UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

G-321
LANDSLIDE SURVEILLANCE
OF
LAKE POWELL

UPPER COLORADO REGION DECEMBER 1980

United States
Department of the Interior
Water and Power Resources Service

Landslide Surveillance of Lake Powell

Upper Colorado Region
Division of Design and Construction
Geology Branch

December 1980

Reviewed by Regional Geologist Fred Thompson

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Marked print of Glen Canyon Recreation Area

Marked prints of 13 USGS Quadrangle Maps (15 minute)

Div. of Design and Construction
Geology Branch
Region 4
Salt Lake City, Utah
December 1980

Geology Report No. G-321
Field Work and Report
by D. Grundvig

Landslide Surveillance of Lake Powell

Introduction

Since the construction of Glen Canyon Dam, public officials have been concerned with the hazards of rockfalls and landslides along the Lake Powell shoreline. To date, rockfalls have resulted in the death of one boater (Padre Bay, August 1975), damage to at least two boats (Padre Bay and Iceberg Canyon, May 1974) and reports of several incidents which could have led to tragedy.

Scope of this Report

While it is not the intention of this report to describe in detail the geologic sequence exposed along the shoreline, a general discussion of the geology and topography of the area will be offered to aquaint the reader with those conditions which lead to slope instability and possible failure. Background information leading up to the 1980 inspection, the results of the shoreline survey, and the necessity for continuing surveillance will also be discussed.

Geology and Topography

The shoreline of Lake Powell, excluding alluvial fans, talus, and wind-blown sand, is comprised entirely of sedimentary rocks. Rock types include shale, sandstone, limestone, and conglomerate. See Fig. 1 for a detailed description of the lithologic units and their stratigraphic relationships.

Throughout most of the reservoir area, the rocks are flat-lying or slightly tilted where folded and are cut into sections by steep-walled, deep canyons. Basically, the width of Glen Canyon is controlled by the varying hardness and erosibility of the different rock types exposed by the river. In general, the reservoir basin is wide where the river flowed through the soft formations, such as the Chinle shale. In areas where the river encountered more resistant formations, such as the Navajo and Entrada sandstone, the reservoir basin is comparatively narrow with sheer walls.

Formations such as the Chinle consist of clay-type shales, some of which are highly bentonitic. When not covered by an overlying resistant bed, the shale weathers to relatively flat slopes with a typical badland expression and landslides are numerous. Many of the landslides, some quite large, were identified by geologists prior to construction of Glen Canyon Dam and were therefore not induced by the reservoir.

Where the soft shale formations are protected from erosion by a cliff-forming sandstone, such as the Wingate, relatively steep slopewash and talus covered slopes form. Talus accumulations derived from the Wingate and other overlying formations rest upon the clay surface of the Chinle, which is slippery when wet. This results in an unstable condition and when the shale is wetted by precipitation or reservoir water, downslope movement of the talus usually occurs.

Where massive sandstone units such as the Wingate, Navajo, and Entrada are found, stress relief joints have developed. These joints generally form in deeply incised canyons where removal of rock by river erosion has placed the wall in an unequal stress pattern. The joints are usually vertical and parallel the cliff face. Slabs and pillars of massive sandstone form where jointing is extensive. For examples see Sites 19, 21, and 26. When the canyon walls are subjected to thermal expansion or relief from removal of support and vibration (sonic booms, earth tremors, etc.) the slabs and pillars may be released from the walls.

All of the previously mentioned conditions exist in a natural environment as well as in man-made reservoirs. Under certain conditions, however, the presence of water can accelerate this erosional process particularly if the materials are susceptible to softening or lubrication. Other erosional processes due to the presence of the reservoir water include wave action, particularly wave erosion of soft materials, saturation and lubrication of old slide planes, increase of pore pressure during drawdown, and possible weakening of intergranular bonds.

Landslide Surveillance Program

Prior to 1973, shoreline inspections have been conducted on an irregular basis generally in response to known incidents such as rockfalls at Iceberg Canyon or reports of potentially hazardous conditions by the National Park Service. In June 1973, Regional Geologist W. Mann became involved in a field study of the problem as a result of Park Service requests for geologic expertise. In August of that same year, Durango Project Geologist C. Rorvik made a reconnaisance grade landslide survey of the shoreline. The trip was taken primarily for the annual sonar survey of sedimentation sections and profiles of previously set courses and covered only the main channel and major arms of the lake. Approximately 145 photographs were taken of various unstable features and types and locations were marked on 15 minute USGS quadrangle sheets. A report entitled "Reconnaissance Geologic Evaluation of Hazardous Features Along Lake Powell" was prepared by the Durango Projects Office in August 1973. Subsequent surveys have been made but they have generally been brief, at infrequent intervals, and have been conducted as part of another trip such as the Rainbow Bridge Monitoring Program.

At the time of the Durango Projects Office survey, the lake elevation stood at 3642 feet. Many of the unstable areas inventoried at that time are now below water and new unstable areas have developed as the lake level has risen. It was felt that a new reconnaisance survey conducted when the reservoir was at maximum storage capacity (3700 foot elevation) or following a short period of drawdown would provide a data-base for continuing surveys. It was felt that this period would be ideal since no new areas could be brought into contact with the water and that some slope movement may have been generated by drawdown. It was also felt that detecting areas in initial stages of movement would permit some analysis time to determine the failure mode and degree of hazard.

Present directives from the Commissioners Office require an effective program for landslide surveillance. This program requires that the regions examine all significant landslides or potential slide areas which could endanger existing project facilities (or persons using them) at least annually. At this time, the landslide register (compiled by the Division of O&M Technical Services, E&R Center) rates only one landslide area in Lake Powell, Iceberg Canyon, as a high risk slope failure. Risk to life is rated extreme, the highest rating given. Possibly, equally hazardous conditions exist at other locations in Lake Powell but at present have not been identified. From the previous discussion it can be seen that erosional processes are continually changing the shoreline of Lake Powell. As rockfalls and landslides occur, some areas become stable while others such as cliffs continue to be subject to stress relief processes and will continue to spall and slab in the future. It is for this reason landslide surveys should be conducted on a regular basis.

Future shoreline surveillance should be conducted at least annually to satisfy present directives. It is preferable that the survey be conducted during the low lake level for that year so more of the reservoir rim could be observed. About 2 weeks are required to view the entire shoreline once yearly and to note significant changes. It is proposed that when scheduling does not permit a complete inspection, Iceberg Canyon and other high potential rockfall areas would have priority and should be examined closely. Areas which are heavily visited, such as Rainbow Bridge, should also be inspected.

Synopsis of 1980 Surveillance

During the period of October 28 to 31, 1980, the Geology Branch made an inspection of portions of the shoreline of Lake Powell for the purpose of identifying existing or potential shoreline hazards. As landslides and unstable conditions were identified the sites were assigned numbers and referenced on 15 minute USGS quadrangle sheets. Photographs were taken of the features for future comparisons to determine what, if any, shoreline changes have occurred since the last inspection. Although numerous unstable areas were identified, the photographs and reference sheets of only 50 sites accompany this report. When many failures occurred in a general area, a representative was chosen and photographed for reference purposes. At the time of the inspection, withdrawals had lowered the lake surface to 3685.6 feet. A high water mark can be seen in most of the accompanying photos.

It should be noted that stereo photography of the entire reservoir was completed just after the maximum lake level was reached (July 1980). This additional photographic record will become an integral part of the data base and will also be used for comparison purposes. The stereo photographs are on file in the Region's Reservoir Regulation Branch.

The survey found frequent unstable rockfall, and landslide conditions in all of the previously mentioned rock types and land forms, i.e., sheer canyon walls, sand accumulations, old landslides, and talus covered slopes. These unstable slope configurations by themselves present little or no risk to boaters but are hazardous because they occur in favored camping, mooring, and fishing spots. This is particularly true of areas where the lake encroaches on sand deposits or rockfall areas.

Sand deposits as high as 100 feet have accumulated beneath cliffs formed by the Navajo, Wingate, and Entrada Formations. When reservoir water comes into contact with these wind-blown deposits, the entire deposit can slide into the water within a few minutes. The level of hazard is variable but of a short term nature since the deposit is easily eroded by wave action with constant sliding of sand into the reservoir. Most of the failures had occurred prior to our inspection leaving some near-vertical slopes approaching 80 feet in height. See the photographs of Site 25. In other cases, small remnants remained with only a white jagged mark on the cliffs to indicate their former presence. Extensive sand deposits had been reported in the Escalante Arm of the reservoir but at the time of our trip very few remained. The deposits had either been inundated by the rising lake or had failed and slid into the water.

Major sand accumulations such as those found west of The Rincon are particularly hazardous to campers because of the high vertical faces and poor consolidation of the materials. The sandy beaches and slopes make this site a favorite camping place. The accompanying photos (see Site 25) illustrate very well the high hazard that is created by actions such as standing beneath an 80-foot-high vertical slope of damp sand to write initials. When failure occurs, a person standing near the base could be buried by tons of sand in a matter of a few seconds.

More abundant and usually larger in size were failures involving talus slopes. Extensive failures were found at the mouth of Ticaboo Creek (see Site 37) and Trachyte Creek (see Site 46). Some continuous scarps were identified that exceeded ½ mile in length. The most frequently seen talus slide occurred where debris, derived from the Wingate and Kayenta Formations rested upon the weathered shale slope of the Chinle. When the slopewash and talus deposits become wetted on these steep shale surfaces they become unstable and slide down slope. Erosion by wave action and saturation generally increases this instability and results in sloughing at the toe of the slide.

It is estimated that the rate of movement for most talus slides would range from slow to moderate (less than 5 feet per month to 5 feet per day) but may result from a single movement followed by a long period of non-movement. The majority of slides had developed high water marks which would indicate that movement had been less than 15 feet (3700'-3685'=15) during the 4 month drawdown period (July through October). Sloughing which takes place at the toe of the slide probably occurs rapidly but is generally limited in size. Although talus slides are of interest geologically, the risk of personal injury or boat damage is not great unless boaters are within several feet of the toe when sloughing takes place.

The most dangerous hazard, yet the least predictable, is rockfall. The greatest potential exists in the Wingate, Navajo, and the Entrada Formations; the Navajo and Entrada because of their tendency to develop stress relief joints and the Wingate because it rests upon a weak foundation, the Chinle Formation. Deeply incised canyons where these massive rocks predominate are prime areas for the continued development of rockfalls. Most active slabbing is occurring along the outside bends of old river meanders where the most active river erosion has taken place.

Perhaps the most dangerous aspect of a rockfall is not the actual fall itself, but the large waves that can be produced. An incident occurred in June of 1974 near Iceberg Canyon (see Site 26) when a large slab released along near-vertical stress relief joints and fell several hundred feet into the lake. The resulting wave lifted a boat, anchored across the main channel, and deposited it approximately 40 feet from the existing shoreline. As previously mentioned, the risk of personal injury resulting from a rockfall at Iceberg Canyon has been rated extreme. It should be noted that the potential for slabbing exists anywhere in the reservoir where massive sandstone formations exist and prominent vertical joints parallel the cliff faces. It is difficult to determine where or when a rockfall will occur but abundant cracks and joints present in canyon walls indicate that rockfalls are occurring and will continue.

Examples of extensive rockfall involving the Wingate and Chinle Formation can be seen in the photographs taken in Two Mile Canyon (see Sites 44 and 45). Most rockfalls involving these formations occurred where the soft Chinle Formation was found at or just below the water surface. Wave action erodes the soft shale removing the support of the overlying sandstone beds. In some cases, inundation saturates, lubricates, and softens the shale resulting in foundation movement with attendant failure of the sandstone beds above.

Wave erosion had undercut some sandstone beds to the point where they were overhanging the reservoir by 10 to 15 feet. The areas are particularly hazardous because they are favored fishing spots. The submerged blocks provide excellent cover for fish andfishermen troll very close to the cliffs. A boat too close to the shore could be struck by falling rocks or swamped by the resulting waves.

Conclusion and Recommendations

Inspection of Lake Powell has led to the following conclusions and recommendations:

(1) Many unstable or potentially unstable slopes exist along the 1900+ miles of shoreline. Geologic conditions are highly varied and there appears to be no single way of predicting when or where failures may occur.

(2) In bringing to your attention the 50 sites photographed for this report, we do not wish to diminish the importance of numerous other hazardous conditions which exist.

(3) Hazards of falling rocks are ever present from the sides and tops of cliffs which are sheer and in some cases, overhanging the waters of Lake Powell. Although it is virtually impossible to predict when rockfalls will occur, open cracks in cliffs such as those present at Iceberg Canyon indicate that they will continue since they are time/gravity dependent. The process can, however, be accelerated by reservoir fluctuation.

(4) Although there is a possibility that a boat and its occupants may be endangered by falling rocks or slides, the possibilities are too remote and the expenses too great to consider such measures as wide-spread blasting to stabilize cliff faces. Any benefits derived from blasting would only be effective for the short term since the processes leading to rockfall will continue. Equally hazardous conditions exist over a broad region and any attempts at stabilization should be applied to those areas as well. Stabilizing all hazards would be an impossible undertaking. This is not to say that isolated features that can be stabilized without great expense, should not be attempted. Sites 6 and 7 should be examined

to determine if blasting is warranted. Obvious and critical hazards when identified should, in most cases, be minimized by appropriate actions.

(5) We do not recommend that hazardous areas be marked with warning buoys since marking only those hazards presently known may give visitors the false impression that any area not marked is safe. The magnitude of on-site marking of dangerous areas would be financially prohibitive even if they could all be identified. That many markers would be esthetically undesirable.

(6) We acknowledge that it is impossible to provide complete protection to boaters but warning should be given in an effort to prevent serious accidents. The hazards of boating on Lake Powell have long been recognized and official publications from the establishment of the reservoir have warned visitors of the potential danger. Much reliance must be placed upon the public's sense of responsibility in identifying and avoiding potentially hazardous areas. We feel the best approach in accomplishing this is the distribution of safety information depicting typical shoreline hazards which may be encountered. Photographic brochures may aid in the public's indoctrination of the basic identities of shoreline hazards. A brochure is presently being prepared by the Public Affairs Office and the Geology Branch.

(7) Surveillance and mapping of the reservoir shoreline by Water and Power employees should be continued and any new developments reported to the Regional Geologist.

Daniel E. Grundvig

Definitions of terms

Column - A singular tall mass of rock composed of beds or blocks arranged vertically and formed by joint separation.

Fractured Point - A narrow rock remnant, usually at the confluence of two canyons and composed of many vertical cracks and blocky columns with block piles and talus at the base.

Landslide - A mass movement resulting from failure of earth or rock under shear stress along one or several surfaces that are either visible or may reasonably be inferred.

Sand Accumulations or Deposits - Deposits of wind-blown sand piled or heaped up behind some fixed object, i.e. sand swept over a cliff and piled up at its base.

Slope Wash - Soil or rock material that has been transported down a slope by running water not confined to channels (sheet wash).

Slab - A very large, massive, tabular unit of rock standing against but nearly free of its backwall or cliff.

Slump - A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward). Characterized by backward tilting of the mass with respect to the slope.

Talus Cone - A small, cone-shaped or apron-like landform at the base of a cliff and consisting of poorly sorted talus.

Talus Slope - A steep, concave slope formed by an accumulation of loose rock fragments at the base of a cliff or steep slope and formed by the coalessing of talus cones.

