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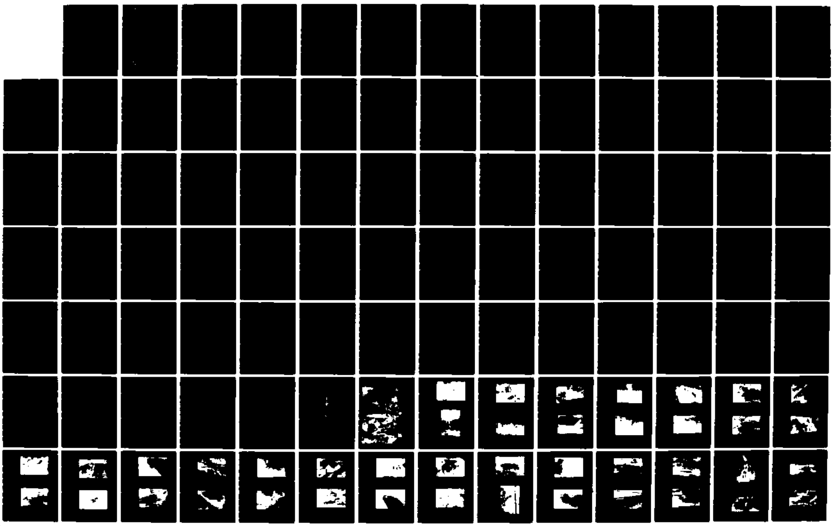

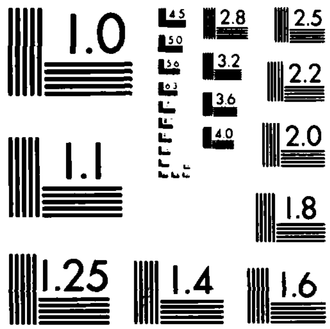

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CONSTRUCTION FOUNDATION REPORT

(3)

SOUTH PLATTE RIVER BASIN
BEAR CREEK LAKE, COLORADO

VOLUME I
TEXT AND PHOTOS

FEBRUARY 1983

US Army Corps
of Engineers
Omaha District

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Bear Creek is a tributary of the South Platte River west of Denver, Colorado, on the east slope of the Front Range. This report summarizes foundation conditions encountered during the construction of Bear Creek Dam. Discussed in the report are:
(1) Site investigations
(2) Dam-site geology, including engineering characteristics of foundation materials.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(3) Excavation procedures
(4) Foundation characteristics
(5) Foundation treatments
(6) Recommendations for future monitoring of project structures.

BEAR CREEK DAM AND LAKE

SOUTH PLATTE RIVER BASIN

COLORADO

CONSTRUCTION FOUNDATION REPORT

VOLUME 1

TEXT AND PHOTOGRAPHS

U.S. ARMY ENGINEER DISTRICT, OMAHA

CORPS OF ENGINEERS

OMAHA, NEBRASKA

1982

DISK 238C
PROJECT C5842

CONSTRUCTION FOUNDATION REPORT

BEAR CREEK LAKE
SOUTH PLATTE RIVER BASIN, COLORADO

VOLUME I

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CHAPTER I - INTRODUCTION

1.1. **Location and Description of Project:** Bear Creek is a left bank tributary of the South Platte River with its mouth near Sheridan, Colorado, a suburb of Denver. Bear Creek basin has a leaf shape, is approximately 36 miles long, and has a maximum width of about 13 miles (Plate 1). It drains 262 square miles including 52 square miles from Turkey Creek, the only major tributary in the Bear Creek basin. The basin shares its boundary with the Clear Creek basin to the north and west, the north fork of the South Platte River basin to the south and west, and numerous small tributary basins near the mouth. The Bear Creek dam site (Plate 2) is located immediately downstream from the confluence of Bear Creek and Turkey Creek. This location is 8 miles upstream from Bear Creek's confluence with the South Platte River. Pertinent data for the dam is tabulated below:

DRAINAGE AREA

Entire South Platte River Basin	24,030 sq. mi.
Entire Bear Creek Basin	262 sq. mi.
Total Above Bear Creek Damsite	236 sq. mi.

RESERVOIR DATA

	Gross Storage Acre-Feet	Elevation m.s.l.	Surface Area Acres
Maximum Pool	75,000	5684.5	1,215
Spillway Crest	55,290	5667.0	980
Design Flood Control	28,290	5635.5	640
Sediment Reserve	2,000	5558.0	110

Surcharge Storage (Design Flood Control to Maximum Pool) = 46,710 Acre-Feet

EMBANKMENT

Type	Rolled earthfill
Crest Elevation	5689.5 m.s.l.
Crest Length	
Main Embankment	5,300 ft.
South Embankment	2,100 ft.
Maximum Height Above Valley Floor	
Main Embankment	179.5 ft.
South Embankment	65.0 ft.

