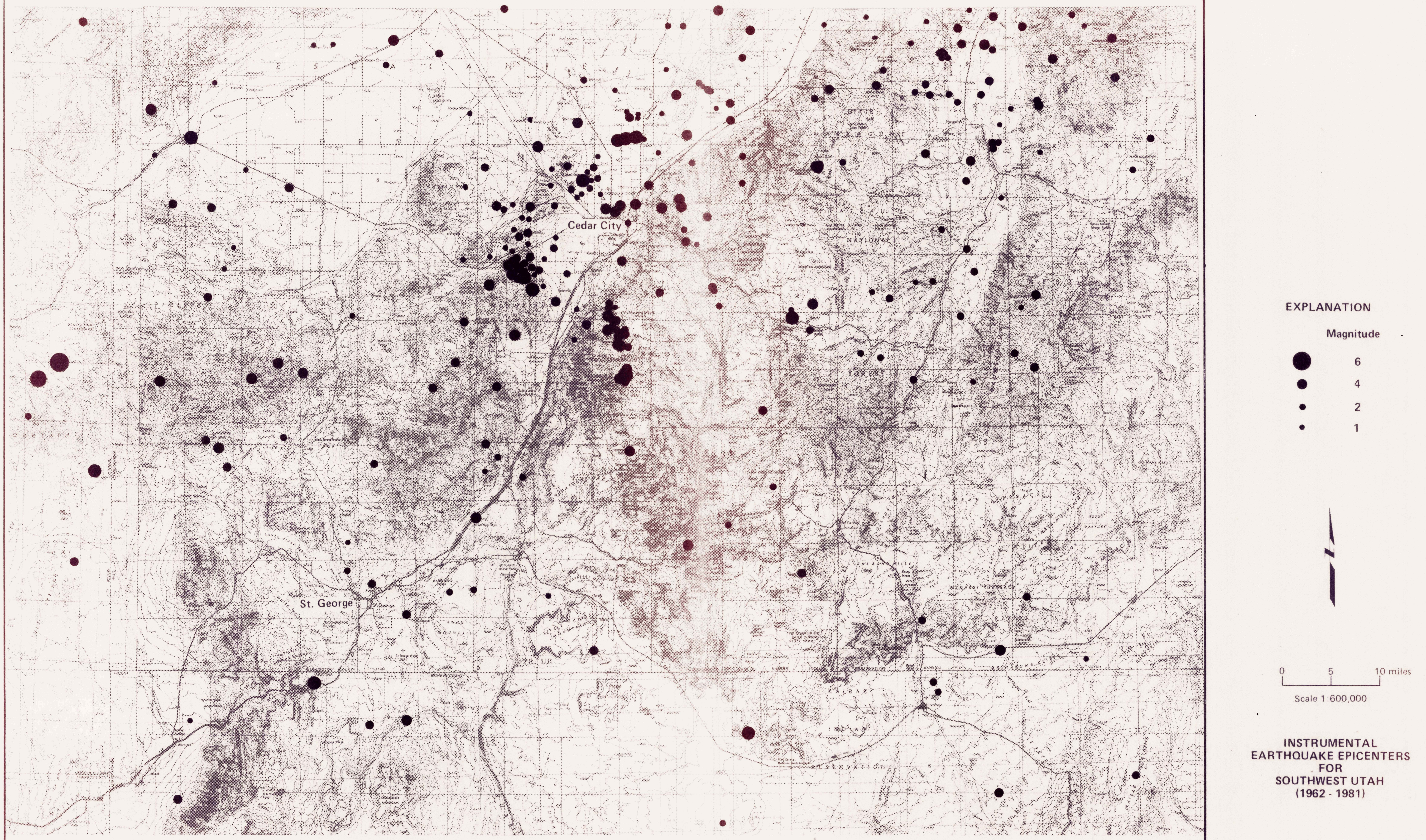


FIGURE F-5.--Epicenter map of the Utah region, July 1962-June 1978 (from Arabasz and others, 1979). Dashed box shows location of Figure F-6.

In the large-scale plot of the Cedar City-St. George area (fig. F-6), instrumental seismicity determined by the University of Utah is plotted for the period from July 1, 1962 to December 31, 1981. Before analyzing details of the epicentral patterns, some preliminary comments on the completeness and quality of earthquake locations in southwest Utah are appropriate (see Arabasz and others, 1979, p. 83, 119; Richins and others, 1981).

Prior to July 1962, earthquake epicenters in southwest Utah were based chiefly on felt reports and are assumed to have an accuracy of about ±25 to ±50 km. Assigned epicenters for non-instrumental locations correspond to the location of a town or city where felt effects were strongest. The availability of felt reports at widely distributed small towns tends to constrain the location of most of the pre-instrumental earthquake locations, particularly those of small magnitude (M_L<4). For the post-1962 period, instrumental locations greatly improve the accuracy of earthquake locations. However, the fairly wide spacing (mostly greater than 50 km) of seismograph stations in southwest Utah--even through 1981 (see Arabasz and others, 1979; Richins and others, 1981)--limits the precision with which earthquakes in the area can be located. Accuracy and precision are certainly lower than in other more densely instrumented areas of the Utah region such as the Wasatch Front area.

For the Wasatch Front area, epicentral precision is estimated as ±5 and ±2 km for the 1962-1974 and post-1974 periods, respectively (Arabasz and others, 1979). For southwestern Utah, precision expectedly would be less--



INSTRUMENTAL
EARTHQUAKE EPICENTERS
FOR
SOUTHWEST UTAH
(1962 - 1981)

FIGURE F-6

perhaps at best about ±10 km and ±5 km for the same two instrumental periods. Richins and others (1981) estimate an epicentral precision of ±2 km for the earthquake locations near Kanarraville in 1981 as a result of special data processing.

The majority of earthquakes plotted in figure F-6 have been located with a restricted focal depth of 7.0 km. Reasonably accurate resolution of focal depth requires a recording station to be roughly as close as the depth of the earthquake--a condition not generally met in southwest Utah.

Post-1962 instrumental earthquake locations in southwest Utah are believed to be systematically complete above about magnitude (M_L) 2.5 (Arabasz and others, 1979; Richins and others, 1981).

Notable features of the intrumental seismicity depicted in figure F-6 include the diffuse scatter of epicenters, the greater abundance of earthquakes in the northern half of the sample area compared to the southern half, and a significant temporal clustering of earthquakes (evaluated from corresponding listings). An area within about 25 km radius of Cedar City displays abundant earthquake activity during the 1962-1981 period.

Earthquakes during the 1962-1974 period were widely scattered throughout the sample area. The largest shock was an event of magnitude (M_L) 5.6 (m_b=6.1) that occurred on August 16, 1966 close to the Nevada-Utah border at the western extremity of the sample area (see Smith and Sbar, 1974). The most significant temporal clustering during this time period was associated with the November 1971 Cedar City earthquake swarm

(Arabasz, 1979). Thirteen of the circles clustered immediately to the north of Cedar City correspond to located earthquakes ($2.1 \leq M_L \leq 3.7$) associated with that swarm.

Earthquakes during the 1974-1981 period scatter throughout the sample area, but the sample for this time period is dominated by intense clustering to the northeast and southeast of Kanarraville--associated with an earthquake swarm ($M_L \leq 4.5$) during the period December 1980-May 1981 (Richins and others, 1981). We discuss this earthquake sequence further in Section F.2.2.

Clustering to the northwest and southeast of Panguitch also relate to an earthquake swarm--a sequence in March 1981 ($M_L \leq 2.3$) that displayed the same curious pattern of paired epicenter clusters observed for the Kanarraville swarm (Richins and others, 1981). Earthquakes in the St. George area are clearly less abundant than to the north. The largest shock in the immediate vicinity of St. George during the entire 1962-1981 period was an earthquake of magnitude (M_L) 3.6 on August 5, 1979, about 15 km southwest of St. George.

F.2 SEISMOTECTONICS AND EARTHQUAKE HAZARD EVALUATION

F.2.1 Implications of Current Geological Studies

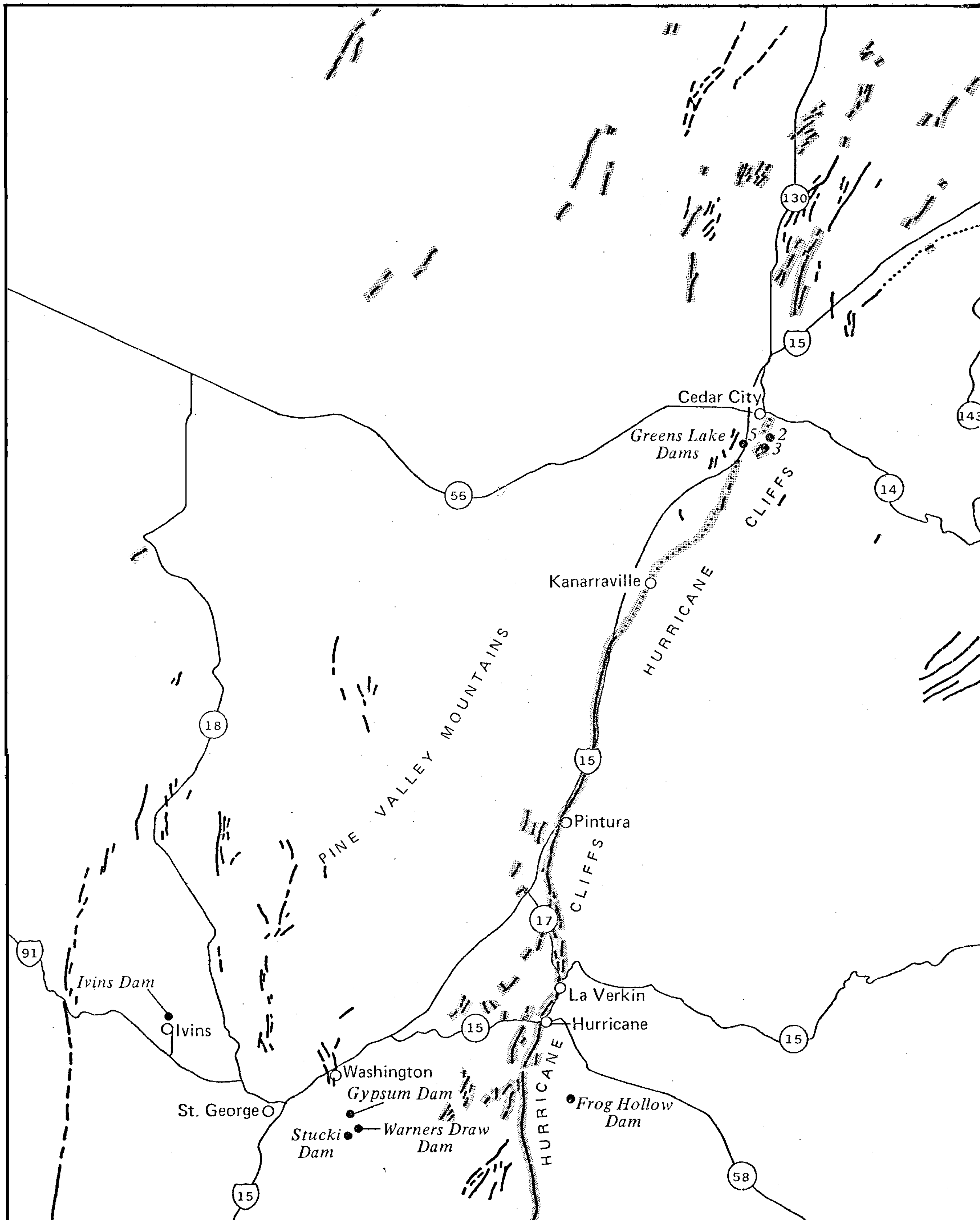
Since about 1975, as part of the National Earthquake Hazards Reduction Program, the U.S. Geological Survey (USGS) has carried out active geological studies in the Utah region aimed at earthquake hazard evaluation. Of particular relevance to this study is a USGS project entitled "Southwestern Utah seismotectonic studies," headed by R. E. Anderson; the goals of the project are: "(1) to define the distribution in space and time of Quaternary faulting and deformation in southwestern Utah and (2) to provide an improved understanding of the late Cenozoic tectonic history and framework of the area" (Anderson, 1981).

R. E. Anderson and R. C. Bucknam of the USGS have jointly carried out mapping of late Quaternary fault scarps in unconsolidated deposits throughout western and southwestern Utah, systematically covering $1^{\circ} \times 2^{\circ}$ quadrangles (see Anderson, 1980). Unfortunately, no compilation for the Cedar City $1^{\circ} \times 2^{\circ}$ sheet (1:250,000 scale), which encompasses the Cedar City-St. George area, is yet available. However, abundant information is directly relevant to the seismotectonics of the study area has been published by R. E. Anderson, R. C. Bucknam, and colleagues at the USGS (e.g., Anderson, 1978, 1979, 1980, 1981; Anderson and others, 1978; Anderson and Mehnert, 1979; Anderson and Bucknam, 1979; Bucknam and Anderson, 1979; Bucknam and others, 1980; and Zoback and others, 1981). Much of this section involves a distillation of on-going USGS work to identify key information relevant to the present SCS project.

F. 2.1.1 Identification of Active Faults. Although results of current USGS fault studies in the Cedar City - St. George area are not yet available in regional map form, the "Quaternary Fault Map of Utah" (1:500,000 scale) recently compiled by L. W. Anderson and D. G. Miller (1979) provides the following preliminary summary, which is modified as noted by the results of the detailed photogeology and geological field work carried out as part of this project and discussed in detail in Chapters IV and VIII of the report and Appendix E.3.2.5.

Figure F-7 shows part of the Anderson and Miller (1979) fault map relevant to the present study indicating fault traces associated by Anderson and Miller with either late Pleistocene (10,000 to about 500,000 yr B.P.) movement or suspected Quaternary (0 to about 2 or 3 m.y. B.P.) movement. No Holocene (<10,000 yr B.P.) faulting was indicated in the study area before trench exposures developed during this study were examined (see Chapter VIII of this report).

The main active faults shown in figure F-7 are the northernmost part of the Grand Wash fault (comprising segments variously named the Cedar Pocket Canyon fault and the Gunlock-Veyo fault) and the Hurricane-Parowan fault system. Fault traces of probably late Pleistocene age that are indicated in the northern part of figure F-7 in the Escalante Desert region displace Quaternary basalts and alluvial deposits, and are based on personal communications to Anderson and Miller (1979) by W. K. Hamblin and R. E. Anderson. Only the northwesternmost part of the Washington fault near the town of Washington is indicated in figure F-7 as being active during the Quaternary, although subsurface exploration conducted as part of this study across the fault at Gypsum Wash Dam revealed probable early Holocene faulting (see Appendix E.3.4 and Chapter VIII).



0 5 miles

Scale 1:500,000

Shading indicates Pleistocence faulting; other traces, suspected Quaternary faults.

From: *Geologic Map of Utah*, by Lehi F. Hintze, 1980.

Earth Sciences Associates

Palo Alto, California

SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

MAP OF QUATERNARY FAULTING IN CEDAR CITY – ST. GEORGE AREA

Checked by RY [illegible]	Date 27/may/82	Project No. D118	Figure No. F-7
Approved by E A Nelson	Date 27 May 82		

F.2.1.2 Late Quaternary Versus Holocene Faulting. A critical problem prior to the current study was whether there is convincing evidence anywhere in the study area for Holocene faulting (i.e., the occurrence of scarp-forming earthquakes during the last 10,000 years). The absence of any historic surface rupture in southwest Utah has led to emphasis on Quaternary studies relating to the geomorphic evolution of fault scarps (Anderson, 1978; Bucknam and Anderson, 1979), Lake Bonneville history and its correlation with glacial deposits and soil stratigraphy (Anderson and Bucknam, 1979), and the stratigraphy of faulted Quaternary extrusive rocks (Hamblin and others, 1981).

Published statements by R.E. Anderson (1978, p. 5; 1978a) indicating Holocene faulting northeast of Cedar City relate to a graben structure at Braffits Creek (see fig. F-7) which Anderson has subsequently interpreted as a tensional collapse structure along the rising and spreading mountain front of the eastern Markagunt Plateau (Anderson and Bucknam, 1979; Anderson, 1980, p. 528). Another area of probable Holocene deformation in southwestern Utah described by Anderson and Bucknam, 1979) is in Escalante Valley, more than 30 km northwest of Cedar City, where Lake Bonneville shorelines have been deformed by regional uplift. Anderson (1980, p. 525) also describes deformation within the Enoch graben, about 10 km north-northeast of Cedar City (see fig. F-7), where Holocene faulting may have occurred; however, the interpretation of faulting is equivocal.

At Shurtz Creek to the south of Cedar City (see fig. F-7) there is a prominent alluvial scarp along the trace of the Hurricane fault that may not be much older than Holocene in age. Anderson (1980), p. 536) summarizes the following key information:

"Averitt (1962) described and illustrated a conspicuous scarp at the mouth of Shurtz Creek about 8 km south-southwest of Cedar City. The scarp is at least 20 m high, is formed on very coarse bouldery alluvium, has a slope angle of 29°, and is deeply incised by active streams. On the basis of its profile, the scarp appears to be pre-Holocene, but its age is probably close to the Pleistocene-Holocene boundary. The surface that is displaced at this scarp was referred to by Averitt (1962) as the Schurtz Creek pediment. Recent studies have shown that the Quaternary gravels that mantle the pediment serve as parent material for a soil that is definitely pre-Holocene and is probably more than 50,000 years old."

A second, more subdued and probably older scarp in alluvial fan deposits located upslope to the east of this location was identified during this investigation (see Chapter IV and figure IV-2).

Bucknam and others (1980) have summarized the results of USGS studies of late Quaternary faulting in western and southwestern Utah, including a preliminary map of seismic source zones defined on the basis of geologic data. That source zone map is reproduced here as figure F-8. (Note that the fault scarps shown in the figure are only those formed in unconsolidated deposits.) Most of southwestern Utah lies within seismic zone IIb (fig. F-8) defined by "the occurrence of late Quaternary fault scarps and the absence of Holocene fault scarps" (Bucknam and others, 1980, p. 304). Adjacent region IIIb is defined by the absence of fault scarps in unconsolidated deposits, whereas region Ia is characterized by abundant Holocene fault scarps. Faults at Braffits Creek and near Enoch are not included in the compilation because of major uncertainties; the interpretation of faulting within the Enoch graben is equivocal, and faulting at Braffits Creek may be associated with an aseismic style of deformation (Anderson, 1980; Bucknam and others, 1980).

In the absence of definitive dates on samples of materials offset by fault traces exposed in trenches excavated as part of this study, the characterization of most of southwestern Utah as without Holocene faulting must be considered a working hypothesis; it seems to be consistent with the morphology of fault scarps encountered in the area (e.g., Bucknam and Anderson, 1979; Anderson, 1980, 1979). The position of USGS workers such as R. E. Anderson remains that unless it can be proven that dated Holocene sedimentary strata have been faulted, the assignment of a Holocene age to any

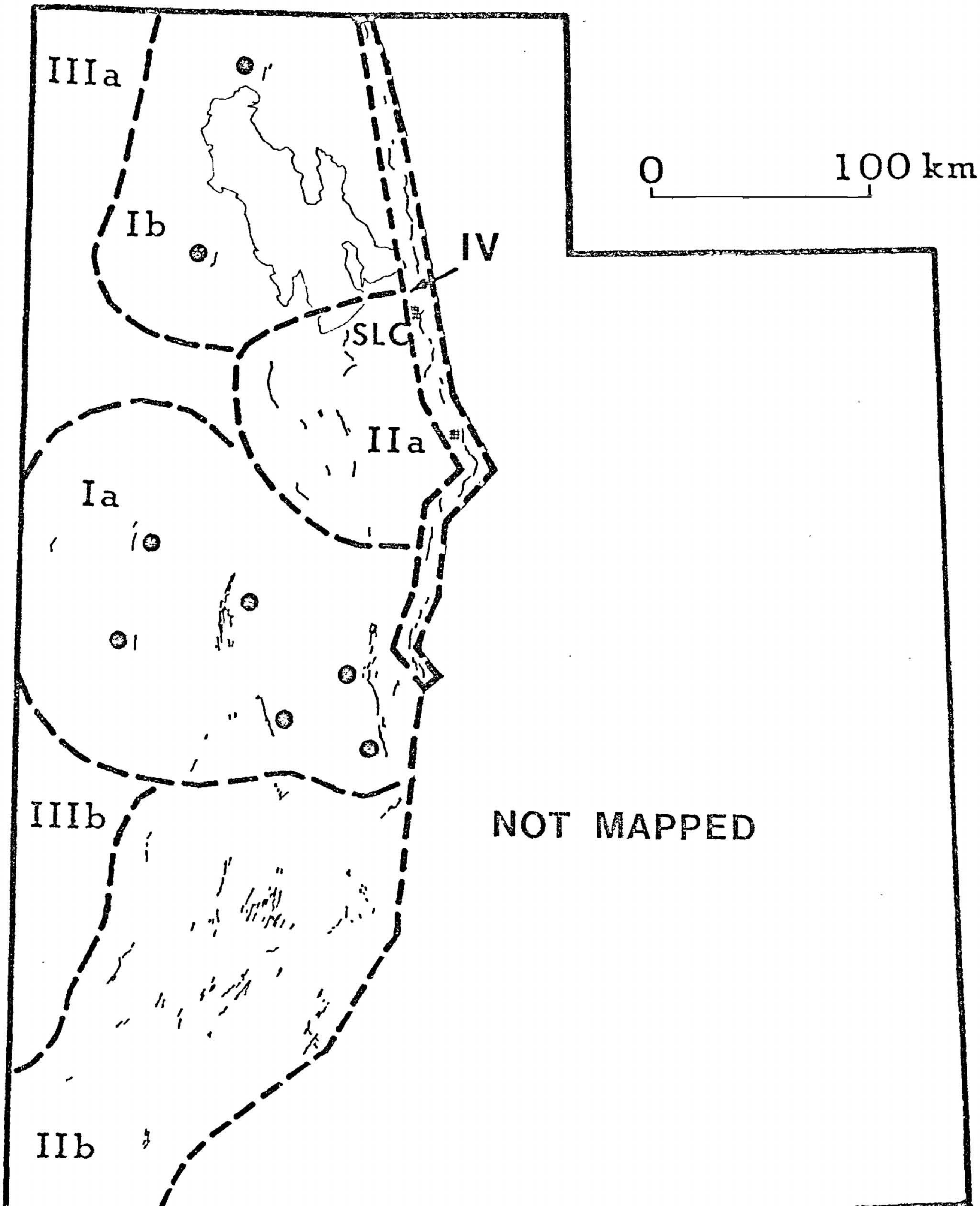


FIGURE F-8.--Map from Bucknam and others (1980) showing late Quaternary fault scarps in unconsolidated sediments (fine lines), Holocene fault scarps in unconsolidated sediments (fine lines with adjacent dot), and seismic source regions I, II, III, IV (heavy dashed lines).

faulting in southwestern Utah should be considered uncertain (e.g., see Anderson, 1979, and Huntoon, 1979).

It should be emphasized that the absence of Holocene faulting in southwestern Utah, if valid, does not imply no likelihood of a future scarp-forming earthquake in that region. Fault-scarp data in region IIb (fig. F-8) over the last 100,000 years or so lead to the expectation of about two earthquakes in the magnitude range 7-7½ somewhere in region IIb during Holocene time--and the apparent absence of any such event is not rigorously inconsistent with a Poisson process (Bucknam and others, 1980). Bucknam and others (1980, p. 306) conclude: "We believe that the observed [relatively high rate of] historic seismicity of the region IIb is consistent with strain release primarily by numerous relatively small earthquakes and comparatively infrequent large events (M = 7.0 to 7.6)."

F.2.2 Implications of Current Seismological Studies

F.2.2.1 Listric Faulting and Problematic Correlation of Seismicity With Geologic Structure. Critical problems facing earthquake researchers in the Utah region include uncertainties about the subsurface structure of major normal fault zones in the area, the correlation of diffuse seismicity with geologic structure, and evaluation of the relative importance of low-angle, listric (downward-flattening) normal faulting (see Figure F-9) as part of the seismogenic process (Arabasz and Smith, 1981).

During the past few years, seismic reflection surveys have been conducted in seismically active areas of the Intermountain region as part of oil industry efforts to explore and extend knowledge of the foreland "overthrust belt" into the Great Basin (e.g., MacDonald, 1976; Royse and others, 1975; Effimoff and Pinezich, 1981). New high-resolution seismic reflection data indicate that the seismogenic upper 10 km of the crust along the Intermountain seismic belt is more deformed than previously envisaged, and the style of normal faulting is more complicated than perceived from surface mapping. Converging evidence suggests that the structural style along the eastern Great Basin is that of "thin-skinned" tectonics involving low-angle detachment surfaces. Low-angle thrust faults, formed during the Sevier and Laramide orogenies fundamentally influenced the development of Cenozoic basin-range structure, and pre-Cenozoic low-angle faults may now be accommodating normal dip-slip displacement in an extensional stress field (Arabasz and Smith, 1981; Arabasz, 1981; Smith, 1981).

Older low-angle faulting in parts of the Great Basin, including the study area (Anderson, 1981) resulted from a pre-basin-range extensional episode in about Miocene time. The important point here is that active normal faults mapped at the surface within the study area probably do not have a simple subsurface geometry, and the deformational behavior of these faults is poorly understood. For example, little information is available about the subsurface geometry of the Hurricane fault. However, conspicuous reverse-drag flexing of basin-fill strata observed along the Hurricane fault (Hamblin, 1965; Hamblin and others, 1981) is now known to typify downward-flattening listric normal faults (e.g., Anderson and Zoback, 1981). Confidential data acquired by Mobil Oil Corporation suggests that the Hurricane fault probably is listric at depth (R.E. Anderson, personal communication to W.J. Arabasz, January 1982).

Complicated upper-crustal structure undoubtedly has a fundamental bearing on the significance of diffuse background seismicity in the Intermountain seismic belt and on how infrequent large earthquakes are generated in the area. California-type models that assume high-angle faulting and the planar clustering of small-magnitude earthquakes on simple fault planes clearly are inapplicable to southwest Utah.

Recent detailed microearthquake studies in central and south-central Utah (Arabasz, 1981; see fig. F-9) suggest that diffuse seismicity in areas where listric normal faulting has been identified in the subsurface does not simply reflect seismic slip on low-angle normal faults; rather, seismic slip seems to predominate on relatively high-angle fracture planes--either the upper portion of west-dipping downward-flattening faults, related east-dipping antithetic faults, or moderately dipping secondary faults within the major fault blocks. Research on such problems is underway, but is still in an early stage.

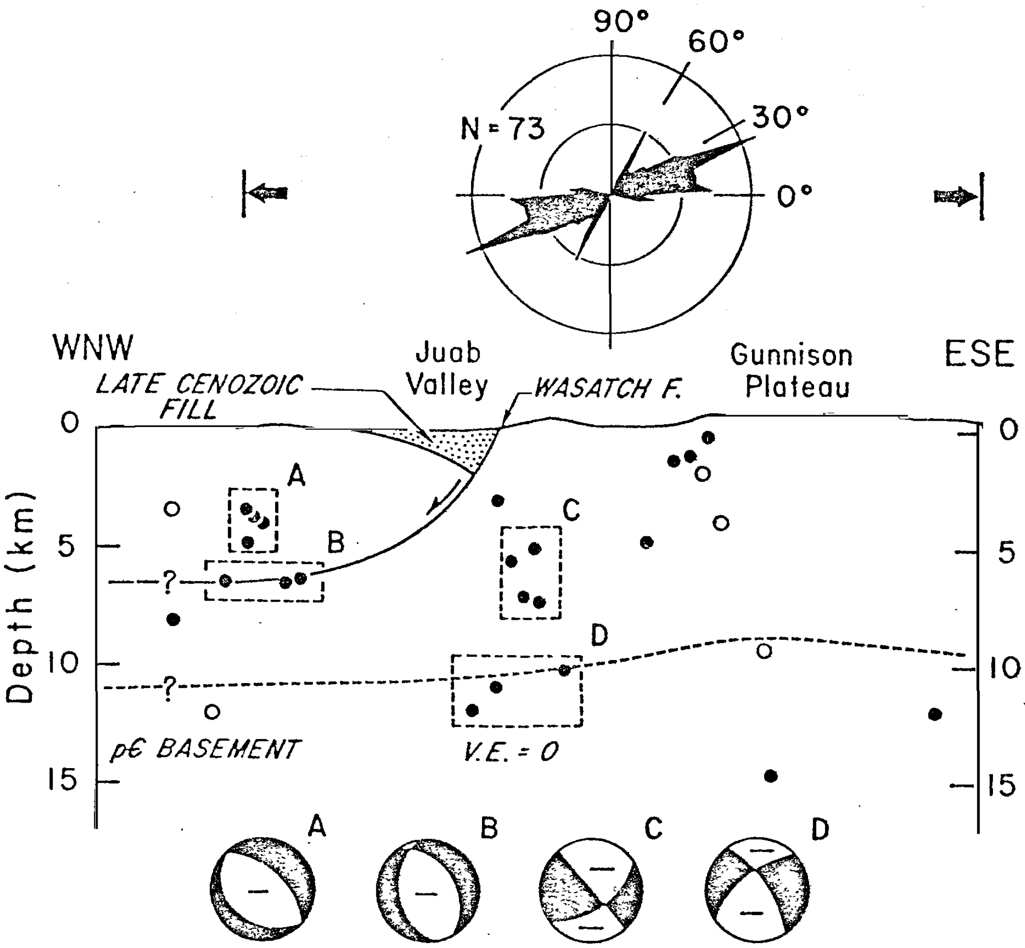


FIGURE F-9.--Cross-section depicting results of detailed study of microseismicity, focal mechanisms, and correlation with geological structure near the southern end of the Wasatch fault (from Arabasz, 1981). Earthquake hypocenters, shown as small circles (open for lesser quality), are from field study by McKee and Arabasz (1981). Geology adapted and "sanitized" from confidential oil-company information. Rose diagram in upper part of figure summarizes fault dips from subsurface structure chiefly deleted from diagram. Faults within area of section delineated by heavy arrows were discretized into 1-km-long segments, and the average orientation of the discrete segments was then measured and summarized. Focal mechanisms A, B, C, and D were determined for clustered hypocenters in the correspondingly labeled boxes by iteratively inverting SV/P amplitude ratios (Kisslinger et al., 1981)--with constraints from P-wave first motions. Despite the predominance of low-angle faulting inferred by oil-company scientists in the subsurface, the focal mechanisms do not indicate seismic slip on low-angle (listric) faults. Focal mechanisms are lower-hemisphere projections, equatorial plane.

F.2.2.2 Implications of Swarm Occurrence. A recent earthquake swarm sequence ($M_L \leq 4.5$) occurred during December 1980-May 1981 near Kanarraville, 20 km southwest of Cedar City, and was studied in detail by Richins and others (1981a). Epicenters located to an estimated precision of $\pm$ 2 km by a joint-hypocenter-determination technique (e.g., Dewey, 1979) separate into two clusters, 5-10 km northwest and southeast, respectively, of the main trace of the Hurricane fault (fig. F-10). During the swarm there was a temporal migration of activity from the southwest cluster to the northwest cluster involving "the complete cessation of earthquakes ($M_L \leq 1.5$) in the first cluster prior to activation of the second cluster 10 days later" (Richins and others, 1981a).

The Kanarraville earthquake sequence typifies swarm seismicity characteristic of southwest Utah (see Section F.1.2.2) as well as the absence of any clear correlation with mapped geologic structure. Richins and others (1981a) interpret that the sequence reflects deformation on subsidiary structures, related in some complicated way to the Hurricane fault.

The tectonic significance of swarm seismicity in southwest Utah is poorly understood. One might argue that the apparent predominance of swarm seismicity--with maximum events of only moderate size (M_L 4½ to 5)-- perhaps diminishes the likelihood of large mainshock earthquakes in this area. Such a position would be difficult to maintain in view of geological evidence for large, albeit infrequent, earthquakes (see Section F.2.1). Dewey and others (1973) caution that swarm-producing tectonic conditions may be highly localized and do not necessarily exempt a site from large "non-swarm" earthquakes nearby. For example, they note that a magnitude 6 3/4 earthquake occurred in 1925 east of Helena, Montana, only 60 km from areas such as Flathead Lake, Montana, and

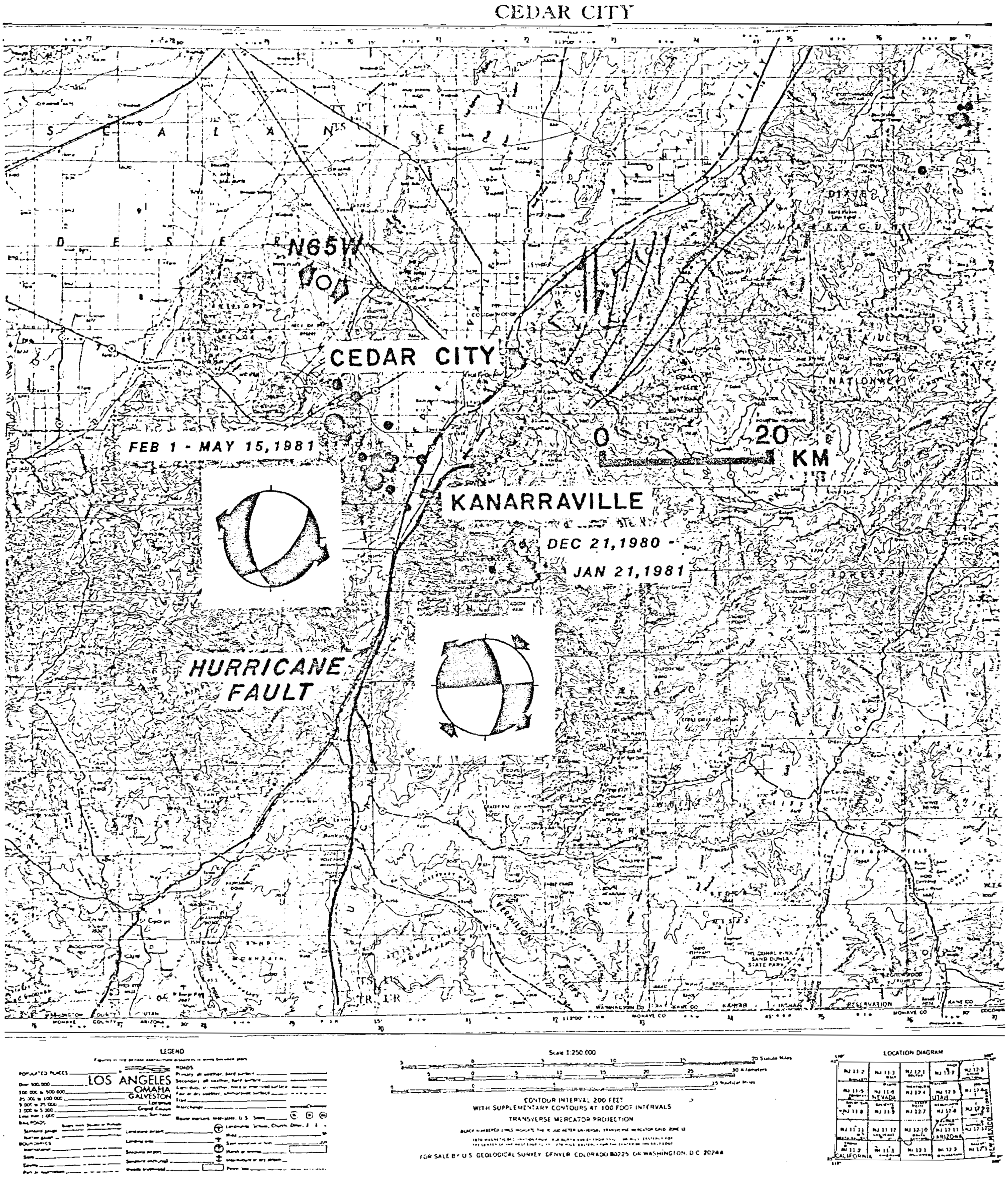


FIGURE F-10.--Summary map of swarm seismicity ($M_L \leq 4.5$) located by the University of Utah near Kanarraville, Utah, during December 1980-May 1981 (after Richins and others, 1981a). Earthquake epicenters (solid circles) cluster northwest and southeast of the trace of the Hurricane fault. Beach balls indicate composite focal mechanisms (lower-hemisphere, equal-area projections; compressional quadrants shaded) for the two clusters. Outward-directed arrows indicate extensional direction; extensional direction shown with open circle is from Anderson (1980), inferred from late Quaternary geology.

Helena itself--areas characterized by historical swarm seismicity (e.g., Smith and Sbar, 1974).

In summary, the significance of earthquake swarm occurrence in southwestern Utah is:

1. There is no observable correlation of such activity (which includes earthquakes up to Magnitude 4½ to 5) with known major structures, and they are not thought to be associated with volcanic activity, and

2. Therefore, it is possible that renewed swarm activity could occur anywhere in southwestern Utah on a relatively frequent basis, and such activity could be located near any of the dam sites (especially those in the Cedar City area).