FIGURE 1

System	Series		Formation	Section	Thickness (feet)	Character of rocks
CRETACEOUS	Upper Cretaceous		Mancos shale		800+	Steel-gray marine shale with a few thin beds of buff to brown sandstone.
CRETACEOUS	Upper Cretaceous		Dakota (?) sandstone		0-40	Yellowish-brown conglomeratic sandstone with chert pebbles as much as 1 inch or more in maximum diameter and with abundant silicified wood; contains some yellow sandy clay and carbonaceous shale.
JURASSIC	Upper Jurassic		Morrison formation (Salt Wash sandstone member)		590-637	Upper part consists of well-banded variegated shale with a few siliceous conglomeratic sandstone beds containing varicolored chert pebbles; Salt Wash sandstone member constitutes approximately lower third of formation and consists of irregularly bedded gray sandstone interbedded with red mudstone and with a thick bed of gypsum at the base.
JURASSIC	Upper Jurassic	San Rafael group	Summerville formation		96-205	Thin regularly bedded red-brown more or less earthy sandstone and shale with some veins and beds of gypsum.
JURASSIC	Upper Jurassic	San Rafael group	Curtis formation		34-235	Greenish-gray to brown fine- to coarse-grained sandstone and greenish-gray to red shale; contains locally geodes lined with celestite crystals and nodules and beds of light-gray to flesh-colored gypsum.
JURASSIC	Upper Jurassic	San Rafael group	Entrada sandstone		405-460	Silty red sandstone with a few ledge-forming beds of buff to gray sandstone in the western part; grades eastward into massive cross-bedded red to buff sandstone.
JURASSIC	Upper Jurassic	San Rafael group	Carmel formation		85-230	Brown to gray fossiliferous sandy limestone and limy sandstone at the base, overlain by interbedded red to gray silty sandstone and shale; abundant gypsum near the San Raphael Swell; grades eastward into interbedded silty red sandstone and shale.
JURASSIC (?)		Glen Canyon group	Navajo sandstone		420-552	Massive cross-bedded buff to gray sandstone with a few thin lenses of sandy limestone.
JURASSIC (?)		Glen Canyon group	Kayenta formation		270-294	Irregularly bedded fine- to coarse-grained red to gray thin-bedded to massive, in part cross-bedded, sandstone, locally conglomeratic, with some red, gray, and green shale.
JURASSIC (?)		Glen Canyon group	Wingate sandstone		270-323	Massive cross-bedded buff to brownish-red medium-grained sandstone, which weathers into cliffs characterized by vertical joints.
TRIASSIC	Upper Triassic		Chinle formation		265-455	Variegated shale with some interbedded red to gray sandstone, conglomerate, and a few beds of sandy limestone; contains fossil wood.
TRIASSIC	Upper Triassic		Shinarump conglomerate		0-135	Gray medium- to coarse-grained cross-bedded and irregularly bedded sandstone with lenses and streaks of conglomerate containing pebbles of quartzite, limestone, and clay pellets and with interbedded gray shale; contains fossil wood.
TRIASSIC	Lower Triassic		Moenkopi formation (Sinbad limestone member)		326-684	Thin and regularly bedded red-brown and greenish-gray siltstone with thin beds of ripple-marked gray to red-brown sandstone with the Sinbad limestone member in the lower part on the San Rafael Swell; locally thick parts of the formation are greenish gray.
PERMIAN		Cutler formation	Unnamed upper unit		0-60	Coarse- to fine-grained red to purplish-brown micaceous sandstone and siltstone similar in lithology to Organ Rock tongue.
PERMIAN		Cutler formation	White Rim sandstone member		0-230	Massive cross-bedded tan to light-gray, medium- to coarse-grained sandstone.
PERMIAN		Cutler formation	Organ Rock tongue		117-870	Red siltstone, silty more or less arkosic sandstone, and sandy shale, weathering into fluted surfaces.
PERMIAN		Cutler formation	Cedar Mesa sandstone member		747	Light-gray to tan friable, fine- to coarse-grained thick-bedded and cross-bedded sandstone, which grades northward into red shale, siltstone, and arkosic sandstone.
PERMIAN			Rico formation		575	Interbedded gray to reddish-purple fine- to coarse-grained sandstone, red to purplish shale and siltstone, and gray to greenish-gray fossiliferous limestone.
CARBONIFEROUS	Pennsylvanian		Hermosa formation		913+	Massive to thin-bedded light- to dark-gray dense to coarsely crystalline cherty, fossiliferous limestone interbedded with gray to brown massive to thin-bedded sandstone, with a few thin beds of gray to red shale.
CARBONIFEROUS	Pennsylvanian		Paradox formation		?	Crops out as small gypsum plugs shown by drilled wells to contain salt and anhydrite with interbedded black and brown shale and some limestone.

ROCKS EXPOSED IN THE REGION EXCLUSIVE OF THE CARBONIFEROUS AND PERMIAN ROCKS OF THE SAN RAFAEL SWELL.

System	Series	Formation	Section	Thickness (feet)	Character of rocks
PERMIAN		Kaibab limestone		0-102	Light-gray to brown cherty fossiliferous limestone, commonly sandy.
PERMIAN		Coconino sandstone		685	Massive cross-bedded light-gray to buff sandstone with irregular patches of red, medium- to coarse-grained sandstone.
CARBONIFEROUS	Pennsylvanian	Hermosa (?) formation		432+	Interbedded gray to tan sandstone and gray to pink more or less cherty limestone; exposed in Straight Wash Canyon.

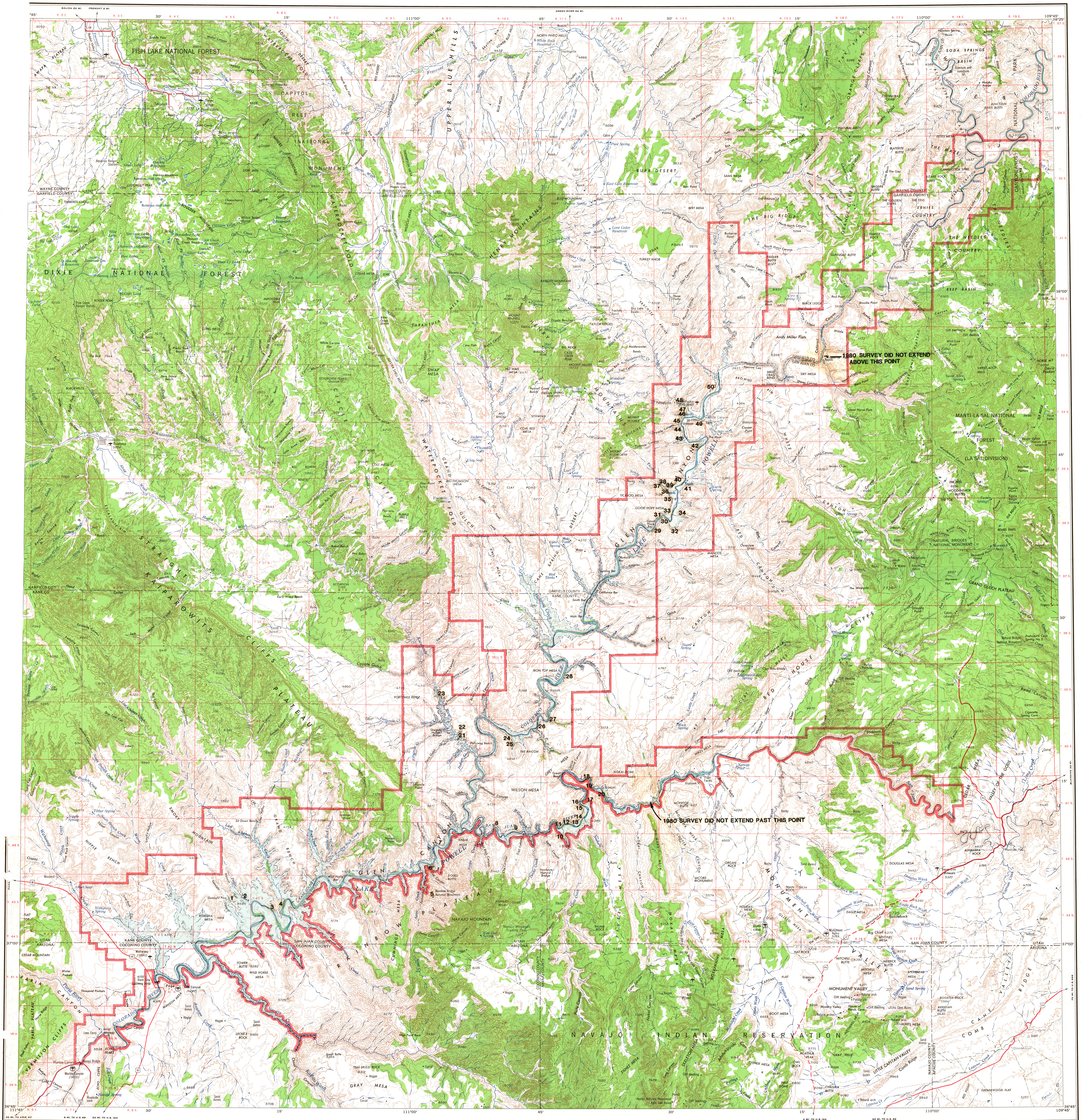
CARBONIFEROUS AND PERMIAN ROCKS EXPOSED IN THE SAN RAFAEL SWELL.

GENERALIZED COLUMNAR SECTION OF THE ROCKS EXPOSED IN THE GREEN RIVER DESERT-CATARACT CANYON REGION, UTAH.

UNITED STATES
ARTMENT OF THE INTERIOR
UREAU OF RECLAMATION
NATIONAL PARK SERVICE

GLEN CANYON NATIONAL RECREATION AREA

UTAH–ARIZONA



Prepared for the Bureau of Reclamation and the National Park Service by the Geological Survey

1980 LANDSLIDE SURVEILLANCE - SITE LOCATION MAP

Scale 1:250,000

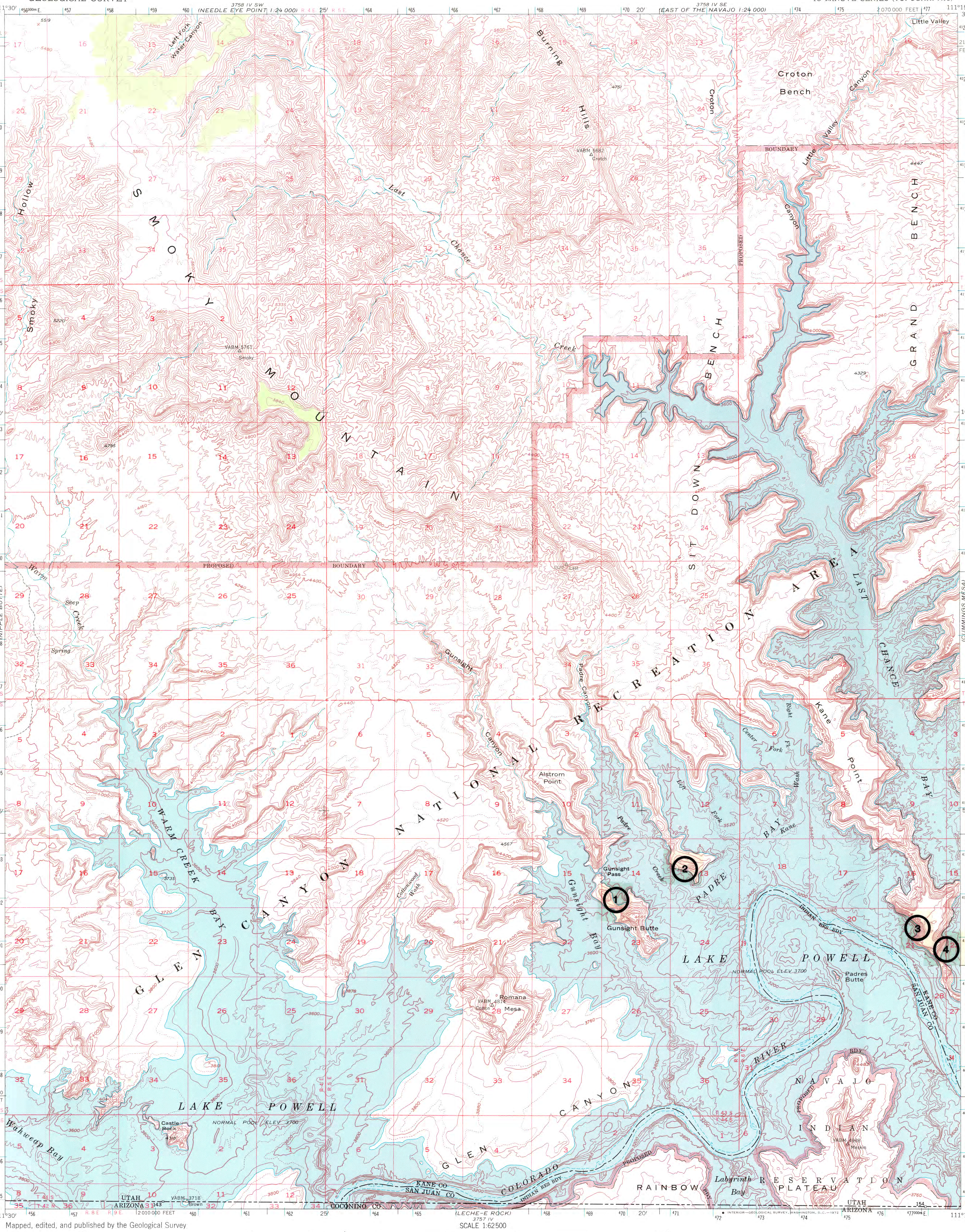
CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1967

SITES 1–4

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GUNSIGHT BUTTE QUADRANGLE
UTAH—ARIZONA
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951. Advance field check 1953

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone

Unchecked elevations are shown in brown

1000-meter Universal Transverse Mercator grid ticks,
zone 12, shown in blue

Where omitted, land lines have not been established

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Trails

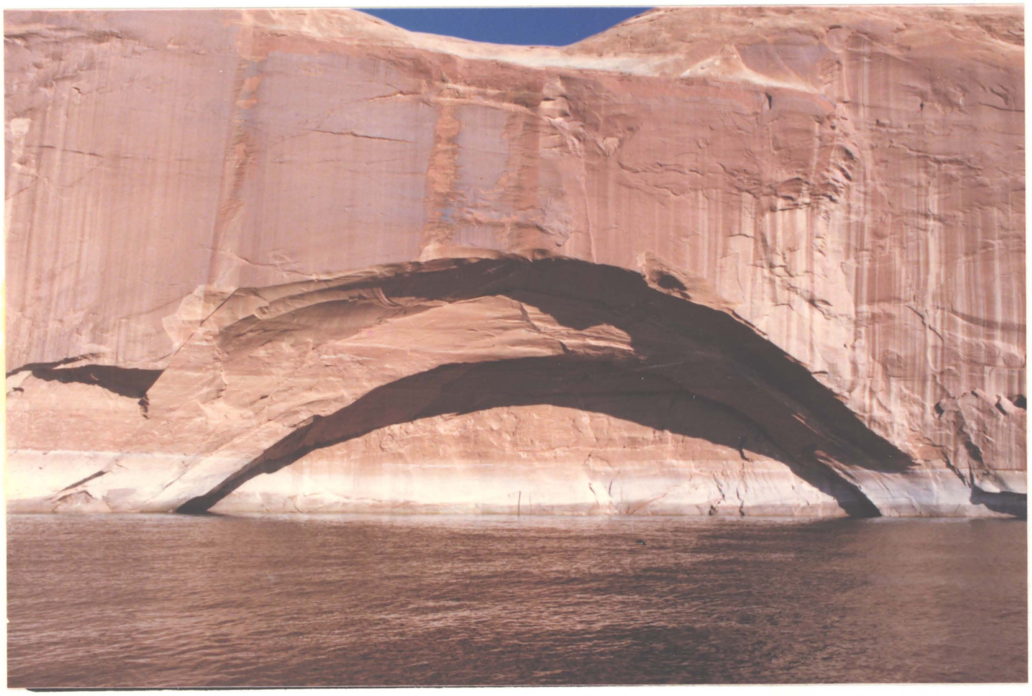
GUNSIGHT BUTTE, UTAH—ARIZ.
N3700—W11115/15

1953
MINOR CORRECTIONS MADE 1972
AMS 3758 III—SERIES V797

SITE 1

SITE 1: Active failure located about ¼ mile south of Gunsight Pass. Sand deposit is approximately 200 feet long and 50 feet high. Note absence of high water mark.