Fill Volume	
Main Embankment	11,345,000 cu. yd.
South Embankment	770,000 cu. yd.

OUTLET WORKS

Type of Intake Structure	Drop Inlet
Weir Elevation	5558.0 m.s.l.
Invert Elevation	5525.0 m.s.l.
Low Level Releases, No. of Gates	2
Size-36 Dia., Inv. Elev.	5528 and 5538 m.s.l.
Length	60 ft.
Gate Structure, Type	Buried Hemispherical
Service Gates	Two 3.0 ft. x 6.0 ft.
Emergency Gates	Two 3.0 ft. x 6.0 ft.
Low Flow Gate-in-a-Gate	Two 1.0 ft. x 1.0 ft.
Length	37 ft.
Upstream Conduit, Circular	7.0 ft. diameter
Downstream Conduit, Twin Oblong	7.0 ft. x 10.5 ft. water passage 8.5 ft. x 9.5 ft. access tunnel
Total Length, Inlet to Outlet	1,687 ft.
Outlet Invert Elevation	5495.0 m.s.l.
Discharge Capacity	2,000 c.f.s. with Pool at 5667 m.s.l.
Stilling Basin, Type	Conventional Hydr. Jump
Chute Length	140 ft.
Basin Width and Length	30 ft. x 48 ft.
Basin Floor Elevation	5483 m.s.l.
Streambed Elevation	5591 m.s.l.
Design Tailwater Elevation	5501 m.s.l.

SPILLWAY

Type	Earthen and Rock Cut
Crest Width	800 ft.
Crest Elevation	5667 m.s.l.
Longitudinal Length	3,400 ft.
Excavation Volume	14,400,000 cu. yd.
Discharge Capacity	153,500 c.f.s.

DOWNSTREAM CHANNEL

Maximum Capacity Without Undue Flood Hazard	2,500 c.f.s.
Width, Minimum	20 ft.
Length (Approximately)	8 mi.

1.2. **Construction Authority:** The Bear Creek Lake Project is one unit of the comprehensive plan for flood control of the South Platte River and its tributaries in Colorado, Wyoming, and Nebraska. The project was authorized for construction by the Flood Control Act of 1968, as follows:

> "The project for the Bear Creek Dam and Reservoir, South Platte River, Colorado, is hereby authorized substantially in accordance with the recommendations of the Chief of Engineers in the Senate Document Numbered 87, Ninetieth Congress, at an estimated cost of $32,314,000."

1.3. **Purpose and Scope of Report:** In accordance with ER 1110-1-1801, this report is to insure the preservation for future use of foundation conditions encountered during construction and methods used to adapt structures to these conditions.

1.4. **Location of Structure:** The right abutment of the dam and the right embankment are located in Section 5, T.5S., R.69W., Jefferson County. The left abutment and outlet works are located in Section 32, T.4S., R.69W, Jefferson County. The outlet works is located 155 feet north of the left abutment and parallel to Morrison Road. The spillway is located in Sections 31 and 32, T.4S., R.69W., and Sections 5 and 6, T.5S., R.69W., Jefferson County.

1.5. **Contractor and Contract Supervision:** Numerous contractors participated in the exploratory work, construction of the dam and relocation of utilities and irrigation ditches. Their names and work detail are listed in the table on the following pages. The Holloway Co. of Wixom, Michigan was the prime contractor; the conduit was built by a subcontractor, H. W. Siddle, Inc. of Denver, Colorado. Contract supervision was by the Rocky Mountain Area Engineer, Colorado Springs, Colorado, through the Resident Engineer office at Chatfield Dam, Littleton, Colorado.