F.2.2.3 Focal Mechanisms and Stress Orientation. Available focal-mechanism information for the main seismic belt in central and southwest Utah is summarized in figure F-11, which shows a predominance of normal faulting with extension predominant in a general east-west direction. There clearly are local complications, however, as reflected by reverse faulting (solution 6) or a large component of strike-slip displacement (solutions 9, 10, 13, 17, 19, 21).

The mean direction of the T-axes (the direction of least principal horizontal stress) for the earthquake focal mechanisms shown in figure F-11 is in the 093^{o}-273^{o} direction ($\pm$ 29^{o}), i.e., approximately east-west. The modern regional stress field in the Basin and Range province is characterized on a regional scale by a horizontal least principal stress trending approximately WNW-ESE (Zoback and Zoback, 1980). Along the eastern Great Basin there is some variation. In north-central Utah the least-principal-stress orientation is approximately N75^{o}E, a direction consistently indicated by average T-axes from focal mechanisms, moment-tensor summation, hydrofrac measurement, and measurements of the orientation of young faults and slickensides (Zoback, 1981).

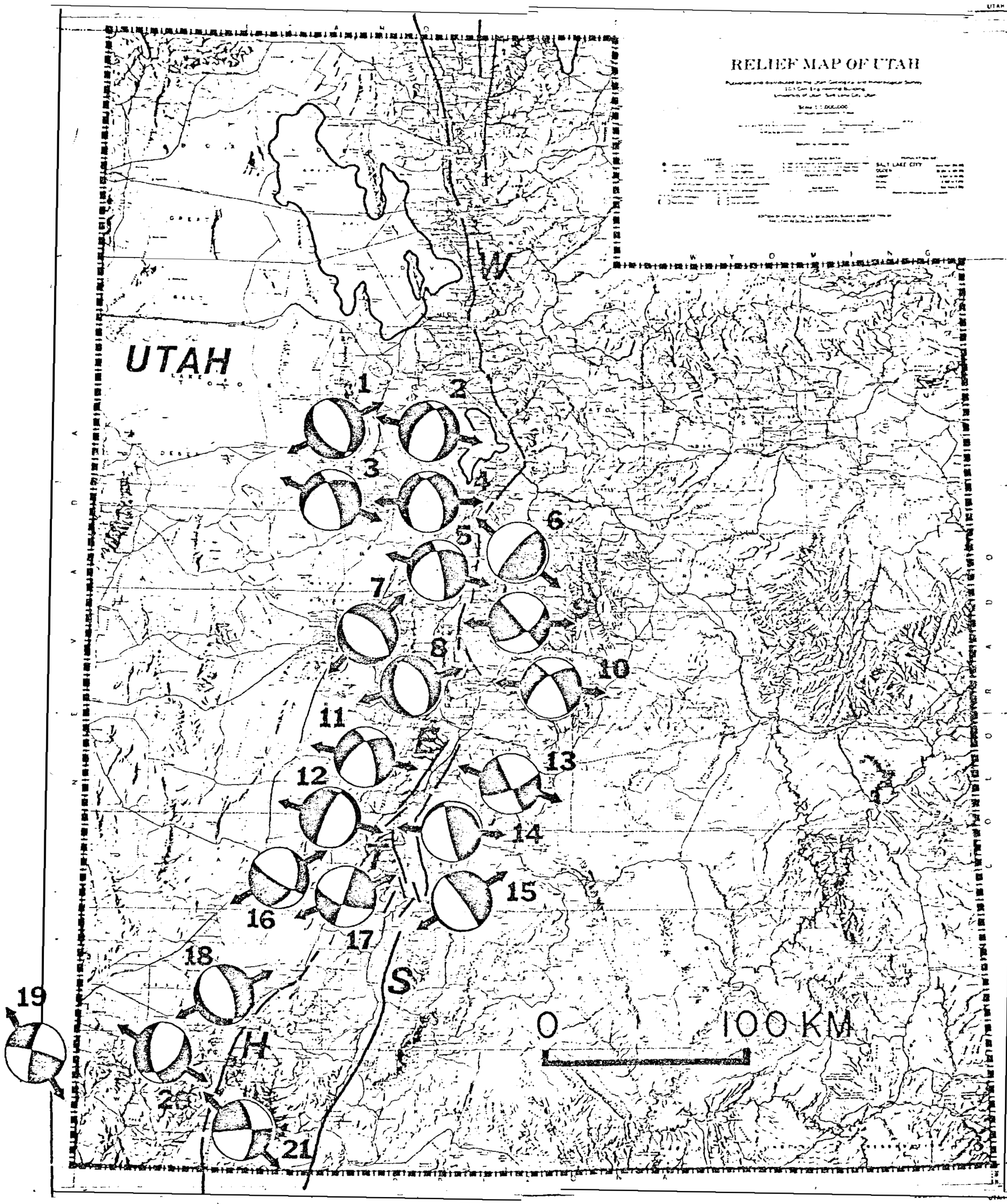


FIGURE F-11.--Summary of available focal mechanism information for the main seismic belt in central and southwest Utah (after Arabasz, 1981). Focal mechanisms are lower-hemisphere, equal-area projections, with compressional quadrants shaded. Outward-directed arrows indicate extensional direction. Sources: 5, 14, 18, 19 (Smith and Sbar, 1974); 6, 15 (Sbar and others, 1972); 11, 12 (Olson, 1976); 20, 21 (Richins and others, 1981a); others (unpub. data, University of Utah). H = Hurricane fault, S = Sevier fault, E = Elsinore fault, W = Wasatch fault, T = Tushar fault.

For the data in figure F-11 the mean least-principal-stress orientation is significantly different from N75°E, as verified by applying Student's t test. The N75°E trend is intriguing, however, because there appear to be local areas where NE-SW trending T-axes represent local deviations from more general WNW-ESE extension typical of the Great Basin on a regional scale. In southwestern Utah, for example, mechanisms 15, 16, 17 and 18 lie in an east-west belt coincident with ENE-trending geophysical anomalies (Stewart and others, 1977). Each mechanism comes from a different source of data, yet together they display a remarkable consistency. A measurement of in situ stress near Cedar City reported by Smith (1978, fig. 6-12) shows a direction of minimum compressive stress that also trends NE-SW. These observations raise the possibility that local stress orientation near Cedar City may be different than that to the south near St. George--perhaps somehow related to observed differences in background seismicity in the two areas.

F.2.2.4 Measurements of Ground Response in the Cedar City Area. W.W. Hays and K.W. King of the USGS have recorded nuclear explosions with portable broadband velocity seismographs in various urban areas in Utah to evaluate ground-shaking hazard (e.g., Hays and others, 1980). Characteristics of ground response determined by these studies are of value because of the existence of only one strong-motion record in Utah--that for the 1962 Cache Valley earthquake (M_L 5.7) in northern Utah (Smith and Lehman, 1979).

King (1982) reports results of ground-response measurements recently made in the Cedar City area at ten sites, where values of mean transfer functions (velocity spectra), relative to rock sites, show differences of a factor of 5 in the period band 0.2-1.0 sec. According to K.W. King (personal communication to W.J. Arabasz, March 1982), one of the ten sites occupied during the Cedar City ground-response study was at one of the SCS dam-site embankments at the southeastern corner of Cedar City; at this site, ground response compared to rock sites was only higher by about a factor of two.

F.3 EARTHQUAKE RECURRENCE AND FAULT ACTIVITY RATES

F.3.1 General Statement

Rates of earthquake recurrence in any seismically active region can be variously estimated using both seismological and geological data. If a catalog of historical and/or instrumental seismicity is available, then relationships of earthquake frequency versus magnitude can be used to estimate the average recurrence interval or inter-event time for shocks of a specified magnitude. Recurrence estimates can also be made from seismic moment rates determined from available geologic data on Quaternary faulting (e.g., J.G. Anderson, 1979; Molnar, 1979). Recurrence of surface faulting events and fault displacement rates can be estimated from trenching studies or other special geologic studies of specific fault segments.

Each of the above-mentioned approaches has been recently applied to different seismically active areas in Utah. In this section we summarize available information on earthquake recurrence in southwestern Utah and evaluate parameters of earthquake generation and surface fault displacement specific to the Cedar City-St. George area.

The region considered for this study is shown in Fig. F-12a as subregion III. This region of southwest Utah encompasses an area of approximately 56, 160 km^2.

F.3.2 Earthquake Frequency Versus Magnitude

The relationship of earthquake frequency (of occurrence) versus magnitude is commonly expressed by the well-knowm equation:

$$\log N(M) = a - bM \tag{1}$$

where N(M) is the number of earthquakes of specified magnitude M per unit time. Here we will designate N(M) as either n, the annual frequency of occurrence of earthquakes of a given magnitude, or as N_c (i.e., "cumulative N"), the annual frequency of occurrence of earthquakes equal to or greater than a given magnitude.

Equation (1) defines a linear relationship between log N(M) and M in which the slope coefficient b determines the relative proportion of small to large earthquakes. The constant a depends both on the temporal and spatial distribution of earthquakes within the region being considered. It is important to note that calculations of recurrence always imply a distribution of earthquake activity within the region that must be clearly specified to compare recurrence intervals in a meaningful way. In most seismic risk studies this distribution is usually assumed to be uniform throughout the entire region.

The following factors pose problems for establishing frequency-magnitude relationships for the study area: (1) the non-uniformity of the regional 200-km-radius seismicity sample surrounding the study area (fig. F-2), and (2) relatively low local seismic activity that precludes, say, the establishment of a reliable frequency-magnitude relationship for the St. George area separate from the Cedar City area--much less separate relationships for individual faults. Even for the rectangular region encompassing the Cedar City-St. George area (fig. F-6), it is doubtful that the post-1962 instrumental seismicity provides a good basis for estimating the frequency of occurrence of damaging earthquakes. For the 19.5-yr period July 1962-December 1981, the latter sample includes only 36 earthquakes of magnitude 3.0 or greater and is dominated by swarm earthquakes.

In our judgment the most meaningful approach is to follow the analyses of seismicity in the Utah region carried out by Arabasz and others (1980) and Smith and Arabasz (1979), restricting attention to the University of Utah earthquake catalog. Smith and Arabasz (1979) performed analyses specific to the southwest Utah region (region III, fig. F-12a). This region encompasses an area of 56, 160 km^2 and reflects the seismotectonics of the study area more appropriately than the 200-km-radius sample.

Only independent mainshocks (or the largest event of a swarm sequence) were included in the following analyses, in order not to invalidate the assumption of a Poisson distribution. Accordingly, predicted numbers of earthquakes based on the various recurrence relationships likewise refer to independent shocks.

Figure F-12 summarizes recurrence relations for the defined southwest Utah region. Figure F-12b shows the annual frequency of occurrence versus maximum Modified Mercalli epicentral intensity in southwest Utah, based upon the 129-yr record from 1850 through 1978. Stepp's (1972) technique was used to correct the historical catalog for sample incompleteness. Assuming the Gutenberg and Richter (1956) relationship: $M_L = 1 + 2/3\ I_o$, as justified for the Utah region by the U.S. Geological Survey (1976), the results of figure F-12b can be transformed to express either n or N_c in terms of M_L:

$$\log n = 1.64 - 0.54\ M_L \tag{2}$$

$$\log N_c = 2.38 - 0.65\ M_L \tag{3}$$

For the 16.0-yr sample of instrumental seismicity (1962-1978), the following relationships apply to the southwest Utah region (fig. F-12c ; Smith and Arabasz, 1979):

$$\log n = 2.38 - 0.74\ M_L \tag{4}$$

$$\log N_c = 2.73 - 0.74\ M_L \tag{5}$$

Note that equations (2) through (5) apply to the frequency of occurrence of earthquakes for the entire southwest Utah region (region III, fig. F-12a which has an area of 56, 160 km^2).

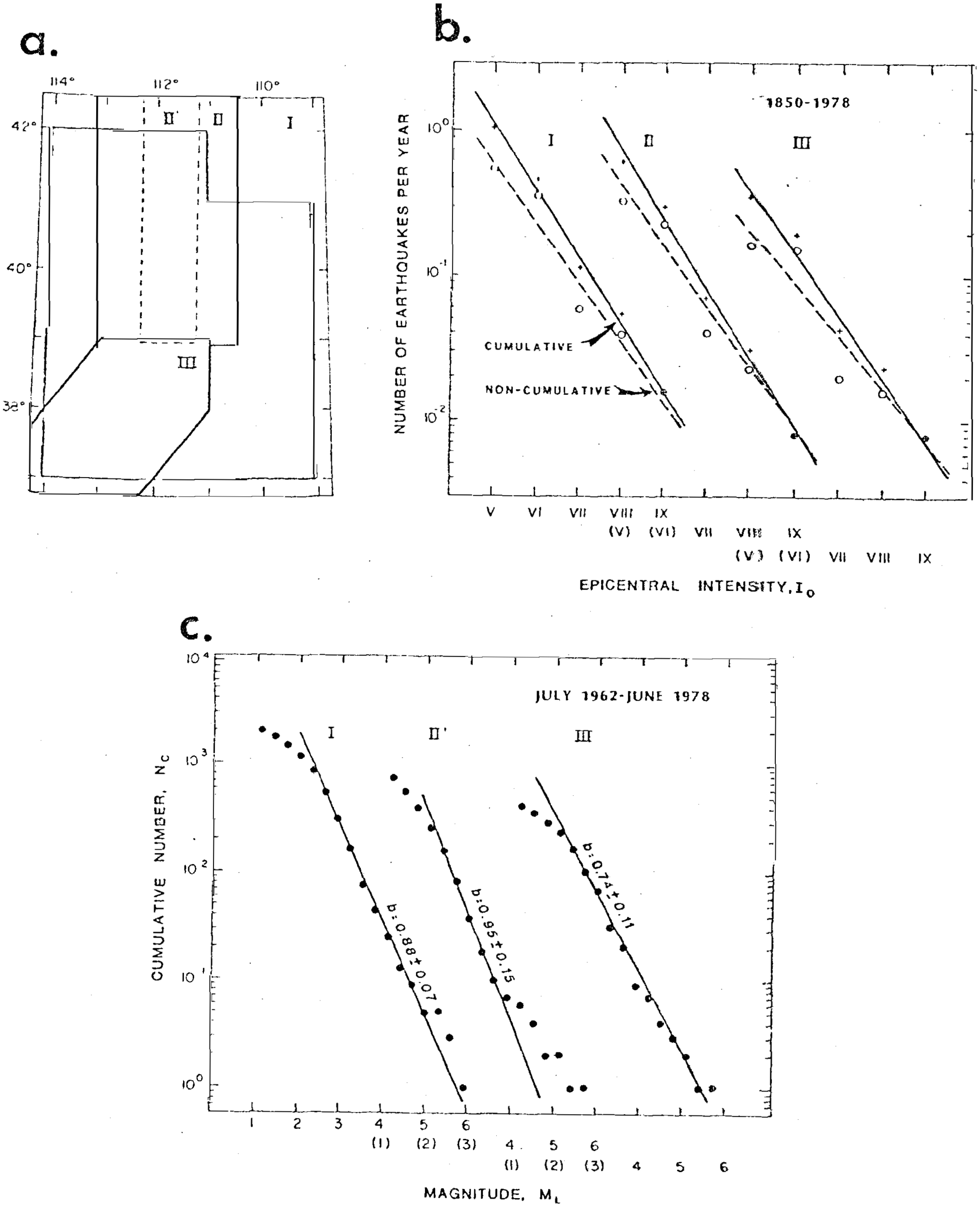


FIGURE F-12.-- Earthquake recurrence data for the Utah region and subregions outlined in (a). (b) Annual frequency of occurrence versus Modified Mercalli epicentral intensity, corrected for sample incompleteness, based upon the 129-yr record: 1850 through 1978. Letting N_C = the annual number of earthquakes equal to or greater than a given magnitude, and n = the annual number of a given magnitude, the regression coefficients are: (I) $\log N_C = 2.34 - 0.46\ I_0$, $\log n = 1.81 - 0.41\ I_0$; (II) $\log N_C = 2.26 - 0.48\ I_0$, $\log n = 1.72 - 0.42\ I_0$; and (III) $\log N_C = 1.73 - 0.43\ I_0$, $\log n = 1.10 - 0.36\ I_0$. (c) Cumulative number of earthquakes versus magnitude for the 16.0-yr sample of instrumental seismicity compiled in section 8. Values of the slope coefficient b at the 95 percent confidence limits computed from non-cumulative distributions by the method of maximum likelihood.

The method of extreme values (e.g., U.S. Geological Survey, 1976; Arabasz and others, 1980) was also applied to the historical data set for 1850-1978 in southwest Utah to minimize errors for sample incompleteness; the results (fig. F-13) are close to those computed by the relationship: $\log N_c = 1.73 - 0.43\ I_o$ outlined in figure F- b. The extreme-value distribution of maximum intensities in each year of the historical record is estimated by:

$$F(x) = \exp\{-\exp[-(x - 3.50)/ 1.14]\}, \quad -\infty < x < +\infty \qquad (6)$$

where F(x) is the probability that the largest earthquake in a year will have intensity less than or equal to x. The return period R, the interval in which an earthquake of a given intensity or greater has a 63 percent probability of occurrence, is estimated by (see U.S. Geological Survey, 1976):

$$R = 1/[1 - F(x)] \qquad (7)$$

Here also, maximum epicentral intensity can be transformed to magnitude using: $M_L = 1 + 2/3\ I_o$.

Estimates of the frequency of occurrence for a range of earthquake sizes--using the various relationships derived from seismicity--are outlined in table F-3. Values for estimated recurrence within 50-km radius of any site within the defined southwest Utah region simply assume uniform seismic activity throughout the region (a reasonable assumption for the larger earthquakes (see fig. F-3)), and they account for the proportionality of a 50-km-radius area to the total southwest Utah sample area.

A fundamental assumption regarding the estimation of earthquake recurrence is that the data used to calculate the constants a and b in equation (1) accurately represent the long-term seismicity of a region. Ideally the data should represent a long enough period of time that includes at least one repeat interval of the largest earthquake. This clearly is not the case in southwest Utah for earthquakes larger than about 6, so there is considerable uncertainty in extrapolating to earthquakes of larger size. Cluff and others (1980), for example, discuss this problem at length for the Wasatch Front area of north-central Utah where extrapolation of the historical seismicity does not adequately represent the rate of occurrence of moderate to large earthquakes. Prior to the present investigation, the apparent absence of Holocene fault scarps in southwest Utah (Bucknam and others, 1980) seemed inconsistent with the estimated recurrence intervals of $\sim$200-700 yr for $M_L \geq 7.5$ indicated in table F-3. The identification of Holocene and probable Holocene faulting during this investigation (see Section VIII) removes some of this inconsistency and suggests that rather than being absent, Holocene faulting in southwest Utah is probably present in many areas, but not yet identified by site specific studies.

Rates of earthquake occurrence in southwest Utah can be estimated fairly well for magnitudes up to about 6-6½ on the basis of past seismicity. Comparing the data of tables F-1 and F-3, it can be seen that for the 129-yr historical record of southwest Utah the observed number of independent earthquakes in that region is 1 $\geq M_L$ 6.5, 3 $\geq M_L$ 6.0, 8 $\geq M_L$ 5.5, and 18 $\geq M_L$ 5.0--whereas the respective numbers of predicted earthquakes is $\sim$ 2, $\sim$ 4, 7-8, and 14-17.

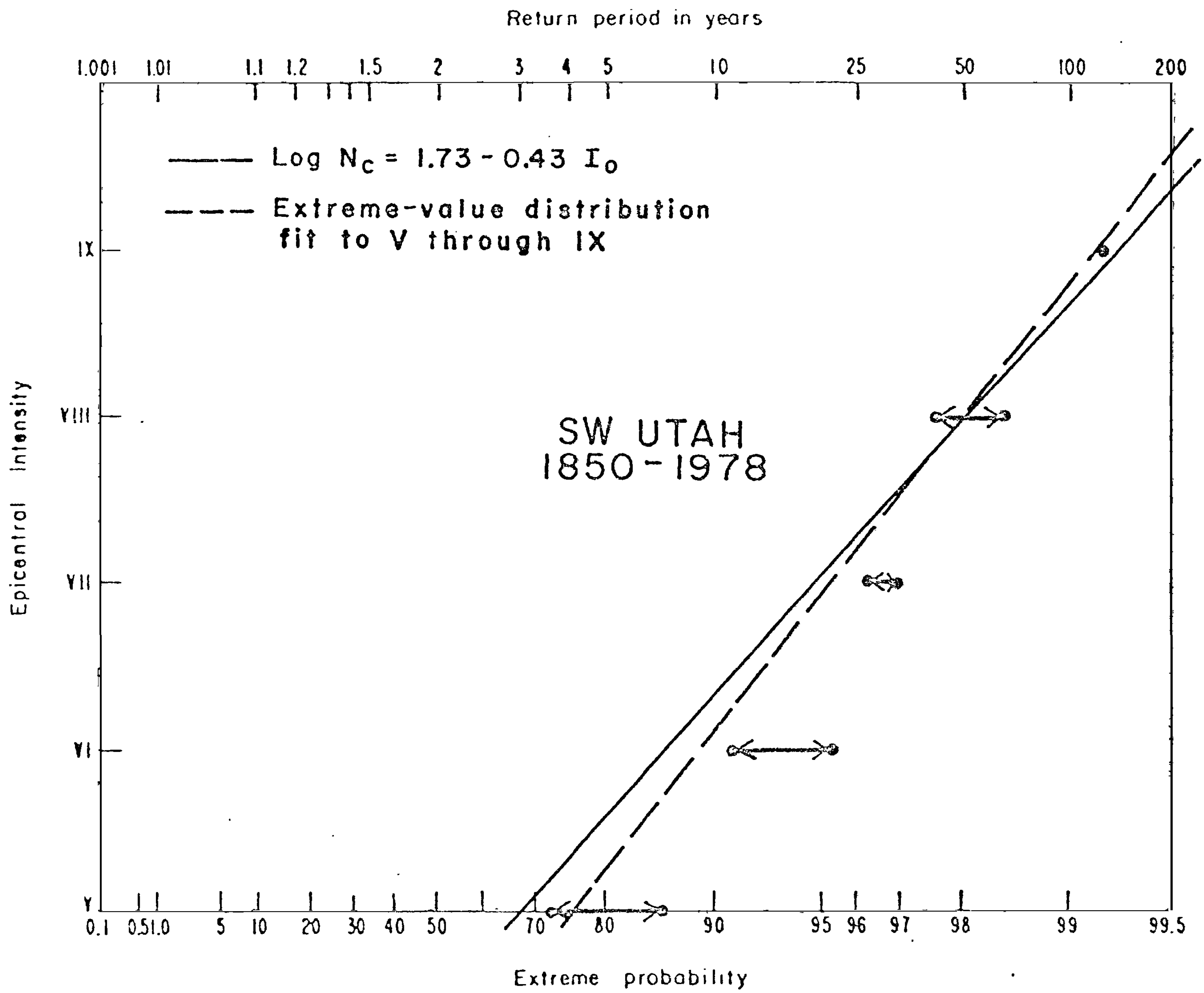


FIGURE F.-13.--Extreme-value distribution (dashed line) showing the probability that a given intensity is the largest intensity in a given year. Also shown is the return period or the interval in which a given intensity or greater has a 63 percent probability of occurrence. The solid line indicates the recurrence relationship derived by Smith and Arabasz (1979) for southwest Utah, transformed to extreme probability.

Table F-3--Estimated Frequency of Occurrence of Damaging Earthquakes (in years)

Earthquake	Recurrence for Entire SW Utah			Recurrence Within 50 km of any Site		
Size	Case I	Case II	Case III	Case I	Case II	Case III
$M_L \geq 7.5$	313	241	660	2,240	1,720	4,720
$M_L \geq 7.0$	148	125	282	1,060	894	2,020
$M_L \geq 6.5$	(1) [2] 70	65	120	500	465	858
$M_L \geq 6.0$	(3) [4] 33	34	51	236	243	365
$M_L \geq 5.5$	(8) [7-8] 16	18	22	114	129	157
$M_L \geq 5.0$	(18) [14-17] 7.4	9.5	9.3	53	68	66

Case I: Historical data, 1850-1978: $\log N_c = 2.38 - 0.65\ M_L$

Case II: Historical data, 1850-1978: $R = 1/[-F(x)]$

where

$$F(x) = \exp\{-[-\exp[-(x-3.50)/1.14]\}, \quad -\infty<x<+\infty$$

Case III: Instrumental data, 1962-1978: $\log N_c = 2.73 - 0.74\ M_L$

F.3.3 Seismic Moment Rates

The frequency of occurrence of moderate-to-large earthquakes can also be estimated from geologic data by relating geologically determined slip rates on individual faults to seismic moment rates (e.g., J.G. Anderson, 1979; Molnar, 1979). Such an approach usefully complements analysis based on the historic record of seismicity, which is generally too short to evaluate with confidence the long-term seismic flux over hundreds or thousands of years.

Seismic moment M_0 is a fundamental parameter now used by seismologists to describe the "size" of an earthquake. In practice, M_0 is generally determined from spectral measurements of seismic-wave recordings. An important result based on elastic dislocation theory is that seismic moment is proportional to the average slip on a fault during an earthquake: $M_0 = \mu A \bar{u}$, where μ is the shear modulus, A is the fault area, and $\bar{u}$ is the average slip on the fault during an earthquake. Seismic moment rate $\dot{M}_0$, the rate of occurrence of seismic moment, would then directly relate to the time derivative of $\bar{u}$, which is the average slip rate along a fault. In simple terms, moment rate can be calculated from geological information on fault slip rate and fault length, assuming some estimate of the depth of faulting. For a region, a moment rate can be estimated by summing the moment rates of major faults throughout the region, or by using a relationship involving the average rate of deformation of a region (e.g., J.G. Anderson, 1979).

Assuming that all slip on faults occurs seismically, a theoretical expression can be derived for $N(M_0)$, the number of earthquakes per unit time of moment M_0 or greater (Molnar, 1979). The complicated expression is a function of geologically-determined moment rates, the moment of the largest possible earthquake in the region, the slope coefficient _b_ from the frequency-magnitude relationship appropriate for the region, and another slope coefficient defining an empirical linear relationship between seismic moment and magnitude in a region (Molnar, 1979). The expression provides an upper limit for $N(M_0)$ if some aseismic slip occurs on faults.

Doser and Smith (1982; see also Doser, 1980) have applied the moment rate method to various regions in Utah, including the southwest Utah region (region III, fig. F-12a) defined by Smith and Arabasz (1979) for recurrence analysis of seismicity. They first determined a moment-magnitude scale for Utah based on the spectral analysis of 19 earthquakes in the Utah region in the magnitude (M_L) range 3.7 to 6.6. Moment rates were calculated from a compilation of geologic information on slip rates of Quaternary faulting in southwest Utah. Earthquake recurrence rates were then calculated using the _b_-values of Smith and Arabasz (1979) and an appropriate coefficient defining the moment-magnitude relationship. Results for southwest Utah are shown in figure F-14 (from Doser and Smith, 1982).

For southwest Utah, the frequency of earthquake occurrence based on geologically determined moment rates is essentially in agreement with that calculated from historical earthquake data (fig. F-14). The estimated recurrence interval for an earthquake of $7.0 \leq M_L \leq 7.5$ somewhere in the southwest Utah region is between 200 and 600 years (Doser and Smith, 1982), where the range results from an uncertainty in the moment-magnitude scale for Utah. For the same magnitude range and area, extrapolated seismicity (equations 3, 5, 6, and 7) would predict a recurrence interval between 200 and 500 years. The discrepancy between such expectation of a scarp-forming earthquake somewhere in southwestern Utah every few to several hundred years and the apparent absence of Holocene

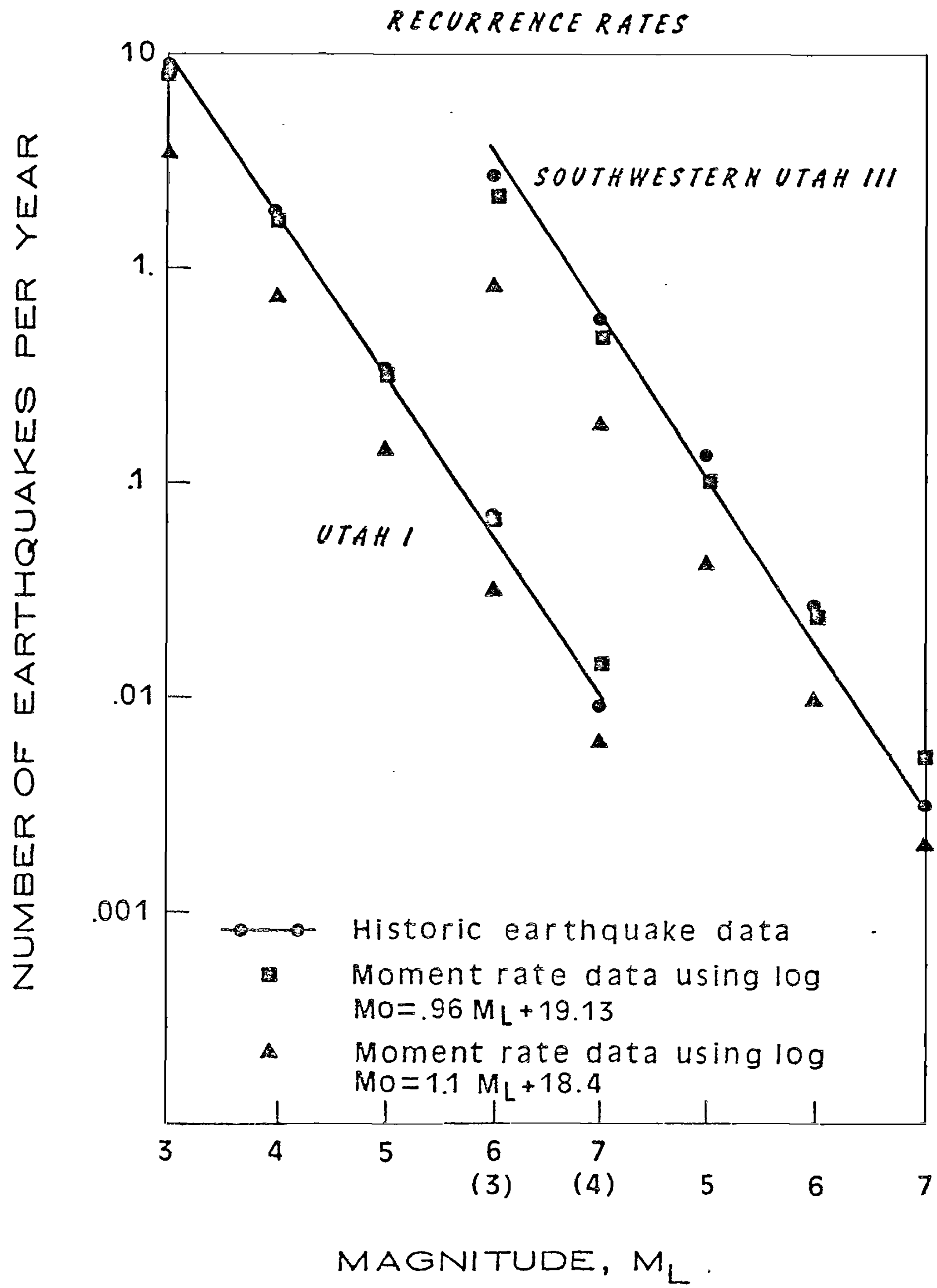


FIGURE F-14.--Comparison of earthquake recurrence data for the southwestern Utah region (as well as the entire Utah region) based on seismic moment rates and historical seismicity (from Doser and Smith, 1982).

fault scarps in southwest Utah is unresolved. Anderson (1980) and Bucknam and others (1980) consider various interpretations relevant to this problem and believe that there has been no radical change in the rate of occurrence of large earthquakes during Holocene time compared to the late Quaternary record in southwest Utah. Two implications are: (1) the recurrence interval of surface faulting on individual faults in southwest Utah may be very long, and (2) there may be different frequency-magnitude relations for earthquakes smaller than and larger than, respectively, about magnitude 6-6½ in southwest Utah.

Greensfelder and others (1980) have used independent data to estimate moment rates for various parts of the Great Basin. The moment-rate analysis of Doser and Smith (1982) is judged more reliable for application to southwest Utah because of more careful attention to extensive local geological information and, particularly, because of the derivation of a moment-magnitude relationship specific for the Utah region--as opposed to assuming a relationship derived for California.

APPENDIX G

EMBANKMENT AND FOUNDATION CONDITIONS

Appendix G

EMBANKMENT AND FOUNDATION CONDITIONS

G-1. Green's Lake Dam No. 2

Green's Lake Dam No. 2 was built in 1958. It is a zoned compacted earth fill embankment with a height of approximately 20 feet, a crest length of 1,315 feet and a total fill of about 53,700 cubic yards. The dam has an estimated total capacity of 45 ac-ft. A representative cross section of the embankment is shown in Figure G-1.

"As built" construction drawings of the embankment specify the core (Zone II) materials as compacted select fill. Construction records and corresponding laboratory tests suggest that the material used to construct the core is a calcareous sandy clayey silt or sandy silty clay with varying amounts of gravel. Similar materials were encountered in one exploratory borehole drilled through the core of the embankment during this investigation (see Appendix B). It appears that these materials were to be originally compacted to at least 95 percent relative compaction as determined by the Standard Proctor test procedure. It should be noted that the maximum particle size of the materials used in the available construction compaction tests could not be determined. In addition, the compactive effort specified for these test differs somewhat from the ASTM D698-70 testing standard. Results of some of the in situ density tests performed during construction indicate relative compactions much less than this and some of the materials which did not meet the specified compaction requirement do not appear to have been rechecked or recompacted. Relative compactions ranging from 81 to 111 percent were achieved during construction in the core materials yielding an average relative compaction of about 99 percent.

Standard Penetration Test (SPT) results obtained from the borehole drilled through the core of the embankment range from 25 to over 100 blows/foot. In most cases, however, the higher blow counts were the result of pushing large pieces of gravel or small cobbles. Nevertheless, the materials comprising the core of the embankment are probably dense and well compacted.

The Zone I material which makes up the outer shell of the embankment is specified on the "as built" construction drawing as a compacted soil, gravel and cobble fill. It appears that only one in situ density test was performed on these materials during construction. This test yielded a relative compaction of 105 percent. In situ density tests performed in the test pits excavated as part of this investigation gave relative compactions ranging from 85 to 90 percent as determined by test procedure ASTM D698-70 method C. The materials logged in the test pits were primarily silty sands and sandy silts with varying amounts of gravel and cobbles (see Appendices C and D). Based on the results of the in situ density tests, these materials are probably medium dense and are moderately compact.

The foundation at Green's Lake Dam No. 2 consists of alluvial and colluvial deposits. These deposits are stratified sands, silts, clays and gravels which contain varying amounts of gypsum. Cobbles and boulders are also commonly present. SPT blow counts taken in the boreholes drilled during this investigation range from 12 to more than 82 blows/foot with typical values around 20 to 40 blows/foot. In situ density tests performed in one test pit excavation gave an average relative compaction of approximately 92 percent. These results and the SPT blow count data indicate that the foundation soils are probably dense and are moderately compact.

The Green's Lake Dam No. 2 has performed satisfactorily since its construction. However, some minor caving of the embankment into the reservoir area has been reported to have occurred in 1980. At the time of the field investigation, some differential settlement along the axis of the embankment and some cracks which run parallel to the embankment centerline were observed. Cracks were also observed in the foundation in the vicinity of the embankment.

G-2. Green's Lake Dam No. 3

Green's Lake Dam No. 3 was built in 1958. It is a zoned compacted earth fill embankment and is similar in construction to Green's Lake Dam No. 2. The embankment has a height of approximately 17 feet, a crest length of 2,030 feet and a total fill of about 74,600 cubic yards. A representative cross section of the embankment is shown in Figure G-2.

"As built" construction drawings of the embankment show the core (Zone II) materials as compacted select fill. Records indicate that these materials are similar to those used to construct the core of Green's Lake Dam No. 2; that is, they consist of clayey sandy silts and sandy silty clays with some gravel. These types of materials were present in the exploratory borehole drilled through the core of the embankment during this investigation (see Appendix B). However, the materials appear to be generally more cohesive than the core materials of Green's Lake No. 2. The core materials were to be originally compacted to at least 95 percent relative compaction as determined by the Standard Proctor test procedure. As in the case of Green's Lake Dam No. 2, limitations exist in the available compaction test data used in construction. In addition, some of the in situ density tests performed during construction gave relative compactions less than the specified compaction criterion. Out of a total of 9 in situ density tests performed in the core of the embankment during construction, three tests had relative compactions less than 95 percent. Relative compactions ranged from 93 to 102 percent. Standard Penetration Test (SPT) results obtained from the one borehole drilled through the core of the embankment range from 20 to 52 blows/foot. This data and the in situ density tests performed during construction suggest that the core of the embankment to be medium dense to dense, stiff to hard and moderately to well compacted.

The shell (Zone I) materials consist of a compacted soil, gravel and cobble fill. A total of five in situ density tests were performed in these materials during construction. Relative compactions from these tests range from 98 to 106 percent. Nine in situ density tests were performed in the shell materials in the test pits excavated as part of this investigation. Relative compactions obtained from these tests range from 79 to 95 percent as determined by test procedure ASTM D698-70 method C. These tests yield an average relative compaction of 86 percent. This data suggest that the upstream and downstream shells of the embankment are probably medium dense and poorly to moderately compacted.