SITE 2



SITE 2: Site of recent arch collapse in Padre Bay. Presence of open cracks parallel to the arch indicate that additional slab failures may occur in the near future.

SITE 2: Closeup of open crack (indicated by arrow) Slab is separated from the wall of the cliff by an open vertical crack. Slab dimensions are approximately 60 feet by 20 feet by 10 feet.

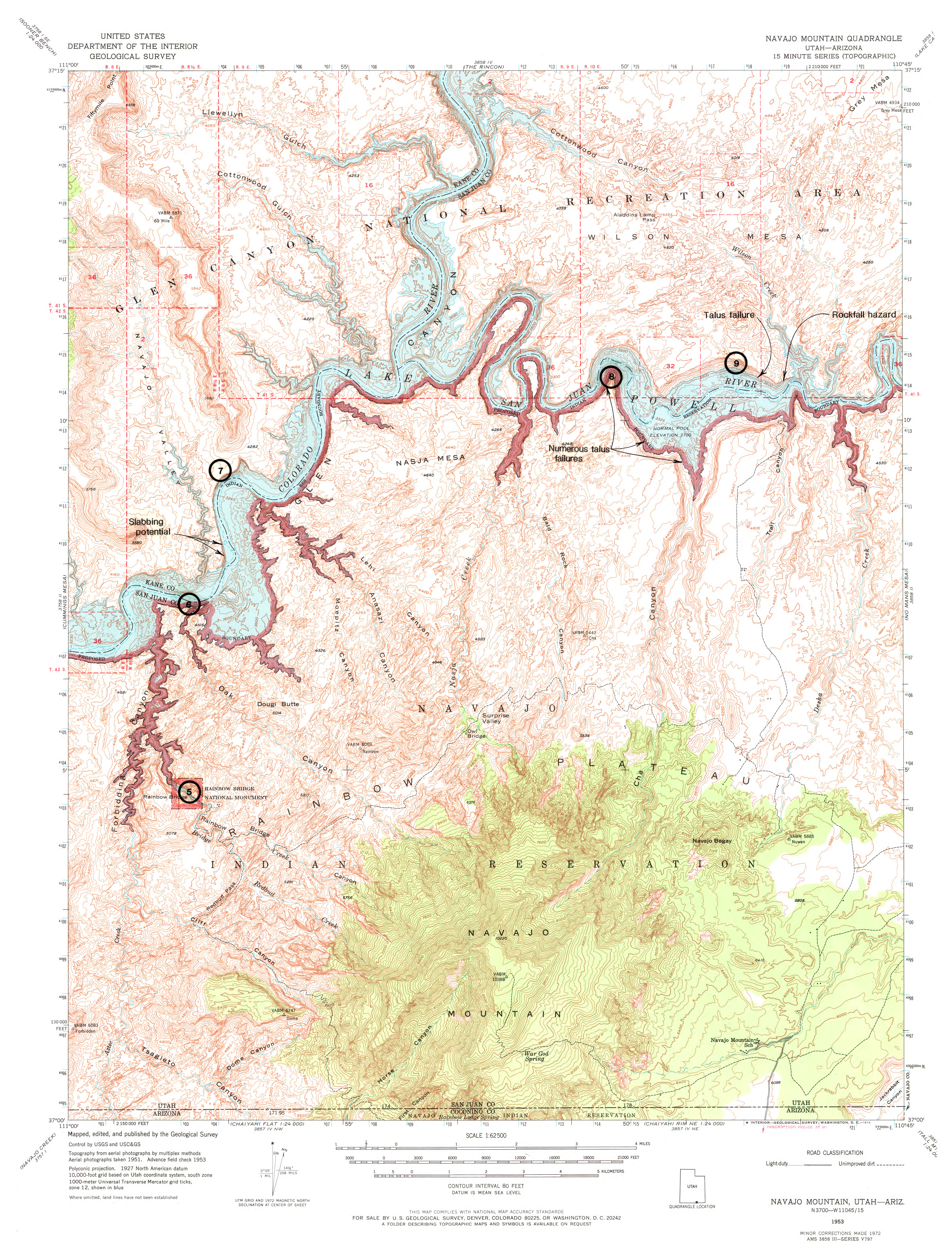
SITE 3

SITE 3: Active talus failure on Kane point. Wave action has caused sloughing and oversteepening of the slope. Talus slope is approximately 200 feet long and 60 feet high.

SITE 4

SITE 4: Active sand and talus failure in Last Chance Bay. High water mark (indicated by arrow) is 15 feet above the reservoir. The sand and talus deposit is approximately 600 feet long and 130 feet high.

SITES 5-9



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
NAVAJO MOUNTAIN QUADRANGLE
UTAH—ARIZONA
15 MINUTE SERIES (TOPOGRAPHIC)
Talus failure
Rockfall hazard
Numerous talus failures
Slabbing potential
7
8
9
6
5
GLEN CANYON NATIONAL RECREATION AREA
WILSON MESA
Aladdins Lamp Pass
Cottonwood Canyon
Llewellyn Gulch
Cottonwood Gulch
Fiftymile Point
NAVAJO VALLEY
LAKE POWELL
SAN JUAN RIVER
COLORADO RIVER
GLEN CANYON
NASJA MESA
KANE CO
SAN JUAN CO
NORMAL POOL ELEVATION 3700
Lehi Canyon
Anasazi Canyon
Moepitz Canyon
Nasja Creek
Bald Rock Canyon
Cha Canyon
Desha Creek
Trail Canyon
Oak Canyon
Dougi Butte
Forbidding Canyon
RAINBOW BRIDGE NATIONAL MONUMENT
Rainbow Bridge
Surprise Valley
Owl Bridge
NAVAJO PLATEAU
RAINBOW
INDIAN RESERVATION
Redbud Pass
Redbud Creek
Cliff Canyon
Bridge Creek
NAVAJO MOUNTAIN
Navajo Begay
War God Spring
Navajo Mountain Sch
Horse Canyon
First Canyon
Dome Canyon
Tsagieto Canyon
Aztec Creek
Jackrabbit Canyon
Grey Mesa
UTAH
ARIZONA
SAN JUAN CO
COCONINO CO
NAVAJO INDIAN RESERVATION
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951. Advance field check 1953
Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
Where omitted, land lines have not been established
UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SCALE 1:62500
CONTOUR INTERVAL 80 FEET
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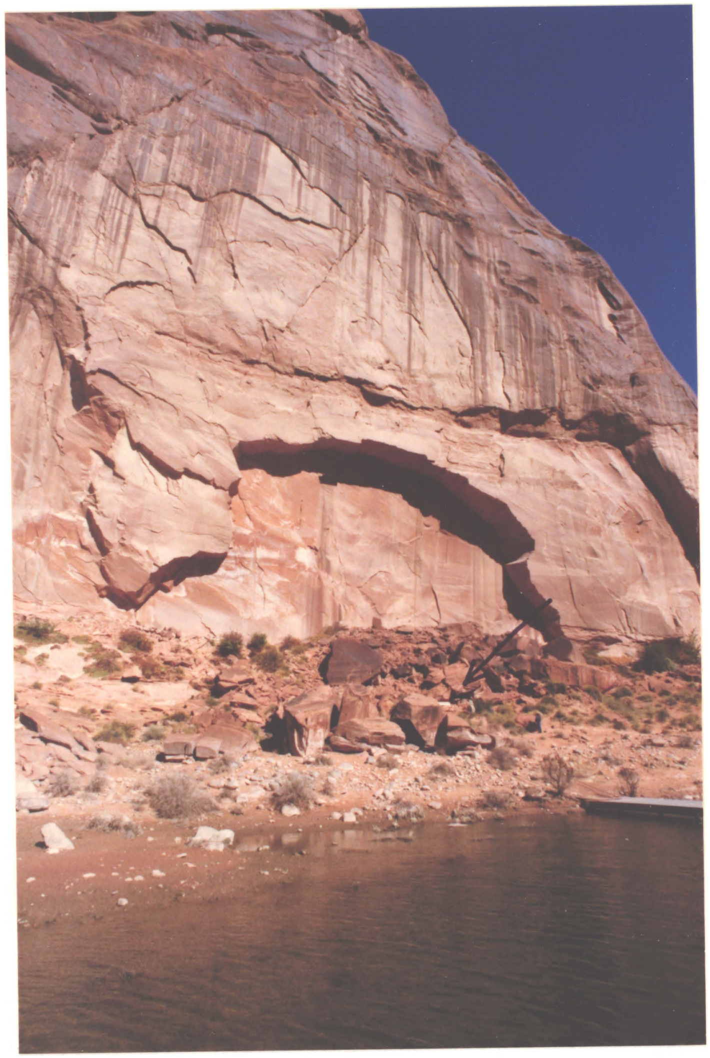
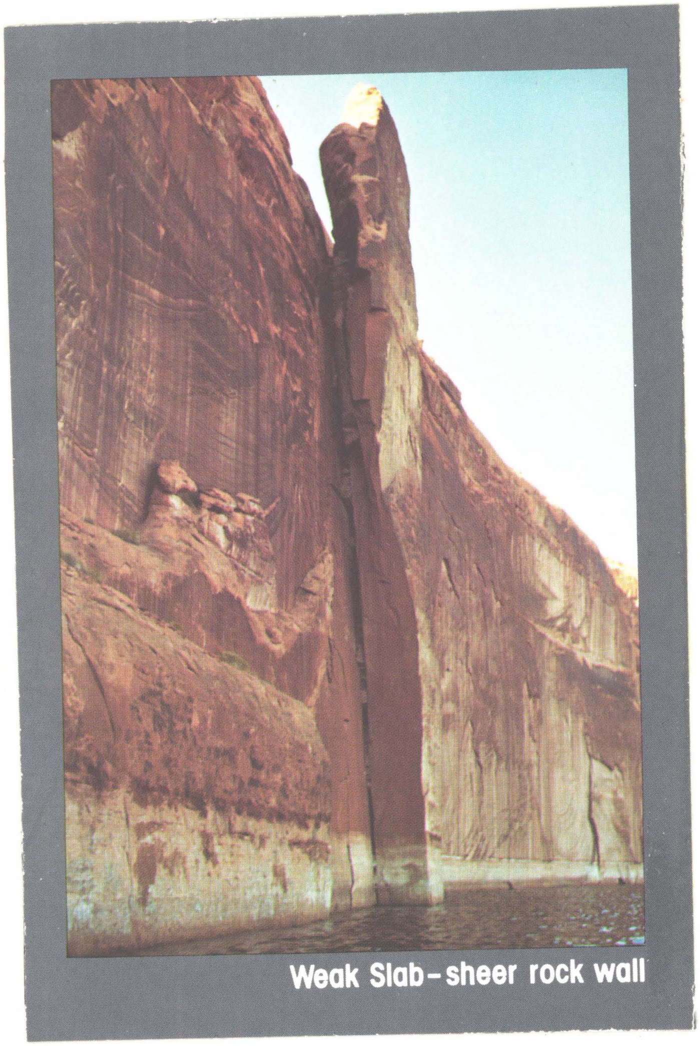
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
QUADRANGLE LOCATION
ROAD CLASSIFICATION
Light-duty
Unimproved dirt
NAVAJO MOUNTAIN, UTAH—ARIZ.
N3700—W11045/15
1953
MINOR CORRECTIONS MADE 1972
AMS 3858 III—SERIES V797



SITE 5: Rainbow Bridge National Monument. Visitors' rest area (indicated by arrow) located among large blocks resulting from slab failure. Location of bench and presence of open cracks and fresh breaks in the wall have combined to create a hazardous situation which could result in serious injuries or death of visitors if a rockfall should occur.

SITE 7



SITE 7: Pillar developed in Navajo Sandstone. Pillar extends approximately 240 feet above the reservoir and is approximately 30 feet wide and 20 feet thick. Risk of injury to boaters is high.

SITE 8

SITE 8: Failure of talus deposits located approximately 1½ miles west of Cha Canyon. Note the presence of the high water line which is approximately 15 feet above the reservoir.

SITE 8

SITE 8: A fractured point in the San Juan arm of the reservoir. Failure may have resulted from movement of the underlying Chinle Formation (primarily shale) resulting in rockfall of the overlying Wingate Sandstone. Note the absence of high water mark over most of the slope.

SITE 8: Failure of the Chinle Formation and talus deposits. Arrow indicates the contact between the Wingate Sandstone and the Chinle Formation. Failure is 1100 feet long and 200 feet high.

SITE 9

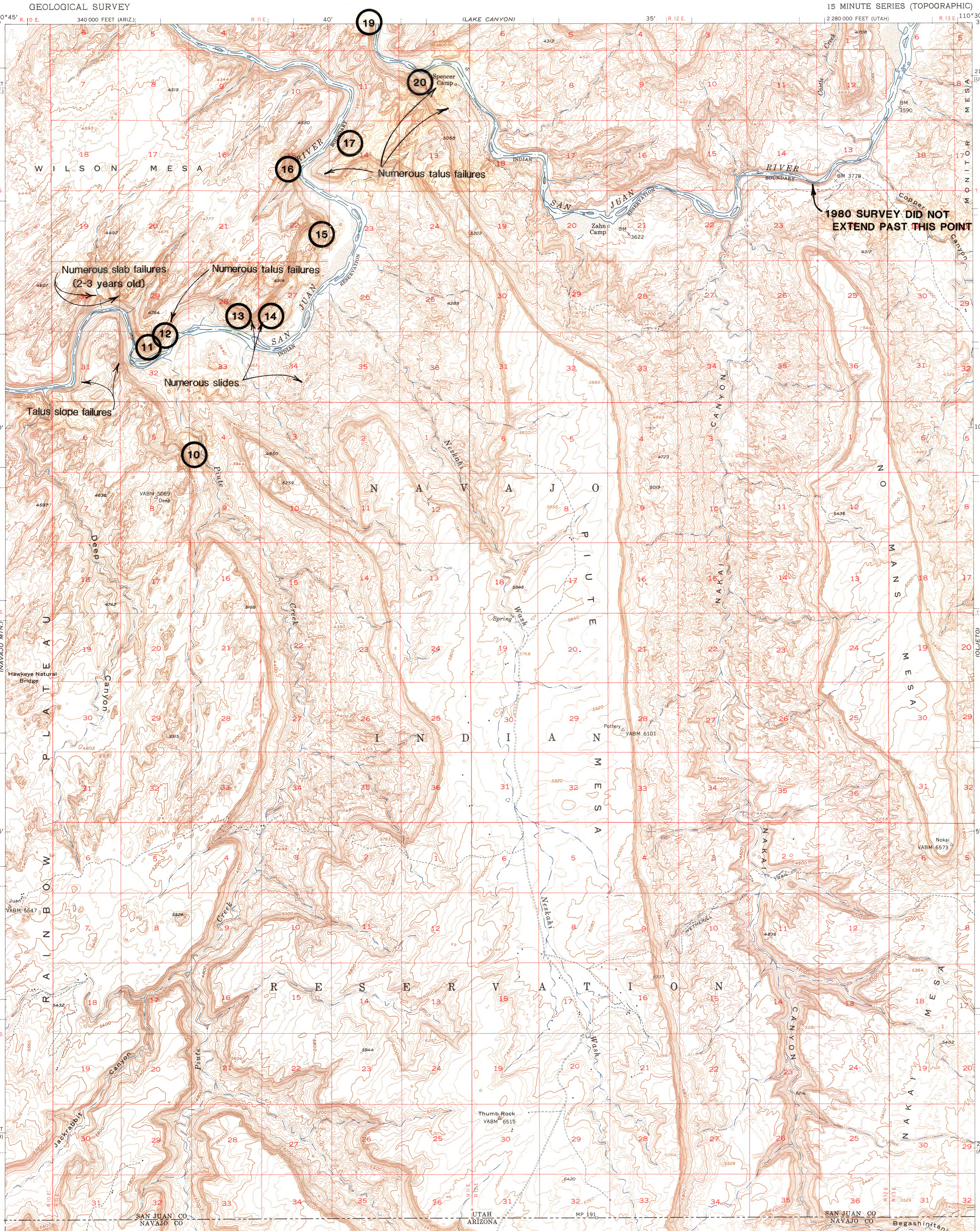
SITE 9: Failure of the Chinle Formation and overlying talus deposits. Note the absence of a high water line indicating that failure occurred after drawdown.