Work Performed and Contractor	Contract No. and Amount of Contract
Exploratory Drilling Boyles Brothers Drilling Company	DACW45-72-C-0028 $34,520
Large Diameter Borings Al Amidon Drilling Company	DACW45-74-C-0055 $32,844
Spillway Excavation and Test Embankments Winslow Const. Company	DACW45-74-C-0041 $236,489.70
Outlet Works Centric Corp.	DACW45-74-C-0170 $4,102,471.25
Relocation Colo. Highway No. 8 Division of Highways State of Colorado (Leone)	DACW45-73-C-0071 $5,900,000.00

Work Performed and Contractor	Contract No. and Amount of Contract
Relocation of Telephone Facilities Mountain Bell Telephone Company	DACW45-75-C-0047 $32,650.59
Relocation of Electric and Gas Facilities Public Service Co. of Colorado	DACW45-75-C-0068 $360,000.00
Alteration of Ward Canal Ward Canal Company	DACW45-75-C-0077 $10,000.00
Alteration of Pioneer-Union Ditch Pioneer Union-Ditch Company	DACW45-75-C-0008 $5,000.00
Relocation and/or Alterations of Irrigation and Water Supply Ditches Harriman Ditch Company City and Co. of Denver Warrior Ditch Company	DACW45-76-C-0024 $908,000.00

Work Performed and Contractor	Contract No. and Amount of Contract
Earthwork Stage II Holloway Const. Company	DACW45-75-C-0129 $27,254,543.00
Temporary Pump Station Dougan Const. Company	DACW45-76-C-0053 $106,890.00
Warrior Canal Relocation Lillard and Hanes Const. Company	DACW45-76-C-0119 $278,122.00

CHAPTER II - FOUNDATION EXPLORATION

2.1. **Initial Site Investigations:** Initial site selection explorations were made in 1944. Additional borings were made from 1970 until the first part of 1976. This covered a period of time prior to construction and through the outlet works construction stage (see Plates 62-66).

2.1.1. **Initial Drive Sample Investigations:** An interim report of the initial site explorations that was prepared in November 1966 was based on data obtained from 15 borings. This initial investigation was completed in June 1944 and consisted of 11 cable tool drive sampler borings and 4 hand auger holes. The depth of the borings varied from 18 to 45 feet with a total footage of 323 linear feet. Since the dam and outlet works were relocated a considerable distance downstream from the originally proposed site so that the axis could be more favorably placed on the Arapahoe Formation, these borings were of little significance.

2.2. **Preconstruction Core Borings:** The Omaha District inaugurated a drilling program in the spring of 1970 and had drilled 281 holes (24,757 linear feet) at the time construction was started. The purpose of the core borings was to determine the competency of the bedrock and the engineering characteristics of the overlying soil in order to locate the structures in the most favorable location. Overburden sampling was by drive sampling or 6-inch Denison barrel. Bedrock sampling was by 6-inch Denison or 5-3/8-inch double tube rotary coring.

2.2.1. The Omaha District started a drilling program for the south embankment in the summer of 1970 and had drilled 70 holes (4,051 linear feet) by the time construction started. Overburden sampling was accomplished by drive sampling or 6-inch Denison barrel. Bedrock sampling was performed by 6-inch Denison barrel or 5-3/8-inch double tube rotary coring.

2.2.1.1. **Instrumentation:** Eight of the drill holes had open tube piezometers installed within for instrumentation. Instrumentation was provided to measure conditions relating to the structural safety and stability of the south embankment throughout the life of the structure. They have been monitored continuously since installation, and no significant or adverse conditions have been recorded.

2.3. <u>**Preconstruction Geologic Investigations**</u>: Prior to the beginning of stage II construction, 59 borrow holes were drilled, a 500-foot long exploratory trench was dug, two 36-inch diameter holes were augered (Plate 111), and 156 test pits were dug with a backhoe (Plates 112-118). The borrow holes and test pits were dug to check the availability and quality of borrow materials to be used in the embankment. The 36-inch diameter holes were augered to observe and evaluate bedrock discontinuities. The 500-foot long exploratory trench was dug on the right abutment to expose the change between steeply dipping and flat lying beds (see Plate 5). Abandoned mines and depressions which could represent subsidence were located, surveyed, and photographed for future reference.

2.4. <u>**Geophysical Exploration Work**</u>: Three types of geophysical work were accomplished at the Bear Creek site since starting exploratory investigations in June 1970. They include seismic refraction, bore hole geophysical logging, and remote sensing.