The foundation at Green's Lake Dam No. 3 consists of alluvial and colluvial deposits. The foundation materials are stratified sands, silts, clays and gravels which contain considerable amounts of lime and gypsum. Cobbles and boulders are also commonly present. Overall, the foundation conditions at the site are unfavorable due to the permeable soils which are high in gypsum.

SPT blow counts taken in the boreholes drilled in the foundation materials during this investigation range from 9 to over 100 blows/foot, however, the higher blow counts were recorded in the gravelly foundation soils present at depth. SPT blow counts recorded in the finer-grained foundation soils are typically around 15 to 30 blows/foot. In situ density tests performed in the foundation materials during this investigation yield relative compactions which average around 86 percent. These data indicate that the foundation soils are stiff to very stiff and medium dense.

The Green's Lake Dam No. 3 has experienced some operational problems since its construction. Subsidence was first noted in the basin area following a flood runoff which occurred during the summer of 1963. The area that subsided was circular in shape and was restricted to the east part of the reservoir adjacent to the upstream toe of the embankment. Total vertical displacement along the fractures that developed amounted to approximately 2 feet. The embankment itself did not experience any cracking or settlement and there appeared to be no seepage through the foundation.

Subsidence in the reservoir became progressively worse after each storm and in 1965 the area was repaired by placing a compacted blanket and by grading the area to provide drainage toward the outlet. In 1967, flood water was retained in the reservoir for about 3 months. This caused extensive settlement in the reservoir basin and in the dam. The reservoir basin near the east end of the dam subsided more than 5 feet and the subsided area extended through the dam. Cracks widened to depths of 15 to 20 feet by erosion and piping. Some block rotation was also observed along the crest of the dam. The dam was considered ineffective as a flood-control structure at this time and extensive repairs had to be made to make the structure operational. Consolidation of water-sensitive soils and piping along cracks through the dam and the foundation are the suspected causes of these problems.

The cracks in the embankment and reservoir area were repaired during the spring of 1969 by grouting them with a soil-slurry mixture. In all, approximately 580 cubic yards of slurry were pumped into the cracks in the dam and reservoir bottom. The cracks in the dam were filled using about 465 cubic yards and the cracks in the reservoir bottom took 115 cubic yards. Most cracks in the dam were found to be interconnected while the cracks in the reservoir were found to be generally quite shallow and not usually connected.

At the time of the field investigation conducted as part of this study, cracks along the upstream face and transverse to the crest on the embankment were observed. Settlement along the dam crest was also noticeable.

G-3. Green's Lake Dam No. 5

Green's Lake Dam No. 5 was built in 1958. It is an uniform compacted earth fill dam with a height of 22 feet at maximum cross section, a crest length of about 235 feet and a total fill of 27,100 cubic yards. A representative cross section of the embankment is shown in Figure G-3.

The logs from one exploratory borehole and three test pits excavated as part of this investigation show that the embankment materials consist primarily of clayey silts and silty clays (see Appendices B and C). Available construction records indicate that these materials were to be compacted to at least 95 percent relative compaction as determined by the Standard Proctor test procedure. Of nine in situ density tests performed during construction of the embankment, four tests did not pass and results of one test are questionable and are probably in error. The relative compactions of the remaining four tests which passed the compaction criterion range from 95 to 107 percent. In situ density tests performed in the test pit excavated in the embankment during this investigation gave relative compactions ranging from 70 to 82 percent as determined by test procedure ASTM D698-70 method C (see Appendices C and D). Standard Penetration Test (SPT) blow count data obtained from the one borehole drilled through the centerline of the embankment range from 17 to 63 blows/foot (see Appendix B). Most of the SPT blow count data indicate, however, that the sampled embankment materials are very stiff/medium dense. Based on these data, it is prudent to assume that the embankment was not uniformly compacted during construction and zones of poorly compacted materials probably exist within the embankment. Despite this, the embankment has performed satisfactorily up to the present time. Some minor cracking was observed in the embankment, however, it shows no obvious signs of structural distress.

"As built" drawings of Green's Lake Dam No. 5 show the foundation of the embankment to consist of clayey sands, sandy clays and clayey silts overlying stratified clayey sands, sandy clays, gravel and boulders. Most of the foundation materials contain considerable amounts of lime. The available drawings show that the cutoff trench of the embankment was excavated to the lower coarse-grained soil units. The logs of the boreholes drilled during this investigation encountered similar types of foundation materials. SPT blow counts taken in the foundation soils are typically very high (>100 blows/foot). These measurements are probably not a good basis upon which to estimate density or strength of the soil due to the high percentage of gravel present. In situ density tests were performed in test pits excavated into the finer-grained foundation soils. Relative compactions of these materials range from 84 to 91 percent indicating that these soils are medium dense and moderately compact.

G-4. Gypsum Wash Dam

Gypsum Wash dam was built in 1974 and 1975. It is a zoned compacted earth fill dam with a height of approximately 30 feet, a crest length of 3,128 feet and an estimated total fill of 238,600 cubic yards (Margheim, 1972). The dam has an estimated total capacity of 440 ac-ft. A representative cross section of the embankment is shown in Figure G-4.

According to the design report for Gypsum Wash Dam (Margheim, 1972), the materials that were to be used in the construction of the core (Zone I) consist of silty sands and sandy silts, with 20 to 65 percent passing the No. 200 sieve. Logs of exploratory boreholes drilled through the core of the embankment during this investigation show this to be generally true, however, some clayey sands and gravels were also encountered. The core materials were originally compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method A (Standard Proctor). Relative compactions ranging from 95 to 105 percent were obtained from density tests performed at the time of construction. An average relative compaction of 99 percent was computed from 77 available in situ density tests. Standard Penetration Test (SPT) blow count data obtained from the boreholes drilled through the core of the embankment (see Appendix B) range from 23 to well over 100 blows/foot with values typically being about 30 to 40 blows/foot. These results, along with available construction records, show that the Zone I materials are dense to very dense and are well compacted.

According to the design report for Gypsum Wash Dam, the upstream and downstream shells (Zone III) of the embankment were to be constructed of poorly graded to silty gravels and silty sands with less than 25 percent fines. Coarser gravels were to be routed to the outside of the shell to provide protection against rilling and wind erosion. Test pits excavated in the upstream and downstream shells of the embankment during the course of this investigation show this to be generally true. The Zone III materials were compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method C. Construction records indicate that relative compactions between 95 and 104 percent were obtained during construction and an average relative compaction of 99 percent was obtained from all the in situ density tests. Two in situ density tests performed in the test pits excavated as part of this investigation have relative compactions of 85 and 88 percent. These values are not as high as those given in the construction records (see Appendix D), however, these materials were logged as being dense and compact.

The left and right abutments and foundation of the embankment consists of gypsiferous interbedded shale and siltstone which are moderately fractured and weathered. The bedrock was originally overlain with a relatively shallow veneer of gypsiferous alluvial soils consisting of low plasticity silts, clays and silty sands. This material was removed prior to the construction of the embankment. A cutoff trench was excavated into the firm shale deposits. SPT blow counts recorded in the foundation materials during this investigation range from 25 to well over a 100 blows/foot. Overall, the foundation conditions at Gypsum Wash Dam are good and the performance of the dam has been satisfactory. During the field investigation, some bulges were noted along the downstream slope of the embankment, however, there was no evidence of any settlement or excessive cracking along the crest of the embankment.

G-5. Warner Draw Dam

Warner Draw Dam was built in 1974. The embankment has a height of approximately 60 feet at its maximum cross section and a crest length of about 1,300 feet. The structure was constructed using about 164,000 cubic yards of fill material with a total capacity of approximately 1,048 ac-ft (Deming and Bridges, 1971).

"As built" drawings and construction records of Warner Draw dam indicate that it is a zoned earthfill embankment. A representative cross section of the dam is shown in Figure G-5. The Zone I core materials of the embankment consist primarily of clayey sands and clayey silty sands. The core materials were compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method A (Standard Proctor). Relative compactions ranging from 95 to 107 percent were achieved during construction in the Zone I materials. An average relative compaction close to 100 percent was computed from the available construction records.

Standard Penetration Test (SPT) results obtained from the exploratory boreholes drilled through the core during this investigation (see Appendix B) were found to range from 15 to 74 blows/foot. SPT blow counts were typically within 40 to 60 blows/foot indicating that the Zone I materials are dense to very dense and are well compacted.

The upstream and downstream shells of the embankment (Zone III) are constructed of silty and clayey sands with some gravel and cobbles. The Zone III materials were also compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method C. Relative compactions ranging from 95 to 101 percent were achieved during construction and an average relative compaction of 98 percent was computed from the available construction records.

The SPT blow counts obtained in the Zone III materials during this investigation averaged about 50 to 60 blows/foot indicating that these materials are dense to very dense. In situ density tests performed in a test pit excavated near the crest of the embankment (see Appendices C and D) verified the dense nature of the Zone III embankment materials.

Foundation conditions at the Warner Draw Dam site are generally good. The right abutment of Warner Draw Dam consists primarily of sandstone with some interbedded siltstone and shale. The left abutment consists of alluvial materials. Logs of boreholes available in the geologic report for Warner Draw Dam (Deming and Bridges, 1971) indicate that the alluvial materials are very dense, interbedded sands, silty sands and some clayey sands. These soils are weakly to moderately cemented with lime and overlay shale and sandstone bedrock. The foundation of the dam embankment near its maximum cross section consists of weathered siltstone and shale.

G-6. Stucki Dam

Stucki Dam was built in 1974. The embankment has a height above the surrounding ground surface of approximately 30 feet. However, because of the poor foundation conditions that were anticipated from geologic investigations, deep foundation excavations were made and the actual filled embankment height is about 45 feet. The crest length of the embankment is about 1,400 feet. A preliminary estimate of the amount of fill material required to construct the embankment is approximately 63,000 cubic yards. The estimated capacity of the reservoir is about 126 ac-ft.

Stucki Dam is a zoned earthfill embankment. A representative cross section of the embankment is shown in Figure G-6. Exploratory boreholes drilled as part of this investigation in the Zone I core of the embankment indicate that it consists of silty sands, clayey silty sands and clayey sands. These materials were compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method A (Standard Proctor). Relative compactions ranging from 95 to 103 percent were achieved during construction in these materials yielding an average relative compaction of about 99%. Standard Penetration Test (SPT) results obtained from the boreholes drilled within the core as part of this investigation range from 20 to 84 blows/foot with typical values on the order of 30 to 50 blows/foot (see Appendix B). These results, along with construction records, indicate that the Zone I core materials are very stiff to dense and are well compacted.

The upstream and downstream shells of the embankment (Zone III) consist primarily of silty sands which contain varying amounts of gravel and cobbles. The Zone III materials were compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method C. Available construction records indicate relative compactions ranging from 96 to 105 percent were achieved and an average relative compaction of about 99% was calculated for these materials.

The SPT blow counts obtained in the Zone III materials during this investigation averaged about 40 to 50 blows/foot. Relative compactions obtained from in situ density tests performed in test pit excavated along the upstream shell of the embankment were found to range from 93 to 106 percent (see Appendices C and D). These results are in good agreement with the available construction records indicating that the Zone III materials are dense to very dense and are well compacted.

The geologic report for Stucki Dam reported that geologic conditions at the site are poor (Deming and Bridges, 1971). Pervious, gypsiferous alluvial and colluvial deposits were found to underlie the foundation and right abutment. Soft, fractured silty sandstones were also discovered in the left abutment. In order to prevent settlement and piping in the foundation, nearly all of the highly gypsiferous and pervious deposits were removed prior to the construction of the embankment and rather deep cutoff excavations were constructed. These measures appear to have yielded a satisfactory design since the embankment does not show any significant signs of distress at the present time. Logs of boreholes available in the geologic report indicate that the foundation of the embankment primarily consists of sand, silty sands and clayey sands. Some of these deposits contain varying amounts of gypsum. SPT blow counts indicate that the foundation soils are dense to very dense. SPT blow counts data and in situ density tests performed during this investigation generally agree with the findings of previous investigations.

G-7. Frog Hollow Dam

Frog Hollow Dam was constructed in two stages. The original embankment was constructed in 1956 and had a height of approximately 33 feet at maximum cross section and a crest length of 600 feet. Major portions of the old embankment were removed and used as construction materials in the 1978 reconstruction of the dam. The reconstruction effectively raised the old dam about 16 feet. The present dam has a total height of 48 feet at the maximum cross section and a crest length of 1,900 feet.

"As built" drawings and construction records of Frog Hollow dam indicate that the portion of the embankment built in 1978 consisted of zoned earth fill. A representative cross section of the embankment is shown in Figure G-7.

No information was available at the time of writing of this report on the composition and geometry of the original embankment. Logs of three exploratory boreholes drilled along the crest of the embankment and four test pits excavated during this investigation (see Appendices B and C) show that the Zone I (see Figure G-7) materials consist of sandy and silty clays, sandy silts and silty sands with varying amounts of gravel and a few scattered cobbles. The Zone I materials in the portion of the embankment constructed in 1978 were compacted to at least 95 percent relative compaction as determined by test procedure ASTM D-698 method A (Standard Proctor). Relative compactions ranging from 94 to 128 percent were achieved during construction in the Zone I materials. A number of in situ density tests performed during construction yielded relative compactions less than the specified compaction criterion (i.e., 95 percent relative compaction). For these tests, it appears that additional compactive effort was applied to these lifts before additional fill was placed.

Standard Penetration Test (SPT) results obtained from one exploratory borehole drilled through the Zone I materials during this investigation range from 26 to 48 blows/foot with typical values being around 30 blows/foot. Logs from three exploratory boreholes drilled through the Zone I materials during this investigation do not indicate any changes in material type or consistency at the depths where the original embankment materials (i.e., the embankment constructed in 1956) should have been encountered. It was discovered after the completion of the field exploration program that the borings drilled along the crest were located in the vicinity of the old corrugated metal pipe which was part of the principal spillway of the original embankment. The original embankment was removed in this area in order to remove the pipe and was probably backfilled with Zone I fill materials. Therefore, materials comprising the original embankment were never encountered in any of the boreholes. The log from one shallow borehole drilled along the crest of the original embankment during the geologic investigation for the new embankment (Deming, 1976) indicates that the old embankment materials consists of gravelly silty sand which contains some cobbles.

In situ density tests performed in one test pit excavated in the Zone I materials of the new embankment during this investigation yield relative compactions of 95 and 100 percent (see Appendices C and D) as determined by test procedure ASTM D-698 method C (Standard Proctor). These results and the SPT blow count data suggest that the Zone I materials are very stiff to hard and are well compacted.

Construction records and the "as built" construction drawings of the embankment do not specify the types of materials used to construct the downstream shell (Zone II). The log from one test pit excavated during this investigation shows that the shell material consists of coarse gravel and cobbles in a silty clay matrix. Two in situ density tests performed in the test pits gave relative compactions of 79 and 92 percent. Construction records suggest that in situ density tests were not performed in the Zone II shell materials during construction. The materials were probably compacted using the same techniques as were used to place the Zone I embankment materials. Based on the limited amount of available data, it is prudent to assume that the Zone II shell materials are probably stiff/medium dense and are moderately compact.

The geologic report for the Frog Hollow dam site indicates that the site is geologically a poor location for a flood control structure (Deming, 1976). Most of the site's foundation consists of basalt flows and gypsiferous unconsolidated alluvial and colluvial deposits. The left abutment of the dam is formed by two basalt flows which are separated by a three to five foot thick deposit of highly compacted sandy silt which can be classified locally as a siltstone. Approximately 10 to 20 feet of alluvium originally covered the basalt flows at the left abutment, however, most of this material was removed in the cut-off and drain trench excavations.

The basalt flows are dark gray to black in color, fractured, very fine-grained and highly vesicular along the top and bottom cooling zones. The permeability of the rock is high in the fractured zones and along most joints. Piping of fine-grained embankment materials and the materials separating the two basalt flows was considered a possibility because of the highly permeable basalt. Construction drawing of the portion of the embankment built in 1978 show that a protective blanket of Zone I embankment materials was placed along the left abutment to prevent piping.

The younger basalt flow is absent in the right abutment of the dam, however, the upper cooling zone of the older basalt flow was found to be highly permeable. The inner portion of the flow (below the upper cooling zone) is dense and lightly fractured (Deming, 1976) with small nonconnecting vesicles. The joints in this portion of the basalt are generally tight with some joints being filled with silt and clay. The right abutment basalt was overlain by approximately 5 to 10 feet of calcareous, gypsiferous, sandy and clayey alluvium, however, this material was removed prior to the construction of the embankment. Piping between the vesicular, upper cooling zone found in the right abutment and the fine-grained embankment materials was considered a possibility at the time of the geologic investigation.

The valley foundation of the embankment is a narrow channel cut in the older (deeper) basalt flow. Both abutments slope steeply towards the channel foundation. Erosion has removed the upper cooling zone of the flow and the basalt remaining in the valley is only "lightly fractured and intensely (Deming, 1976) weathered". Joints in the rock were reported to be generally tight and permeability rates were low.

Frog Hollow dam has experienced some cracking problems since the construction of the raised portion of the embankment in 1978. In early 1981, the cracks were investigated by SCS by digging a series of trenches along the centerline of the embankment. The cracks that were noted were mostly transverse to the centerline of the embankment and ranged from 3 to 9 feet in depth. Many cracks were found to extend through the entire embankment fill. The width of the cracks ranged from hairline fractures to 1½ inches and averaged about ½ inch. All cracks were open at the surface and gradually narrowed at depth. Many of the cracks were found to be filled with grass and roots.

In addition to the transverse cracking of the embankment, one longitudinal crack was also found. It extended from about station 11+00 to 12+00 and was 35 feet upstream of the centerline. Additional longitudinal cracking was noted along the upstream face of the embankment during the field investigation conducted as part of this study. No explanation has been offered in the available studies that have been conducted to date as to the cause of this cracking. However, "as built" construction drawings of the portion of the embankment built in 1978 show that the cut-off trench in the vicinity of the cracks was probably placed in old debris basin deposits and/or alluvial and colluvial deposits. Consolidation of these materials could, therefore, be a possible cause of these cracks.

During the drilling operations conducted as part of this investigation, a significant zone of apparently low density materials was encountered in the interval between 50½ feet to 55 feet of borehole FH-1. This hole was drilled to a depth of 50½ feet on the first day of the drilling operations at the dam site. The drill rods were pulled out of the hole at the end of the day and the water level in the hole was very near the surface. At the beginning of the next day, there was no water in the hole to the depth of 50½ feet. Drill rods were let down to this depth and subsequently "dropped" to a depth of 55 feet. No circulation was established below a depth of 50½ feet and no soil samples were obtained between 50½ to 55 feet. A Pitcher barrel soil sample was obtained from 55 to 56.8 feet and was found to be a sandy silt/sandy clay.

Because of the anomalous water loss and the apparently very weak soils encountered, two additional boreholes were drilled on either side of boring FH-1. The soils encountered in the two additional boreholes at depths comparable to the anomalous water loss zone of boring FH-1 consisted of sandy clay/sandy silt. SPT blow counts taken in these soils were somewhat less than those recorded in the surrounding soils.

The anomalous water loss experienced in borehole FH-1 could be the result of several factors. First, the 50 feet of hydraulic head acting on the soils overnight could have softened them to the extent that they could not be sampled. Second, borehole FH-1 was drilled at the approximate location of the old 24 inches corrugated metal pipe which was part of the principal spillway structure of the original embankment, as was previously noted. This pipe was removed and the trench was backfilled prior to the construction of the new embankment raise. It is possible that the backfill of the trench was poorly placed resulting in the weak zone of soils encountered in borehole FH-1.

The causes of the embankment cracking of Frog Hollow dam and remedial measures to repair the embankment are presently being investigated by the SCS.

G-8. Ivins Diversion Dam No. 5

The Ivins Diversion Dam No. 5 was built in 1977. The embankment is an uniform compacted earth fill dam with a crest length of about 5,300 feet and a height of 20 feet at its maximum cross section. A representative cross section of the embankment is shown in Figure G-8.

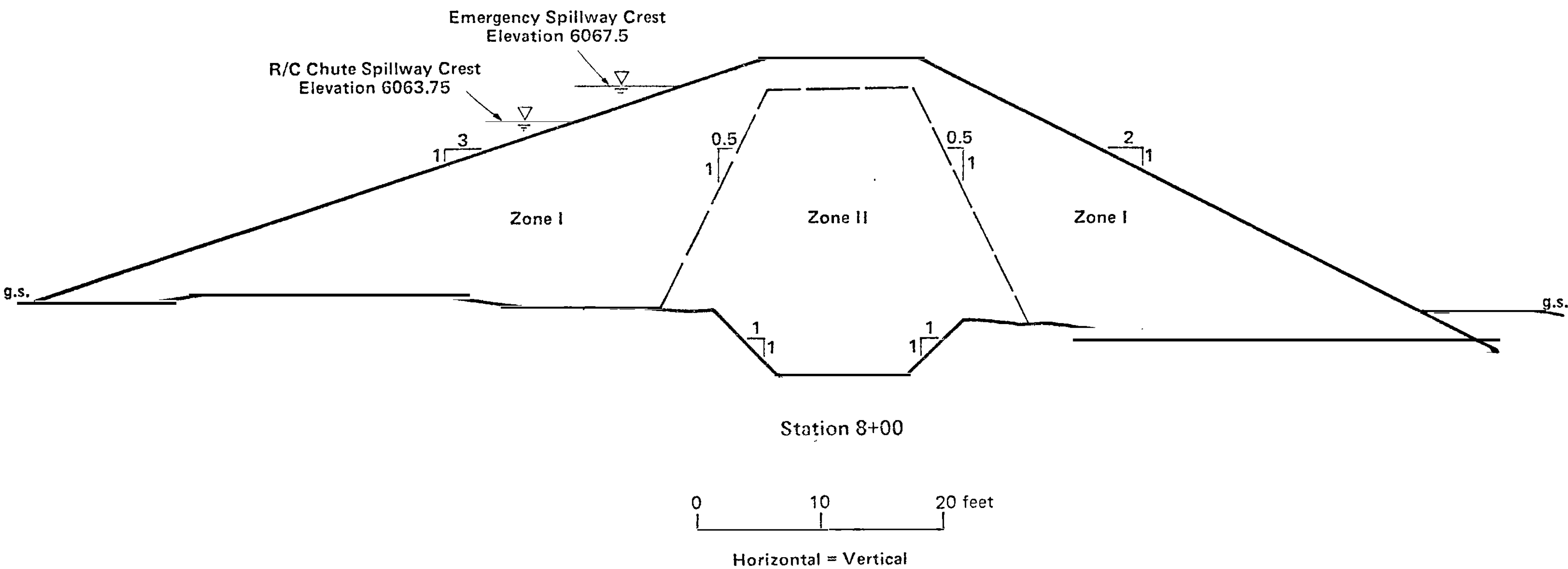
Information obtained from the exploratory boreholes and test pits excavated as part of this investigation suggest that some attempt might have been made during construction to place the finer-grained fill materials near the centerline of the embankment. The logs of three exploratory boreholes drilled along the crest of the embankment indicate that the center of embankment consists of silty sands and sandy silts containing some medium to coarse sand and fine gravel. Standard Penetration Tests (SPT) performed in these materials range from 33 to 90 blows/foot (see Appendix B) indicating that these materials are dense to very dense.

Logs of the test pit excavations show that the materials near the slopes of the embankment are sandy silts and silty sands with varying amounts of coarse sand, gravel and scattered cobbles. Three in situ sand core density tests performed in these materials during this investigation show that they are generally dense and have a relative compaction averaging about 97 percent (see Appendices C and D) as determined by test procedure ASTM D-698 method C (Standard Proctor). In situ density tests performed at the time of construction of Ivins Diversion Dam No. 5 are limited. However, they do show that the embankment was compacted to at least 95 percent relative compaction as determined by test procedure ASTM D698-70 method A.

The geologic report for the Ivins site (Bridges, 1972) states that the site is geologically a poor location for this type of flood structure. The foundation and abutments are underlain by gypsiferous, pervious, water-sensitive soils and weathered, gypsiferous bedrock. Vugs and small solution channels were reported in the upper part of the bedrock which consists of interbedded siltstones and sandstones. The foundation and abutments are reported to be subject to settlement and/or piping because of the gypsiferous water-sensitive soils and bedrock. The geologic report recommended that the loose materials in the foundation should be removed or consolidated to prevent excessive settlement and that a cutoff should be dug into the bedrock to prevent possible piping.

Available advanced copies of the "as built" drawings of the dam suggest that the location of the centerline and the configuration of the embankment were modified several times from those reported in the geologic report. The preconstruction drawings show a cutoff trench only 4 feet deep. The available drawings do not show whether or not the cutoff trench was excavated into the bedrock.

Logs of the exploratory boreholes and test pits excavated during this investigation indicate that the foundation soils consist of medium dense to very dense sandy silts and silty sands which contain varying amounts of gypsum. SPT blow counts range from 14 to over 80 blows/foot with typical values around 40 to 50 blows/foot. In situ density tests performed in two test pit excavations yield relative compactions ranging from 82 to 95 percent. Siltstone bedrock was encountered in two of the exploratory boreholes and was found to be deeply weathered and to contain abundant gypsum. Despite the poor geologic conditions, only some minor cracks and erosion in the embankment was observed at the time of the field investigation.



Zone	Material
I	Compacted soil, gravel and cobble fill.
II	Clayey silt, sandy silty clay with some gravel.

Note: g.s. indicates approximate ground surface.

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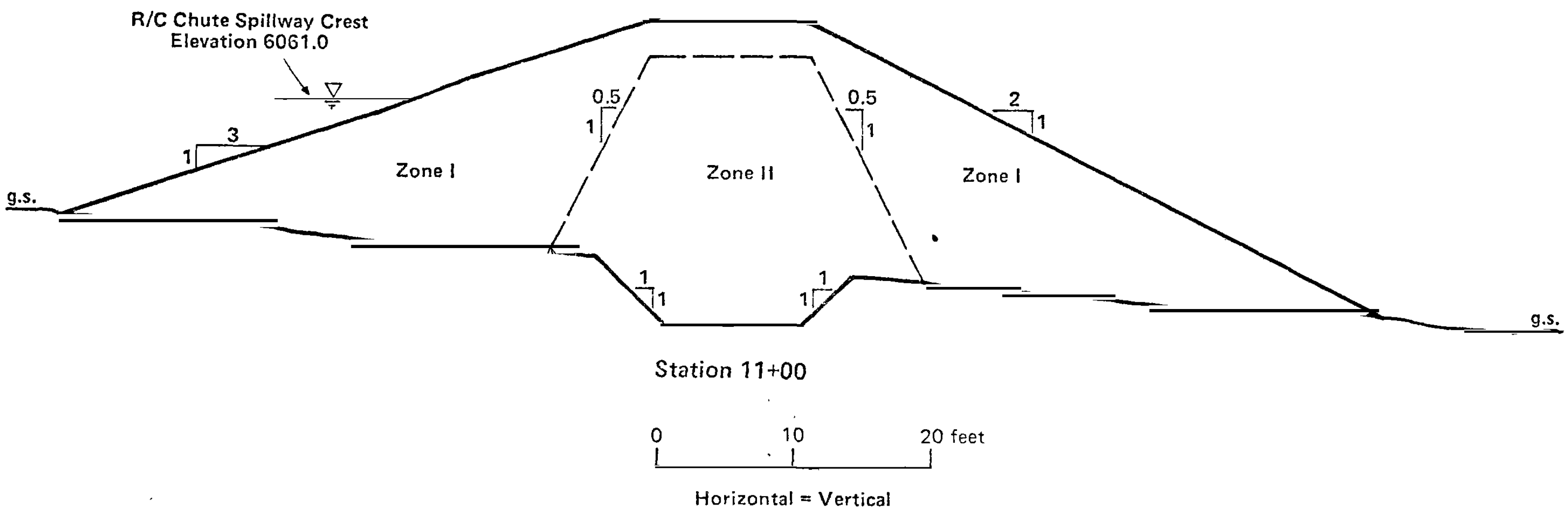
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS **REPRESENTATIVE EMBANKMENT CROSS SECTION** **GREEN'S LAKE DAM NO. 2**		
Checked by MGT Date 5/21/82 Approved by SA Nelson Date 27 MAY 82	Project No. D118	Figure No. G-1



Zone	Material
I	Compacted soil, gravel and cobble fill.
II	Clayey sandy silt, sandy silty clay with some gravel.

Note: g.s. indicates approximate ground surface.

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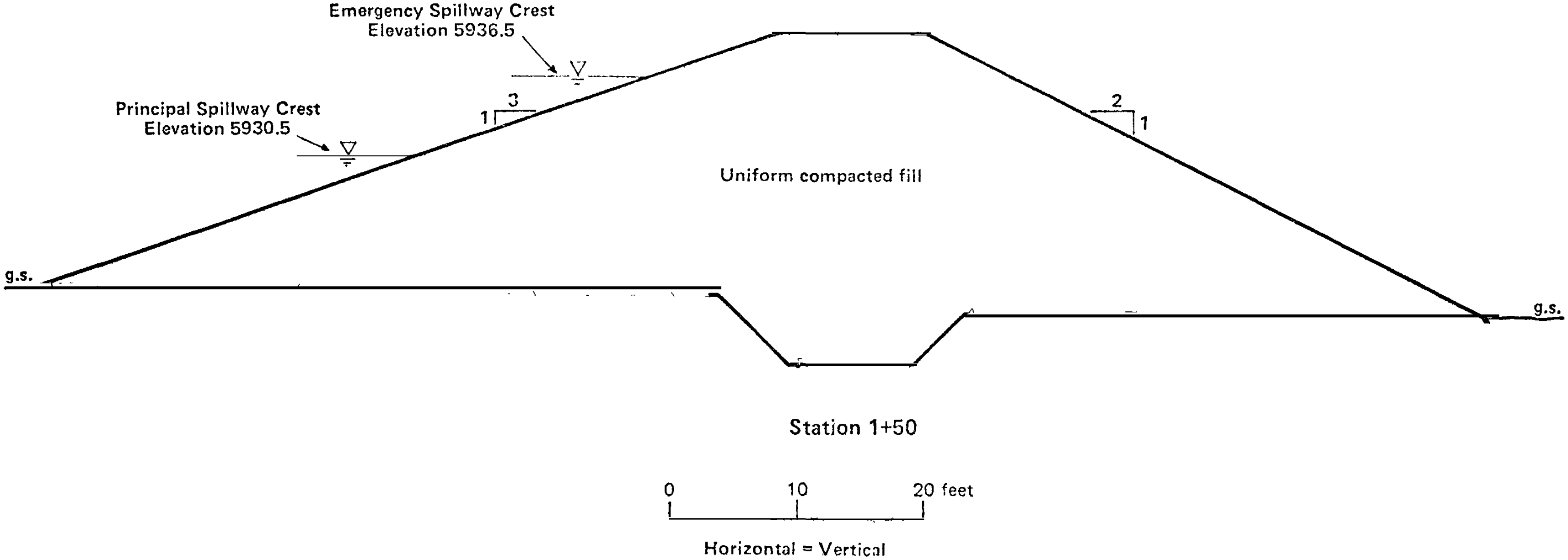
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
GREEN'S LAKE DAM NO. 3

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson Date 27 MAY 82	D118	G-2



Station 1+50

Material
Uniform compacted fill consists of clayey silt and silty clay with trace gravel.

Note: g.s. indicates approximate ground surface.

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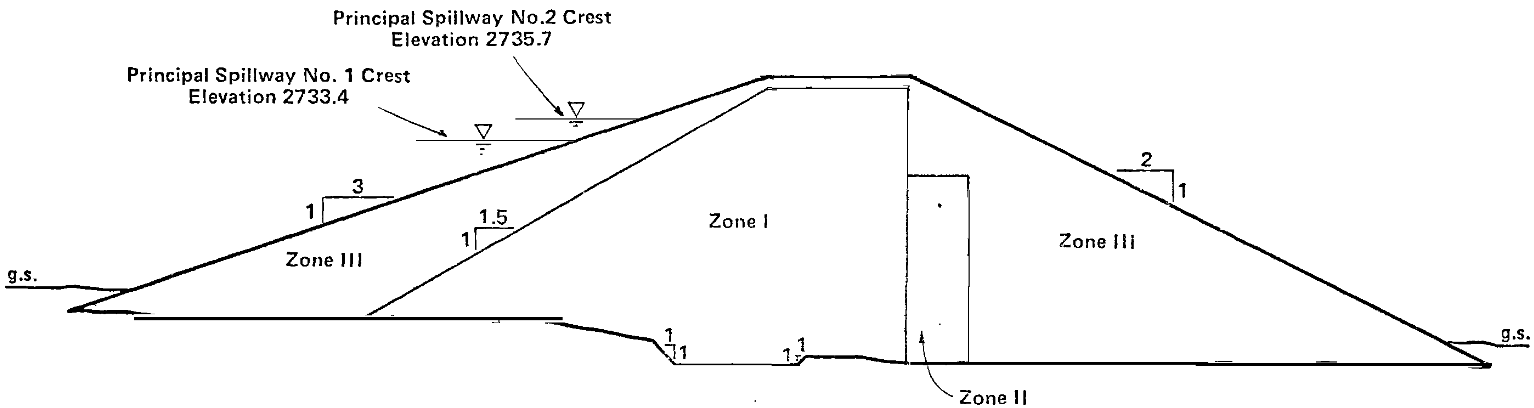
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
GREEN'S LAKE DAM NO. 5

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by [signature]	Date 27 May 82	D118	G-3



Station 37+20

0 10 20 feet

Horizontal = Vertical

Zone	Material
I	Silty sand, sandy silt, some clayey sand and clayey gravel.
II	Select drain fill.
III	Silty gravel and silty sand.

Note: g.s. indicates approximate ground surface.

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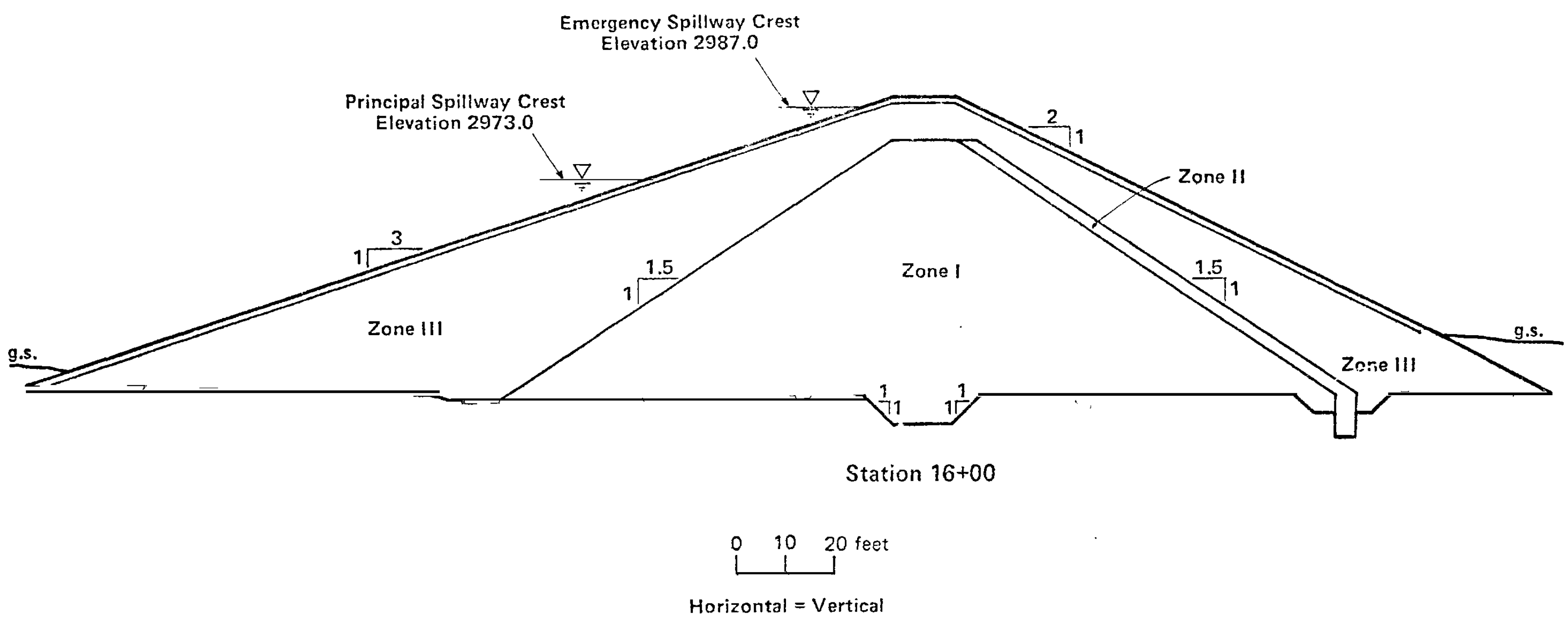
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
GYPSUM WASH DAM

Checked by MCT Date 5/27/82 Approved by [signature] Date 27 May 82	Project No. D118	Figure No. G-4



Zone	Material
I	Clayey sand and clayey silty sand.
II	Select drain fill.
III	Silty sand and clayey sand with gravel and cobbles.

Note: g.s indicate approximate ground surface.