SITE 9: Recent rockfall involving the Wingate Sandstone. Presence of high water mark indicates that failure occurred prior to June, 1980.

SITES 10-17,20

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

NO MANS MESA QUADRANGLE
UTAH—ARIZONA
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS, USC&GS, and USBR

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951–52. Advance field check 1953

Polyconic projection. 1927 North American datum
10,000-foot grids based on Utah coordinate system, south zone
and Arizona coordinate system, east zone

Unchecked elevations are shown in brown

APPROXIMATE MEAN DECLINATION, 1953

SCALE 1:62500

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Unimproved dirt .... Trails ....

QUADRANGLE LOCATION

NO MANS MESA, UTAH—ARIZ.
N3700—W11030/15

1953

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER 2, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

SITE 10

SITE 10: Large landslide involving the Chinle Formation. Slide is located in the San Juan arm at the mouth of Piute Canyon and is over one mile long. A closeup panorama of the slide can be found on the next page.

SITE 10

SITE 10: A panorama of the landslide at the mouth of Piute Canyon. The dashed line indicates the top of the main scarp. Numerous small scarps can be seen in the foreground (indicated by arrows). If failure continues, (which is expected) portions of Piute Wash may be closed off.

SITE 11

SITE 11: Failure of point located opposite Piute Creek. Slide involves talus derived from the Wingate and shale of the Chinle Formation. Contact between the Wingate Sandstone and the Chinle Formation is indicated by arrow. Note the recent slope failure (to the right of shadow) which has destroyed the high water mark. Vertical landslide scarp is approximately 100 feet high.

SITE 12

SITE 12: Failure of talus slope (in inital stages of movement) with attendant rockfall of the Wingate Sandstone. Slide is approximately 250 feet high and 1200 feet long and is presently active. Note absence of high water mark in left half of slide.

SITE 13

SITE 13: Old slump developed within the Chinle Formation. Note backward rotation of block to right of slide plane (indicated by arrow). Slump predates the reservoir, indicating that large scale landsliding can occur without wetting by reservoir water. Presence of reservoir may generate renewed movement along old slide planes, however.

SITE 14: Renewed movement of an old slide has resulted in the failure of talus covered Chinle slopes. Slide is active as evidenced by the lack of a high water mark in the left half of the slide. Slide is approximately 250 feet high and 1200 feet long.

SITE 15

SITE 15: Oversteepened slopes and sloughing of talus resulting from slumping in Chinle. Slide is active as evidenced by lack of a high water mark. Slide scarp is approximately 100 feet high and 450 feet long.

SITE 16

SITE 16: The sliding of talus into the reservoir has removed support from the base of the cliff (Wingate Sandstone) resulting in rockfall. Note the presence of the water line. Slide scarp is approximately 700 feet long and 90 feet high.

SITE 17

SITE 17: Sliding of talus down and away from cliff. Note presence of high water mark. Faint scarp outline is indicated by arrows. Slide is approximately 150 feet high and 1400 feet long. Entire mass appears to be moving as a unit.

SITE 20

SITE 20: Talus slide located approximately ½ mile west of Spencer Camp. Slide is approximately 100 feet high and 700 feet long. Chinle shale can be seen at the extreme left of the photo.

SITES 21-26

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE RINCON QUADRANGLE
UTAH
15 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951. Advance field check 1953

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

Recreation Area boundary not determined pending legislative action

UTM GRID AND 1953 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

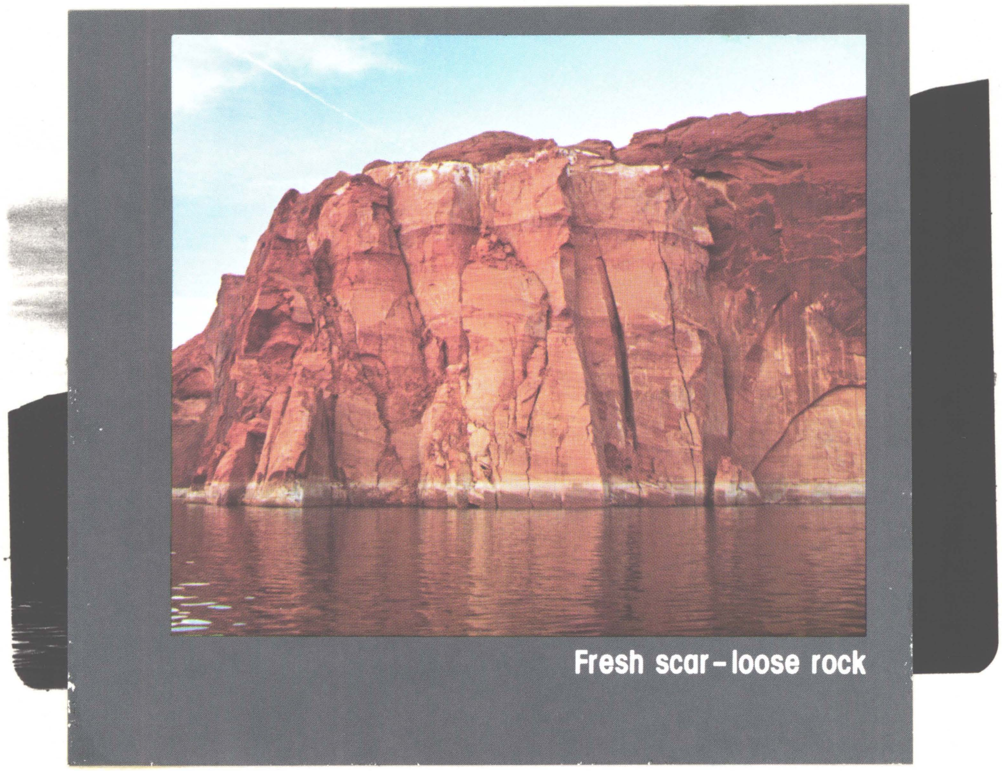
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Unimproved dirt

THE RINCON, UTAH
N3715—W11045/15

1953
MINOR CORRECTIONS MADE 1968
AMS 3858 IV—SERIES V797

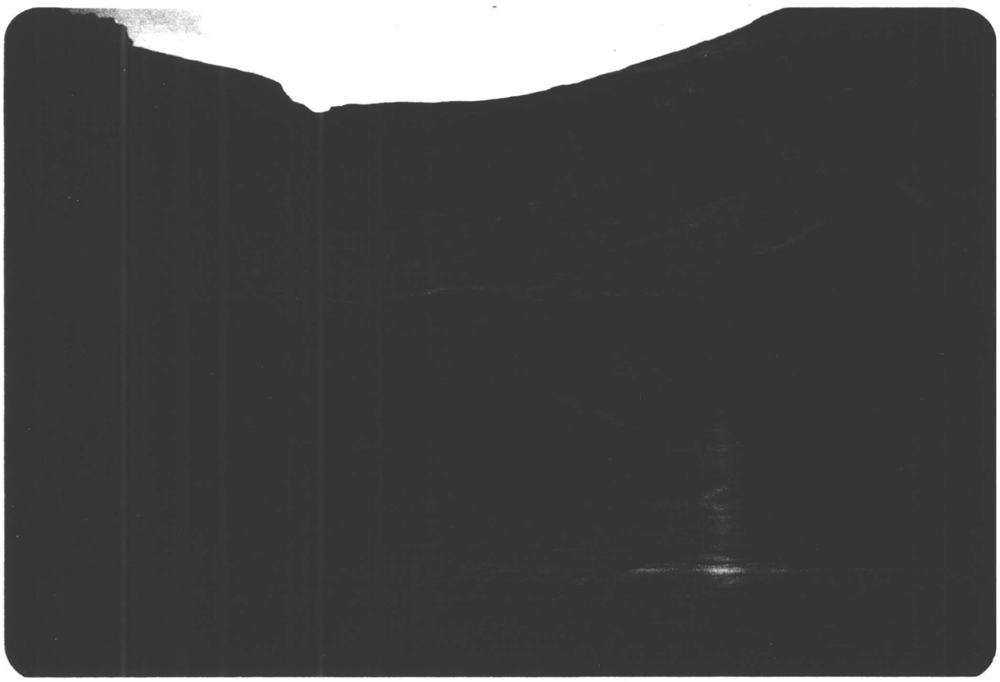
SITE 21



Fresh scar - loose rock

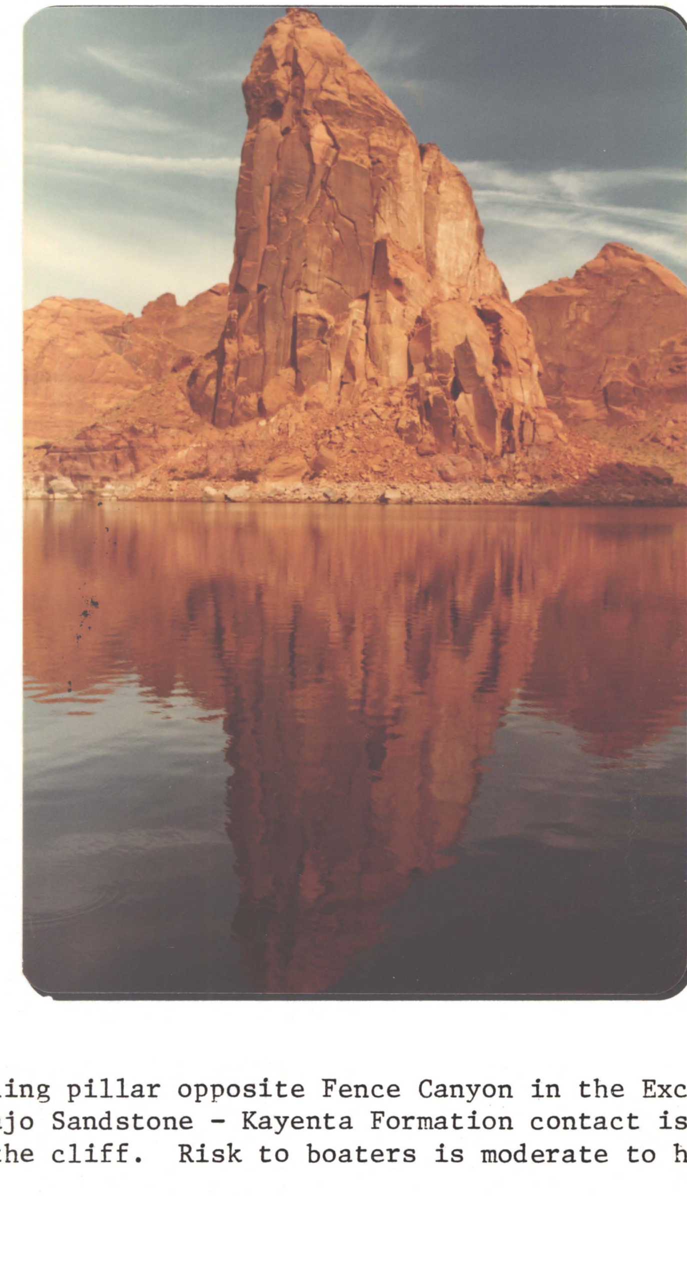
SITE 21: Fractured point in Navajo Sandstone. Point is located approximately ¼ mile downstream from Davis Gulch in the Escalante Arm. Canyon wall is approximately 190 feet high and is covered by abundant loose rock of all sizes. Risk to boaters is high.

SITE 22



SITE 22: Ampitheater eroded into Navajo Sandstone. Risk to boaters is high due to the fact that boats can dock under the overhang. Arrows indicate areas of active or potential rockfall. Note the absence of the high water mark in the left center of the photo due to very recent rockfall.

SITE 23



SITE 23: Failing pillar opposite Fence Canyon in the Excalante arm. Navajo Sandstone - Kayenta Formation contact is at the base of the cliff. Risk to boaters is moderate to high.

SITE 24

SITE 24: Talus slope failure located about 2 miles west of The Rincon. The Wingate - Chinle contact is just below base of cliff. Note the absence of the high water mark.

SITE 25

SITE 25: Failure of shoreline, involving sand and talus, located immediately west of The Rincon.

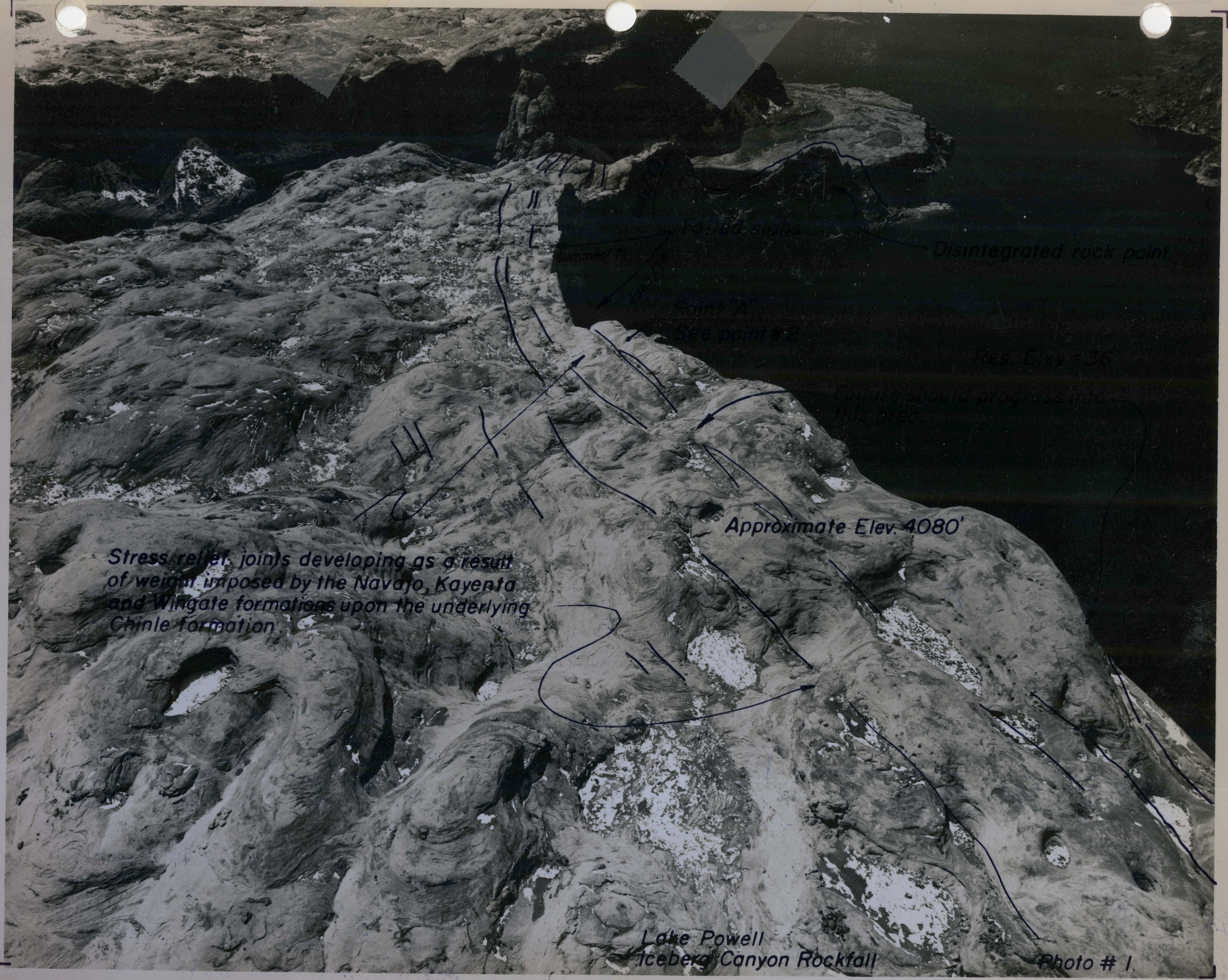
SITE 25: Note the very recent slide (dark color) indicated by the arrow. This area is a favorite of boaters because of the sandy beaches and slopes. Risk to boaters is high due to the high faces and poor consolidation of the deposits.