2.4.1. <u>**Seismic Refraction**</u>: In April 1971, 15 seismic lines, each about 500 feet long, broadly covering the spillway area, were made by MRD Lab personnel using a refraction seismograph. Geophones were generally spaced at 50-foot intervals except for the beginning of the line where the spacing was 10 feet in order to pick slower velocities of near surface material. About 1/2 pound of dynamite, placed at depths from 2 to 4 feet, was used to create shock energy for each line. The purpose of the seismic work was to aid in a determination of the rippability of bedrock in the spillway area and to provide general information on the nature of the rock material for design and construction work. The determination of rippability was necessary for cost estimates and construction specifications. Cost of excavation usually correlates directly with the seismic velocity of rock material. The higher the velocity, the harder the rock and the more costly the excavation. In this case, the spillway contained a well-cemented sandstone and conglomerate unit which required heavy-duty ripping and blasting. Reporting the seismic velocity in the bid documents enabled bidders to more accurately assign costs to this excavation work. Since there were 10 million yards to be excavated from the spillway cut, every penny by which the bid price was reduced per yard saved $100,000. On 29 March 1973, seismic line number 16 was made to take advantage of the test quarry which was to be excavated in this material. This line was placed directly over the future quarry and allowed direct comparison between seismic velocity and ripping or blasting of this particular rock material. This was an opportunity to make all of the seismic data gathered more meaningful to bidders. Seismic velocities were found to be as high as 10,000 feet per second within the excavation prism. Most of the sandstone and conglomerate velocities were between 6,000 and 9,000 feet per second (fps). An upper limit of rippable rock of this nature is about 8,000 fps, but this represents difficult ripping using a single shank and a D-9 tractor. When this point of difficult excavation is reached, the excavation method used, either easy blasting or hard ripping, is more a matter of Contractor preference. The cost may very well be the same. A complication that makes the rippability of this particular rock difficult to assess is the fact that conglomerates may give higher than normal velocities due to contact between individual cobbles. Also, this particular rock, when unweathered, contains few fractures. Unfractured rock is more difficult to rip.

2.4.2. **Bore Hole Logging**: Down-hole geophysical logs were made of borings at Bear Creek damsite on four different occasions. This work was agreed upon at the site selection conference, and results are reported herein. The first logs were made by the U. S. Geological Survey as a cooperative study on borings spaced 150 feet apart, forming an upstream-downstream line in the main valley. Lithologic correlation had been achieved between these holes, and the intention was to compare this correlation to that derived from down-hole logs to judge their usefulness. Several different types of logs were made because it was not known which would have the greatest potential. Quantitative values were not particularly being sought.

Drill holes logged on 16 and 17 December 1970 were the following: DH-3, 12, 13, 16, 19, 20, 21, and 22. Logs made of these borings were caliper, natural gamma, single point resistivity, spontaneous potential, normal resistivity, neutron, and temperature. On 19 February 1971, the U.S.G.S. returned to the site and made normal resistivity logs of DH-12, 16, 20, 21, 22, and 23. Results of the work proved to be very beneficial. Although lithologic changes in short distances and the lack of key horizons showing characteristic log signatures prevented correlation based on geophysical logs alone, the geophysical logs aided and increased confidence in the lithologic correlation. Variations in core logging judgment between different geologists on adjacent borings were evident. Misidentification of materials made lithologic correlation more difficult. As an example, the siltstone in DH-19, starting at a depth of 118 feet, looks more like a sandstone in the natural gamma and resistivity logs. Many benefits and advantages were derived from down-hole geophysical logging. These are discussed in the following paragraphs. However, it could only be used as a tool to supplement the regular core logging program. More information could have been derived from this work given the proper interpretive tools, training, experience, and format for handling.

2.4.2.1. The geophysical logs pointed up a significant but subtle difference between sandstone of the "correlation unit" and other sandstones, thereby increasing confidence in the correlation. Resistivity logs show sandstone of the "correlation unit" to have high resistance like any sandstone containing fresh water. However, the natural gamma count is much higher than it should be for sandstone. Sand and gravel size particles of the "correlation unit" are evidently more radioactive than usual. One explanation of this would be a higher percentage of feldspar particles in this sandstone. Feldspar contains radioactive potassium and is encountered more often in formations deposited quickly before feldspar particles can deteriorate to clay and other products of weathering. The presence of granite particles in this unit reinforces this assumption.

2.4.2.2. Caliper logs proved valuable because highly fractured or slickensided zones could almost be correlated on the basis of hole enlargements alone. They also determined if lost core was due to the grinding away of solid rock or the drill bit spinning in a seam of easily destroyed soft material. Hole diameter identified areas of soft zones in this material. Caliper logs are specifically necessary for quantitative interpretation of other geophysical logs. During all of the bore hole logging work, natural gamma, single point resistivity, and caliper logs proved to be the most valuable and reliable for correlation purposes. No particular advantage was seen in the neutron or normal resistivity logs. Temperature logs were not very informative, and spontaneous potential logs varied in their usefulness. Natural gamma and single point resistivity logs are shown in the Record of Boring plates.