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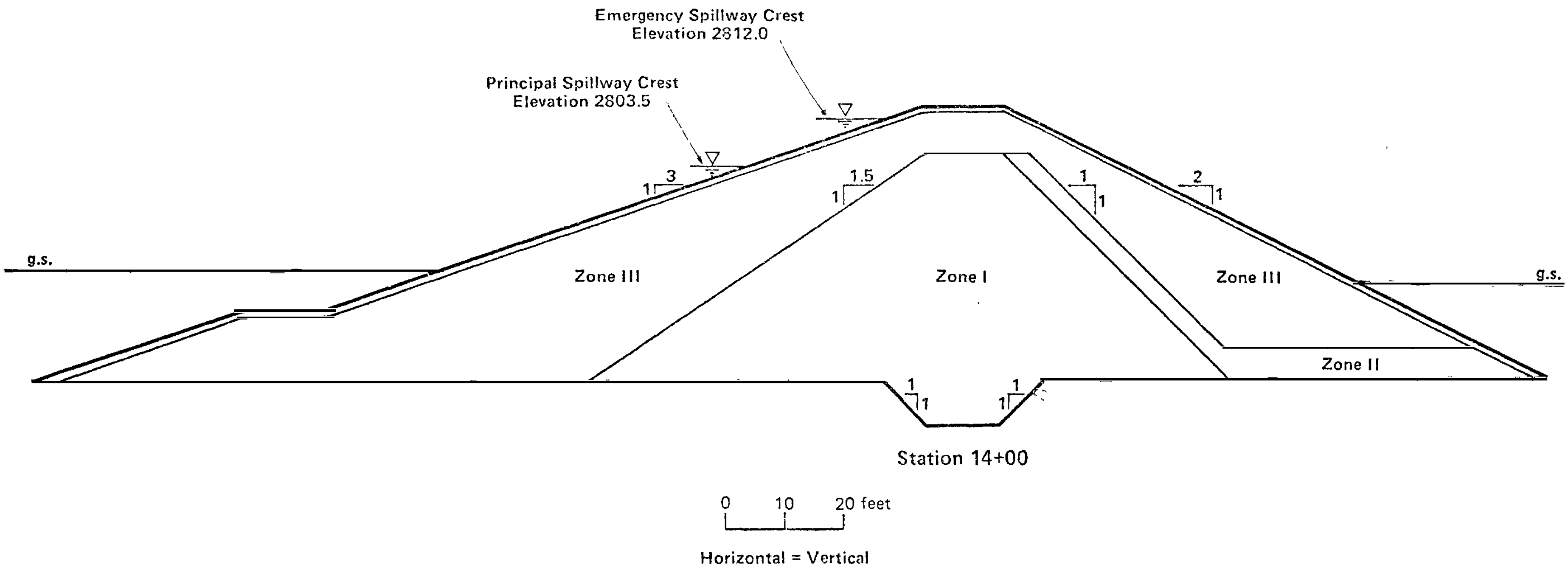
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
WARNER DRAW DAM

Checked by MGT Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson Date 27 May 82	D118	G-5



Zone	Material
I	Silty sand, clayey silty sand and clayey sand.
II	Select drain fill.
III	Silty sand with gravel and cobble.

Note: g.s indicates approximate ground surface.

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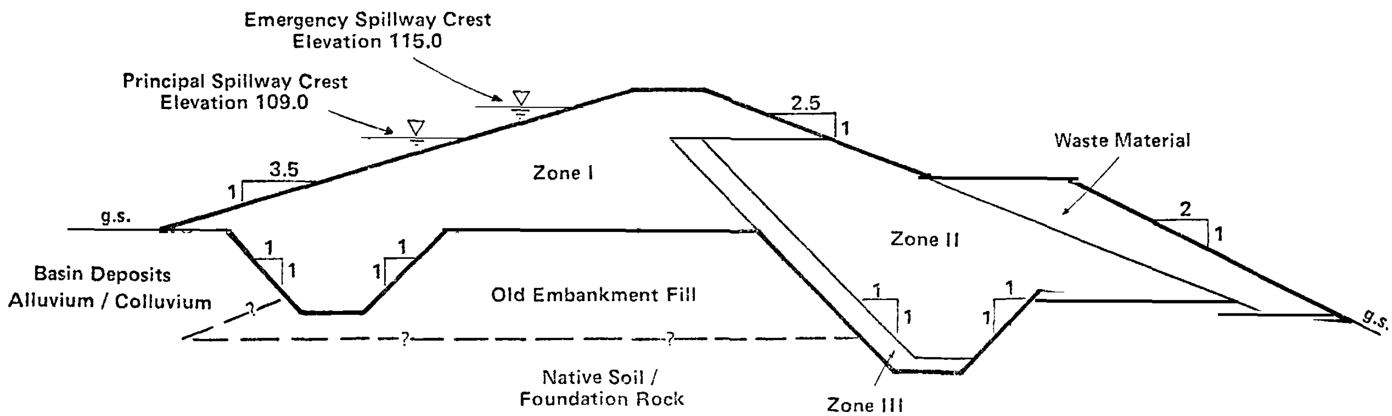
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
STUCKI DAM

Checked by MLT Date 5/27/82	Project No. D118	Figure No. G-6
Approved by EA Nelson Date 27 May 82		



Station 11+77

0 20 40 feet

Horizontal = Vertical

Zone	Material
I	Sandy clay, silty clay and silty sand with varying amounts of gravel and scattered cobbles.
II	Coarse gravel and cobbles in a silty clay matrix.
III	Select drain fill.
Old Embankment Fill.	Graveley silty sand with some cobbles.

Note: g.s indicates approximate ground surface.

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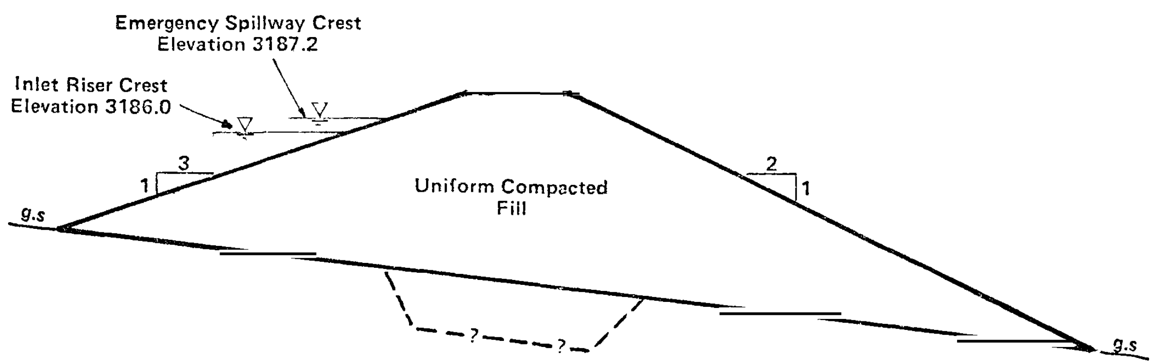
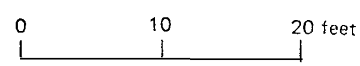
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
FROG HOLLOW DAM

Checked by MLT Date 5/27/82	Project No.	Figure No.
Approved by EA Wilson Date 27 MAY 82	D118	G-7



Typical Cross Section



Horizontal = Vertical

Material

Uniform compacted fill consists of silty sand and sandy silt with varying amounts of gravel and scattered cobbles.

Note: g.s indicates approximate ground surface.

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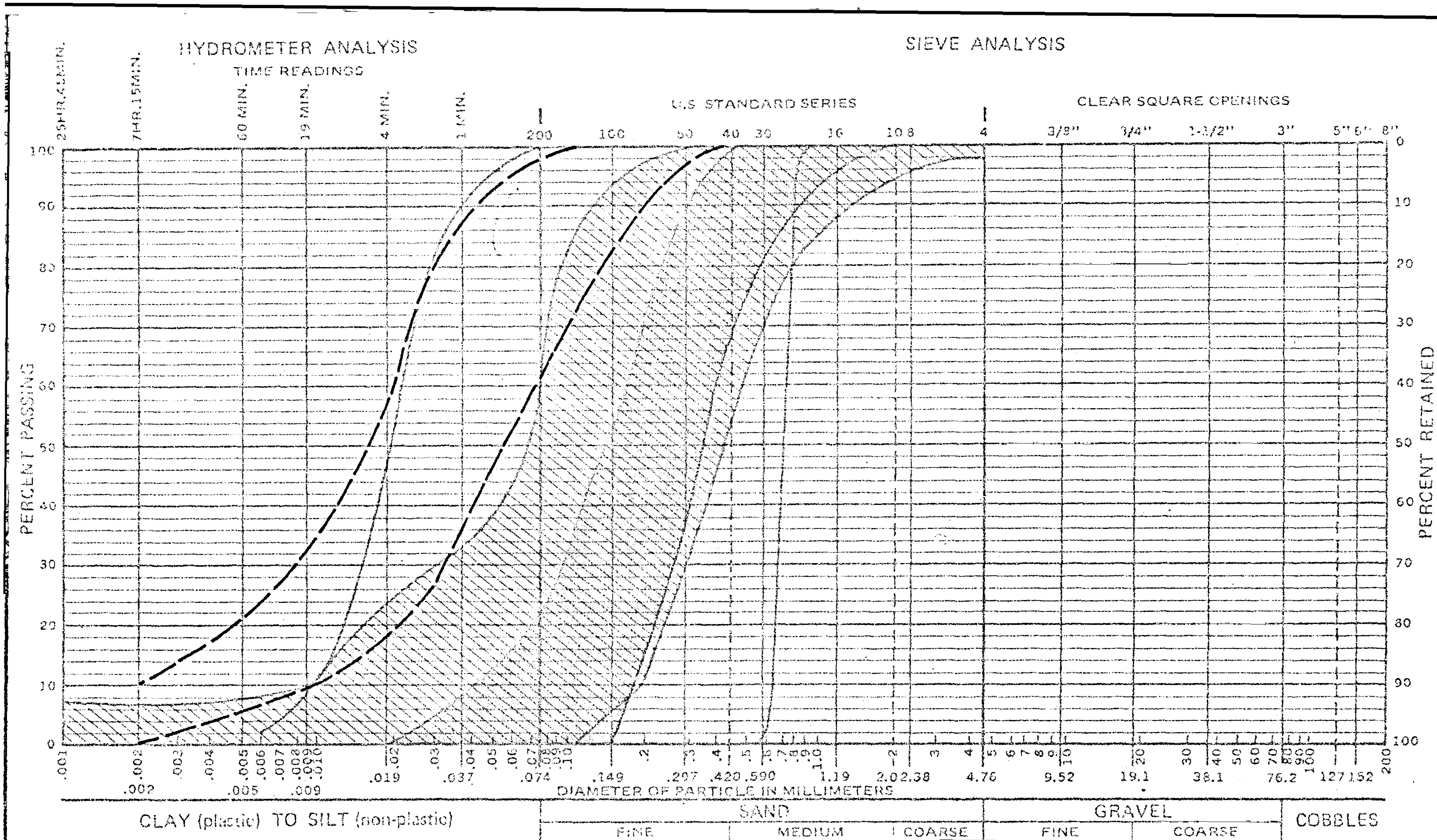
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
REPRESENTATIVE EMBANKMENT CROSS SECTION
IVINS DIVERSION DAM NO. 5

Checked by MLT	Date 5/27/82	Project No.	Figure No.
Approved by EA Nelson	Date 27 MAY 82	D118	G-8



KEY

Most liquefiable soils based on laboratory tests. **Lee and Fitton (1968)**

Sands at Niigata in 15 to 30 feet depth range. **Seed and Idriss (1967)**

Envelope of 19 curves of sands that liquefied during earthquakes in Japan. **Kishida (1969)**

Envelope of 7 curves of silts that liquefied during Western Argentina Earthquake of 1977 (Youd, 1982)

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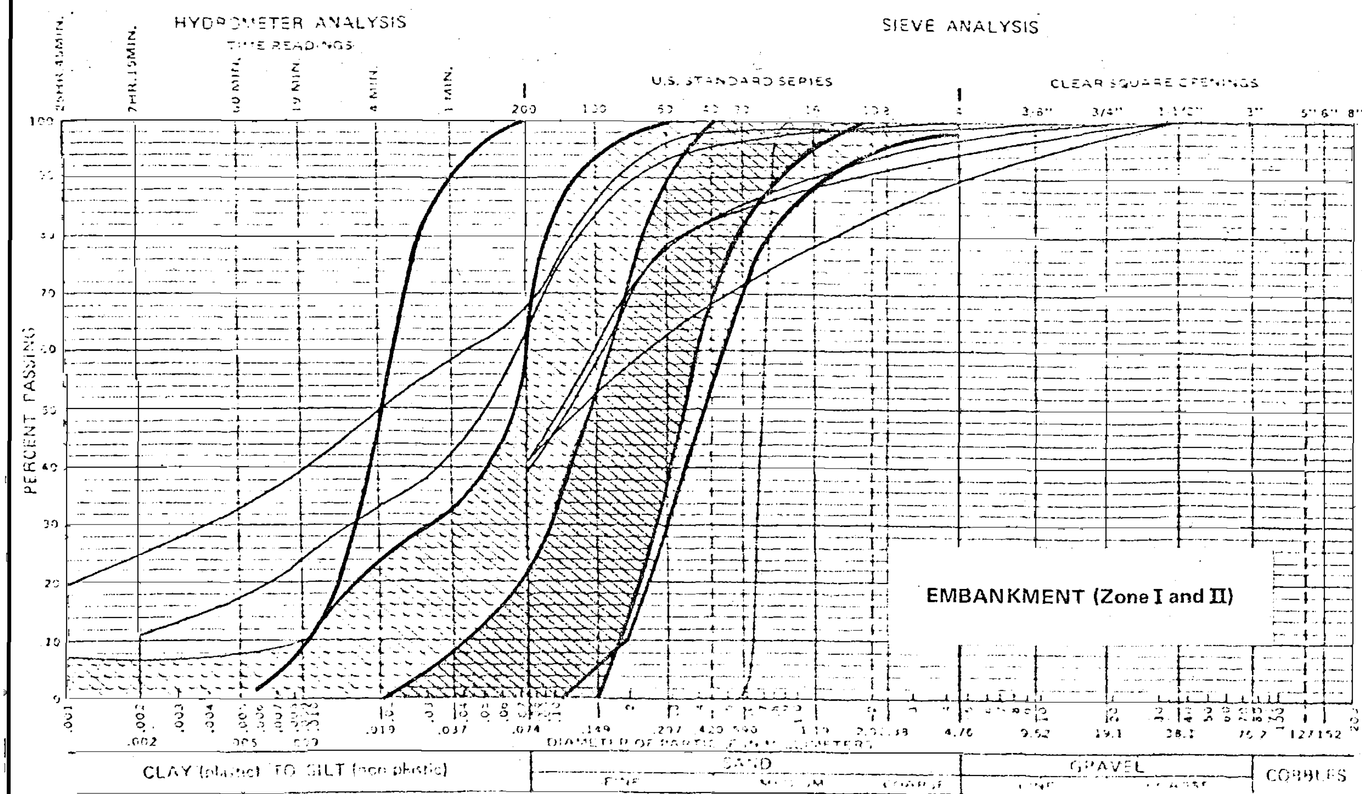
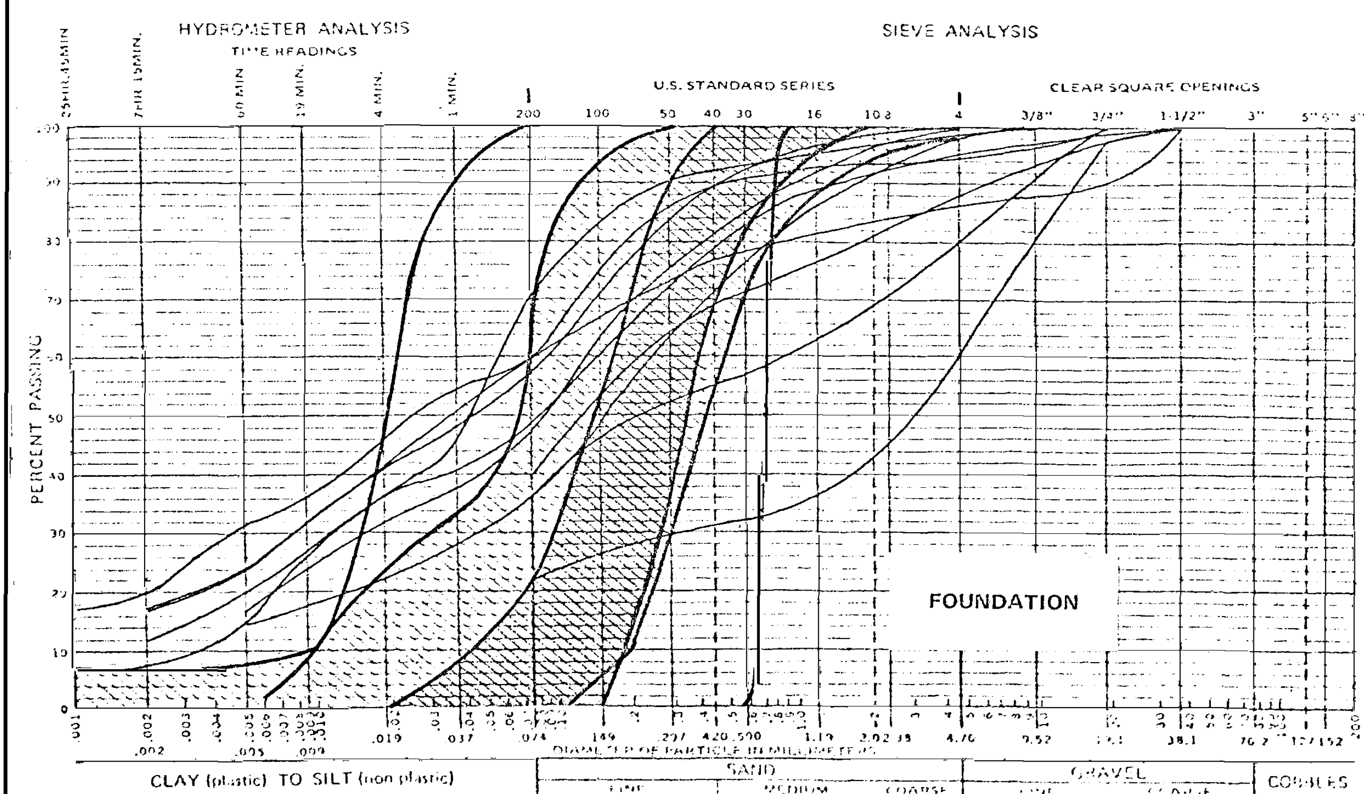
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
GRADATIONS OF SOILS CONSIDERED SUSCEPTIBLE TO LIQUEFACTION

Checked by MLT	Date 9/20/82	Project No.	Figure No.
Approved by J. E. Valera	Date 9/22/82	D118	G-9





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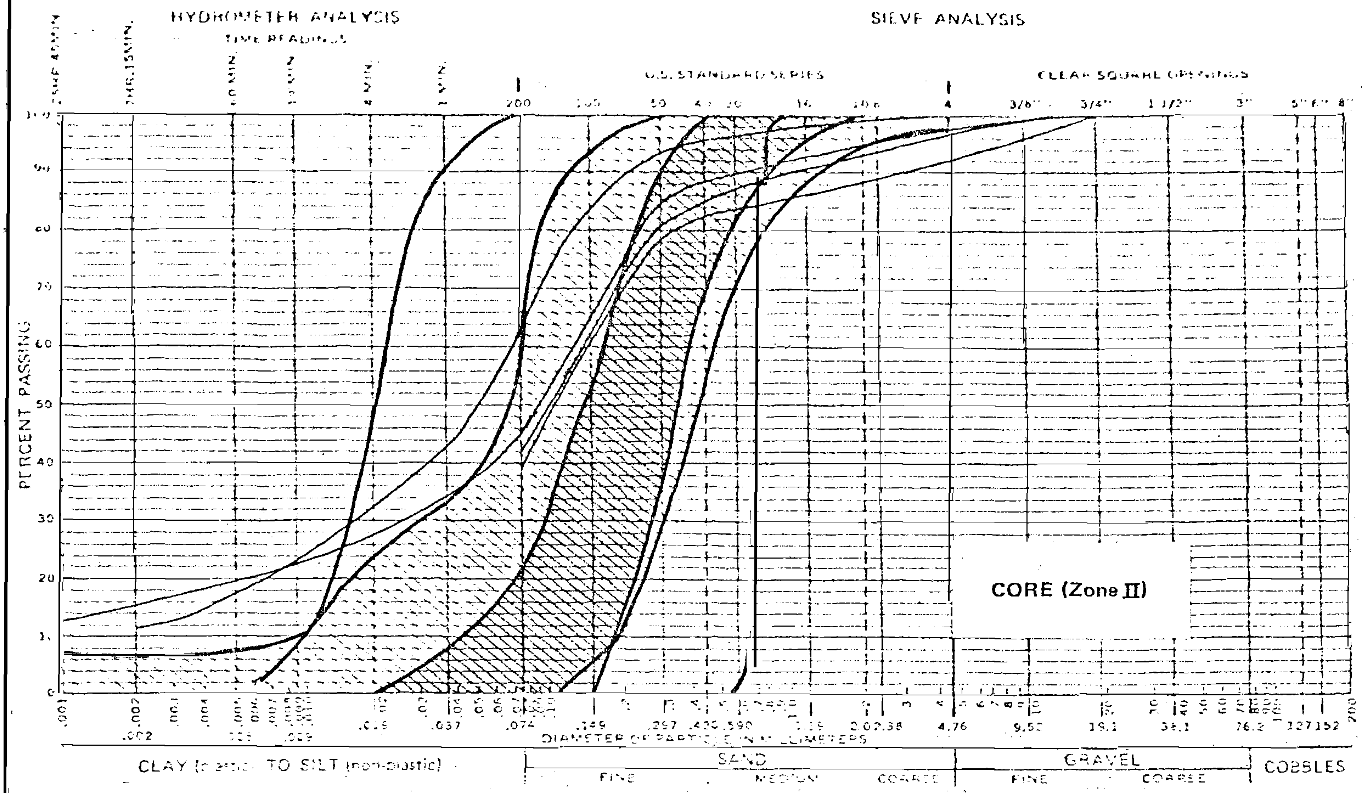
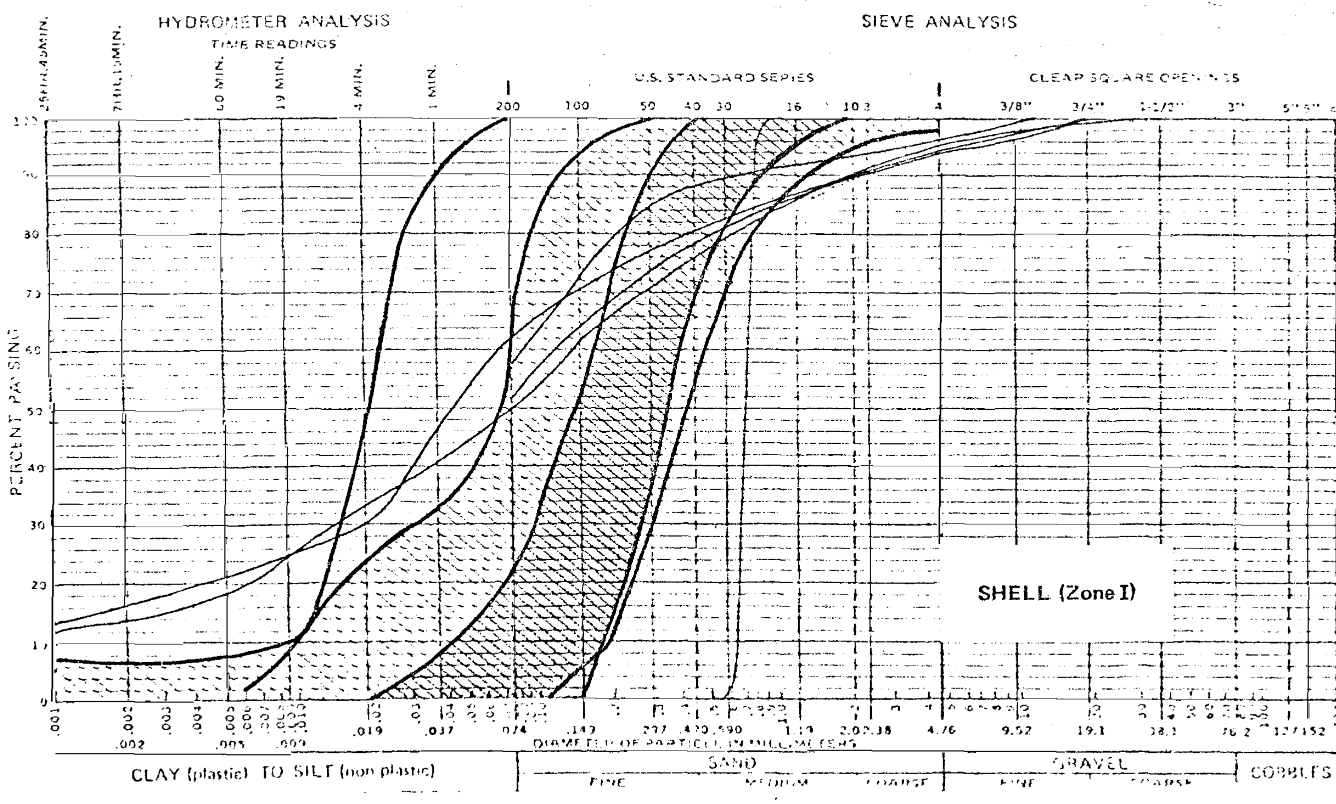
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISONS OF GRADATIONS
GREEN'S LAKE DAM NO. 2

Checked by MLT	Date 9/20/82	Project No.	Figure No.
Approved by J.E. Valera	Date 9/22/82	D118	G-10





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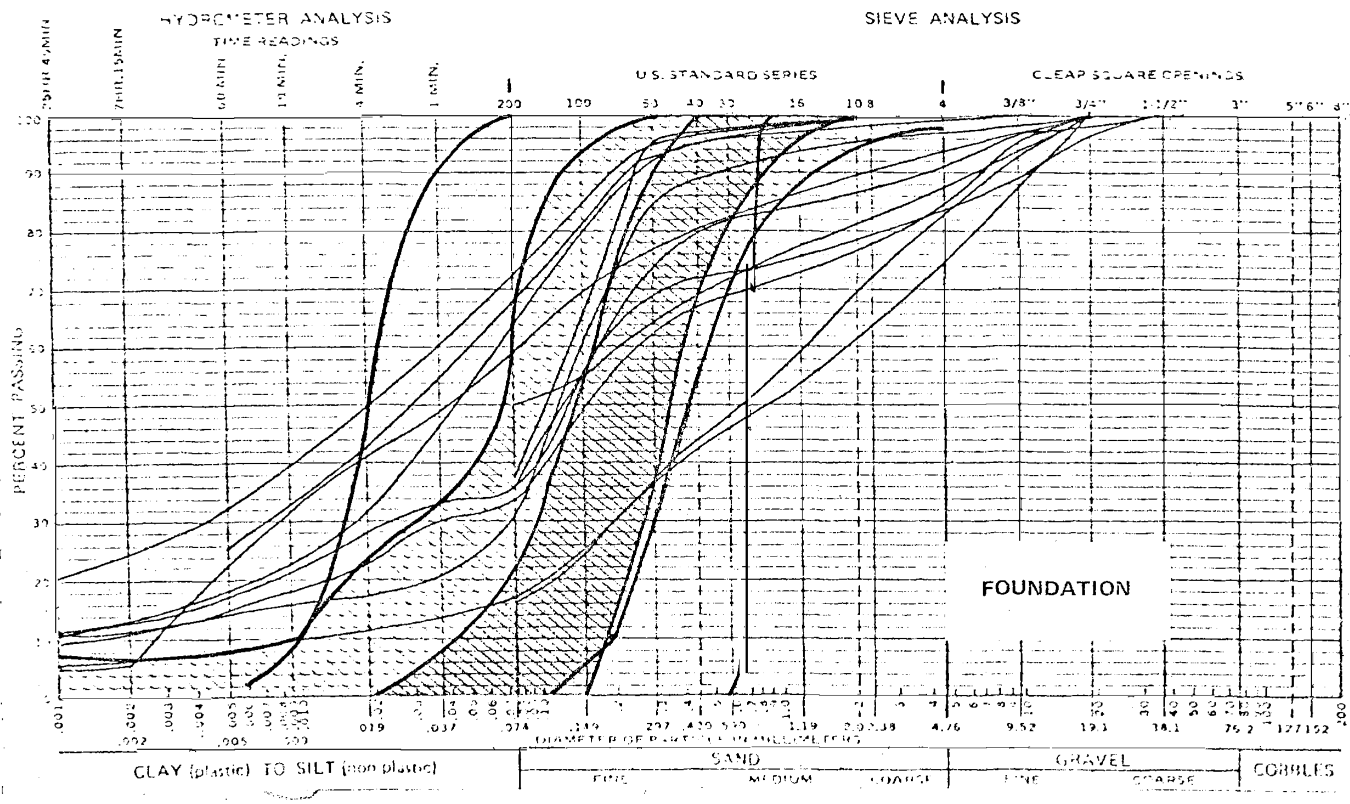
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

COMPARISONS OF GRADATIONS

GREEN'S LAKE DAM NO. 3

Checked by MLT Date 9/20/82	Project No.	Figure No.
Approved by J.E. Valera Date 9/22/82	D118	G-11



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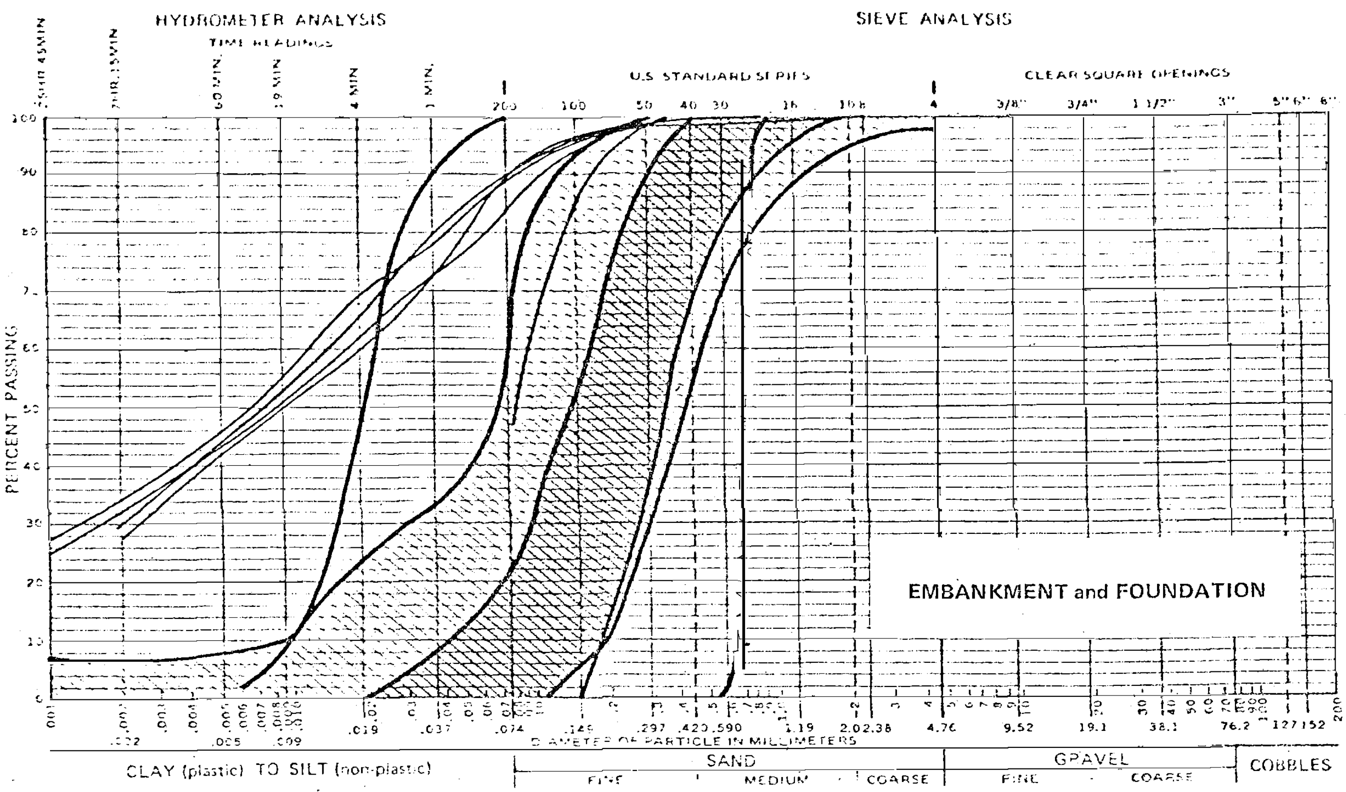
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISONS OF GRADATIONS
GREEN'S LAKE DAM NO. 3

Checked by MLT	Date 9/20/82	Project No. D118	Figure No. G-12
Approved by J.E. Valera	Date 9/22/82		



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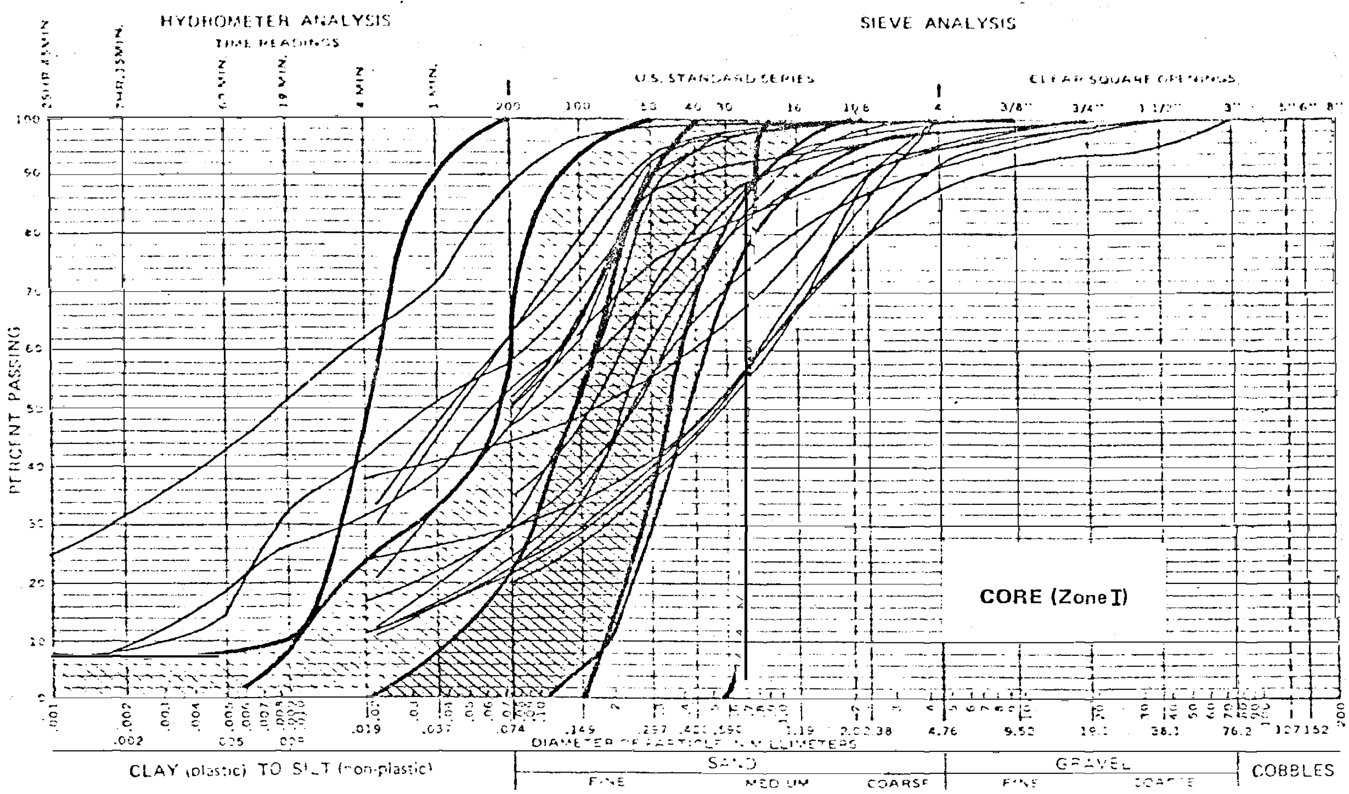
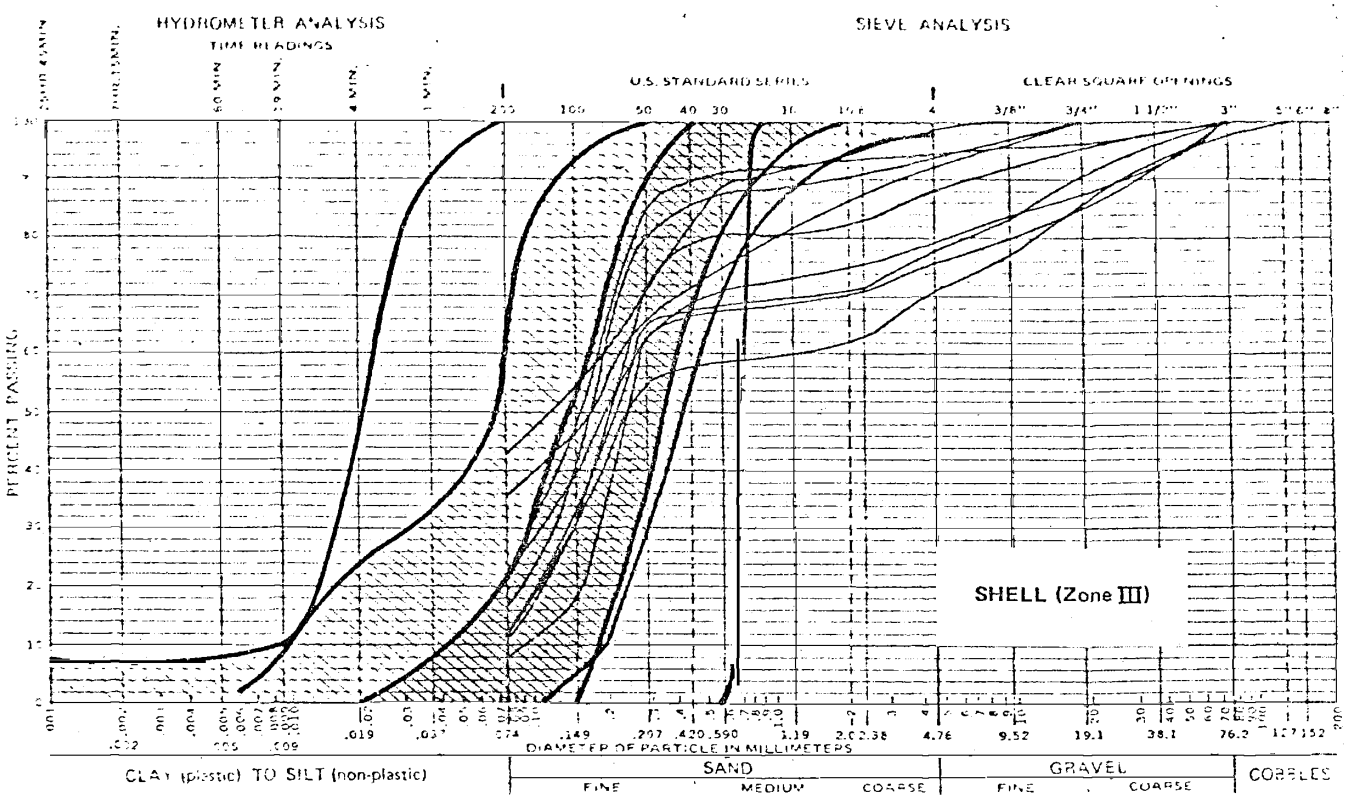
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISONS OF GRADATIONS
GREEN'S LAKE DAM NO. 5