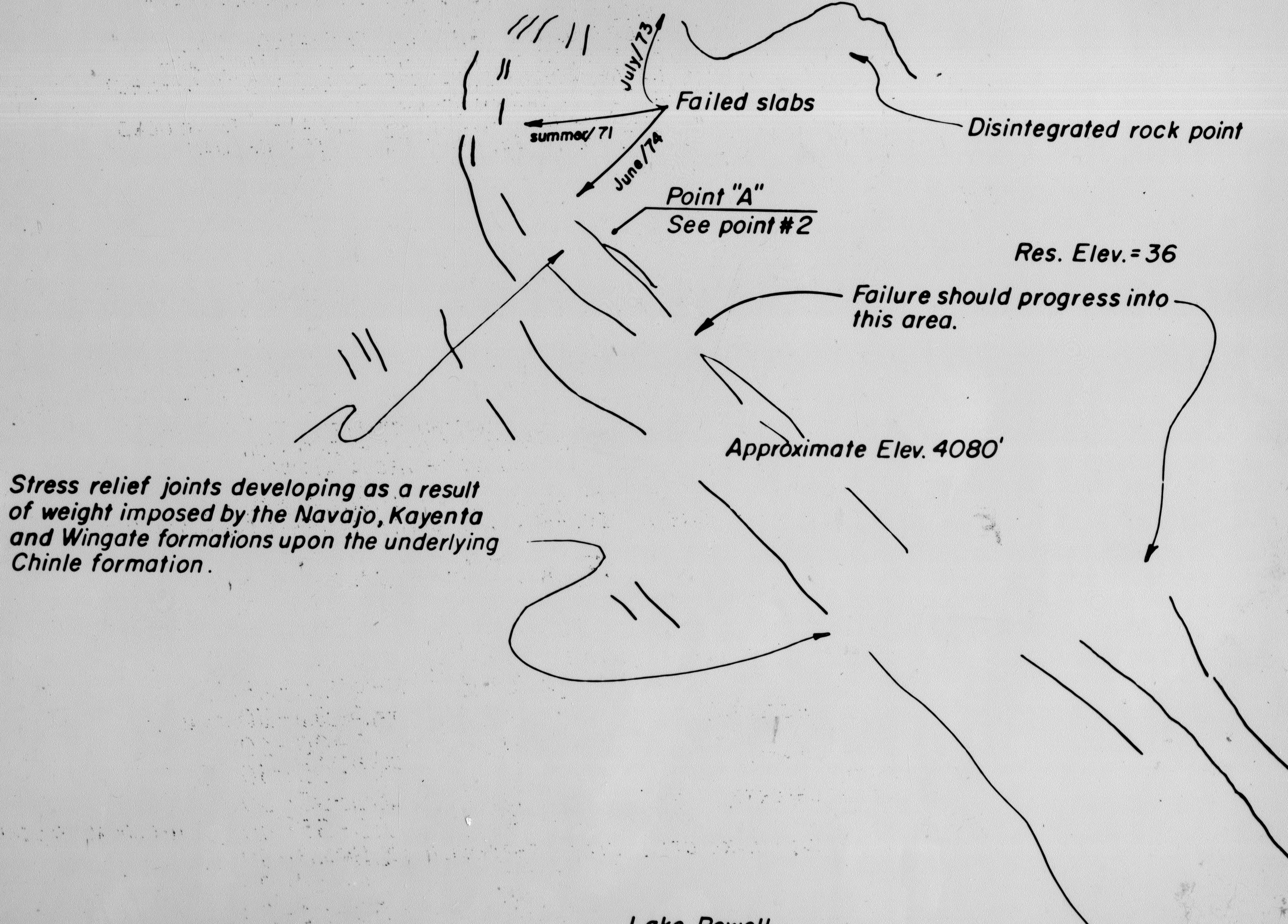
SITE 25

SITE 25: Closeup of failure surface showing initials carved in vertical face. Such a practice subjects the boater to high risk since the deposits are poorly consolidated and the vertical faces in places approach 80 feet in height.

SITE 26

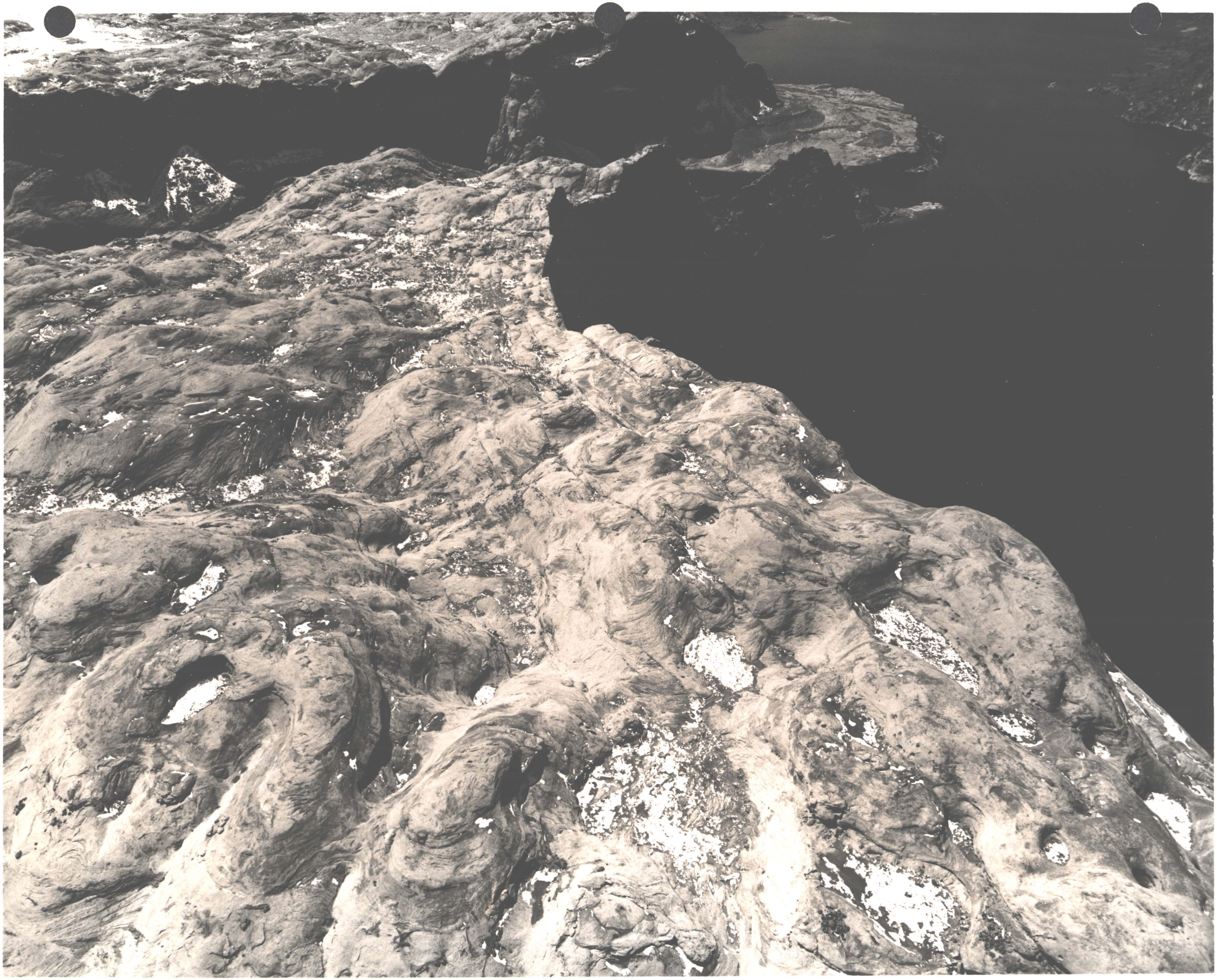
SITE 26: Slab failure near Iceberg Canyon. Most recent failure occurred in June, 1974 and resulted in damage to one boat. Area is presently being monitored by Glen Canyon personnel. Risk to boaters is rated extreme.


Failed slabs
Disintegrated rock point
Point "A"
See point #2
Res. Elev.
Failure should progress into this area.
Approximate Elev. 4080'
Stress relief joints developing as a result of weight imposed by the Navajo, Kayenta and Wingate formations upon the underlying Chinle formation
Lake Powell
Iceberg Canyon Rockfall
Photo # 1.



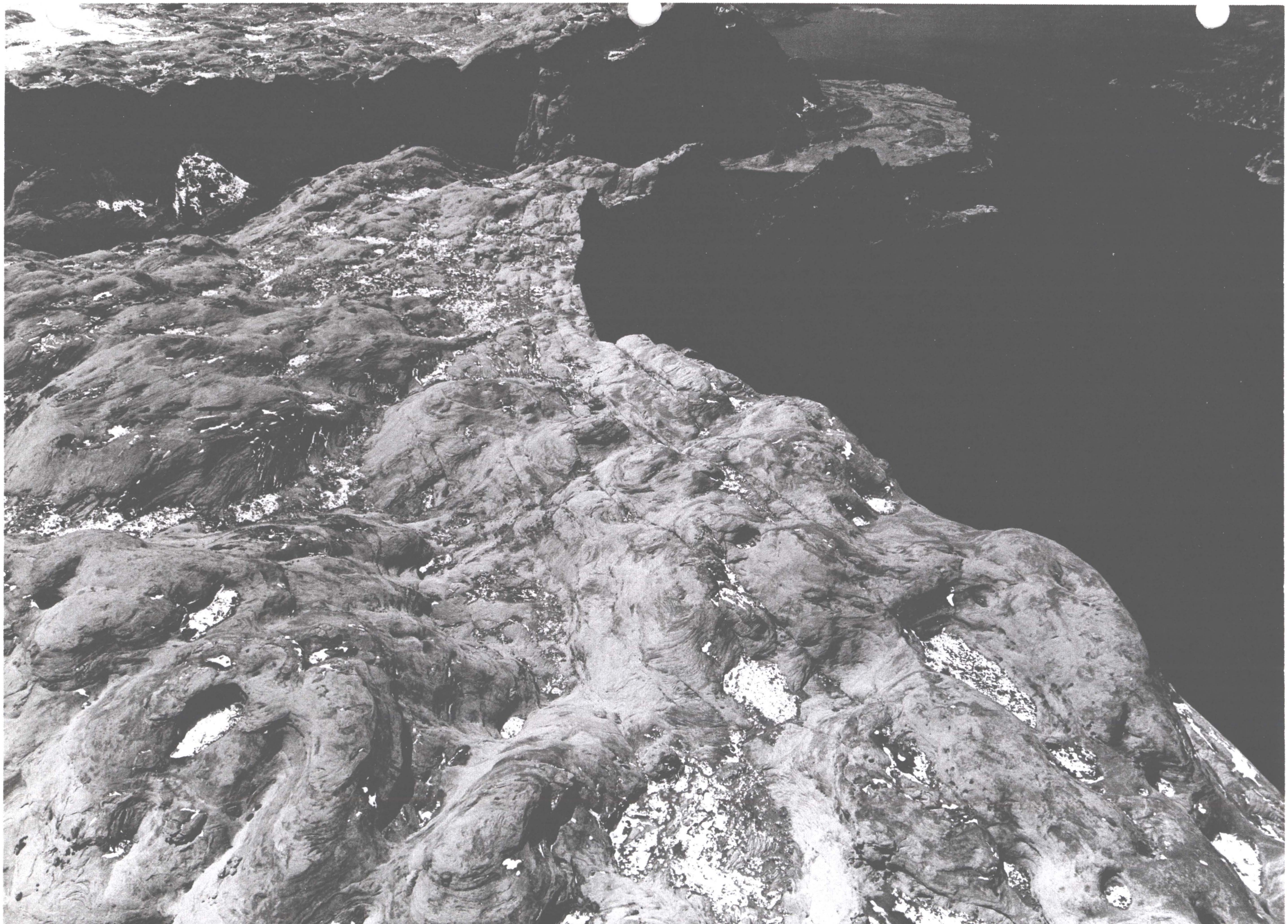
Lake Powell
Iceberg Canyon Rockfall

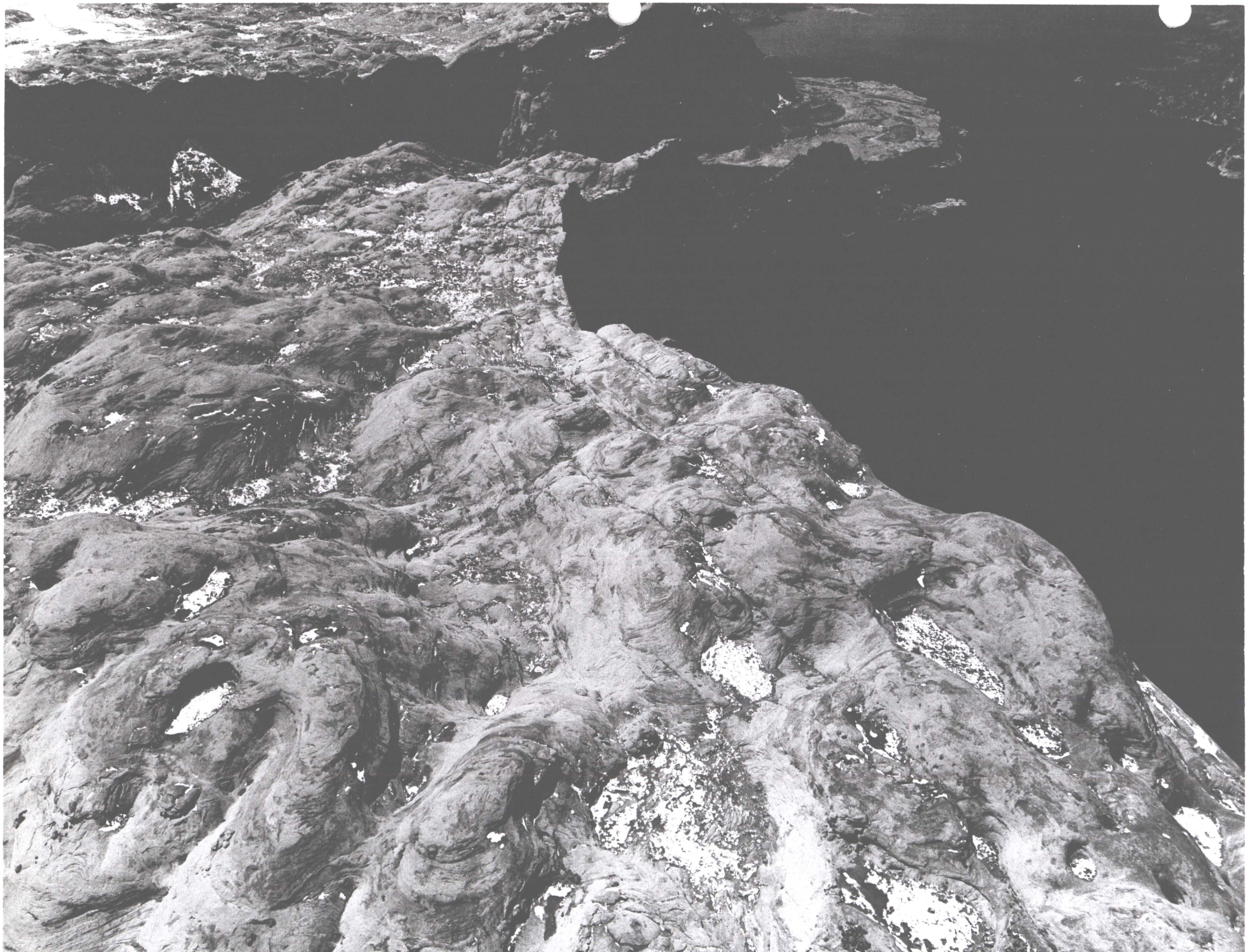
Photo # 1.