Checked by MCC	Date 9/20/82	Project No. D118	Figure No. G-13
Approved by J. E. Valera	Date 9/22/82		





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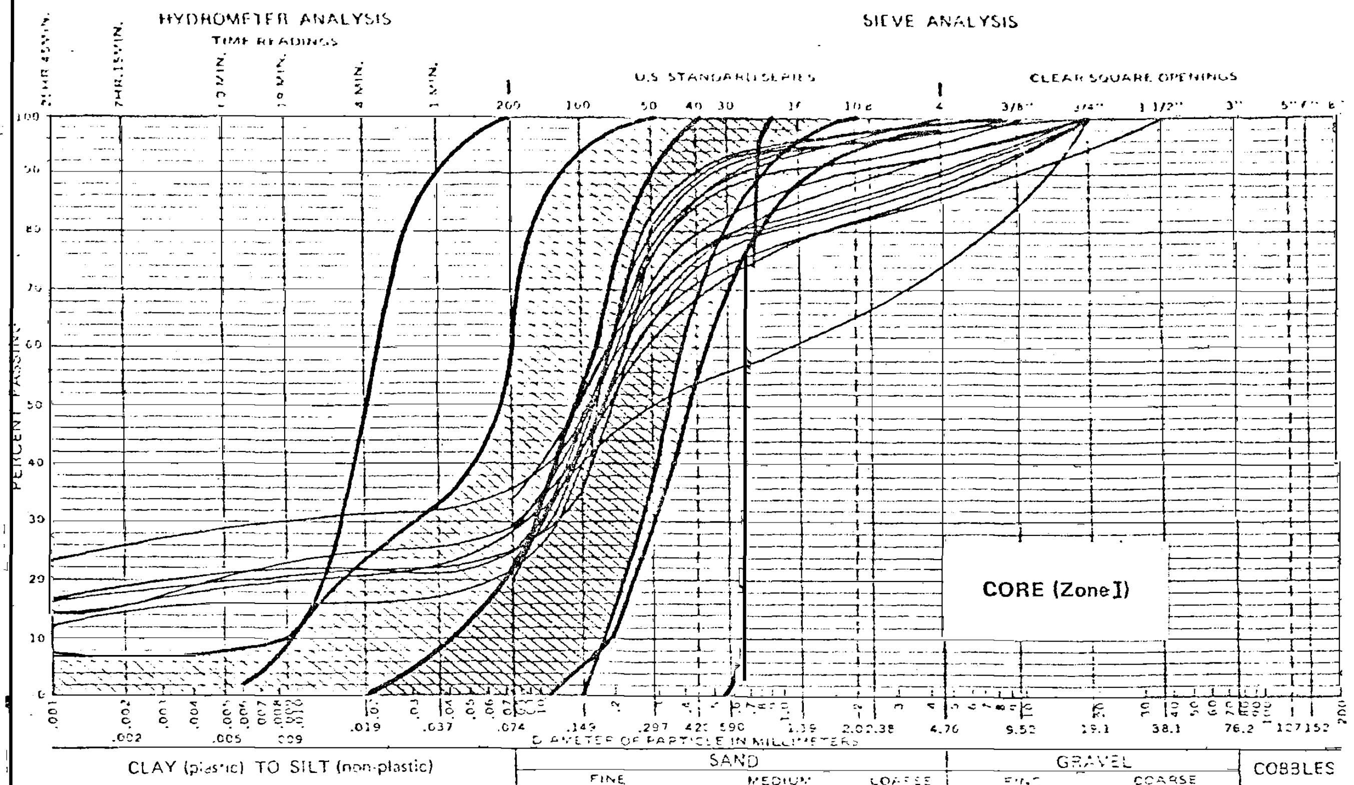
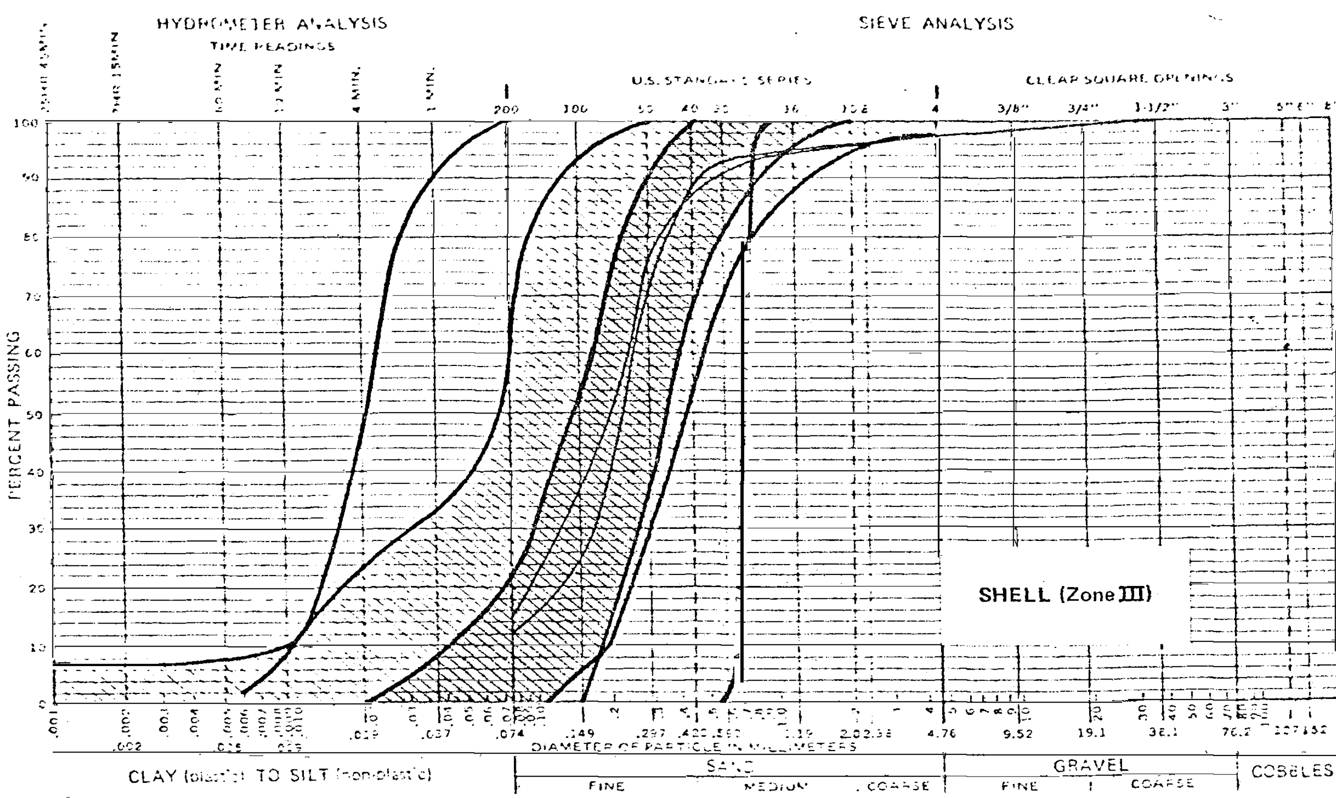
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISONS OF GRADATIONS
GYPSUM WASH DAM

Checked by MLT	Date 9/20/82	Project No. D118	Figure No. G-14
Approved by J. E. Valera	Date 9/22/82		





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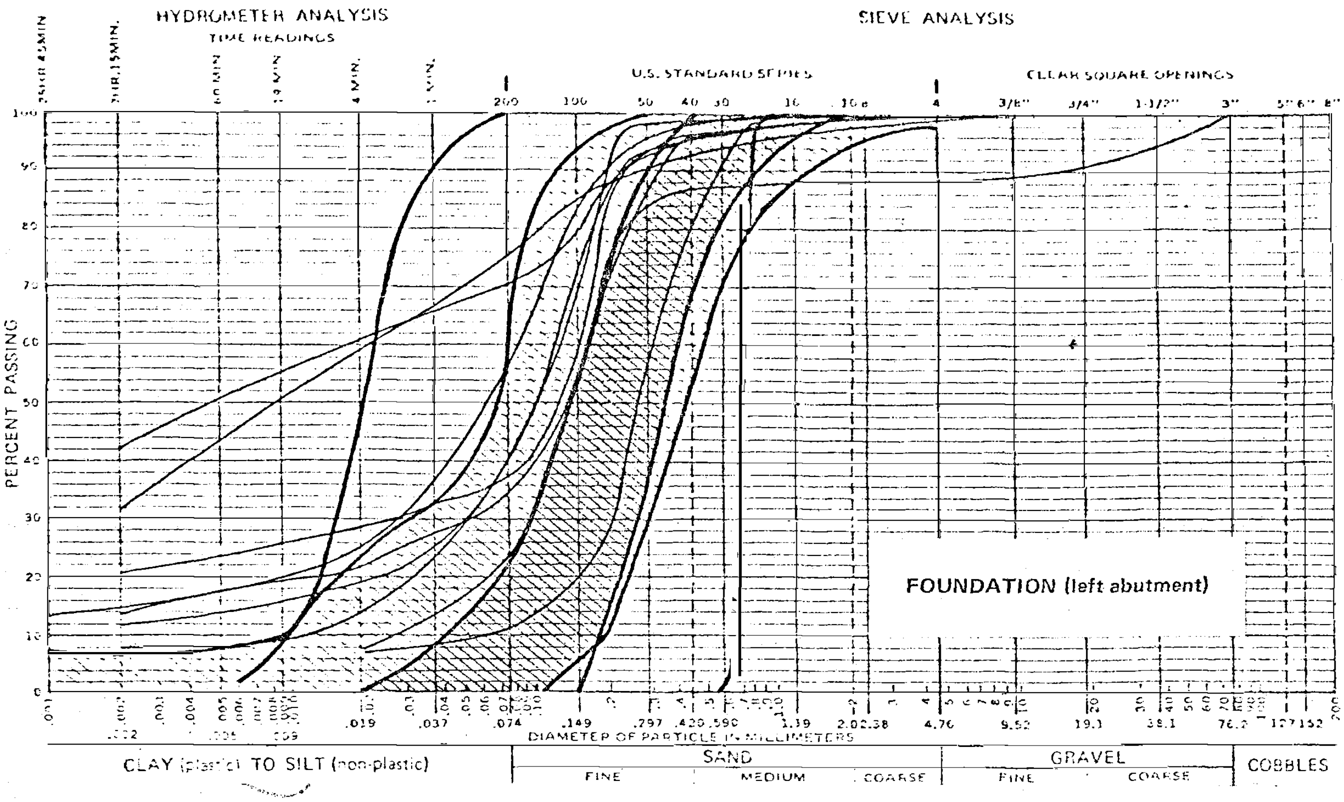
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISON OF GRADATIONS
WARNER DRAW DAM

Checked by MLT Date 9/20/82	Project No.	Figure No.
Approved by J.E. Valera Date 9/22/82	D118	G-15



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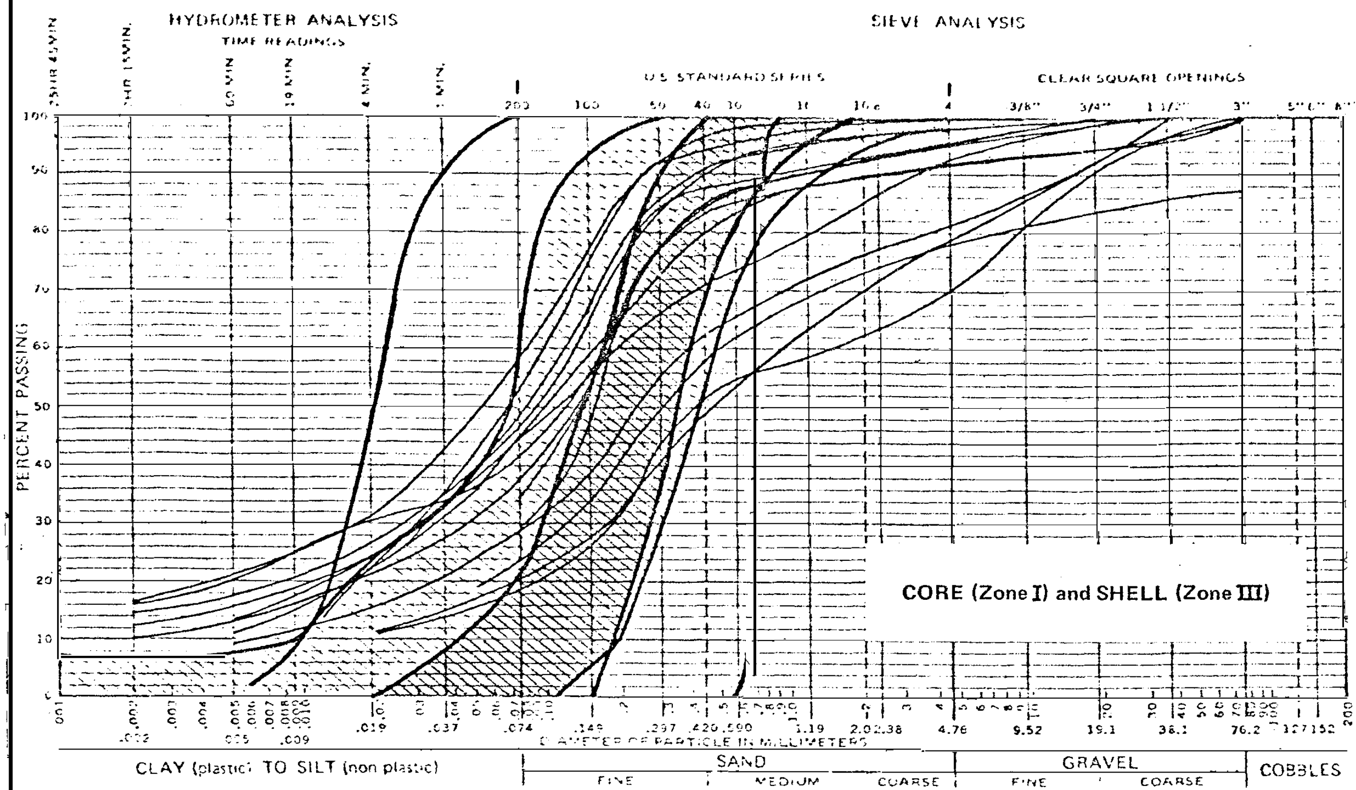
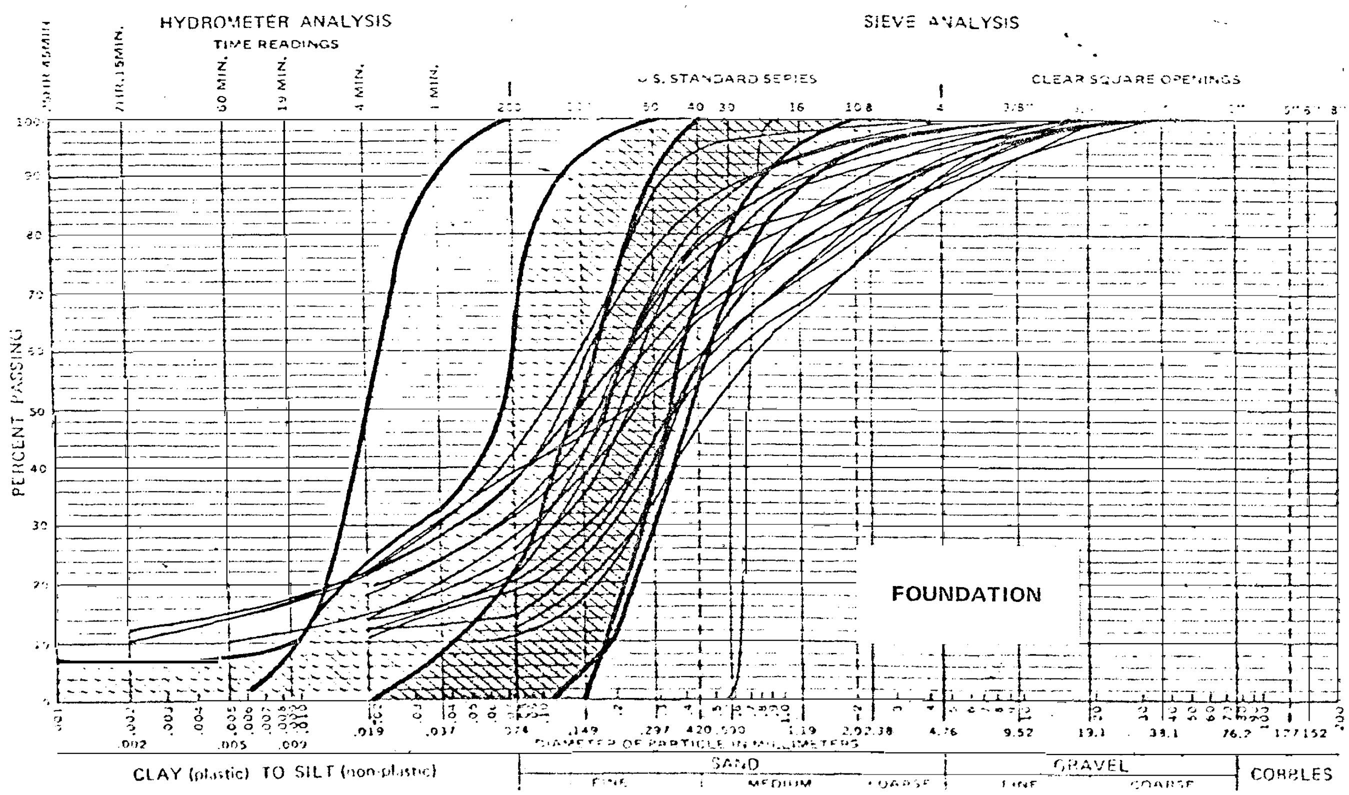
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISON OF GRADATIONS
WARNER DRAW DAM

Checked by MLT	Date 9/20/82	Project No.	Figure No.
Approved by J. E. Valera	Date 9/22/82	D118	G-16





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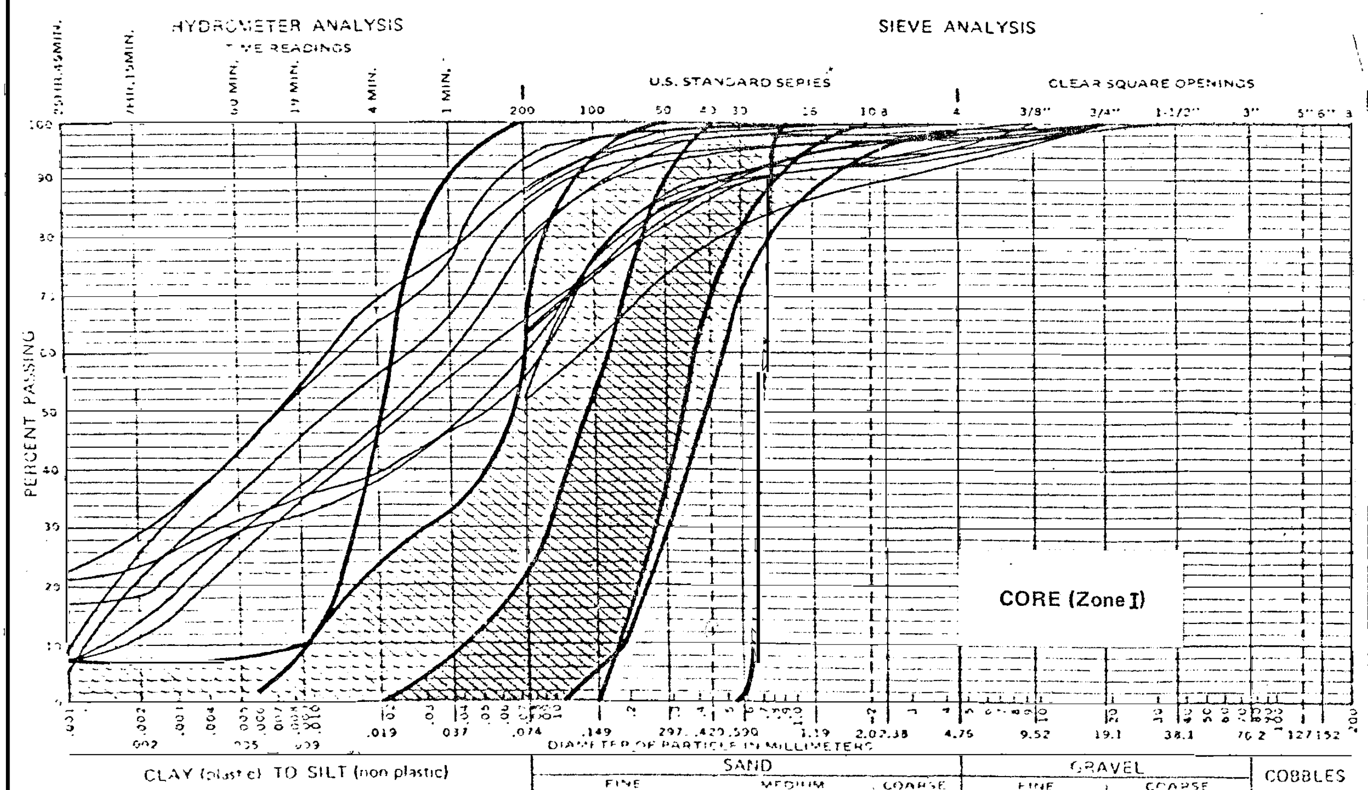
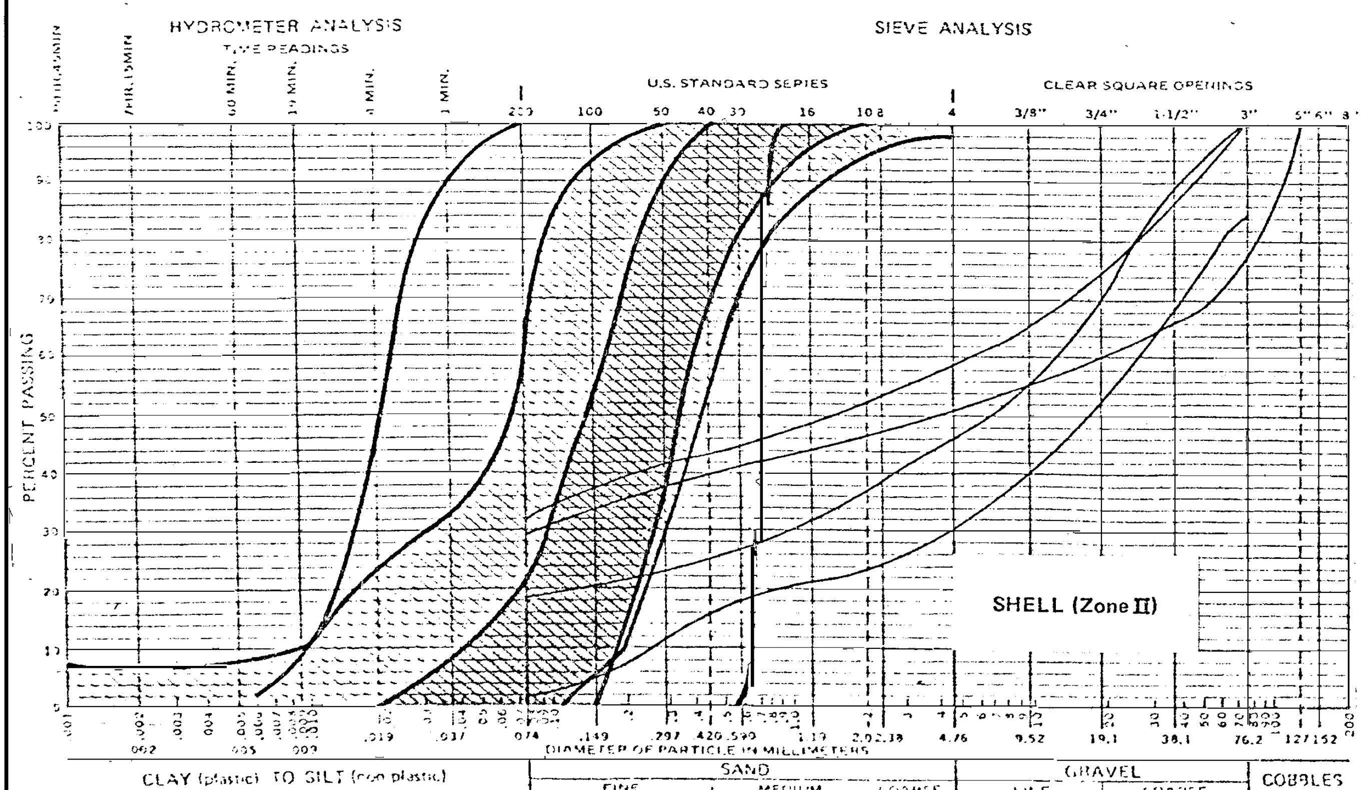
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

COMPARISON OF GRADATIONS

STUCKI DAM

Checked by MLT	Date 9/20/82	Project No.	Figure No.
Approved by J. E. Valera	Date 9/22/82	D118	G-17





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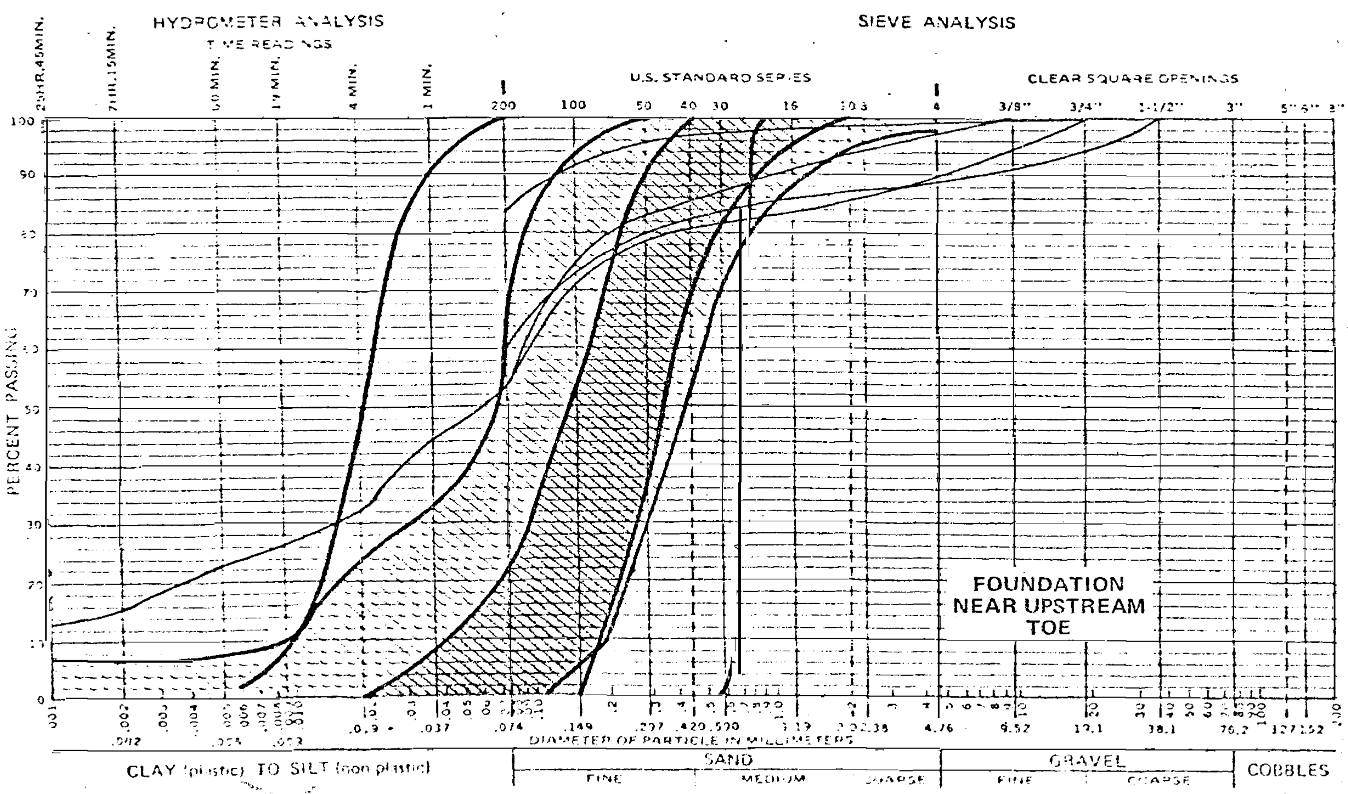
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISON OF GRADATIONS
FROG HOLLOW DAM

Checked by MLT	Date 9/20/82	Project No.	Figure No.
Approved by J. E. Valera	Date 9/22/82	D118	G-18



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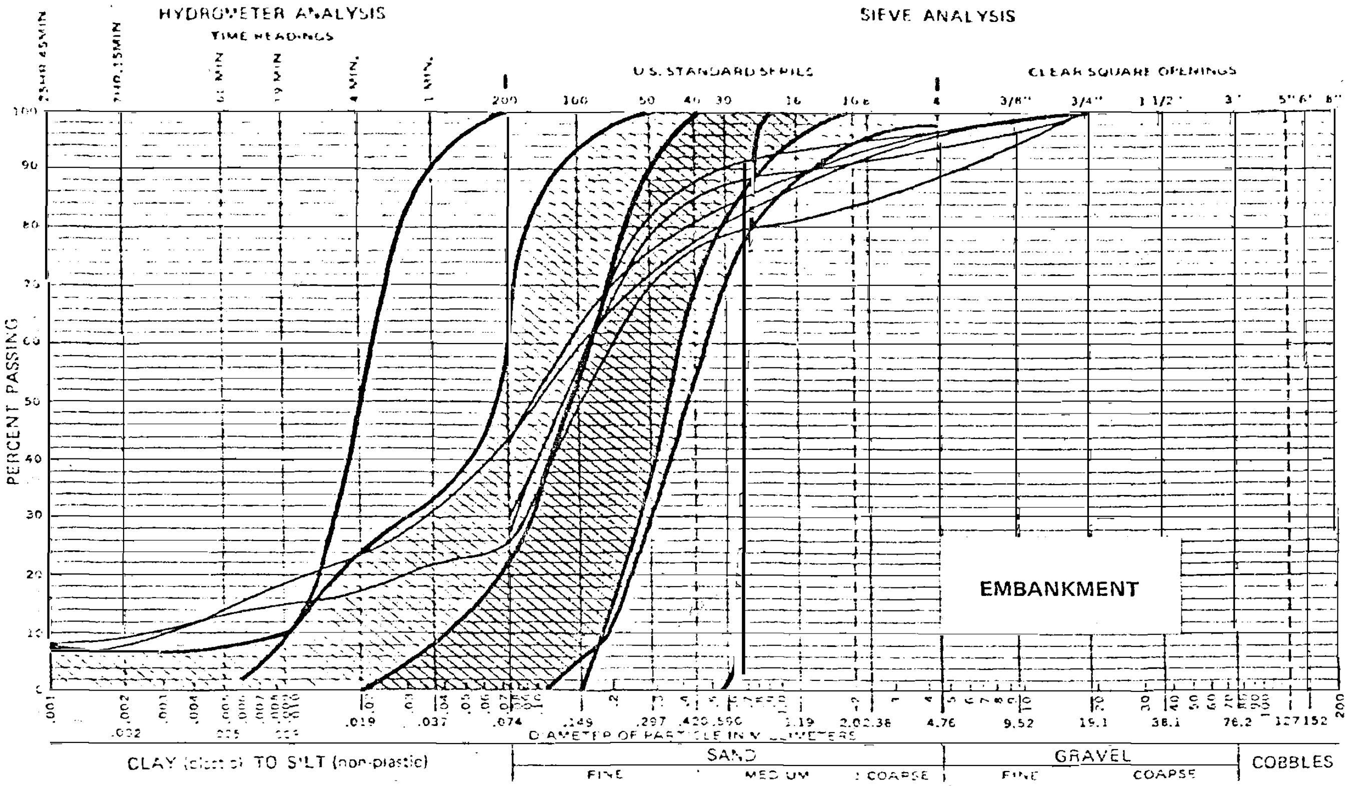
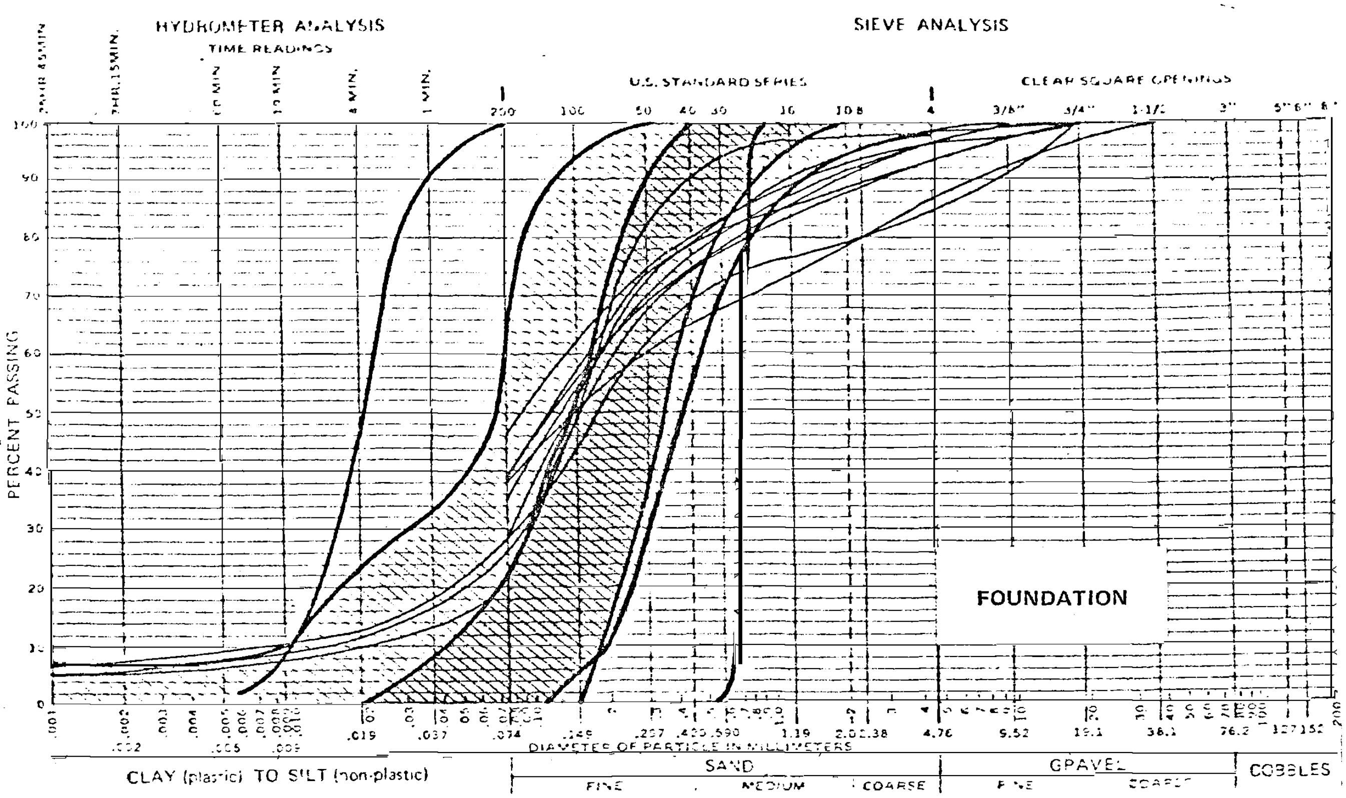
SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS
COMPARISON OF GRADATIONS
FROG HOLLOW DAM

Checked by MLT Date 9/20/82	Project No. D118	Figure No. G-19
Approved by J. E. Valera Date 9/22/82		





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SEISMIC SAFETY INVESTIGATION OF EIGHT SCS DAMS

COMPARISON OF GRADATIONS

IVINS DIVERSION DAM NO. 5

Checked by MCT	Date 9/20/82	Project No.	Figure No.
Approved by J. E. Valera	Date 9/22/82	D118	G-20

APPENDIX H

LISTING OF EARTHQUAKES OF $M \geq 3$ WITHIN 200 KM OF LAT. 30° 25' N, LONG 113° 15' W (1850-1981)

UTAH EARTHQUAKE CATALOG 1850 - June 1962

Compiled by Walter J. Arabasz and Mary E. McKee

(EXPLANATION)

This catalog chronologically lists all earthquakes in the Utah region, 36°45'N - 42°30'N and 108°45'W - 114°15'W, that have been identified since 1850, the year of publication of the first newspaper in Utah, through June 1962. The following data are listed for each event:

1. Year (YR), date, and origin time (ORIG TIME) in Universal or Greenwhich Mean Time (GMT). "Local time" is 7 hours earlier than GMT (i.e., local time = GMT - 7 hours) except for three time periods when it was 6 hrs earlier: (1) 02:00 Mar. 31, 1918 - 02:00 Oct. 27, 1918; (2) 02:00 Mar. 30, 1919 - 02:00 Oct. 26, 1919; and (3) 02:00 Feb. 9, 1942 - 02:00 Sept. 30, 1945. Origin time given in hours and minutes for non-instrumental locations, and in hours, minutes, and seconds for instrumental locations.

2. Earthquake location coordinates in degrees and minutes of north latitude (LAT-N) and west longitude (LONG-W). For non-instrumental locations, epicenter is assumed; in most cases, assigned coordinates correspond to location of town or city where felt effects were strongest. Epicentral accuracy ≅ ±25-50 km.

3. MAG, estimated Richter magnitude determined in one of four ways, as indicated by a suffix: (1) I implies estimate from maximum Modified Mercalli Intensity (INT) assuming the Gutenberg-Richter relation (Gutenberg and Richter, 1956, Bull. Seism. Soc. Am. 46, 105-145): MAG = 1 + 2/3 (INT); (2) M implies magnitude determined by Seismological Laboratory in Pasadena, (3) N implies magnitude estimated by University of Nevada (Reference 5, see below); and (4) X implies value arbitrarily assumed for event of unidentified size; X = 2.3 for non-instrumental locations, and 3.0 for instrumental locations.

4. INT, maximum Modified Mercalli Intensity. Unless otherwise noted, intensity is from Reference 1 (see below) for earthquakes through 1949, and from Reference 8 (see below) thereafter. Where sources disagree on maximum intensity, range is indicated as a comment and a maximum value has been interpreted. For events of unidentified size (X suffix in MAG column), intensity II arbitrarily assumed for non-instrumental locations--and no intensity assigned for instrumental locations.

5. Comments: Compilation of the 1850 - 1962 catalog has involved the careful checking and correlation of numerous sources--and extensive annotation. For convenience, several abbreviations and numbered references have been used, as outlined below. Earthquakes without comments generally are from Reference 1 for 1850-1949, and from either Reference 6 (instrumental) or Reference 8 (non-instrumental) for 1950-1962.

Abbreviations

LOC:	location	ASSGN:	assigned
INT:	intensity (Modified Mercalli)	A'SHOCK:	aftershock
PAS:	Pasadena, Seismological Laboratory	F'SHOCK:	foreshock
NEV:	University of Nevada, Reno	SALT LK:	Salt Lake
ID:	Idaho	MAG:	magnitude
UT:	Utah		

References and Footnotes

(1) Williams, J. S. and M. L. Tapper (1953). Earthquake history of Utah, 1850-1949, Bull. Seism. Soc. Am. 43, 191-218.

(2) U.S. Geological Survey (1976). A study of earthquake losses in the Salt Lake City, Utah area, U.S. Geological Survey Open-File Report 76-89, 357 p.

(3) Townley, S. D. and M. W. Allen (1939). Descriptive catalog of earthquakes of the Pacific Coast of the Unites States, 1769 to 1928, Bull. Seism. Soc. Am. 29 (1), Ch. 4, 5, 6.

(4) Coffman, J. L. and C. A. von Hake, editors (1973). Earthquake History of the United States, Publ. 41-1, U.S. Dept. Commerce, 208 p.

(5) Jones, A. E. (1975). Recording of earthquakes at Reno, 1916-1951, Bull. of the Seismological Laboratory, University of Nevada, Reno, 199 p.

(6) NOAA earthquake data file, National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado.

(7) Pack, F. J. (1921). The Elsinore earthquakes in central Utah, September 29 and October 1, 1921, Bull. Seism. Soc. Am. 11, 155-165.

(8) U.S. Department of Commerce. United States Earthquakes, annual publication, U.S. Government Printing Office, Washington, D. C.

(9) Gutenberg, B. and C. F. Richter (1954). Seismicity of the Earth, 2nd ed., Princeton Univ. Press, Princeton, N.J.

(10) Berg, J. W. Jr. and R. C. Resler (1958). Investigation of local earthquakes February 13, 1958, near Wallsburg, Utah, Utah Acad. Sci., Arts. Lett. Proc. 35, 113-117.

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Note: Coordinates listed in catalog for non-instrumental locations correspond arbitrarily to center of town or city where felt effects were strongest. Decimal-point accuracy is by no means implied for the earthquake epicenters.

UTAH EARTHQUAKE CATALOG: JULY 1962 - PRESENT

(EXPLANATION)

Utah earthquakes for July 1, 1962 through present are listed in chronological order. The following data are listed for each event:

1. Year (YR), date and origin time in Universal Coordinated Time (UTC). Subtact seven hours to convert to Mountain Standard Time (MST).

2. Earthquake location coordinates in degrees and minutes of north latitude (LAT-N) and west longitude (LONG-W), and depth in kilometers. "*" indicates depth restricted to the initial trial depth due to poor depth resolution.

3. MAG, computed local magnitude for each earthquake. "W" indicates original Wood-Anderson records used. "M" indicates a magnitude less than 1.5.

4. NO, number of P, S and S-P readings used in solution.

5. GAP, largest azimuthal separation in degrees between recording stations used in the solution.

6. DMN, epicentral distance in kilometers to the closest station.

7. RMS, root-mean-square error in seconds of the travel-time residuals:

$$RMS = \left(\sum_i (W_i R_i^2)/NO\right)^{\frac{1}{2}}$$

where:

R_i is the observed minus the computed arrival times of P, S, or S-P data at the i-th station,

W_i is the relative weight given to the i-th station (0.0 for no weight through 1.0 for full weight) for the type of data (P, S, or S-P).

NO as described above.

8. Q, quality class of the hypocenter.

a) July 1962 through September 1974.

Quality	NO	RMS	ERH
A	6	0.25	5.0
B	6	0.50	10.0
C	6	0.75	15.0
D	Others		

b) October 1974 through present--Q is the average of S and D defined as follows:

S	RMS	ERH	ERZ
A	0.15	1.0	2.0
B	0.30	2.5	5.0
C	0.50	5.0	
D	Others		

D	NO	GAP	DMN
A	6	90°	Depth or 5 km
B	6	135°	2xDepth or 5 km
C	6	180°	50 km
D	Others		

Where:

ERH and ERZ represent the largest horizontal and vertical deciation respectively in kilometers within the error ellipsoid.

NOTE: The values in these tables represent the minimum acceptable values for each quality class.

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig time		lat-n	long-w	depth	mag	km	az
1859	828	0	.00	37-50.52	112-49.63		3.7	60.2	38.3
1873	731	315	.00	38-16.74	112-38.38		4.3	109.8	29.3
1876	1130	500	.00	37-40.97	113- 3.95		3.0	33.7	28.9
1876	1230	515	.00	38-46.15	112- 5.02		3.0	181.7	34.3
1877	101	0	.00	38-46.15	112- 5.02		3.7	181.7	34.3
1877	115	1200	.00	38-34.80	112-15.30		3.0	155.9	34.1
1878	814	0	.00	38-36.00	112-34.80		4.3	143.9	24.1
1878	816	244	.00	38-36.00	112-34.80		3.7	143.9	24.1
1881	326	215	.00	37-35.00	113-43.00		4.3	52.0	290.8
1881	804	430	.00	38-16.74	112-38.38		3.0	109.8	29.3
1885	905	335	.00	37- 2.84	112-31.34		3.0	76.5	122.4
1885	1026	610	.00	38-12.89	112-53.43		3.0	93.1	18.0
1885	1026	800	.00	38-25.80	113-17.40		3.0	112.5	358.2
1885	1026	900	.00	38-25.80	113-17.40		3.0	112.5	358.2
1885	1217	100	.00	38-10.32	112-16.27		3.7	120.3	45.8
1885	1217	320	.00	38-17.10	111-28.80		3.0	183.2	58.3
1887	1205	1530	.00	37- 2.84	112-31.34		5.7	76.5	122.4
1891	420	1355	.00	37- 6.38	113-34.41		5.0	44.8	219.8
1891	913	348	.00	37-40.97	113- 3.95		3.0	33.7	28.9
1894	205	330	.00	38-48.30	112-26.32		3.7	169.7	24.8
1894	206	1500	.00	38-48.30	112-26.32		3.0	169.7	24.8
1899	1110	900	.00	38-16.74	112-38.39		3.7	109.8	29.3
19 1	1114	439	.00	38-46.15	112- 5.02		7.0	181.7	34.3
19 2	601	0	.00	38-16.74	112-38.38		3.0	109.8	29.3
19 2	731	700	.00	38-16.74	112-38.38		4.3	109.8	29.3
19 2	1117	1950	.00	37-23.58	113-31.20		6.3	24.0	263.7
19 2	1205	0	.00	37-23.68	113-31.20		5.0	24.0	264.2
19 3	712	1630	.00	38-46.15	112- 5.02		3.0	181.7	34.3
19 3	1104	2340	.00	37- 6.38	113-34.41		3.0	44.8	219.8
19 3	1123	1000	.00	37- 6.38	113-34.41		4.3	44.8	219.8
19 8	415	0	.00	38-23.58	113- .44		5.0	110.4	11.1
1910	110	1300	.00	38-40.97	112- 8.98		5.0	170.5	34.5
1910	112	300	.00	38-40.97	112- 8.98		5.0	170.5	34.5
1912	818	2112	.00	36-30.00	111-30.00		5.7	186.1	123.1
1913	1020	1000	.00	37-49.36	112-26.02		3.7	85.0	58.0
1914	1214	530	.00	37-34.37	113-42.79		4.3	44.5	292.9
1914	1221	525	.00	37-34.37	113-42.79		3.0	44.5	292.9
1915	212	1950	.00	37-34.37	113-42.79		3.7	44.5	292.9
1915	213	830	.00	37-34.37	113-42.79		3.7	44.5	292.9
1915	1025	1713	.00	38-37.90	112-13.00		3.0	162.5	33.9

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig time		lat-n	long-w	depth	mag	km	az
1920	818	820	.00	38-16.74	112-38.38		3.0	109.8	29.3
1920	1126	0	.00	37- 6.38	113-34.41		4.3	44.8	219.8
1921	602	2130	.00	37-40.97	113- 3.95		3.0	33.7	28.9
1921	912	1018	.00	38-46.15	112- 5.02		4.3	181.7	34.3
1921	912	1327	.00	38-46.15	112- 5.02		3.7	181.7	34.3
1921	913	930	.00	38-46.15	112- 5.02		4.3	181.7	34.3
1921	929	1412	.00	38-40.97	112- 8.98		6.3	170.5	34.5
1921	930	230	.00	38-40.97	112- 8.98		5.7	170.5	34.5
1921	1001	1532	.00	38-40.97	112- 8.98		6.3	170.5	34.5
1921	1015	1227	.00	38-40.97	112- 8.98		3.0	170.5	34.5
1921	1027	1415	.00	38-40.97	112- 8.98		4.3	170.5	34.5
1921	1101	1535	.00	38-40.97	112- 8.98		3.7	170.5	34.5
1921	1220	945	.00	38-40.97	112- 8.98		3.0	170.5	34.5
1921	1220	1510	.00	38-40.97	112- 8.98		3.7	170.5	34.5
1923	514	1210	.00	38-10.00	113-14.00		4.3	83.3	1.0
1925	714	1347	.00	37-48.60	113-55.80		3.7	74.2	306.0
1926	515	1951	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	605	1100	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	712	520	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	1001	1515	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	1004	2030	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	1023	0	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	1112	340	.00	37-19.04	112-35.47		3.0	59.4	100.7
1926	1116	1415	.00	37-19.04	112-35.47		3.0	59.4	100.7
1927	522	500	.00	38-46.15	112- 5.02		3.0	181.7	34.3
1927	1123	930	.00	37-19.04	112-35.47		3.0	59.4	100.7
1933	120	1310	.00	37-50.52	112-49.63		5.0	60.2	33.3
1934	1225	1000	.00	37- 2.84	112-31.34		3.7	76.5	122.4
1935	1006	300	.00	37-55.47	111-25.61		3.7	170.4	70.7
1936	122	338	.00	36-18.00	113-30.00		4.3	125.9	190.2
1936	509	1025	.00	37-15.00	112-57.48		4.3	31.8	125.6
1936	902	2337	.00	38-30.00	112-23.00		3.0	142.3	32.4
1936	921	620	.00	38- .00	113-18.00		4.7	64.9	356.1
1937	218	415	.00	37-49.36	112-26.02		4.3	85.0	58.0
1937	218	900	.00	37-49.36	112-26.02		3.7	85.0	58.0
1937	221	830	.00	37-49.36	112-26.02		3.0	85.0	58.0
1937	226	130	.00	37-49.36	112-26.02		3.7	85.0	58.0
1938	817	908	6.00	36-42.00	113-42.00		3.0	89.0	206.7
1938	1228	437	36.00	37- .00	114- .00		3.0	81.1	235.2
1939	1121	2340	48.00	36-30.00	115- .00		3.0	196.1	236.9

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1940	310	1801	54.00	37- .00	115- .00		3.0	162.1	253.4
1940	311	6	30.00	37- .00	115- .00		3.0	162.1	253.4
1940	407	842	.00	37- .00	115- .00		3.0	162.1	253.4
1940	920	1221	54.00	36-30.00	115- .00		3.0	186.1	236.9
1940	1026	124	24.00	38- .00	113- .00		3.0	68.4	18.8
1941	322	1208	6.00	36- .00	114-36.00		3.0	198.2	217.5
1941	506	311	42.00	37-18.00	114-18.00		3.0	93.9	262.1
1942	328	1310	.00	38-10.32	112-16.27		3.7	120.3	45.8
1942	830	2208	.00	37-40.97	113- 3.95		5.0	33.7	28.9
1942	918	0	.00	37-40.97	113- 3.95		3.0	33.7	28.9
1942	918	200	.00	37-40.97	113- 3.95		3.0	33.7	28.9
1942	918	520	.00	37-40.97	113- 3.95		3.7	33.7	28.9
1942	926	1116	.00	37-40.97	113- 3.95		4.3	33.7	28.9
1942	926	1450	.00	37-40.97	113- 3.95		5.0	33.7	28.9
1942	928	1330	.00	37-15.00	112-57.48		3.7	31.8	125.6
1943	116	1150	18.00	37-40.97	113- 3.95		4.3	33.7	28.9
1943	306	2014	30.00	37-24.00	114- 6.00		3.0	75.3	268.6
1943	1103	930	.00	38-34.80	112-15.60		4.3	155.7	34.0
1943	1103	1130	.00	38-34.80	112-15.60		3.0	155.7	34.0
1943	1104	200	.00	38-34.80	112-15.60		3.0	155.7	34.0
1943	1106	354	.00	37-21.00	114-15.00		3.7	88.9	265.2
1943	1209	1606	.00	37-40.97	113- 3.95		3.7	33.7	28.9
1944	131	424	58.00	36-54.00	112-24.00		3.0	94.8	127.2
1944	308	754	51.00	37-36.00	114- 9.00		3.0	82.1	284.3
1944	320	931	.00	37-12.00	114- .00		3.0	70.7	250.1
1944	503	2345	.00	37- 6.38	113-34.41		3.7	44.8	219.8
1944	1108	2030	6.00	38-48.00	112-54.00		3.0	156.6	11.3
1945	111	1156	.00	37-24.00	114-54.00		3.8	146.1	269.3
1945	1118	107	41.00	38- .00	112- .00		3.0	127.8	59.6
1945	1118	115	.00	38-45.90	111-59.21		5.0	186.2	36.5
1949	1102	230	.00	37- 6.38	113-34.41		4.7	44.8	219.8
1950	505	735	.00	38-14.33	112-13.25		3.7	128.6	44.8
1951	305	2300	.00	37- .00	112-32.40		3.7	78.2	126.3
1952	502	1015	.00	37-14.47	113-16.90		3.7	19.7	188.2
1952	524	415	15.00	36- 6.00	114-42.00		5.0	195.2	221.5
1952	524	448	12.00	36- 6.00	114-42.00		3.7	195.2	221.5
1952	524	952	52.00	36- 6.00	114-42.00		3.7	195.2	221.5
1952	525	1306	30.00	36- 6.00	114-42.00		3.7	195.2	221.5
1953	418	515	.00	38-38.21	112- 7.40		3.7	167.7	36.1
1953	518	703	2.00	36- .00	114-30.00		3.0	192.8	215.4

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1953	809	2200	2.00	37-15.00	114-30.00		3.0	112.3	260.5
1953	1022	300	.00	37-49.36	112-26.02		4.3	85.0	58.0
1955	110	1007	.00	37- .00	114-30.00		4.3	120.2	247.4
1955	1120	1057	54.00	37- 6.00	113-54.00		3.7	67.5	238.6
1959	227	2219	52.00	38- .00	112-30.00		5.0	92.6	45.6
1959	721	1739	29.00	37- .00	112-30.00		5.5	81.1	124.8
1959	727	1115	.00	37-32.36	113-10.51		3.7	15.1	25.9
1959	917	620	.00	38-26.93	112-13.80		3.7	145.5	38.1
1961	926	2146	20.00	37-39.96	114-20.00		3.0	99.7	286.1
1962	215	712	42.90	36-54.00	112-24.00		4.5	94.8	127.2
1962	215	906	45.00	37- .00	112-54.00		3.0	55.7	146.1
1962	217	329	26.90	38-36.00	111-36.00		3.0	195.6	47.8
1962	605	2229	45.00	38- .00	112- 6.00		3.0	120.3	57.4
1962	819	1732	41.43	38- 3.08	112- 5.31	7.0	3.2	124.3	55.5
1963	217	1734	20.64	37-48.10	113-54.21	7.0	3.7	71.8	306.5
1963	619	838	44.87	38- 1.10	112-31.50	7.0	3.7	92.4	43.7
1963	930	917	39.33	38- 5.90	111-13.05	7.0	4.3	194.4	67.1
1963	1113	617	30.12	38-17.72	112-39.39	7.0	3.2	110.6	28.2
1964	101	1643	5.82	37-33.22	112-43.85	7.0	3.1	48.4	71.7
1964	117	15	3.45	38-11.11	112-37.30	7.0	3.3	101.7	33.0
1964	824	151	.55	38-46.33	112-13.93	7.0	3.1	175.0	30.7
1964	824	155	30.44	38-47.00	112-14.83	7.0	3.0	175.4	30.1
1964	921	36	23.17	38-47.76	112-12.75	7.0	3.0	178.1	30.7
1964	1129	931	34.35	38-58.05	112-13.81	7.0	3.1	193.9	27.4
1965	130	1348	53.21	37-32.24	113- 6.95	7.0	3.2	17.9	41.5
1965	713	1803	15.41	37-42.72	112-39.00	7.0	3.0	40.4	35.7
1965	720	1449	24.86	38- 1.57	112-26.49	7.0	3.0	98.3	46.5
1965	830	43	13.20	37-26.92	113-41.34	7.0	3.2	39.0	275.2
1966	520	1211	37.39	38- 3.03	112-12.09	7.0	3.0	116.2	52.7
1966	520	1340	47.87	37-59.99	111-51.25	7.0	4.1	138.2	62.9
1966	816	1802	32.85	37-27.31	114- 9.07	7.0	5.6	79.9	273.7
1966	819	1051	37.92	37-26.33	114-11.48	7.0	4.7	83.4	271.7
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	88.6	272.3
1966	903	753	18.55	36-30.27	112-15.24	7.0	3.5	134.6	138.8
1966	923	13	57.11	37-30.50	113-17.47	7.0	3.2	10.8	340.3
1966	1021	713	48.88	38-11.74	113- 9.45	7.0	4.2	86.8	5.4
1967	722	2151	27.40	38-48.14	112-13.01	7.0	3.6	178.5	30.5
1967	1004	1020	12.80	38-32.59	112- 9.39	7.0	5.2	157.7	37.5
1967	1113	1648	53.77	37-34.97	113-20.32	7.0	3.5	20.0	337.0
1968	320	1533	3.98	37-55.28	112-16.55	7.0	3.0	102.6	56.9

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1968	408	1608	14.65	37-22.40	114-17.12	.9	3.3	91.8	267.0
1968	412	640	7.05	36-55.12	114-37.59	7.0	3.1	134.2	245.7
1968	924	210	49.63	38- 2.50	112- 4.92	7.0	3.6	124.2	56.0
1969	410	837	5.46	38-39.89	112- 4.39	7.0	3.6	172.8	36.7
1969	815	30	30.57	37-47.48	113-14.97	7.0	3.0	41.6	.1
1970	418	1042	11.46	37-52.47	111-43.26	7.0	3.7	144.2	69.4
1970	523	2255	23.20	38- 3.47	112-28.13	7.0	3.9	99.0	44.1
1970	901	1152	17.81	37-26.47	113-47.17	7.0	3.0	47.5	273.3
1971	623	608	35.87	38-36.49	112-42.38	7.0	3.1	140.6	19.9
1971	1110	1114	10.32	37-41.60	113- 6.16	7.0	3.1	33.4	23.0
1971	1110	1124	34.89	37-41.87	113- 7.28	7.0	3.1	33.2	20.0
1971	1110	1338	14.19	37-42.14	113- 5.58	7.0	3.1	34.6	23.6
1971	1110	1410	23.01	37-48.03	113- 5.99	7.0	3.7	44.6	17.3
1971	1110	1443	58.51	37-48.25	113- 4.89	7.0	3.4	45.5	19.1
1971	1110	1608	37.68	37-42.01	113- 1.03	7.0	3.1	37.6	33.2
1971	1110	1941	33.89	37-48.37	113- 3.75	7.0	3.5	46.3	21.0
1972	103	1020	38.85	38-38.81	112- 9.91	7.0	4.4	166.5	34.9
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	114.7	174.0
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	115.4	175.6
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	118.4	190.9
1972	602	315	48.21	38-40.27	112- 4.32	7.0	4.0	173.4	3[illegible].6
1972	702	2007	1.15	37-20.15	113-50.77	7.0	3.0	53.6	269.4
1972	902	1530	35.47	37-14.01	113-21.78	7.0	3.2	22.7	206.2
1972	1116	217	45.16	37-31.93	112-46.18	7.0	3.6	44.4	73.2
1973	122	1024	55.94	37-11.54	112-57.90	7.0	3.0	35.5	134.6
1973	218	931	39.62	38- 5.87	113-10.57	7.0	3.3	75.9	4.9
1973	310	503	9.25	38- 7.61	113- 8.74	7.0	3.3	79.4	6.7
1973	320	1620	6.62	37-57.07	113-31.37	7.0	3.1	64.0	337.9
1974	1104	902	26.60	38-20.45	112-14.13	7.0	3.5	136.0	41.0
1975	111	1820	24.95	38- 2.88	113-28.30	7.0	3.2	72.7	344.4
1976	813	1030	21.13	38-25.27	112-10.81	7.0	3.1	145.9	40.2
1978	224	1949	48.77	38-19.97	112-50.60	1.5	3.5	107.8	19.4
1978	830	1534	38.87	38- 1.76	112-29.38	7.0	3.0	95.5	44.6
1978	1116	818	57.33	38- 5.29	112-28.73	7.0	3.1	100.9	42.4
1978	1209	1459	48.36	38-39.36	112-31.32	4.6	3.3	151.7	24.9
1978	1209	2349	8.00	38-38.84	112-31.08	5.5	3.3	151.0	25.2
1979	112	928	59.54	37-44.33	113-10.05	.0	3.2	36.5	11.5
1979	805	1910	21.35	36-58.89	113-40.08	7.0	3.6	60.9	217.5
1979	815	211	30.27	36-44.36	113-49.01	7.0	3.2	90.5	213.8
1979	816	1733	4.98	37-45.58	112-43.41	7.0	3.1	60.1	50.7

Earthquakes within 200km of 37 25N & 113 15W, mag 3.0 and above

year	date	orig time		lat-n	long-w	depth	mag	km	az
1980	428	2147	35.00	37-18.11	114- 5.00	7.0	3.4	74.9	260.2
1980	803	608	28.57	37-48.43	112-58.16	16.5	3.1	49.9	29.8
1980	1221	1825	9.12	37-26.71	113- 4.93	1.7	3.3	15.2	78.0
1980	1227	434	15.52	37-30.83	113- 7.03	3.5	3.0	15.9	47.5
1980	1229	712	52.50	37-27.28	113- 4.92	1.7	3.1	15.5	74.2
1981	116	1036	29.90	37-26.52	113- 5.51	3.5	3.4	14.3	78.6
1981	116	1450	45.61	37-26.34	113- 5.28	1.2	3.2	14.6	80.2
1981	201	221	47.37	37-34.47	113-15.56	.0	3.8	17.5	357.3
1981	405	540	40.06	37-36.61	113-18.02	1.3	4.5	21.9	348.3
1981	529	309	16.98	37-27.13	111-16.11	7.0	3.0	175.4	88.7
1981	714	1613	46.72	37-56.67	111-33.25	7.0	3.1	160.7	68.6
1981	808	620	17.09	38- 4.15	112-48.54	.0	3.3	82.2	28.2
1912	818	2112	.00	36-30.00	111-30.00	.0	5.7	186.1	123.1
1936	122	339	.00	36-19.00	113-30.00	.0	4.3	125.9	190.2
1938	817	908	6.00	36-42.00	113-42.00	.0	3.0	89.0	206.7
1938	1217	843	.00	36- .00	114- .00	.0	3.5	170.9	203.1
1939	1121	2240	.00	36-30.00	115- .00	.0	4.0	186.1	236.9
1939	1121	2340	48.00	36-30.00	115- .00	.0	3.0	186.1	236.9
1940	920	1221	54.00	36-30.00	115- .00	.0	3.0	186.1	236.9
1941	322	1208	6.00	36- .00	114-36.00	.0	3.0	198.2	217.5
1945	107	2225	32.00	36-30.00	111-48.00	.0	4.9	164.4	128.2
1952	524	448	12.00	36- 6.00	114-42.00	.0	3.7	195.2	221.5
1952	524	952	52.00	36- 6.00	114-42.00	.0	3.7	195.2	221.5
1952	525	1306	30.00	36- 6.00	114-42.00	.0	3.7	195.2	221.5
1953	518	703	2.00	36- .00	114-30.00	.0	3.0	192.8	215.4
1963	402	940	45.00	36-12.00	114-54.00	.0	3.3	199.8	227.5
1963	518	2058	52.50	36- 6.00	114-42.00	5.0	4.4	195.2	221.5
1966	903	753	18.55	36-30.27	112-15.26	7.0	3.5	134.6	138.8
1966	121	920	40.90	36-12.00	113-54.00	26.0	3.7	146.9	203.2
1970	1124	1647	56.00	36-21.42	112-16.37	6.0	3.0	146.3	143.5
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	114.7	174.0
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	115.4	175.6
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	118.4	190.9
1973	226	355	10.10	36-41.90	115-15.33	5.0	3.6	195.7	246.0
1973	1226	618	16.60	36- 4.86	114-38.34	5.0	3.1	193.3	219.9
1979	815	211	30.27	36-41.36	113-49.01	7.0	3.2	90.5	213.8
1981	112	859	13.20	35-39.47	113-29.13	5.0	3.5	196.2	185.7
1934	330	1627	.00	37-42.00	115-18.00	.0	4.9	183.8	279.8
1934	330	1851	.00	37-42.00	115-18.00	.0	4.0	183.8	279.8
1934	331	824	.00	37-42.00	115-18.00	.0	4.0	183.8	279.8

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1934	415	1209	.00	38- .00	115- .00	.0	5.0	167.4	292.8
1934	417	350	.00	38- .00	115- .00	.0	4.0	167.4	292.8
1934	417	1446	.00	38- .00	115- .00	.0	4.0	167.4	292.8
1937	128	314	.00	37- 6.00	114-42.00	.0	4.0	133.3	254.7
1940	310	1801	54.00	37- .00	115- .00	.0	3.0	162.1	253.4
1940	311	6	30.00	37- .00	115- .00	.0	3.0	162.1	253.4
1940	407	842	.00	37- .00	115- .00	.0	3.0	162.1	253.4
1941	506	311	42.00	37-18.00	114-18.00	.0	3.0	93.9	262.1
1943	610	2225	30.00	37-18.00	115- .00	.0	3.5	155.6	265.2
1943	116	355	.00	37-21.00	114-15.00	.0	4.0	88.9	265.2
1944	320	930	57.00	37-30.00	114-42.00	.0	4.0	128.6	274.1
1945	111	1156	.00	37-24.00	114-54.00	.0	3.8	146.1	269.3
1953	809	2200	2.00	37-30.00	114-30.00	.0	4.5	111.0	274.8
1955	110	1007	28.00	37- .00	114-30.00	.0	4.4	120.2	247.4
1961	926	2146	20.00	37-39.96	114-20.00	.0	3.0	99.7	286.1
1964	529	111	10.40	37-18.00	114-48.00	33.0	3.6	137.9	264.6
1964	821	2203	51.60	37- .00	115- 6.00	33.0	3.8	170.6	254.3
1965	1117	941	28.30	37-36.00	115-12.00	16.0	3.7	173.6	276.7
1966	406	1756	32.10	37-12.00	115-24.00	33.0	4.1	192.1	262.8
1966	818	928	56.90	37-24.00	114-18.00	33.0	3.7	93.0	268.9
1966	820	822	3.40	37-18.00	114-18.00	33.0	3.6	93.9	262.1
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	88.6	272.3
1966	825	309	48.90	37-18.00	114-18.00	33.0	3.7	93.9	262.1
1966	827	1531	49.50	37-18.00	114-18.00	33.0	3.6	93.9	262.1
1967	507	1801	35.70	37- 2.40	115- .72	15.0	4.7	161.9	255.0
1967	509	42	24.10	37- 2.51	115- .60	15.0	4.0	161.6	255.1
1967	126	133	4.60	37- 6.00	115-12.00	33.0	3.7	176.5	258.5
1967	1211	275	21.10	37-12.00	115-12.00	33.0	3.3	174.5	262.1
1968	402	1609	14.65	37-22.40	114-17.12	.9	3.3	91.8	267.0
1968	412	640	7.65	36-55.12	114-37.59	7.0	3.1	134.2	245.7
1969	1008	1555	1.50	37-30.00	115-28.97	10.0	3.7	197.8	272.7
1969	1108	658	1.30	37- 8.74	114-58.69	4.0	3.3	156.2	258.9
1970	102	2001	31.60	37-25.70	114-57.77	.0	4.0	151.6	270.5
1970	208	1556	26.60	37-19.20	115-34.10	.0	3.5	190.9	266.8
1970	1103	1641	25.00	37-31.26	115-18.36	.0	3.8	192.3	273.6
1971	1125	1827	25.00	37-47.70	114-57.00	.0	3.7	155.9	293.6
1971	1208	1718	55.90	37-36.00	115-16.97	8.0	4.8	190.9	276.5
1971	1208	1523	51.90	37-46.56	114-59.40	.0	3.5	159.8	284.5
1971	1209	47	11.20	37-26.15	114-25.50	.0	3.8	104.0	271.2
1971	1226	603	55.30	37-20.52	114-19.86	.0	4.2	96.1	265.1

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1972	421	2248	34.80	38-16.79	114-57.60	.0	3.0	178.4	302.5
1972	424	212	30.70	37-39.65	115- 3.24	.0	3.0	161.7	279.6
1972	927	1229	49.00	38-28.73	114-48.84	.0	3.8	181.1	310.6
1972	1028	1901	24.90	37-13.38	114-53.34	5.0	3.4	146.9	261.6
1972	1029	1135	2.50	36-59.81	114-37.86	.0	3.5	131.2	249.2
1972	1029	2027	10.00	37-16.92	115-13.43	.0	3.2	175.5	265.1
1972	1101	1857	31.30	37-13.92	115-11.22	.0	3.4	172.9	263.2
1972	1117	746	56.10	37-34.91	115- 4.44	.0	3.7	162.3	276.5
1972	1117	929	13.30	37-49.31	115-24.12	.0	3.5	195.2	283.3
1972	1117	950	8.80	37-53.63	115-16.79	.0	3.6	186.8	286.5
1972	1117	2318	46.10	37-52.31	115-14.27	.0	3.8	182.6	286.1
1972	1123	552	10.20	37-53.22	115-22.13	.0	3.8	194.1	285.6
1972	1129	545	43.40	38- 1.67	114-47.22	.0	3.7	151.5	296.6
1972	1129	553	24.60	38- .66	114-40.25	.0	3.9	141.6	297.8
1972	1217	20	53.30	37-41.34	115-21.71	.0	3.0	189.0	279.2
1973	129	1438	50.20	37-57.18	114-56.88	.0	3.1	161.2	291.7
1973	304	1112	51.40	38- 3.77	115-11.10	.0	3.0	185.0	293.8
1973	527	239	29.80	37-10.97	115-13.50	.0	4.0	177.0	261.6
1973	610	557	16.10	37-41.15	114-55.20	.0	3.1	150.6	281.4
1973	730	918	42.10	37-36.65	115- 8.93	5.0	3.5	169.3	277.3
1973	914	2219	4.50	37-26.57	115- 3.18	.0	4.1	159.6	271.0
1973	1105	250	22.20	37-57.54	115- 6.59	.0	3.2	174.7	290.1
1974	405	27	31.80	37-41.27	114-50.22	.0	3.8	143.4	282.1
1974	611	1253	7.60	37-36.11	115-17.39	11.0	3.9	181.5	276.5
1974	826	805	41.70	37-19.50	115-11.93	.0	3.6	172.9	266.6
1975	620	222	29.67	37-49.58	115-24.76	1.9	4.2	199.1	283.2
1976	108	1614	8.83	37-37.24	115-24.21	3.4	4.5	191.7	276.8
1976	220	1713	50.20	38- 6.96	114-58.79	.0	3.6	171.0	297.0
1977	721	1606	22.10	37-13.92	114-58.31	7.0	3.3	154.0	262.4
1977	1113	1844	45.50	37-19.55	115-11.22	.0	3.5	171.9	266.6
1977	1116	1253	22.20	37-20.28	115-18.23	6.0	3.0	182.1	267.3
1977	1205	9	46.20	38- 1.25	114-26.94	.0	3.8	125.2	302.4
1977	1216	1652	36.30	38- 1.74	114-36.77	.0	3.5	138.0	299.5
1979	122	1806	25.44	36-50.06	115-12.19	5.0	3.1	185.2	249.6
1979	812	1131	21.00	37-16.86	115- .72	.0	4.2	156.8	264.5
1979	812	1253	3.90	37-19.20	115- 3.83	.0	3.1	161.0	266.2
1979	812	1546	39.50	37-16.62	115- 3.48	.0	3.8	161.0	264.5
1979	813	950	2.70	37-24.18	114-52.13	.0	3.4	143.3	269.4
1979	813	1823	39.30	37-21.95	114-56.70	.0	3.8	150.2	267.0
1979	813	2332	29.20	37- 8.27	115- 4.19	.0	3.0	164.3	259.1