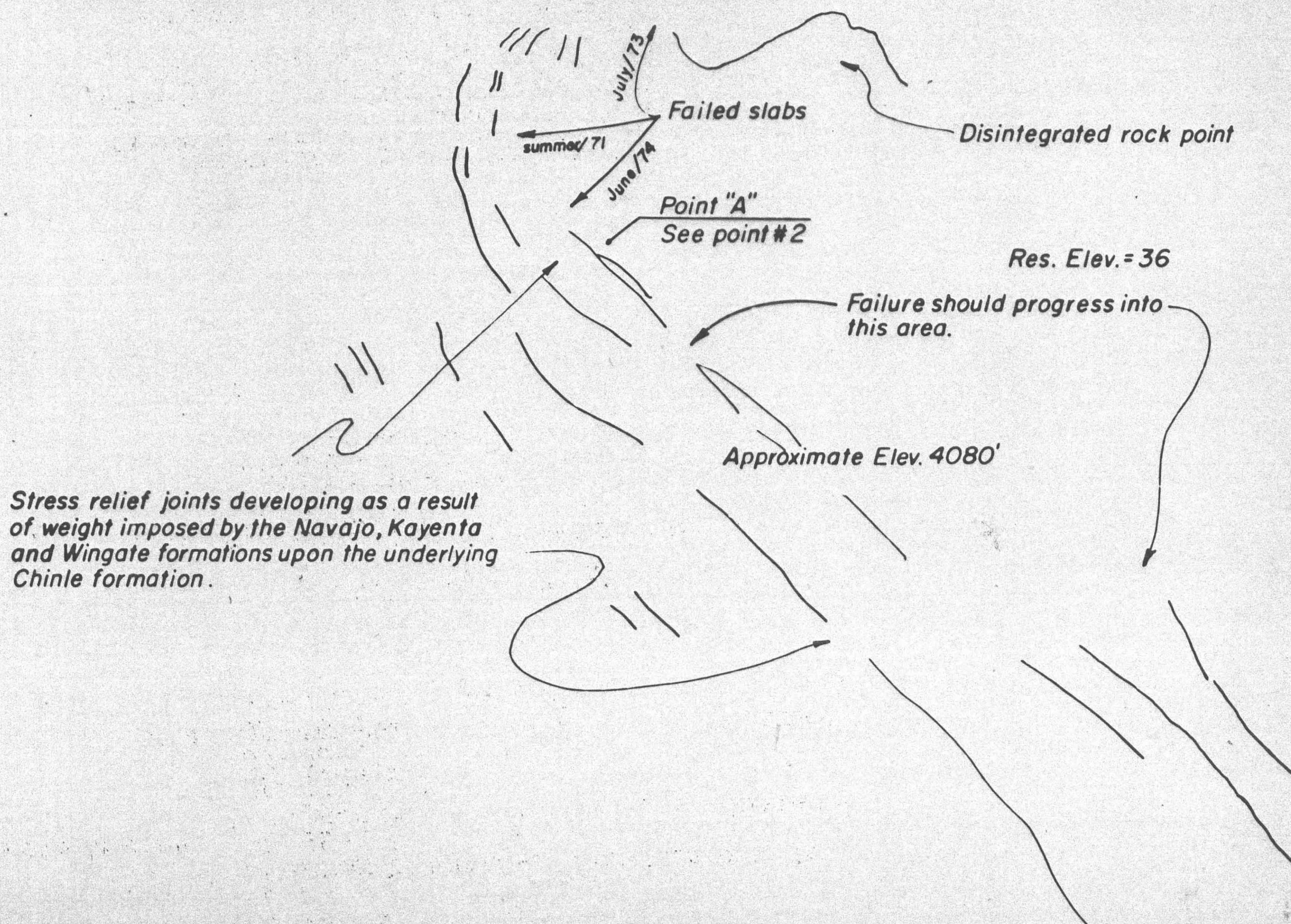


P557 -427-1006 NA

APR 2 1975

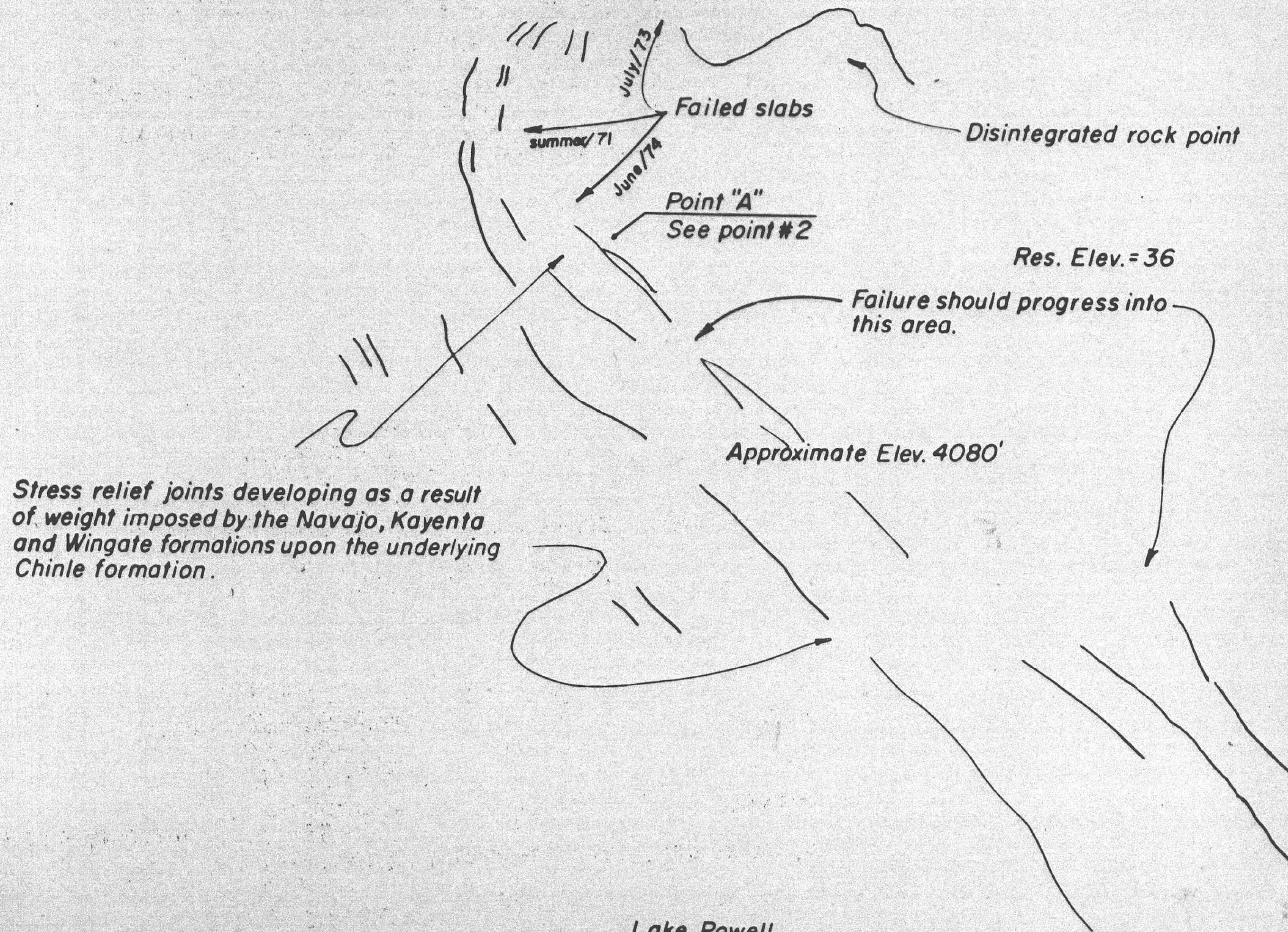






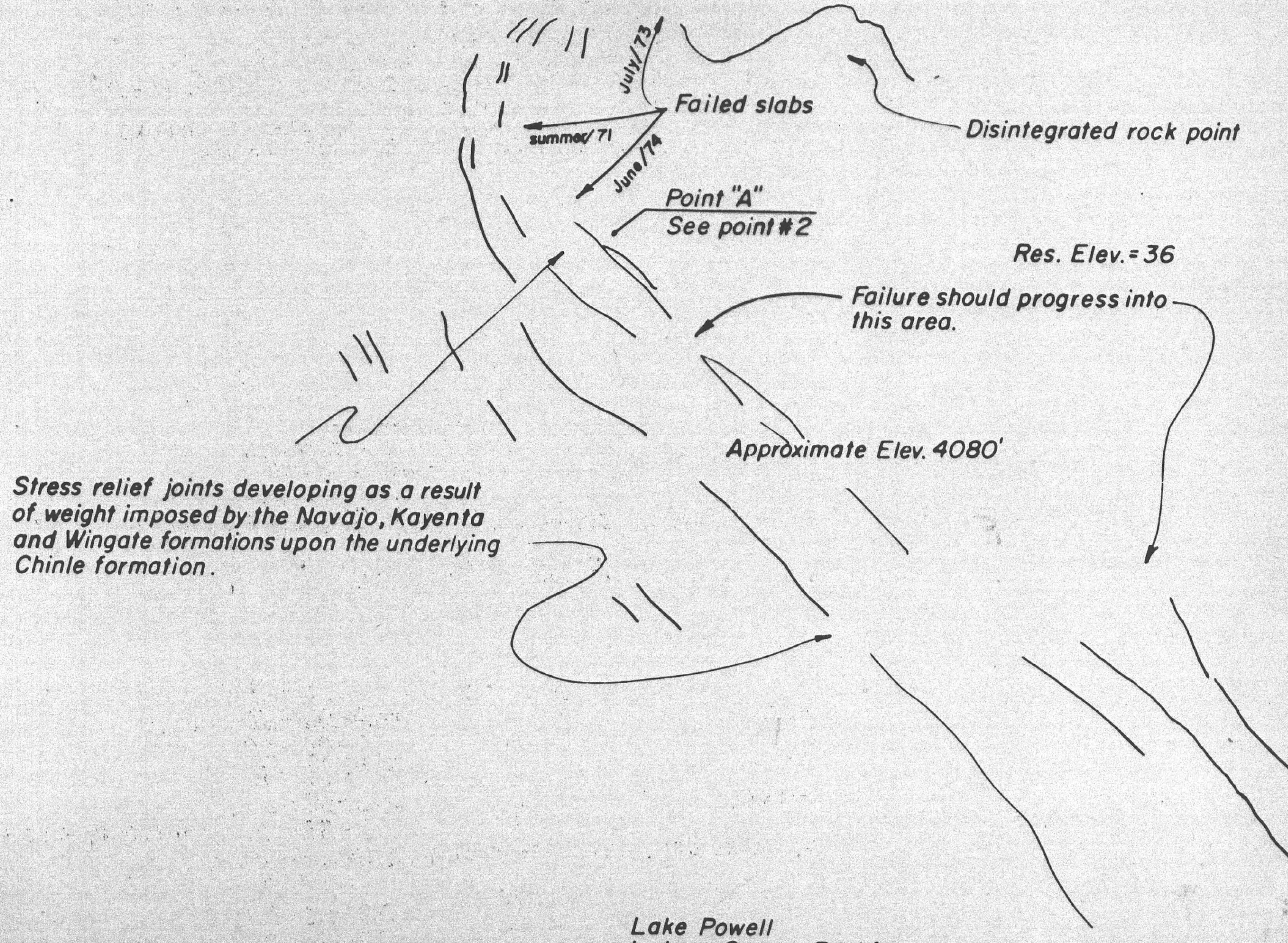
Lake Powell
Iceberg Canyon Rockfall

Photo # 1.



Lake Powell
Iceberg Canyon Rockfall

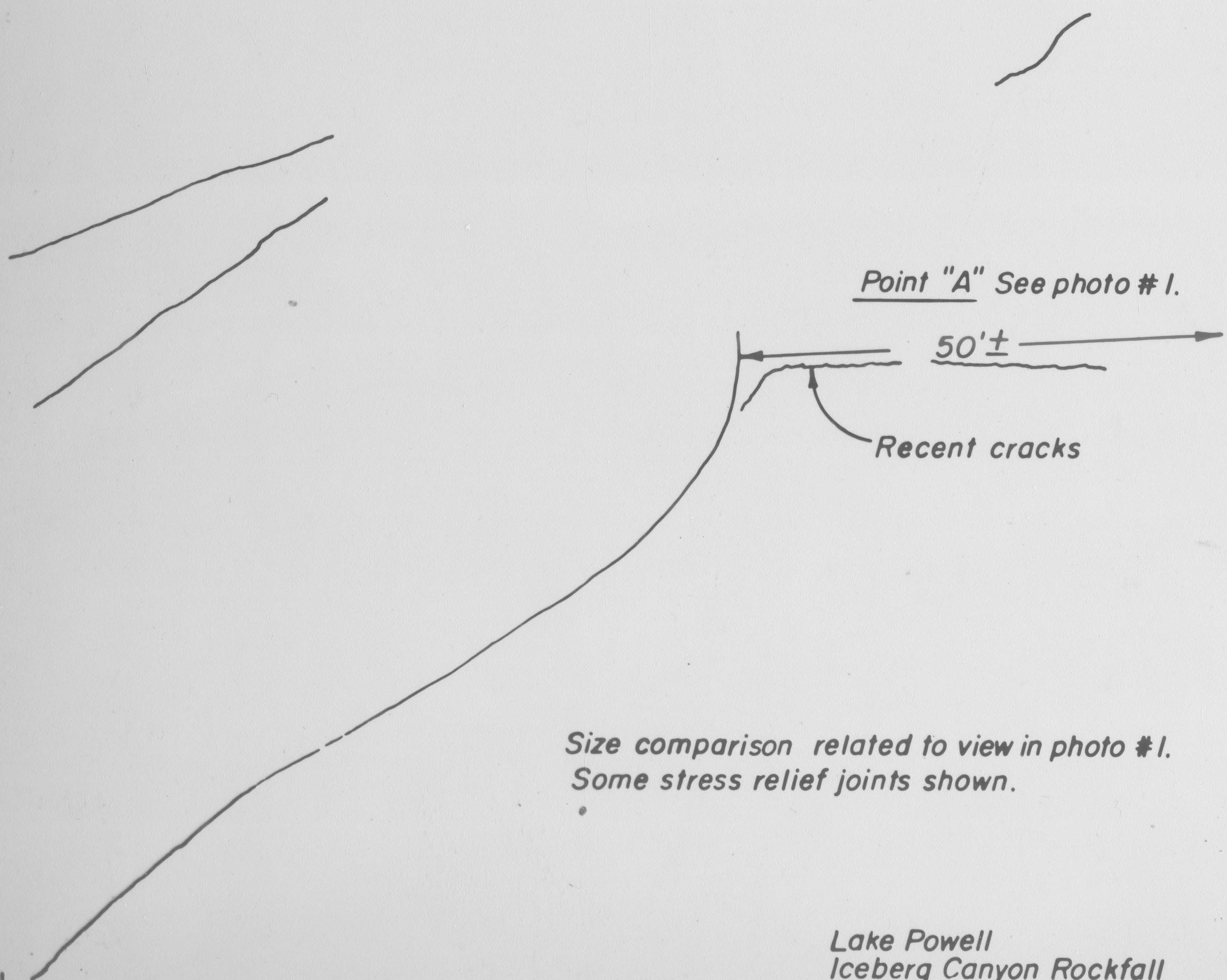
Photo # 1.