Earthquakes within 200km of 37 25N & 113 15W, Mag 3.0 and above

year	date	orig time		lat-n	long-w	depth	mag	km	az
1979	814	303	16.20	37-14.88	115- 8.27	.0	3.9	168.4	263.6
1979	816	337	46.50	37-19.26	114-57.65	.0	3.7	151.9	266.0
1979	816	1549	58.90	37-18.84	115- 2.46	.0	3.1	159.1	265.9
1980	416	1124	36.30	37-10.70	115-27.18	.0	3.3	197.1	262.3

number of events = 324

APPENDIX I

LISTING OF EARTHQUAKE OF $M \geq 3$ WITHIN 150 KM OF CEDAR CITY AND ST. GEORGE (1850-1981)

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1859	828	0	.00	37-50.52	112-49.63		3.7	30.3	45.3
1873	731	315	.00	38-16.74	112-38.38		4.3	79.5	28.5
1876	1130	500	.00	37-40.97	113- 3.95		3.0	3.7	8.0
1877	115	1200	.00	38-34.80	112-15.30		3.0	125.6	34.8
1878	814	0	.00	38-36.00	112-34.80		4.3	113.9	22.2
1878	816	244	.00	38-36.00	112-34.80		3.7	113.9	22.2
1881	326	215	.00	37-35.00	113-48.00		4.3	64.7	263.4
1881	804	430	.00	38-16.74	112-38.38		3.0	79.5	28.5
1885	905	335	.00	37- 2.84	112-31.34		3.0	82.7	144.0
1885	1026	610	.00	38-12.89	112-55.43		3.0	64.0	11.7
1885	1026	800	.00	38-25.80	113-17.40		3.0	88.7	347.5
1885	1026	900	.00	38-25.80	113-17.40		3.0	88.7	347.5
1885	1217	100	.00	38-10.32	112-16.27		3.7	91.2	50.5
1887	1205	1530	.00	37- 2.84	112-31.34		5.7	82.7	144.0
1891	420	1355	.00	37- 6.38	113-34.41		5.0	74.9	216.4
1891	913	348	.00	37-40.97	113- 3.95		3.0	3.7	8.0
1894	205	330	.00	38-48.30	112-26.32		3.7	139.7	23.4
1894	206	1500	.00	38-48.30	112-26.32		3.0	139.7	23.4
1899	1110	900	.00	38-16.74	112-38.38		3.7	79.5	28.5
19 2	601	0	.00	38-16.74	112-38.38		3.0	79.5	28.5
19 2	731	700	.00	38-16.74	112-38.38		4.3	79.5	28.5
19 2	1117	1950	.00	37-23.58	113-31.20		6.3	48.8	234.3
19 2	1205	0	.00	37-23.68	113-31.20		5.0	48.7	234.4
19 3	1104	2340	.00	37- 6.38	113-34.41		3.0	74.9	216.4
19 3	1123	1000	.00	37- 6.38	113-34.41		4.3	74.9	216.4
19 8	415	0	.00	38-23.58	113- .44		5.0	82.7	3.9
1910	110	1300	.00	38-40.97	112- 8.98		5.0	140.3	35.2
1910	112	300	.00	38-40.97	112- 8.98		5.0	140.3	35.2
1913	1020	1000	.00	37-49.36	112-26.02		3.7	59.4	71.2
1914	1214	530	.00	37-34.37	113-42.79		4.3	57.3	261.4
1914	1221	525	.00	37-34.37	113-42.79		3.0	57.3	261.4
1915	212	1950	.00	37-34.37	113-42.79		3.7	57.3	261.4
1915	213	830	.00	37-34.37	113-42.79		3.7	57.3	261.4
1915	1025	1713	.00	38-37.90	112-13.00		3.0	132.3	34.5
1920	818	820	.00	38-16.74	112-38.38		3.0	79.5	28.5
1920	1126	0	.00	37- 6.38	113-34.41		4.3	74.9	216.4
1921	602	2130	.00	37-40.97	113- 3.95		3.0	3.7	8.0
1921	929	1412	.00	38-40.97	112- 8.98		6.3	140.3	35.2
1921	930	230	.00	38-40.97	112- 8.98		5.7	140.3	35.2
1921	1001	1532	.00	38-40.97	112- 8.98		6.3	140.3	35.2

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1921	1015	1227	.00	38-40.97	112- 8.98		3.0	140.3	35.2
1921	1027	1415	.00	38-40.97	112- 8.98		4.3	140.3	35.2
1921	1101	1535	.00	38-40.97	112- 8.98		3.7	140.3	35.2
1921	1220	945	.00	38-40.97	112- 8.98		3.0	140.3	35.2
1921	1220	1510	.00	38-40.97	112- 8.98		3.7	140.3	35.2
1923	514	1210	.00	38-10.00	113-14.00		4.3	59.1	346.1
1925	714	1347	.00	37-48.60	113-55.80		3.7	77.7	283.2
1926	515	1951	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	605	1100	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	712	520	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	1001	1515	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	1004	2030	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	1023	0	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	1112	340	.00	37-19.04	112-35.47		3.0	56.3	131.0
1926	1116	1415	.00	37-19.04	112-35.47		3.0	56.3	131.0
1927	1123	930	.00	37-19.04	112-35.47		3.0	56.3	131.0
1933	120	1310	.00	37-50.52	112-49.63		5.0	30.3	45.3
1934	1225	1000	.00	37- 2.84	112-31.34		3.7	82.7	144.0
1935	1006	300	.00	37-55.47	111-25.61		3.7	148.1	78.1
1936	509	1025	.00	37-15.00	112-57.48		4.3	45.5	167.2
1936	902	2337	.00	38-30.00	112-23.00		3.0	112.0	32.6
1936	921	620	.00	38- .00	113-18.00		4.7	43.7	332.6
1937	218	415	.00	37-49.36	112-26.02		4.3	59.4	71.2
1937	218	900	.00	37-49.36	112-26.02		3.7	59.4	71.2
1937	221	830	.00	37-49.36	112-26.02		3.0	59.4	71.2
1937	226	130	.00	37-49.36	112-26.02		3.7	59.4	71.2
1938	817	908	6.00	36-42.00	113-42.00		3.0	119.3	207.9
1939	1228	437	36.00	37- .00	114- .00		3.0	109.4	228.8
1940	1026	124	24.00	38- .00	113- .00		3.0	39.4	9.2
1941	506	311	42.00	37-18.00	114-18.00		3.0	115.4	250.3
1942	328	1310	.00	38-10.32	112-16.27		3.7	91.2	50.5
1942	830	2208	.00	37-40.97	113- 3.95		5.0	3.7	8.0
1942	918	0	.00	37-40.97	113- 3.95		3.0	3.7	8.0
1942	918	200	.00	37-40.97	113- 3.95		3.0	3.7	8.0
1942	918	520	.00	37-40.97	113- 3.95		3.7	3.7	8.0
1942	926	1116	.00	37-40.97	113- 3.95		4.3	3.7	8.0
1942	926	1450	.00	37-40.97	113- 3.95		5.0	3.7	8.0
1942	928	1330	.00	37-15.00	112-57.48		3.7	45.5	167.2
1943	116	1150	18.00	37-40.97	113- 3.95		4.3	3.7	8.0
1943	306	2014	30.00	37-24.00	114- 6.00		3.0	95.0	253.0

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1943	1103	930	.00	38-34.80	112-15.60		4.3	125.4	34.6
1943	1103	1130	.00	38-34.80	112-15.60		3.0	125.4	34.6
1943	1104	200	.00	38-34.80	112-15.60		3.0	125.4	34.6
1943	1106	354	.00	37-21.00	114-15.00		3.7	109.4	252.3
1943	1209	1606	.00	37-40.97	113- 3.95		3.7	3.7	8.0
1944	131	424	58.00	36-54.00	112-24.00		3.0	102.4	144.4
1944	308	754	51.00	37-36.00	114- 9.00		3.0	95.4	266.7
1944	320	931	.00	37-12.00	114- .00		3.0	96.2	238.7
1944	503	2345	.00	37- 6.38	113-34.41		3.7	74.9	216.4
1944	1108	2030	6.00	38-48.00	112-54.00		3.0	128.5	6.7
1945	1118	107	41.00	38- .00	112- .00		3.0	102.0	67.6
1949	1102	230	.00	37- 6.38	113-34.41		4.7	74.9	216.4
1950	505	735	.00	38-14.33	112-13.25		3.7	99.3	48.9
1951	305	2300	.00	37- .00	112-32.40		3.7	86.2	146.8
1952	502	1015	.00	37-14.47	113-16.90		3.7	49.0	202.3
1953	418	515	.00	38-38.21	112- 7.40		3.7	137.5	37.2
1953	809	2200	2.00	37-15.00	114-30.00		3.0	134.0	250.6
1953	1022	300	.00	37-49.36	112-26.02		4.3	59.4	71.2
1955	110	1007	.00	37- .00	114-30.00		4.3	145.7	240.3
1955	1120	1057	54.00	37- 6.00	113-54.00		3.7	95.4	230.2
1959	227	2219	52.00	38- .00	112-30.00		5.0	63.6	52.3
1959	721	1739	29.00	37- .00	112-30.00		5.5	88.2	114.9
1959	727	1115	.00	37-32.36	113-10.51		3.7	15.3	216.7
1959	917	620	.00	38-26.93	112-13.80		3.7	115.4	39.8
1961	926	2146	20.00	37-39.96	114-20.00		3.0	111.3	270.9
1962	215	712	42.90	36-54.00	112-24.00		4.5	102.4	144.4
1962	215	906	45.00	37- .00	112-54.00		3.0	73.7	168.1
1962	605	2229	45.00	38- .00	112- 6.00		3.0	94.0	65.6
1962	819	1732	41.43	38- 3.08	112- 5.31	7.0	3.2	97.3	62.8
1963	217	1734	20.64	37-48.10	113-54.21	7.0	3.7	75.2	282.9
1963	619	838	44.87	38- 1.10	112-31.50	7.0	3.7	63.1	49.7
1963	1113	617	30.12	38-17.72	112-39.39	7.0	3.2	80.4	27.0
1964	101	1643	5.82	37-33.22	112-43.85	7.0	3.1	31.9	109.6
1964	117	15	3.45	38-11.11	112-37.30	7.0	3.3	71.4	33.7
1964	824	151	.55	38-46.33	112-13.93	7.0	3.1	144.6	30.6
1964	824	155	30.44	38-47.00	112-14.83	7.0	3.0	115.0	29.0
1964	921	36	23.17	38-47.76	112-12.75	7.0	3.0	147.8	30.6
1965	130	1348	53.21	37-32.24	113- 6.95	7.0	3.2	13.1	197.6
1965	713	1803	15.41	37-42.72	112-59.00	7.0	3.0	10.4	48.6
1965	720	1449	24.86	38- 1.57	112-26.49	7.0	3.0	69.4	53.0

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1965	830	43	15.20	37-26.92	113-41.34	7.0	3.2	59.0	247.7
1966	520	1211	37.39	38- 3.03	112-12.09	7.0	3.0	88.6	59.9
1966	520	1340	47.87	37-58.99	111-51.25	7.0	4.1	113.4	71.0
1966	816	1802	32.85	37-27.81	114- 9.07	7.0	5.6	97.6	257.8
1966	819	1051	37.92	37-26.33	114-11.48	7.0	4.7	101.7	256.7
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	106.5	257.9
1966	903	753	18.55	36-30.27	112-15.26	7.0	3.5	146.4	150.2
1966	923	13	57.11	37-30.50	113-17.47	7.0	3.2	25.0	231.0
1966	1021	713	48.88	38-11.74	113- 9.45	7.0	4.2	61.0	352.9
1967	722	2151	27.40	38-48.14	112-13.01	7.0	3.6	148.2	30.3
1967	1004	1020	12.80	38-32.59	112- 9.39	7.0	5.2	127.6	39.0
1967	1113	1648	53.77	37-34.97	113-20.32	7.0	3.5	24.7	252.5
1968	320	1533	3.98	37-55.28	112-16.55	7.0	3.0	76.3	66.8
1968	409	1608	14.65	37-22.40	114-17.12	.9	3.3	111.6	254.0
1968	924	210	49.63	38- 2.50	112- 4.92	7.0	3.6	97.4	63.5
1969	410	837	5.46	38-39.89	112- 4.39	7.0	3.6	142.6	37.8
1969	815	30	30.57	37-47.48	113-14.97	7.0	3.0	22.2	315.0
1970	418	1042	11.45	37-52.47	111-43.26	7.0	3.7	121.6	78.2
1970	523	2255	23.20	38- 3.47	112-28.13	7.0	3.9	69.7	49.5
1970	901	1152	17.81	37-26.47	113-47.17	7.0	3.0	67.3	249.8
1971	623	608	35.87	38-36.49	112-42.38	7.0	3.1	111.1	16.9
1971	1110	1114	10.32	37-41.60	113- 6.16	7.0	3.1	5.5	330.4
1971	1110	1124	34.89	37-41.87	113- 7.28	7.0	3.1	6.9	320.5
1971	1110	1338	14.19	37-42.14	113- 5.58	7.0	3.1	6.1	342.0
1971	1110	1410	23.01	37-48.03	113- 5.99	7.0	3.7	16.9	351.5
1971	1110	1443	58.51	37-48.25	113- 4.89	7.0	3.4	17.1	357.1
1971	1110	1608	37.68	37-42.01	113- 1.03	7.0	3.1	7.4	40.8
1971	1110	1941	33.59	37-48.37	113- 3.75	7.0	3.5	17.4	2.7
1972	103	1020	38.65	38-38.81	112- 9.91	7.0	4.4	136.2	35.7
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	140.0	181.6
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	141.2	182.8
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	147.2	195.1
1972	602	315	48.21	38-40.27	112- 4.32	7.0	4.0	143.3	37.7
1972	702	2007	1.15	37-20.15	113-50.77	7.0	3.0	76.9	243.0
1972	902	1530	35.47	37-14.01	113-21.78	7.0	3.2	52.9	209.2
1972	1116	217	45.16	37-31.93	112-46.18	7.0	3.6	29.7	116.1
1973	122	1024	55.94	37-11.54	112-57.90	7.0	3.0	51.7	169.5
1973	218	931	39.62	38- 5.87	113-10.57	7.0	3.3	50.5	349.5
1973	310	503	9.25	38- 7.61	113- 8.74	7.0	3.3	53.3	353.0
1973	520	1620	6.62	37-57.07	113-31.37	7.0	3.1	51.9	310.1

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1974	1104	902	26.60	38-20.45	112-14.13	7.0	3.5	106.2	43.8
1975	111	1820	24.95	38- 2.88	113-28.30	7.0	3.2	56.5	321.4
1976	813	1030	21.13	38-25.27	112-10.81	7.0	3.1	116.0	42.4
1978	224	1949	48.77	38-19.97	112-50.60	1.5	3.5	78.4	14.8
1978	830	1534	38.87	38- 1.76	112-29.38	7.0	3.0	66.3	50.6
1978	1116	818	57.33	38- 5.29	112-28.73	7.0	3.1	71.3	47.0
1978	1209	1459	48.36	38-39.36	112-31.32	4.6	3.3	121.6	23.3
1978	1209	2349	8.00	38-38.84	112-31.08	5.5	3.3	120.9	23.7
1979	112	928	59.54	37-44.33	113-10.05	.0	3.2	13.0	319.4
1979	805	1910	21.35	36-58.89	113-40.08	7.0	3.6	91.1	215.5
1979	815	211	30.27	36-44.36	113-49.01	7.0	3.2	120.8	213.2
1979	816	1733	4.98	37-45.58	112-43.41	7.0	3.1	33.0	68.4
1980	428	2147	35.00	37-18.11	114- 5.00	7.0	3.4	97.5	246.6
1980	903	608	28.57	37-48.43	112-58.16	16.5	3.1	19.6	27.3
1980	1221	1825	9.12	37-26.71	113- 4.93	1.7	3.3	22.8	182.3
1980	1227	434	15.52	37-30.83	113- 7.03	3.5	3.0	15.6	194.9
1980	1229	712	52.50	37-27.28	113- 4.92	1.7	3.1	21.7	182.4
1981	116	1026	29.90	37-26.52	113- 5.51	3.5	3.4	23.2	184.4
1981	116	1450	45.61	37-26.34	113- 5.28	1.2	3.2	23.5	183.5
1981	201	221	47.37	37-34.47	113-15.56	.0	3.8	18.6	245.2
1981	405	540	40.06	37-36.61	113-18.02	1.3	4.5	20.7	257.6
1981	714	1613	46.72	37-56.67	111-33.25	7.0	3.1	137.6	76.3
1981	808	620	17.09	38- 4.15	112-48.54	.0	3.3	52.0	26.4
1938	817	908	6.00	36-42.00	113-42.00	.0	3.0	119.3	207.9
1966	903	753	18.55	36-30.27	112-15.26	7.0	3.5	146.4	150.2
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	140.0	181.6
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	141.2	182.8
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	147.2	195.1
1979	815	211	30.27	36-44.36	113-49.01	7.0	3.2	120.8	213.2
1941	506	311	42.00	37-18.00	114-18.00	.0	3.0	115.4	250.3
1943	116	355	.00	37-21.00	114-15.00	.0	4.0	109.4	252.3
1944	320	930	57.00	37-30.00	114-42.00	.0	4.0	144.8	263.4
1953	809	2200	2.00	37-30.00	114-30.00	.0	4.5	127.3	262.5
1955	110	1007	28.00	37- .00	114-30.00	.0	4.4	145.7	240.3
1961	926	2146	20.00	37-39.96	114-20.00	.0	3.0	111.3	270.9
1966	818	929	56.90	37-24.00	114-18.00	33.0	3.7	112.1	255.7
1966	820	822	3.40	37-18.00	114-18.00	33.0	3.6	115.4	250.3
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	106.5	257.9
1966	825	309	48.90	37-18.00	114-18.00	33.0	3.7	115.4	250.3
1966	827	1531	49.50	37-18.00	114-18.00	33.0	3.6	115.4	250.3

Earthquakes within 150km of Cedar City site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1968	408	1608	14.65	37-22.40	114-17.12	.9	3.3	111.6	254.0
1971	1209	47	11.20	37-26.15	114-25.50	.0	3.8	121.9	258.8
1971	1226	603	55.30	37-20.52	114-19.86	.0	4.2	116.5	252.9
1972	1129	553	24.60	38- .66	114-40.25	.0	3.9	146.4	285.9
1977	1205	9	46.20	38- 1.25	114-26.94	.0	3.8	128.0	288.8
1977	1216	1652	36.30	38- 1.74	114-36.77	.0	3.5	142.0	287.2

number of events = 206

Earthquakes within 150km of St. George site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1859	828	0	.00	37-50.52	112-49.63		3.7	104.9	33.6
1876	1130	500	.00	37-40.97	113- 3.95		3.0	78.9	28.0
1881	326	215	.00	37-35.00	113-48.00		4.3	65.0	334.4
1885	905	335	.00	37- 2.84	112-31.34		3.0	85.5	90.6
1885	1026	610	.00	38-12.89	112-55.43		3.0	137.9	21.0
1887	1205	1530	.00	37- 2.84	112-31.34		5.7	85.5	90.6
1891	420	1355	.00	37- 6.38	113-34.41		5.0	9.8	305.4
1891	913	348	.00	37-40.97	113- 3.95		3.0	78.9	28.0
19 2	1117	1950	.00	37-23.58	113-31.20		6.3	37.7	355.0
19 2	1205	0	.00	37-23.68	113-31.20		5.0	37.8	355.1
19 3	1104	2340	.00	37- 6.38	113-34.41		3.0	9.8	305.4
19 3	1123	1000	.00	37- 6.38	113-34.41		4.3	9.8	305.4
1913	1020	1000	.00	37-49.36	112-26.02		3.7	126.0	47.5
1914	1214	530	.00	37-34.37	113-42.79		4.3	61.0	340.5
1914	1221	525	.00	37-34.37	113-42.79		3.0	61.0	340.5
1915	212	1950	.00	37-34.37	113-42.79		3.7	61.0	340.5
1915	213	830	.00	37-34.37	113-42.79		3.7	61.0	340.5
1920	1126	0	.00	37- 6.38	113-34.41		4.3	9.8	305.4
1921	602	2130	.00	37-40.97	113- 3.95		3.0	78.9	28.0
1923	514	1210	.00	38-10.00	113-14.00		4.3	125.3	10.1
1925	714	1347	.00	37-48.60	113-55.80		3.7	92.7	334.7
1926	515	1951	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	605	1100	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	712	520	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	1001	1515	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	1004	2030	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	1023	0	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	1112	340	.00	37-19.04	112-35.47		3.0	84.4	69.8
1926	1116	1415	.00	37-19.04	112-35.47		3.0	84.4	69.8
1927	1123	930	.00	37-19.04	112-35.47		3.0	84.4	69.8
1933	120	1310	.00	37-50.52	112-49.63		5.0	104.9	33.6
1934	1225	1000	.00	37- 2.84	112-31.34		3.7	85.5	90.6
1936	122	338	.00	36-18.00	113-30.00		4.3	83.8	181.0
1936	509	1025	.00	37-15.00	112-57.48		4.3	51.4	65.1
1936	921	620	.00	38- .00	113-18.00		4.7	106.1	8.8
1937	218	415	.00	37-49.36	112-26.02		4.3	126.0	47.5
1937	218	900	.00	37-49.36	112-26.02		3.7	126.0	47.5
1937	221	830	.00	37-49.36	112-26.02		3.0	126.0	47.5
1937	226	130	.00	37-49.36	112-26.02		3.7	126.0	47.5
1938	817	908	6.00	36-42.00	113-42.00		3.0	43.9	206.1

Earthquakes within 150km of St. George site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1938	1228	437	36.00	37- .00	114- .00		3.0	46.4	262.4
1939	1121	2340	48.00	36-30.00	115- .00		3.0	148.7	245.5
1940	310	1801	54.00	37- .00	115- .00		3.0	135.1	267.4
1940	311	6	30.00	37- .00	115- .00		3.0	135.1	267.4
1940	407	842	.00	37- .00	115- .00		3.0	135.1	267.4
1940	920	1221	54.00	36-30.00	115- .00		3.0	148.7	245.5
1940	1026	124	24.00	38- .00	113- .00		3.0	113.3	22.2
1941	506	311	42.00	37-18.00	114-18.00		3.0	77.5	290.6
1942	830	2208	.00	37-40.97	113- 3.95		5.0	78.9	28.0
1942	918	0	.00	37-40.97	113- 3.95		3.0	78.9	28.0
1942	918	200	.00	37-40.97	113- 3.95		3.0	78.9	28.0
1942	918	520	.00	37-40.97	113- 3.95		3.7	78.9	28.0
1942	926	1116	.00	37-40.97	113- 3.95		4.3	78.9	28.0
1942	926	1450	.00	37-40.97	113- 3.95		5.0	78.9	28.0
1942	928	1330	.00	37-15.00	112-57.48		3.7	51.4	65.1
1943	116	1150	18.00	37-40.97	113- 3.95		4.3	78.9	28.0
1943	306	2014	30.00	37-24.00	114- 6.00		3.0	66.8	305.0
1943	1106	354	.00	37-21.00	114-15.00		3.7	75.5	295.7
1943	1209	1606	.00	37-40.97	113- 3.95		3.7	78.9	28.0
1944	131	424	58.00	36-54.00	112-24.00		3.0	98.0	100.1
1944	308	754	51.00	37-36.00	114- 9.00		3.0	84.6	315.7
1944	320	931	.00	37-12.00	114- .00		3.0	48.7	289.3
1944	503	2345	.00	37- 6.38	113-34.41		3.7	9.8	305.4
1945	111	1156	.00	37-24.00	114-54.00		3.8	131.4	286.9
1949	1102	230	.00	37- 6.38	113-34.41		4.7	9.8	305.4
1951	305	2300	.00	37- .00	112-32.40		3.7	84.2	94.2
1952	502	1015	.00	37-14.47	113-16.90		3.7	27.3	40.9
1953	518	703	2.00	36- .00	114-30.00		3.0	148.3	217.9
1953	809	2200	2.00	37-15.00	114-30.00		3.0	92.9	283.5
1953	1022	300	.00	37-49.36	112-26.02		4.3	126.0	47.5
1955	110	1007	.00	37- .00	114-30.00		4.3	90.7	266.1
1955	1120	1057	54.00	37- 6.00	113-54.00		3.7	37.4	277.7
1959	227	2219	52.00	38- .00	112-30.00		5.0	136.2	39.7
1959	721	1739	29.00	37- .00	112-30.00		5.5	87.7	94.0
1959	727	1115	.00	37-32.36	113-10.51		3.7	60.3	26.9
1961	926	2146	20.00	37-39.96	114-20.00		3.0	101.3	312.0
1962	215	712	42.90	36-54.00	112-24.00		4.5	98.0	100.1
1962	215	906	45.00	37- .00	112-54.00		3.0	52.3	96.7
1963	217	1734	20.64	37-48.10	113-54.21	7.0	3.7	90.8	335.8
1963	619	838	44.87	38- 1.10	112-31.50	7.0	3.7	136.4	38.4

Earthquakes within 150km of St. George site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1964	101	1643	5.82	37-33.22	112-43.85	7.0	3.1	86.7	50.3
1964	117	15	3.45	38-11.11	112-37.30	7.0	3.3	146.7	31.2
1965	130	1348	53.21	37-32.24	113- 6.95	7.0	3.2	62.7	31.3
1965	713	1803	15.41	37-42.72	112-59.00	7.0	3.0	85.3	31.3
1965	720	1449	24.86	38- 1.57	112-26.49	7.0	3.0	141.8	40.5
1965	830	43	15.20	37-26.92	113-41.34	7.0	3.2	47.3	337.3
1966	816	1802	32.85	37-27.81	114- 9.07	7.0	5.6	74.6	307.4
1966	819	1051	37.92	37-26.33	114-11.48	7.0	4.7	75.9	304.1
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	80.9	302.7
1966	903	753	18.55	36-30.27	112-15.26	7.0	3.5	125.6	119.1
1966	923	13	57.11	37-30.50	113-17.47	7.0	3.2	53.1	18.7
1966	1021	713	48.88	38-11.74	113- 9.45	7.0	4.2	129.8	12.8
1967	1113	1648	53.77	37-34.97	113-20.32	7.0	3.5	60.0	12.3
1968	320	1533	3.98	37-55.28	112-16.55	7.0	3.0	143.7	49.0
1968	408	1608	14.65	37-22.40	114-17.12	.9	6.3	79.5	296.4
1968	412	640	7.05	36-55.12	114-37.59	7.0	3.1	102.9	261.5
1969	815	30	30.57	37-47.48	113-14.97	7.0	3.0	84.3	14.2
1970	523	2255	23.20	38- 3.47	112-28.13	7.0	3.9	142.9	38.8
1970	901	1152	17.81	37-26.47	113-47.17	7.0	3.0	50.6	327.9
1971	1110	1114	10.32	37-41.60	113- 6.16	7.0	3.1	79.5	25.5
1971	1110	1124	34.89	37-41.87	113- 7.28	7.0	3.1	78.2	24.2
1971	1110	1338	14.19	37-42.14	113- 5.58	7.0	3.1	79.7	25.7
1971	1110	1410	23.01	37-48.03	113- 5.99	7.0	3.7	89.4	22.3
1971	1110	1443	58.51	37-48.25	113- 4.89	7.0	3.4	90.4	23.2
1971	1110	1608	37.68	37-42.01	113- 1.03	7.0	3.1	82.7	30.0
1971	1110	1941	33.89	37-48.37	113- 3.75	7.0	3.5	91.3	24.1
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	81.0	156.0
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	80.7	158.3
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	76.1	181.2
1972	702	2007	1.15	37-20.15	113-50.77	7.0	3.0	44.8	314.1
1972	902	1530	35.47	37-14.01	113-21.78	7.0	3.2	22.5	28.4
1972	1116	217	45.16	37-31.93	112-46.18	7.0	3.6	82.5	50.1
1973	122	1024	55.94	37-11.54	112-57.90	7.0	3.0	48.5	71.7
1973	218	931	39.62	38- 5.87	113-10.57	7.0	3.1	118.9	13.2
1973	310	503	9.25	38- 7.61	113- 8.74	7.0	3.3	122.6	14.1
1973	520	1620	6.62	37-57.07	113-31.37	7.0	3.1	99.5	358.0
1975	111	1820	24.95	38- 2.88	113-28.30	7.0	3.2	110.2	.5
1978	830	1534	38.87	38- 1.76	112-29.38	7.0	3.0	139.3	39.1
1978	1116	818	57.33	38- 5.29	112-28.73	7.0	3.1	145.0	37.7
1979	112	928	59.54	37-44.33	113-10.05	.0	3.2	80.9	20.2

Earthquakes within 150km of St. George site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1979	805	1910	21.35	36-58.89	113-40.08	7.0	3.6	18.3	243.6
1979	815	211	30.27	36-44.36	113-49.01	7.0	3.2	45.9	220.3
1979	816	1733	4.98	37-45.58	112-43.41	7.0	3.1	103.2	40.7
1980	428	2147	35.00	37-18.11	114- 5.00	7.0	3.4	59.9	297.2
1980	803	608	28.57	37-48.43	112-58.16	16.5	3.1	95.1	28.6
1980	1221	1825	9.12	37-26.71	113- 4.93	1.7	3.3	56.1	39.4
1980	1227	434	15.52	37-30.83	113- 7.03	3.5	3.0	60.4	32.5
1980	1229	712	52.50	37-27.28	113- 4.92	1.7	3.1	56.9	38.8
1981	116	1026	29.90	37-26.52	113- 5.51	3.5	3.4	55.2	39.0
1981	116	1450	45.61	37-26.34	113- 5.28	1.2	3.2	55.2	39.5
1981	201	221	47.37	37-34.47	113-15.56	.0	3.8	61.0	19.0
1981	405	540	40.06	37-36.61	113-18.02	1.3	4.5	63.7	14.7
1981	808	620	17.09	38- 4.15	112-48.54	.0	3.3	127.4	27.9
1936	122	338	.00	36-18.00	113-30.00	.0	4.3	83.8	181.0
1938	817	908	6.00	36-42.00	113-42.00	.0	3.0	43.9	206.1
1938	1217	843	.00	36- .00	114- .00	.0	3.5	125.9	201.6
1939	1121	2240	.00	36-30.00	115- .00	.0	4.0	148.7	245.5
1939	1121	2340	48.00	36-30.00	115- .00	.0	3.0	148.7	245.5
1940	920	1221	54.00	36-30.00	115- .00	.0	3.0	148.7	245.5
1953	518	703	2.00	36- .00	114-30.00	.0	3.0	148.3	217.9
1966	903	753	18.55	36-30.27	112-15.26	7.0	3.5	125.6	119.1
1966	121	920	40.90	36-12.00	113-54.00	26.0	3.7	101.7	201.4
1970	1124	1647	56.00	36-21.42	112-16.37	6.0	3.0	133.0	125.6
1972	427	153	3.14	36-23.31	113- 6.88	7.0	3.4	81.0	156.0
1972	427	841	13.59	36-22.77	113- 8.99	7.0	3.4	80.7	158.3
1972	514	238	40.66	36-22.14	113-30.10	7.0	3.3	76.1	181.2
1973	1226	618	16.60	36- 4.86	114-38.34	5.0	3.1	149.6	223.7
1979	815	211	30.27	36-44.36	113-49.01	7.0	3.2	45.9	220.3
1937	128	314	.00	37- 6.00	114-42.00	.0	4.0	108.3	272.6
1940	310	1801	54.00	37- .00	115- .00	.0	3.0	135.1	267.4
1940	311	6	30.00	37- .00	115- .00	.0	3.0	135.1	267.4
1940	407	842	.00	37- .00	115- .00	.0	3.0	135.1	267.4
1941	506	311	42.00	37-18.00	114-18.00	.0	3.0	77.5	290.6
1943	610	2225	30.00	37-18.00	115- .00	.0	3.5	137.4	281.4
1943	116	355	.00	37-21.00	114-15.00	.0	4.0	75.5	295.7
1944	320	930	57.00	37-30.00	114-42.00	.0	4.0	118.7	294.6
1945	111	1156	.00	37-24.00	114-54.00	.0	3.8	131.4	286.9
1953	809	2200	2.00	37-30.00	114-30.00	.0	4.5	102.8	298.7
1955	110	1007	28.00	37- .00	114-30.00	.0	4.4	90.7	266.1
1961	926	2146	20.00	37-39.96	114-20.00	.0	3.0	101.3	312.0

Earthquakes within 150km of St. George site, Mag 3.0 and above

year	date	orig	time	lat-n	long-w	depth	mag	km	az
1964	529	111	10.40	37-18.00	114-48.00	33.0	3.6	120.1	283.1
1964	821	2203	51.60	37- .00	115- 6.00	33.0	3.8	144.0	267.6
1966	818	928	56.90	37-24.00	114-18.00	33.0	3.7	82.0	297.8
1966	820	822	3.40	37-18.00	114-18.00	33.0	3.6	77.5	290.6
1966	824	454	28.79	37-26.94	114-15.01	7.0	3.8	80.9	302.7
1966	825	309	48.90	37-18.00	114-18.00	33.0	3.7	77.5	290.6
1966	827	1531	49.50	37-18.00	114-18.00	33.0	3.6	77.5	290.6
1967	507	1801	35.70	37- 2.40	115- .72	15.0	4.7	136.0	269.3
1967	509	42	24.10	37- 2.51	115- .60	15.0	4.0	135.8	269.4
1968	408	1608	14.65	37-22.40	114-17.12	.9	3.3	79.5	296.4
1968	412	640	7.05	36-55.12	114-37.59	7.0	3.1	102.9	261.5
1969	1108	658	1.30	37- 8.76	114-58.68	4.0	3.3	133.3	274.3
1970	102	2001	31.60	37-25.70	114-57.77	.0	4.0	137.7	287.5
1971	1209	47	11.20	37-26.15	114-25.50	.0	3.8	93.6	296.8
1971	1226	603	55.30	37-20.52	114-19.86	.0	4.2	81.7	292.9
1972	1028	1901	24.90	37-13.38	114-53.34	5.0	3.4	126.3	278.5
1972	1029	1135	2.50	36-59.81	114-37.86	.0	3.5	102.3	266.4
1972	1129	553	24.60	38- .66	114-40.25	.0	3.9	149.2	315.3
1973	610	557	16.10	37-41.15	114-55.20	.0	3.1	145.2	298.8
1973	914	2219	4.50	37-26.57	115- 3.18	.0	4.1	145.8	287.2
1974	405	27	31.80	37-41.27	114-50.22	.0	3.8	139.0	300.4
1977	721	1606	22.10	37-13.92	114-58.31	7.0	3.3	133.7	278.4
1977	1205	9	46.20	38- 1.25	114-26.94	.0	3.8	137.0	321.5
1977	1216	1652	36.30	38- 1.74	114-36.77	.0	3.5	147.1	317.3
1979	812	1131	21.00	37-16.86	115- .72	.0	4.2	138.1	280.5
1979	812	1253	3.90	37-19.20	115- 3.83	.0	3.1	143.4	281.8
1979	812	1546	39.50	37-16.62	115- 3.48	.0	3.8	142.0	280.0
1979	813	950	2.20	37-24.18	114-52.13	.0	3.4	128.9	287.4
1979	813	1823	39.30	37-21.95	114-56.70	.0	3.8	134.3	284.9
1979	813	2332	29.20	37- 8.27	115- 4.19	.0	3.0	141.3	273.7
1979	814	303	16.20	37-14.88	115- 8.27	.0	3.9	148.5	278.3
1979	816	337	46.50	37-19.26	114-57.65	.0	3.7	134.5	282.7
1979	816	1549	58.90	37-18.84	115- 2.46	.0	3.1	141.3	281.7

number of events = 193

APPENDIX J

LISTING OF UNIVERSITY OF UTAH EARTHQUAKE CATALOGUE WITHIN A RECTANGULAR AREA ENCOMPASSING ST. GEORGE AND CEDAR CITY (1850-1981)

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W); 1850-June 1962

yr	date	orig time	lat-n	long-w	mag	int	comments
1859	828		37-50.52	112-49.63	3.7	4	
1876	1130	0500	37-40.97	113- 3.95	3.0	3	
1878	1202		37-49.36	112-26.02	2.3	2	SEVERAL SHOCKS (1)
1881	326	0215	37-35.00	113-48.00	4.3	5	HEBRON,UT LOC FROM (16)
1885	905	0335	37- 2.84	112-31.34	3.0	3	
1887	1205	1530	37- 2.84	112-31.34	5.7	7	INT=6-7
1891	420	1355	37- 6.38	113-34.41	5.0	6	ASSGN ST. GEORGE,UT (1)
1891	913	0348	37-40.97	113- 3.95	3.0	3	
19 2	1117	1950	37-23.58	113-31.20	6.3	8	INT=7-8,FOUR SHOCKS (1)
19 2	1205		37-23.68	113-31.20	5.0	6	NUMEROUS A'SHOCKS (1)
19 3	1104	2340	37- 6.38	113-34.41	3.0	3	F'SHOCK?
19 3	1123	1000	37- 6.38	113-34.41	4.3	5	
1913	1020	1000	37-49.36	112-26.02	3.7	4	
1914	1214	0530	37-34.37	113-42.79	4.3	5	(1)
1914	1221	0525	37-34.37	113-42.79	3.0	3	LOC ASSUMED,A'SHOCK? (1)
1915	212	1950	37-34.37	113-42.79	3.7	4	A'SHOCK? (1)
1915	213	0830	37-34.37	113-42.79	3.7	4	A'SHOCK? (1)
1920	1126	0000	37- 6.38	113-34.41	4.3	5	INT=5-6
1921	602	2130	37-40.97	113- 3.95	3.0	3	
1924	101	2315	37-19.04	112-35.47	2.3	3	
1925	714	1347	37-48.60	113-55.80	3.7	4	
1926	515	1951	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	601	0520	37-19.04	112-35.47	2.3	2	SWARM (1)
1926	605	1100	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	622	0340	37-19.04	112-35.47	2.3	2	SWARM (1)
1926	628	0600	37-19.04	112-35.47	2.3	2	TWO SHOCKS,SWARM (1)
1926	712	0520	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	715		37-19.04	112-35.47	2.3	2	SWARM (1)
1926	1001	1515	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	1004	2030	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	1023	0000	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	1112	0340	37-19.04	112-35.47	3.0	3	SWARM (1)
1926	1116	1415	37-19.04	112-35.47	3.0	3	SWARM (1)
1927	1123	0245	37-19.04	112-35.47	2.3	2	TWO SHOCKS,SWARM? (1)
1927	1123	0930	37-19.04	112-35.47	3.0	3	SWARM? (1)
1931	410	0830	37-40.97	113- 3.95	2.3	2	(1)
1932	618	2050	37-50.52	112-49.63	2.3	2	
1933	120	1310	37-50.52	112-49.63	5.0	6	
1934	1225	1000	37- 2.84	112-31.34	3.7	4	
1935	1205	2115	37-37.30	112- 5.20	2.3	2	

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): 1850-June 1962

yr	date	orig time	lat-n	long-w	mag	int	comments
1936	509	1025	37-15.00	112-57.48	4.3	5	INT=5-6,TWO SHOCKS (1)
1936	921	0620	38- .00	113-18.00	4.7	5	INT ASSUMED,NEV (5)
1937	218	0415	37-49.36	112-26.02	4.3	5	INT=4-5,SWARM (1)
1937	218	0630	37-49.36	112-26.02	2.3	2	SWARM (1)
1937	218	0900	37-49.36	112-26.02	3.7	4	SWARM (1)
1937	221	0830	37-49.36	112-26.02	3.0	3	SWARM (1)
1937	226	0130	37-49.36	112-26.02	3.7	4	SWARM (1)
1937	313	1140	37-49.36	112-26.02	2.3	2	SWARM (1)
1937	401	0441	37-49.36	112-26.02	2.3	2	SWARM (1)
1938	1228	0437 36.00	37- .00	114- .00	3.0	0	(6,8)
1940	1026	0124 24.00	38- .00	113- .00	3.0	0	(6,8)
1942	830	2208	37-40.97	113- 3.95	5.0	6	SWARM (1)
1942	918	0000	37-40.97	113- 3.95	3.0	3	SWARM (1)
1942	918	0200	37-40.97	113- 3.95	3.0	3	SWARM (1)
1942	918	0520	37-40.97	113- 3.95	3.7	4	SWARM (1)
1942	926	0700	37-40.97	113- 3.95	2.3	2	SWARM (1)
1942	926	1116	37-40.97	113- 3.95	4.3	5	SWARM (1)
1942	926	1136	37-40.97	113- 3.95	2.3	2	SWARM (1)
1942	926	1450	37-40.97	113- 3.95	5.0	6	SWARM (1)
1942	928	1330	37-15.00	112-57.48	3.7	4	
1943	116	1150 18.00	37-40.97	113- 3.95	4.3	5	INT=4-5 (1,6,8)
1943	306	2014 30.00	37-24.00	114- 6.00	3.0	0	(6,8)
1943	1106	0345	37-21.00	114-15.00	2.3	2	1ST OF THREE SHOCKS (6,8)
1943	1106	0354	37-21.00	114-15.00	3.7	4	(6,8)
1943	1106	0356	37-21.00	114-15.00	2.3	2	(6,8)
1943	1209	1606	37-40.97	113- 3.95	3.7	4	SWARM? (1)
1943	1209	1821	37-40.97	113- 3.95	2.3	2	SWARM? (1)
1943	1210	0117	37-40.97	113- 3.95	2.3	2	SWARM? (1)
1943	1210	0730	37-40.97	113- 3.95	2.3	2	SWARM? (1)
1944	131	0424 58.00	36-54.00	112-24.00	3.0	0	(6,8)
1944	308	0754 51.00	37-36.00	114- 9.00	3.0	0	(6,8)
1944	320	0931 00.00	37-12.00	114- .00	3.0	0	(6,8)
1944	503	2345	37- 6.38	113-34.41	3.7	4	
1944	613	1048	37-40.97	113- 3.95	2.3	2	
1945	1118	0107 41.00	38- .00	112- .00	3.0	0	(6)
1949	1102	0230	37- 6.38	113-34.41	4.7	6	LOC ST.GEORGE,UT(1,5,6,8)
1951	305	2300	37- .00	112-32.40	3.7	4	LOC ASSUMED (8)
1952	502	1015	37-14.47	113-16.90	3.7	4	1ST OF TWO SHOCKS (8)
1952	502	1615	37-14.47	113-16.90	2.3	2	(8)
1953	1022	0300	37-49.36	112-26.02	4.3	5	

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W); 1850-June 1962

yr	date	orig time		lat-n	long-w	mag	int	comments
1953	1024	2050		37-49.36	112-26.02	2.3	2	A'SHOCK? (8)
1955	1120	1057	54.00	37- 6.00	113-54.00	3.7	4	
1959	227	2219	52.00	38- .00	112-30.00	5.0	6	
1959	721	1739	29.00	37- .00	112-30.00	5.5	6	MAG=5.50-5.75 (8)
1959	727	1115	'	37-32.36	113-10.51	3.7	4	
1962	215	0712	42.90	36-54.00	112-24.00	4.5	5	(6,8)
1962	215	0906	45.00	37- .00	112-54.00	3.0	0	A'SHOCK? (6)
1962	605	2229	45.00	38- .00	112- 6.00	3.0	0	(6)

number of events = 88

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): July 1962-Sept 1974

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
63	217	1734	20.64	37-48.10	113-54.21	7.0*	3.7	5	326	216	.26	D
64	101	1643	5.82	37-33.22	112-43.85	7.0*	3.1	6	185	119	.63	C
64	206	753	49.48	37-38.88	112-58.19	7.0*	2.9	6	138	70	.66	C
64	828	650	44.44	37- 2.03	113- 8.46	7.0*	2.5	5	135	138	.37	D
65	118	2008	10.78	37-57.97	112-50.86	7.0*	2.9	4	102	156	.54	D
65	130	1348	53.21	37-32.24	113- 6.95	7.0*	3.2	6	107	148	.55	C
65	516	1904	.51	37-56.71	112-26.88	7.0*	2.5	5	309	233	.33	D
65	713	1803	15.41	37-42.72	112-59.00	7.0*	3.0	6	137	77	.08	A
65	718	1709	45.77	37-43.97	113- 2.33	7.0*	2.8	6	141	81	.44	B
65	830	43	15.20	37-26.92	113-41.34	7.0*	3.2	6	166	192	.73	C
65	1206	1224	42.95	37-42.11	113-19.62	7.0*	2.9	6	161	87	.36	B
66	416	1310	9.36	37-43.70	113-43.06	7.0*	2.8	7	169	111	.87	D
66	505	332	55.75	37- 1.86	112-22.95	7.0*	2.8	7	107	39	.46	B
66	505	615	20.51	36-49.00	112-23.14	7.0*	2.6	5	224	45	.52	D
66	518	1312	40.29	37-57.08	112- 9.91	7.0*	2.3	7	115	119	.67	C
66	526	2348	52.22	37-53.56	112- 9.51	7.0*	2.3	5	144	113	.78	D
66	601	1914	44.27	37-51.49	112-18.30	7.0*	2.1	5	203	116	.27	D
66	716	943	18.93	37-52.97	112-36.50	7.0*	2.2	6	110	97	.58	C
66	816	1802	32.85	37-27.81	114- 9.07	7.0*	5.6W	12	62	127	.71	C
66	819	1051	37.92	37-26.33	114-11.48	7.0*	4.7W	6	126	171	.32	B
66	923	13	57.11	37-30.50	113-17.47	7.0*	3.2	7	215	162	.56	C
67	517	658	35.45	37-51.06	112-18.13	7.0*	2.7	4	203	115	.17	D
67	1113	1648	53.77	37-34.97	113-20.32	7.0*	3.5	6	225	76	.41	B
68	115	303	26.86	37-25.62	113-26.73	7.0*	2.4	5	219	172	.39	D
68	205	1417	27.40	37-26.17	113-57.58	7.0*	2.8	6	177	216	.63	C
68	314	100	27.55	37-42.13	113-56.20	7.0*	2.5	4	207	223	.34	D
68	320	1533	3.98	37-55.28	112-16.55	7.0*	3.0	6	148	121	.45	B
68	506	1826	52.47	37- 2.91	112-33.18	7.0*	2.3	4	144	85	.08	D
68	803	1521	23.97	37-59.13	112-23.19	7.0*	2.5	6	181	226	.63	C
68	1008	1813	47.61	37-50.65	113-58.75	7.0*	2.9	11	93	120	.67	C
69	815	30	30.57	37-47.48	113-14.97	7.0*	3.0	8	153	20	1.00	D
69	1112	2011	40.41	37-46.06	112-25.90	7.0*	2.9	12	96	57	.83	D
69	1117	1637	22.51	37-31.68	113-23.31	7.0*	2.1	4	153	32	.08	D
70	524	154	34.08	37-52.19	112-28.33	7.0*	1.5	9	99	56	1.00	D
70	524	156	6.84	37-56.64	112-24.25	7.0*	2.7	6	109	65	.99	D
70	901	1152	17.81	37-26.47	113-47.17	7.0*	3.0	10	89	42	1.01	D
70	901	1219	42.30	37-27.75	113-44.30	7.0*	2.5	8	108	40	.84	D
70	1025	213	51.61	37-56.13	112-23.38	7.0*	2.3	8	104	66	.42	B
71	124	2037	36.79	37-32.07	112-27.12	7.0*	2.1	7	119	56	1.24	D
71	329	1847	26.96	37-58.62	114- 6.93	7.0*	2.5	9	92	104	.59	C

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W); July 1962-Sept 1974

yr	date	orig time		lat-n	long-w	depth	mag	no	gap	dmn	rms	q
71	1110	1114	10.32	37-41.60	113- 6.16	7.0*	3.1W	13	74	3	.49	B
71	1110	1124	34.89	37-41.87	113- 7.28	7.0*	3.1W	15	72	5	.44	B
71	1110	1338	14.19	37-42.14	113- 5.58	7.0*	3.1W	10	101	3	.40	B
71	1110	1346	55.32	37-42.05	112-58.74	7.0*	2.6W	6	167	8	.48	B
71	1110	1410	23.01	37-48.03	113- 5.99	7.0*	3.7W	24	80	14	.63	C
71	1110	1443	58.51	37-48.25	113- 4.89	7.0*	3.4W	20	78	90	.51	C
71	1110	1454	31.50	37-20.66	113-20.73	7.0*	2.4	4	324	44	.08	D
71	1110	1608	37.68	37-42.01	113- 1.03	7.0*	3.1W	13	77	5	.51	C
71	1110	1703	12.63	37-20.07	113- 4.54	7.0*	2.9	5	323	37	.56	D
71	1110	1907	34.51	37-42.28	113- 3.92	7.0*	2.9W	7	107	3	.36	B
71	1110	1941	33.89	37-48.37	113- 3.75	7.0*	3.5W	17	81	14	.49	B
71	1115	1230	7.25	37-36.03	113-11.62	7.0*	2.1	4	313	13	.19	D
71	1130	337	43.07	37-37.17	113- 5.47	7.0*	2.7	6	319	6	.63	C
71	1208	554	22.83	37-41.83	113-51.81	7.0*	2.4	5	286	70	.06	D
72	123	1129	19.37	37-49.67	113-10.44	7.0*	2.8W	11	78	19	.47	B
72	317	2045	24.91	37-23.68	112-49.52	7.0*	2.2	6	284	37	.43	C
72	513	1340	25.66	37-25.87	113-19.40	7.0*	2.3	4	323	35	.27	D
72	701	1050	19.75	37-27.45	112-18.83	7.0*	2.4	5	253	70	.60	D
72	701	2345	36.10	37- 5.29	113-29.51	7.0*	2.3W	8	124	20	.43	B
72	702	1434	20.71	37-18.47	113-49.85	7.0*	2.5W	10	107	40	.69	C
72	702	2007	1.15	37-20.15	113-50.77	7.0*	3.0W	9	102	42	.85	D
72	805	1115	42.00	37-58.08	112-27.33	7.0*	2.1	6	201	63	.24	A
72	902	1530	35.47	37-14.01	113-21.78	7.0*	3.2	7	324	55	.50	C
72	1006	828	44.48	37-42.03	113-15.74	7.0*	2.8	6	269	17	.38	C
72	1006	1211	8.65	37-35.91	113-17.84	7.0*	2.7	6	301	21	.36	B
72	1017	2334	57.56	37-41.12	112-55.80	7.0*	2.9	8	216	12	.56	C
72	1116	217	45.16	37-31.93	112-46.18	7.0*	3.6W	10	215	30	.49	B
72	1128	2053	24.50	37-34.32	113- 1.12	7.0*	2.2	7	114	12	.57	C
72	1130	2322	55.66	37-28.03	113-24.22	7.0*	2.4	6	150	25	.38	B
73	122	1024	55.94	37-11.54	112-57.90	7.0*	3.0	5	315	54	.34	D
73	122	1123	54.01	37-21.19	113-43.56	7.0*	1.6W	6	137	33	.33	B
73	512	2339	50.60	37-22.94	114-12.56	7.0*	1.2	9	106	75	.58	C
73	514	101	9.84	37- 9.89	114- 7.18	7.0*	2.4	10	117	66	.69	C
73	520	1620	6.62	37-57.07	113-31.37	7.0*	3.1W	10	79	50	.74	C
73	714	1054	1.28	37- 9.00	112-45.20	7.0*	2.3	6	102	16	.91	D
73	1102	1644	5.47	37-58.30	112-19.89	7.0*	2.2	5	207	72	.50	D

number of events = 76

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
74	1225	813	40.38	37-52.10	112-59.39	7.0*	2.7	6	165	22	.49	D
75	112	959	56.89	37-59.76	112-54.63	7.0*	2.9	7	161	38	.34	D
75	1012	1650	17.94	37-59.83	113-19.00	7.0*	2.1	7	222	41	.44	D
76	531	1528	24.57	37-59.36	112-14.47	7.0*	1.6	4	239	58	.36	D
76	708	1739	21.45	37-55.40	112-51.79	7.0*	2.1	6	171	32	.51	D
76	808	346	55.77	37-28.72	112-21.12	7.0*	2.1	5	259	66	.21	D
76	1016	438	31.08	37-51.76	112-43.65	7.0*	2.1	7	194	36	.38	D
76	1025	2151	30.25	37-52.52	112-42.15	7.0*	2.6	4	202	39	.12	D
76	1222	1937	12.02	37-46.02	112-57.43	7.0*	1.7	5	157	14	.54	D
77	217	2321	9.10	37-34.30	112-37.15	7.0*	1.3	6	266	41	.68	D
77	219	818	38.40	37-33.74	112-35.18	7.0*	2.1	8	267	44	.61	D
77	221	46	4.18	37-58.63	112-30.83	7.0*	1.3	6	209	47	.55	D
77	324	330	15.87	37-46.52	112-51.81	7.0*	1.5	4	322	77	.05	D
77	423	205	49.78	37-36.08	112-25.65	7.0*	1.9	5	266	57	.34	D
77	502	2148	53.18	37-32.09	113-35.91	7.0*	1.5	7	317	49	.40	D
77	507	1901	3.51	37-45.50	113-21.07	7.0*	2.0	5	274	26	.38	D
77	519	2145	56.17	37-49.91	113-15.91	7.0*	1.4	4	248	24	.06	D
77	521	1334	52.26	37-32.88	112-20.42	7.0*	1.4	10	203	65	.39	D
77	527	2146	35.72	37-37.18	113-23.57	7.0*	1.3	6	306	29	.44	D
77	531	2128	15.14	37-42.25	113-17.87	7.0*	1.4	6	282	20	.36	D
77	706	1642	42.22	37-50.37	113-22.81	7.0*	1.3	5	265	32	.12	D
77	709	207	11.88	37-53.32	112-23.85	7.0*	2.5	9	109	53	.25	C
77	709	217	53.22	37-52.05	112-24.79	7.0*	2.1	8	108	55	.70	D
77	709	310	54.78	37-50.09	113- 4.76	7.0*	2.4	10	196	17	.47	D
77	718	344	9.65	37-51.38	112-27.47	7.0*	1.7	5	192	58	.25	D
77	1029	938	14.92	37-55.77	113-26.36	3.1	2.0	5	263	43	.06	D
77	1114	810	41.02	37-43.61	113- 9.11	1.5	1.2	6	247	9	.33	D
77	1114	1341	21.61	37-42.88	113-10.55	1.5	1.2	7	261	10	.39	D
77	1115	724	.26	37-43.21	113-10.16	1.5	1.4	9	257	10	.48	D
77	1115	1738	18.11	37-43.12	113- 7.99	1.5	1.2	8	244	7	.44	D
77	1116	1902	56.93	37-45.41	113-13.59	1.5	.8	6	256	16	.15	D
77	1117	145	19.94	37-44.44	113- 9.33	7.0*	1.1	8	242	10	.44	D
77	1117	722	18.63	37-44.60	113- 8.26	2.3	1.7	10	234	9	.28	D
77	1117	2032	38.27	37-43.91	113-13.59	7.0*	1.5	10	264	15	.56	D
77	1123	2057	26.07	37-40.89	113-16.05	7.0*	1.7	6	287	17	.62	D
77	1125	945	14.69	37-54.39	113- .64	7.0*	1.2	9	179	26	.22	C
77	1202	2125	6.65	37-43.69	113-11.30	3.8	1.5	10	219	12	.45	D
77	1204	59	17.45	37-45.16	113- 9.49	2.1	.8	9	238	11	.22	C
77	1205	544	28.95	37-43.57	113-11.39	1.4	1.7	7	259	12	.51	D
77	1206	1903	30.07	37-42.07	113-13.17	11.9	2.0	9	223	13	.79	D

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
77	1227	1928	56.19	37-46.77	112-31.07	7.0*	2.6	11	101	49	.32	C
78	111	1859	16.76	37-41.01	113-16.80	7.0*	1.5	6	287	18	.44	D
78	112	2235	10.30	37-37.50	113-20.45	7.0*	1.1	6	304	24	.36	D
78	118	1748	54.46	37-46.52	113- 8.27	7.0*	1.3	8	224	12	.24	D
78	118	1856	50.00	37-39.28	113-12.97	7.0*	1.3	5	300	13	.51	D
78	118	2238	48.82	37-45.52	113- 8.74	1.2	2.2	9	232	11	.33	D
78	121	2015	.21	37-44.66	113- 9.62	4.6	1.1	9	242	11	.31	D
78	123	714	8.96	37-43.65	113- 9.23	7.0*	1.7	10	216	9	.50	D
78	225	919	27.12	37-52.54	113- 6.41	7.0*	.6	7	204	22	.23	D
78	228	1037	6.33	37- 7.39	113-22.02	7.0*	1.6	7	341	66	.50	D
78	402	1217	10.58	37-50.43	113- 4.98	7.0*	1.3	10	197	18	.32	D
78	402	1219	24.17	37-50.37	113- 3.88	7.0*	.9	10	191	18	.37	D
78	522	750	51.40	37-35.17	112-32.27	7.0*	.7	6	327	102	.12	D
78	606	347	6.76	37-43.19	113- 6.71	7.0*	.7	7	231	6	.65	D
78	625	258	7.12	37-43.78	113-23.30	7.0*	1.3	6	284	28	.14	D
78	706	1016	12.23	37-52.05	112-30.61	7.0*	2.1	7	224	53	.31	D
78	707	1002	41.40	37-54.31	112-35.84	7.0*	1.8	6	163	48	.62	D
78	707	1244	30.02	37-51.77	112-33.72	7.0*	1.4	6	169	49	.36	C
78	1005	858	26.50	37-58.43	112-42.44	7.0*	1.3	4	330	57	.39	D
78	1011	856	54.99	37-33.03	112-54.38	3.5	1.7	7	158	19	.45	C
78	1025	2334	50.43	37-52.93	113-51.88	7.0*	1.4	8	271	73	.53	D
78	1108	229	49.12	37-56.72	112-32.91	7.0*	1.0	7	308	51	.07	D
78	1111	2232	33.06	37-46.99	113- 1.48	11.5	1.2	10	174	12	.51	D
78	1120	900	28.88	37-13.40	112-53.42	7.0*	1.7	9	177	23	.26	C
78	1201	609	16.77	37-50.44	113- .99	12.5	.6	6	178	18	.42	D
78	1203	2210	30.69	37-59.14	112-55.43	7.0*	1.1	6	165	36	.10	C
78	1212	732	10.22	37- 6.89	113-13.66	7.0*	1.5	5	266	37	.27	D
78	1214	2151	18.05	37-28.74	112-38.46	7.0*	1.8	6	178	53	.21	D
78	1218	749	7.49	37- 4.68	112-31.54	7.0*	1.7	6	256	27	.53	D
78	1218	1009	14.95	37-34.72	112-55.14	7.0*	2.8	6	284	17	.46	D
78	1218	1016	34.57	37-26.38	112-32.55	7.0*	2.1	8	284	53	.54	D
78	1220	559	34.11	37-26.24	112-25.88	7.0*	.9	5	221	58	.46	D
78	1221	305	49.59	37-28.39	112-36.21	7.0*	1.7	8	183	46	.24	C
79	107	836	12.50	37-40.47	113- 4.82	.8	1.6	8	208	1	.33	D
79	109	2237	6.32	37-46.85	112-18.17	16.0	.0	4	320	64	.10	D
79	112	928	59.54	37-44.33	113-10.05	.0	3.2W	9	217	11	.13	D
79	119	1807	47.77	37-45.20	112- 7.57	7.0*	2.0	5	220	68	.42	D
79	122	326	38.90	37-59.19	112-37.77	7.0*	.8	8	191	51	.33	D
79	131	943	47.87	37-20.64	113-52.35	7.0*	2.1	9	281	80	.36	D
79	203	543	56.93	37-34.39	112-55.02	7.0*	1.5	7	278	17	.37	D

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
79	208	2237	34.19	37-54.68	113-32.44	7.0*	1.8	6	282	49	.63	D
79	213	139	40.66	37-58.33	113- .38	7.0*	1.8	10	182	33	.52	D
79	322	230	10.74	37- 6.70	112-19.83	7.0*	1.8	6	251	45	.49	D
79	322	1446	30.20	37-57.26	112-36.67	7.0*	1.3	7	199	50	.39	D
79	611	1254	12.85	37-32.71	112-46.27	7.0*	1.6	8	175	58	.33	D
79	703	1904	49.39	37-48.04	112- 5.54	7.0*	2.0	10	140	63	.56	D
79	722	733	33.67	37-58.32	112-13.00	7.0*	1.1	9	312	43	.28	D
79	805	1910	21.35	36-58.89	113-40.08	7.0*	3.6W	8	291	75	.29	D
79	805	1932	35.49	36-48.32	113-55.11	7.0*	2.5	10	219	100	.84	D
79	806	1759	18.85	37-56.45	113-40.62	7.0*	1.4	6	260	93	.20	D
79	816	1733	4.98	37-45.58	112-43.41	7.0*	3.1W	13	99	31	.25	C
79	816	1737	45.20	37-45.41	112-43.36	7.0*	1.8	12	100	31	.50	D
79	816	1743	13.91	37-45.50	112-43.16	7.0*	1.9	12	156	32	.23	C
79	816	1744	23.69	37-45.70	112-43.12	7.0*	2.2	15	101	32	.35	C
79	816	1854	18.82	37-42.86	112-22.48	7.0*	1.2	7	215	61	.76	D
79	821	1220	33.37	37-50.07	113- 3.73	3.5	1.4	10	190	17	.23	D
79	826	958	10.15	37-56.58	113-38.45	7.0*	1.2	10	158	58	.40	D
79	826	1941	27.20	37-16.72	112-48.28	7.0*	1.7	12	167	49	.42	C
79	904	1822	31.60	36-55.18	113-33.58	7.0*	2.3	8	204	142	.46	D
79	916	46	6.23	37-34.01	112-18.66	7.0*	2.3	11	144	68	.37	D
79	920	840	27.39	37-44.28	112-26.48	7.0*	1.9	7	250	55	.58	D
79	1009	1235	23.96	37-38.61	112-56.96	7.5	1.3	10	252	11	.16	C
79	1112	816	17.58	37-48.11	112-51.58	20.1	1.1	8	193	23	.42	D
79	1118	2301	55.85	37- 7.21	113-24.70	7.0*	2.0	10	283	68	.44	D
79	1121	1650	5.08	36-54.41	112-51.12	7.0*	2.7	9	261	87	.69	D
79	1221	448	35.80	36-58.99	112-30.38	7.0*	2.2	7	187	28	.48	D
79	1224	537	53.18	37- 1.11	112-13.27	7.0*	1.2	9	175	53	.40	D
79	1226	138	20.89	37-31.31	113- 6.30	7.0*	1.7	9	332	17	.44	D
80	111	921	57.87	37-49.78	112-53.32	7.0*	2.3	14	134	23	.63	D
80	112	45	41.65	37-59.65	112-26.02	7.0*	1.4	7	303	42	.20	D
80	114	744	1.61	37-18.68	113-33.33	7.0*	2.1	4	339	59	.16	D
80	119	1950	47.54	37-51.30	112-53.31	7.0*	2.4	7	175	25	.40	C
80	315	1113	38.95	37-31.37	113- 9.52	10.3	1.9	8	334	18	.32	D
80	428	2147	35.00	37-18.11	114- 5.00	7.0*	3.4W	10	194	67	.39	D
80	429	1825	10.11	36-55.60	113-29.43	7.0*	2.7	9	224	60	.82	D
80	603	1157	7.12	37-44.09	112-51.96	10.1	1.9	8	140	19	.27	C
80	615	1034	58.09	37-39.62	113-16.28	16.1	2.4	5	273	18	.61	D
80	731	433	13.25	36-50.48	112- 7.70	7.0*	2.3	6	215	49	.37	D
80	803	608	28.57	37-48.43	112-58.16	16.5	3.1W	8	152	17	.27	C
80	1221	1122	56.86	37-29.36	113- 4.84	9.2	2.1	11	154	20	.35	C

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
80	1221	1825	9.12	37-26.71	113- 4.93	1.8	3.3W	18	114	25	.41	C
80	1227	434	15.52	37-30.83	113- 7.03	3.6	3.0W	19	201	18	.32	D
80	1227	1809	21.97	37-29.38	113- 5.68	2.8	2.8W	17	154	20	.35	C
80	1228	521	35.90	37-30.41	113- 5.16	9.2	2.3	14	202	18	.32	D
80	1229	712	52.50	37-27.28	113- 4.92	1.8	3.1W	18	114	24	.50	D
81	102	1720	22.76	37-36.52	113-17.36	1.1	2.0	11	252	20	.47	d
81	116	1026	30.13	37-26.94	113- 6.14	1.5	3.4W	25	113	25	.60	d
81	116	1138	29.86	37-32.05	113- 6.49	2.2	2.5	19	150	16	.40	c
81	116	1207	42.60	37-33.78	113- 6.61	6.2	2.1	14	198	13	.42	d
81	116	1413	56.70	37-30.86	113- 5.30	.1	2.2	19	151	18	.49	c
81	116	1450	45.92	37-26.62	113- 5.74	1.6	3.2W	3	7	25	.59	
81	116	1700	52.22	37-30.94	113- 5.49	1.5	2.4	28	151	17	.45	c
81	116	2341	12.23	37-31.82	113- 5.01	2.8	2.1	23	150	16	.49	c
81	117	2233	23.00	37-33.51	113- 6.16	9.6	2.0	30	199	13	.54	d
81	118	48	25.49	37-33.80	113- 7.44	2.5	1.4	27	148	13	.53	d
81	118	556	22.53	37-34.41	113- 7.09	6.1	2.2	25	198	12	.37	d
81	119	1110	20.22	37-29.68	113- 5.56	3.6	2.1	20	153	20	.44	c
81	119	1445	46.79	37-30.18	113- 6.19	2.7	2.2	20	152	19	.45	c
81	120	123	52.48	37-30.37	113- 5.78	1.9	2.3	19	152	18	.43	c
81	120	1153	27.14	37-31.50	113- 6.35	1.4	1.6	18	201	17	.52	d
81	120	1302	37.52	37-31.95	113- 7.04	1.8	1.5	16	200	16	.63	d
81	121	218	11.49	37-30.05	113-13.43	7.0*	1.0	11	299	23	.36	d
81	121	653	25.66	37-28.46	113- 7.51	6.5	1.8	15	209	22	.51	d
81	122	837	17.48	37-58.95	112-58.83	7.0	1.9	9	112	35	.37	c
81	201	221	47.49	37-34.09	113-14.56	.2	3.8W	26	111	19	.53	d
81	202	351	31.90	37-34.73	113-15.80	1.6	1.5	12	195	20	.49	d
81	204	342	14.50	37-35.01	113-17.15	.7	2.6	14	148	21	.36	c
81	205	1432	45.13	37-32.83	113-14.89	3.6	2.8W	16	116	21	.64	d
81	205	1435	43.29	37-34.34	113-15.99	1.4	1.7	10	195	20	.49	d
81	207	405	31.69	37-35.36	113-17.40	1.3	1.2	9	202	25	.44	d
81	217	1325	22.01	37-33.53	112-30.36	7.0*	1.5	9	216	50	.20	c
81	218	452	47.33	37-44.90	113-58.05	7.0*	1.4	5	172	45	.40	d
81	226	1053	18.68	37-17.09	113-20.22	7.0*	1.4	13	226	49	.71	d
81	227	1557	54.90	37-38.86	113-14.74	.0	1.5	11	201	15	.43	d
81	302	29	12.38	37-52.65	112-32.42	7.0*	1.9	12	103	50	.47	d
81	311	1358	1.74	37-38.16	113-49.38	7.0*	1.4	13	194	37	.89	d
81	311	1622	26.06	37-47.52	112-23.52	7.0*	1.8	8	127	74	.18	d
81	314	341	37.75	37-55.98	112-30.45	7.0*	.9	16	178	55	.25	d
81	314	858	14.10	37-47.71	112-23.82	7.0*	1.1	25	114	59	.30	d
81	314	901	20.11	37-47.70	112-23.81	7.0*	1.7	25	114	59	.33	d

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W); Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
81	314	1824	36.68	37-48.26	112-24.12	7.0*	2.3	23	121	72	.40	d
81	314	1837	41.46	37-51.70	112-22.68	7.0*	1.1	18	190	69	.45	d
81	314	2314	48.39	37-47.39	112-25.03	7.0*	2.0	19	118	73	.29	d
81	315	316	27.16	37-48.28	112-24.74	7.0*	1.2	16	257	72	.26	d
81	316	34	7.64	37-56.97	112-29.43	7.0*	2.3	31	94	55	.55	d
81	316	544	47.36	37-56.61	112-30.43	7.0*	1.8	29	164	55	.58	d
81	316	609	40.08	37-56.48	112-28.91	7.0*	1.7	20	165	56	.28	d
81	318	636	43.64	37-56.93	112-29.54	7.0*	1.4	17	164	55	.30	d
81	318	638	11.07	37-56.81	112-29.73	7.0*	1.7	22	164	57	.27	d
81	318	1411	53.31	37-56.64	112-29.41	7.0*	1.5	18	114	55	.28	c
81	329	706	57.85	37-56.21	112-29.89	7.0*	1.6	12	165	56	.35	d
81	405	540	40.45	37-37.85	113-18.20	1.4	4.5W	30	144	20	.34	c
81	405	545	37.72	37-37.32	113-14.75	2.7	2.0	26	192	16	.42	d
81	405	640	3.33	37-36.80	113-16.54	4.3	2.1	12	154	19	.41	c
81	405	1052	35.63	37-36.83	113-16.45	2.6	1.9	13	154	19	.48	c
81	406	2038	29.43	37-37.98	113-17.87	1.1	2.2	11	152	20	.51	d
81	407	2111	46.87	37-37.95	113-17.91	7.0*	1.4	11	199	85	.43	d
81	408	2325	13.46	37-38.39	113-17.90	7.0*	1.4	10	198	84	.36	d
81	410	1343	27.92	37-36.40	113-15.75	5.1	1.4	10	201	18	.43	d
81	410	1345	21.29	37-37.00	113-16.35	3.1	1.4	14	200	18	.49	d
81	410	1352	3.29	37-37.34	113-15.75	4.9	.9	13	199	17	.49	d
81	411	737	58.56	37-36.09	113-16.14	2.3	1.8	17	155	19	.48	c
81	413	259	59.62	37-37.29	113-14.64	4.9	1.7	9	152	16	.62	d
81	413	416	55.23	37-37.23	113-14.70	5.4	1.5	14	200	16	.62	d
81	413	524	42.61	37-36.08	113-15.27	4.8	1.1	12	202	18	.49	d
81	414	1330	46.15	37-37.12	113-13.87	5.7	1.4	13	200	15	.60	d
81	415	646	8.63	37-40.07	113-17.54	5.1	1.2	10	179	18	.50	d
81	418	1119	37.54	37-35.75	113-14.75	2.7	.9	14	210	17	.48	d
81	419	2126	1.91	36-55.47	113-53.86	7.0*	1.4	7	294	104	.42	d
81	423	254	55.35	37-37.41	113-17.18	1.6	1.7	9	196	19	.46	d
81	423	626	46.23	37-39.75	113-18.42	7.0*	1.6	7	196	82	.52	d
81	423	629	14.50	37-37.70	113-18.14	.1	2.0	14	153	21	.64	d
81	423	632	19.38	37-36.61	113-15.53	3.9	2.0	10	201	18	.43	d
81	423	756	47.31	37-37.85	113-15.46	.6	1.6	11	196	17	.57	d
81	504	357	16.65	37-39.58	113-17.35	4.3	1.9	14	150	19	.57	d
81	504	549	33.21	37-39.02	113-17.72	1.5	1.9	13	186	19	.52	d
81	514	1455	23.39	37-33.50	113-50.07	7.0*	1.5	12	220	42	.67	d
81	611	629	17.19	37-45.65	113-11.79	10.5	1.7	9	189	21	.50	d
81	627	745	10.15	37-48.79	113- 5.68	.1	1.9	10	97	15	.48	c
81	705	928	44.51	37-20.15	113-18.70	7.0*	1.7	19	179	43	.59	d

SW Utah Earthquakes (36.75-38.00N,112.00-114.25W): Oct 1974-Dec 1981

yr	date	orig	time	lat-n	long-w	depth	mag	no	gap	dmn	rms	q
81	729	658	5.77	37-46.55	112-40.62	7.0*	1.6	9	183	35	.30	d
81	729	1652	53.11	37- 9.04	113-36.26	7.0*	1.8	12	201	72	.40	d
81	813	1840	55.00	37-39.85	112-29.29	7.0*	1.5	12	220	82	.28	c
81	827	1901	52.61	37-38.11	112-26.40	7.0*	2.1	13	134	87	.45	d
81	828	237	42.82	37-53.14	112-56.80	7.0*	1.6	12	179	43	.46	c
81	828	243	31.47	37-52.81	112-56.57	7.0*	1.4	12	181	44	.46	d
81	828	2119	9.00	37-51.96	112-55.91	7.0*	2.5	11	128	44	.39	c
81	828	2125	30.54	37-52.41	112-55.31	7.0*	1.5	12	127	45	.45	c
81	831	2316	5.54	36-46.38	112-53.95	7.0*	2.0	11	221	115	.53	d
81	929	2100	33.90	37-34.70	113-15.28	.4	1.6	12	204	28	.59	d
81	930	851	56.67	37-30.85	112-44.27	7.0*	1.8	10	215	67	.36	d
81	1002	1956	27.43	37-39.90	112-58.68	23.7	2.0	8	156	7	.90	d
81	1004	2257	39.30	37-48.19	113- 3.60	.7	1.8	16	83	14	.65	d
81	1016	1937	46.17	37-33.61	113-52.15	7.0*	2.2	15	166	44	.42	c
81	1031	1815	33.45	37-51.53	112-56.63	1.6	1.4	14	133	23	.93	d
81	1101	37	10.41	37-45.48	113-48.40	5.0	1.2	6	174	31	.30	c
81	1115	126	39.03	37-12.32	113-35.82	7.0*	1.4	13	201	66	.53	d
81	1116	432	49.33	36-55.03	112-31.39	7.0*	1.8	10	209	124	.47	d
81	1201	1339	11.94	37-19.51	113-19.42	7.0*	1.6	13	223	44	.55	d
81	1202	2121	16.95	37-10.67	113-34.29	7.0*	2.1	10	235	70	.60	d

number of events = 220

APPENDIX K

LIST OF REFERENCES

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