Lake Powell
Iceberg Canyon Rockfall

Photo # 1.


Point "A" See photo #1.
50'±
Recent cracks
Size comparison related to view in photo #1.
Some stress relief joints shown.
Lake Powell
Iceberg Canyon Rockfall
Photo #2



Size comparison related to view in photo # 1.
Some stress relief joints shown.

Lake Powell
Iceberg Canyon Rockfall

Photo # 2

OFFICIAL PHOTOGRAPH
credit
BUREAU OF RECLAMATION
U. S. DEPARTMENT OF THE INTERIOR

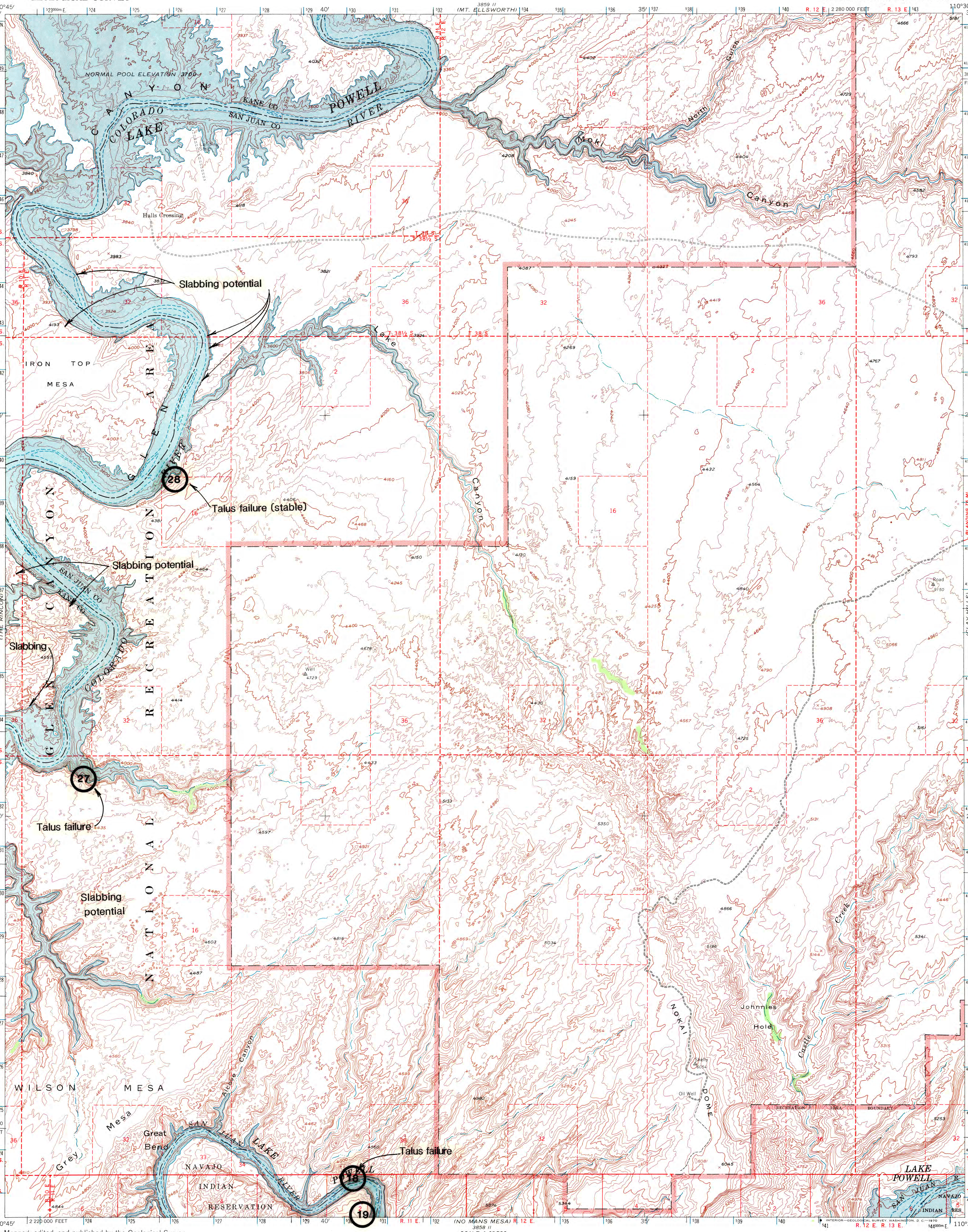
MONTROSE CONSTRUCTION FIELD DIVISION
P. O. BOX 1390
MONTROSE, COLO. 81401

P557 -427-995 NA APR 2 1975

SITES 18–19,27–28

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LAKE CANYON QUADRANGLE
UTAH
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951. Advance field check 1953

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

Recreation Area boundary not determined
pending legislative action

UTM GRID AND 1953 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:62500

1 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION
Unimproved dirt

UTAH
QUADRANGLE LOCATION

LAKE CANYON, UTAH
N3715—W11030/15

1953
MINOR CORRECTIONS MADE 1968
AMS 3858 I—SERIES V797

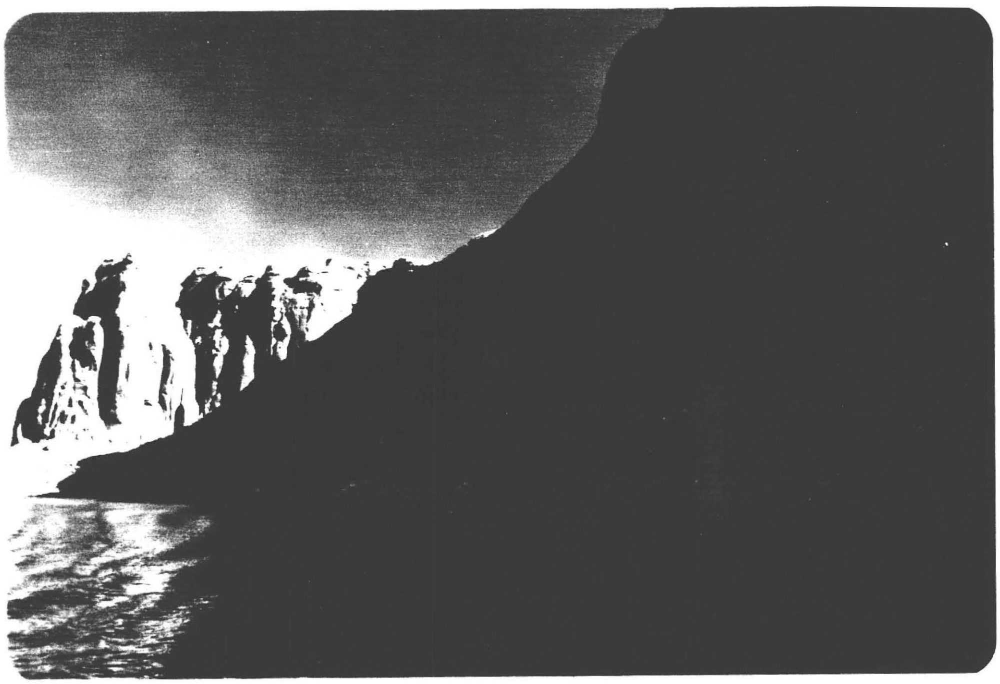
SITE 18

SITE 18: Initial stages of talus slide resulting from saturation and lubrication of shale surface below lake surface and erosion of toe of slope by wave action. Note the presence of a high water mark.

SITE 19

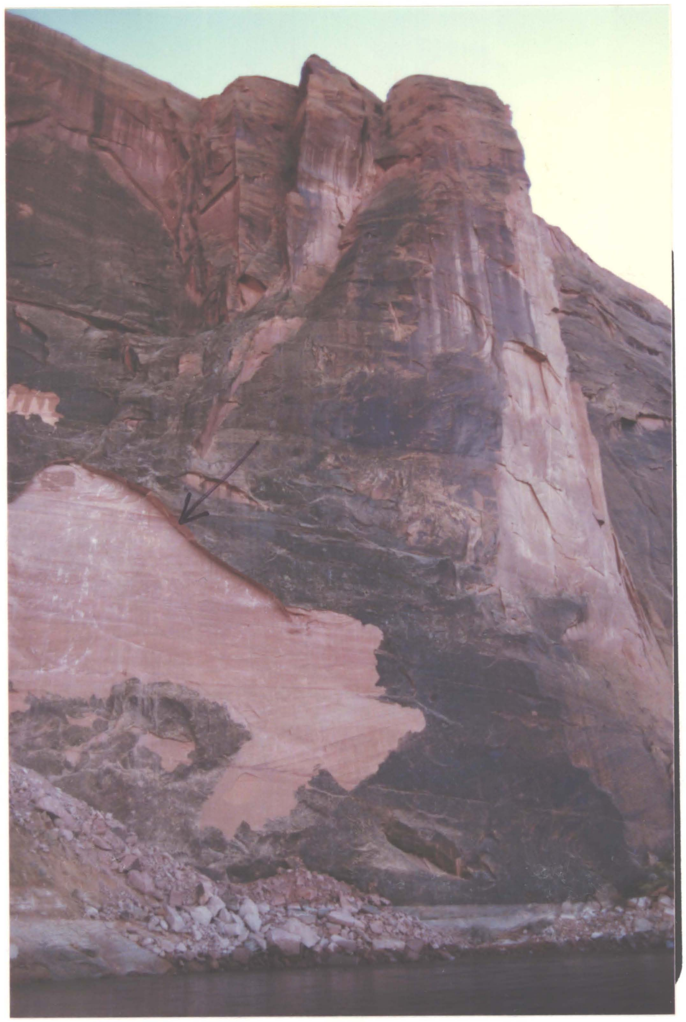
SITE 19: Failed points in the Wingate Sandstone. Note absence of the high water mark at the point indicated by the arrow. Boat operator indicated that several of these points failed only a few weeks before our survey.

SITE 27



SITE 27: Progressive failure of talus deposit probably resulting from wetting and consolidation. Navajo-Kayenta Formation contact is at the water line. Note the high water line and beaching.

SITE 28

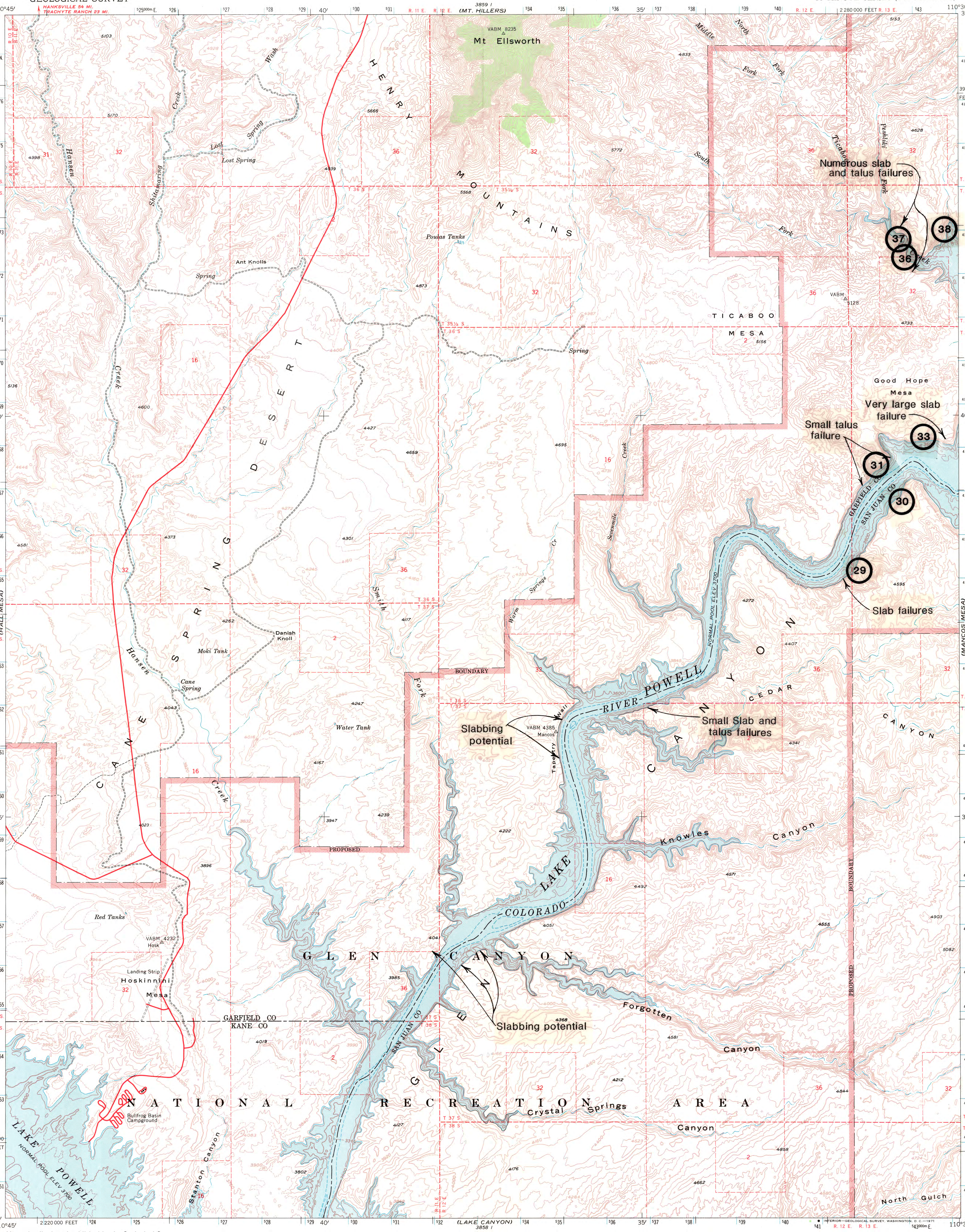


SITE 28: Small slab of Navajo Sandstone has failed (indicated by arrow). Large pillar to the right of slab has potential for failure due to presence of vertical cracks which separate the column from the wall.

SITES 29–31,33,36–38

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MT. ELLSWORTH QUADRANGLE
UTAH
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey
with cooperation by Atomic Energy Commission

Control by USGS

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1951. Advance field check 1953

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks,
zone 12, shown in blue

Unchecked elevations are shown in brown

Where omitted, land lines have not been established

UTM GRID AND 1953 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 80 FEET
DASHED LINES REPRESENT 40 FOOT CONTOURS
CONTOUR INTERVAL ON RIVER SURFACE 5 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Unimproved dirt
Roads added after 1953, not field checked

MT. ELLSWORTH, UTAH
N3730—W11030/15

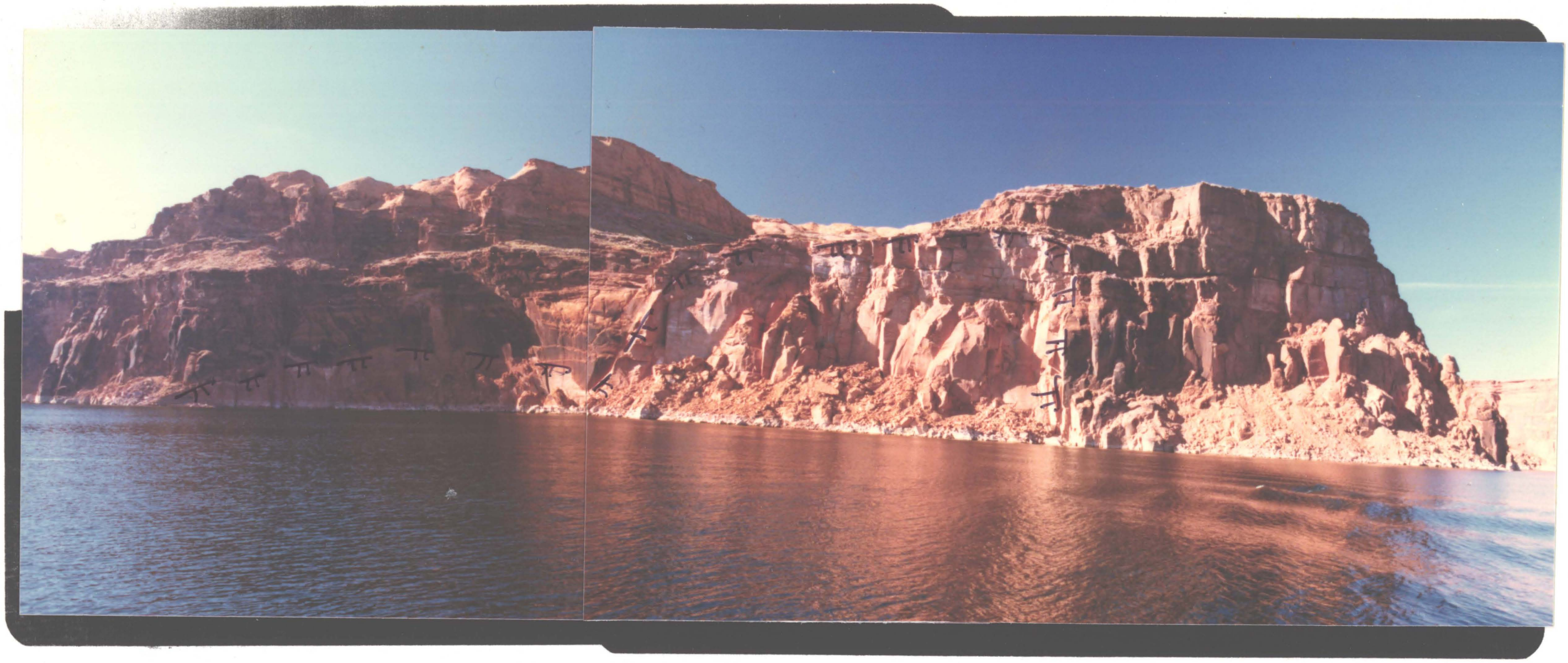
1953
MINOR CORRECTIONS MADE 1970
AMS 3859 II—SERIES V797

SITE 29

SITE 29: Slab failures occurring in Wingate Sandstone (indicated by arrows). Chinle Formation is just below lake surface.

SITE 30: Large scale landsliding located south of Good Hope Mesa. Slide probably results from renewed movement of old slides in the Chinle Formation. The sliding material is mostly talus and large slabs derived from the Wingate and Kayenta Formations. Risk to boaters is high along some portions of the slide particularly where the slide has created fractured vertical walls. Slide is approximately 3/4 mile long and several hundred feet high. With the exception of active rockfall, most sliding occurred prior to June, 1980 (note the high water mark).

SITE 31



SITE 31: Landslide and rockfall located south of Good Hope Mesa. The Wingate-Chinle contact is just below the water surface. The landsliding involves both the Kayenta and Wingate Formations (rockfall) and talus derived from both. With the exception of active rockfall, failure occurred prior to June, 1980 (note the high water mark).

SITE 33

SITE 33: Foundation failure (Chinle Formation) resulting in failure of the point (Wingate Sandstone) below Good Hope Mesa. Movement in the Chinle has resulted in sloughing and sliding of the talus deposits with attendant rockfall. Vertical slide plane is indicated by arrow in both photos.

SITE 36

SITE 36: The above point has dropped as a result of foundation failure (Chinle-MoenKopi). The talus slide below has slid down the cliff face approximately 75 feet. The slide probably results from wetting and lubrication of the Chinle shale (now underwater).

SITE 37

SITE 37: Extensive talus slides probably resulting from wetting and lubrication of underlying Chinle Formation. Slide is located in Ticaboo Creek and is over ½ mile long.

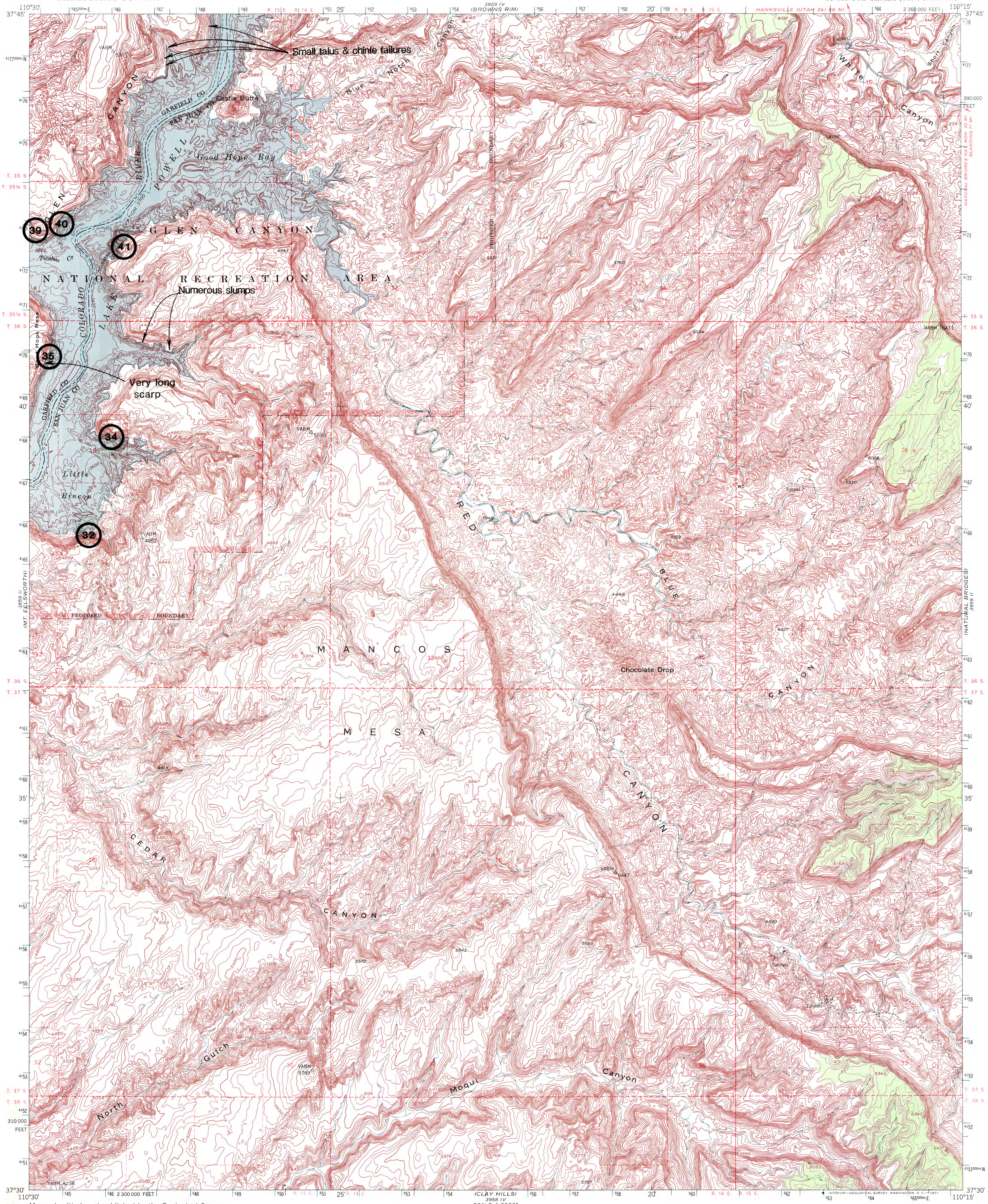
SITE 38

SITE 38: Active sliding occurring on the north side of Ticaboo Creek. Slide involves talus accumulations and some shale beds of the Chinle. Arrows indicate cracks developing in the talus deposits.

SITES 32,34-35,39-41

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MANCOS MESA QUADRANGLE
UTAH
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey in cooperation with the Atomic Energy Commission

Control by USGS

Topography by photogrammetric methods from aerial photographs taken 1951. Field checked 1952

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

UTM GRID AND 1970 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Light-duty
Unimproved dirt
State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

MANCOS MESA, UTAH
N3730—W11015/15

1952
MINOR CORRECTIONS MADE 1970
AMS 3959 III—SERIES V797

SITE 32

SITE 32: Site of previous talus slides. Although most of the talus deposits are now underwater, slide area is still active as evidenced by large open cracks, slabs and broken rock.

SITE 34

SITE 34: Slab and talus failures located upstream of The Rincon involving the Wingate Sandstone. Observers indicate that failures occurred about 2 years ago. The Chinle Formation is just below waterline. One of the larger rockfalls is indicated by the arrow in the photo below. High water mark is 15 feet above the lake to give an idean of scale.

SITE 35

SITE 35: Faint but continuous crack developing in talus deposits below Wingate Sandstone cliffs. Developing landslide scarp is indicated by the arrows.

SITE 39

SITE 39: Landslide in the Chinle Formation and overlying talus accumulations. Slide is approximately 90 feet high and 500 feet long and is located north of Ticaboo Creek.

SITE 40

SITE 40: Slumping and sliding of shale beds in the Chinle Formation and overlying talus. Much of the sliding is renewed movement along old slide planes (indicated by arrow). Photo below is a closeup of the slump above.

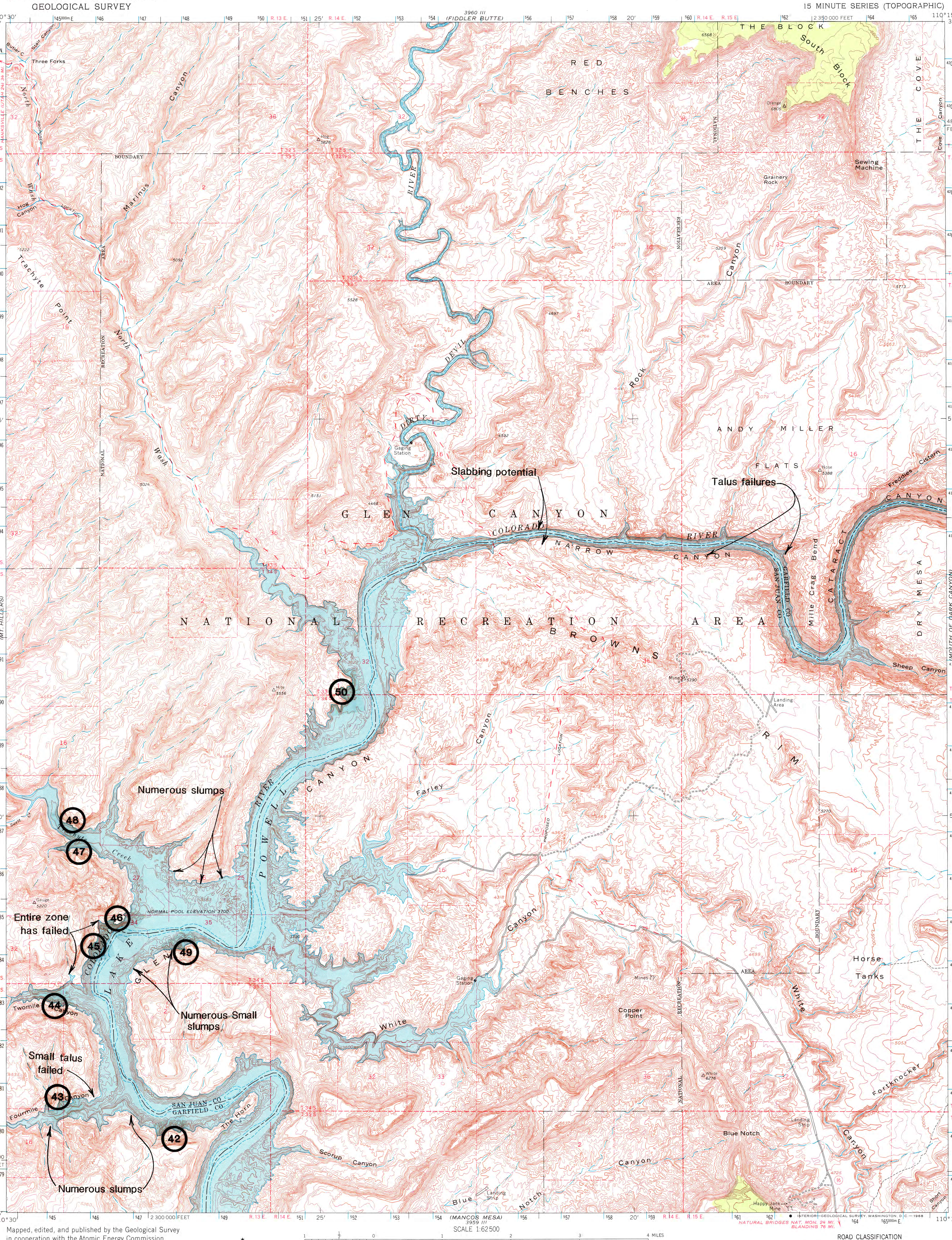
SITE 41

SITE 41: Faint but continuous crack developing in talus deposits south of Ticaboo No. 1 rapids.

SITES 42-50

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BROWNS RIM QUADRANGLE
UTAH
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey in cooperation with the Atomic Energy Commission

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1951. Field checked 1952

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

UTM GRID AND 1952 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Medium-duty — Light-duty
Unimproved dirt
State Route

QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BROWNS RIM, UTAH
(FORMERLY HITE)
N3745—W11015/15

1952
MINOR CORRECTIONS MADE 1967
AMS 3959 IV—SERIES V797

SITE 42

SITE 42: Rockfall and slumping of the Chinle Formation about 1 mile west of the Horn. Some areas present a high risk to boaters as the area has not as yet stabilized.

SITE 43

SITE 43: Renewed movement of old slump blocks in the Chinle Formation. Slides are located on north side of Four-mile Canyon. This particular slide is only one of numerous old slumps along this reach.

SITE 44

SITE 44: Extensive shoreline failure of sandstone beds in the ~~Chinle~~ Shinarump Formation. Site is located on south shore of Two-mile Canyon.

SITE 45

SITE 45: Extensive shoreline failure of sandstone units in the ~~Chinle~~ Shinarump Formation and overlying talus accumulations. Risk to boaters is high as rockfall continues and vertical slopes in the talus are created. Area is located about 1 mile north of Two-mile Canyon.

SITE 46

SITE 46: Sloughing of talus deposits probably resulting from wave action. Site is located approximately 1 mile south of Trachyte Creek.

SITE 47

SITE 47: Slumps occurring in talus covered Chinle slopes on the south shore of Trachyte Creek. Slumps are approximately 50 to 60 feet high. Note the presence of the high water mark.

SITE 48

SITE 48: Slump in the Chinle Formation located on the north shore of Trachyte Creek. Slump is approximately 60 feet high and 200 feet long.

SITE 49

SITE 49: Renewed movement of old slide mass in the Chinle Formation. Slide is located approximately 1 mile west of the mouth of White Canyon.

SITE 50

SITE 50: Recent rockfall has taken out the high water mark (indicated by the arrows in these two photos). Sandstone is the Organ Rock Tongue Member of the Cutler Formation. Photos were taken across the reservoir from Hite Marina.