2.4.2.3. Geophysical logs of the second group were made by the Missouri River Division Laboratory, between 16 and 20 October 1972, as a test on the equipment and for further information on the geophysical response of the formation materials. Several holes were selected from different areas of the damsite. These were: DH-62, DH-72, DH-117, DH-64, and DH-129. Bore hole logs were caliper, natural gamma, single point resistivity, spontaneous potential, gamma, and neutron. Borings DH-64 and DH-129 are only 21 feet apart and were drilled close together to determine the dip of a fractured zone at 110 feet. These two borings offered an opportunity to check on the correlation potential of geophysical logs under known conditions. The results are shown on Plate 69. In an attempt to identify formations masked by thin surficial materials, a natural gamma probe was dragged 360 feet along the ground surface in an area believed to have a thin residual soil covering alternating beds of clay shale and sandstone. Not enough character was produced on the resulting log to be beneficial. One noticeable difficulty was the probe raising from the ground surface several inches, even though the ground appeared relatively smooth. All of the logs made by the MRD Lab showed patterns similar to those made by the U.S.G.S. Spontaneous potential logs were more definitive and useful.

2.4.2.4. Geophysical logs of the third group were made by a private geophysical logging service through the MRD Lab to aid in the correlation of soft seams in the valley area. Three of these holes were drilled, without coring, to the zone of interest and therefore were not logged in the conventional manner. Down-hole logs served to fill in this lost information. These geophysical logs were used to indicate soft seams and slickenside zones. Soft seams often appeared to coincide with high count points on the natural gamma logs and hole enlargements on the caliper logs. It was reasoned that the soft seams and highly slickensided zones occur in the fatter material because this material yielded under the tectonic stresses that affected the area.

2.4.2.5. Geophysical logs of the fourth group (29 March to 9 June 1974) were made by MRD Lab personnel using new portable equipment in an attempt to obtain more information in the form of densities and moisture contents from neutron and gamma-gamma logs.

2.4.3. **Remote Sensing:** In an attempt to apply remote sensing techniques to the location of faults in the dam and lake area, radar imagery was obtained with the help of the Army Surveillance School, Ft. Huachuca, Arizona. The Army Mohawk crew flew many flights in the Denver area and obtained radar imagery negatives looking east and west. Subsequent examination of the imagery failed to locate signs of faulting in the immediate project area, most likely due to the small scale of the imagery (1:250,000) and lack of topographic relief on faults that may be present. Color and color infrared aerial photographs of the damsite area taken by NASA in June 1972 were obtained and examined for surface signs of the Golden Fault. There was no particular advantage in these photos over the vertical black and white aerials shown in Photos 1 through 2a, other than the outstanding presentation of vegetation in red. Initial black and white aerial photographs of the site were taken in August 1969, and do show some linear streaks across part of the lake area that could be due to either the upturned edges of beds or the Golden Fault. More information could have been derived from this work also, given the proper interpretive tools, training, and experience.

2.5. **Investigations During Construction:** Geologic investigations during construction included: (1) Mapping the main embankment inspection trench; (2) mapping bedrock beneath the impervious blanket area; (3) four core borings drilled to locate the Golden Fault, with open tube piezometers placed in three of the borings for piezometric observations; (4) 13 test pits dug west of the south embankment in an attempt to locate the Golden Fault (Plates 112-118); (5) mapping of the outlet works, discharge channel, and Pioneer - Union Ditch drop structure; (6) mapping of the south embankment inspection trench, and conduit and gate house trench; (7) observing blasting fractures and faulting in the spillway; (8) logging and testing the material from holes near the gates structure to determine the suitability of the impervious fill; and (9) eight instrumentation borings near the outlet works structure, provided to measure conditions relating to the structural safety and stability of the outlet works throughout the life of the structures.

2.6. <u>Seepage and Water Pressure Tests in Bedrock</u>: A total of 24 drill holes were pressure tested as a means of locating and estimating potential leakage under and around the proposed embankments and outlet works. One hole was pressure tested in the outlet works area, 14 holes were pressure tested in the south embankment area, and 9 drill holes were pressure tested in the main embankment area (see Record of Borings, Plates 70 through 118).

2.6.1. Pressure testing was accomplished by lowering the packer to several convenient locations in the hole and using a high and low pressure for each zone tested. An examination of the results show an extremely low potential for seepage through rock material below the highly weathered, near surface rock. The highly weathered rock was removed before placement of clay in the impervious blanket area, cut-off trench, and the inspection trench. Based on all exploratory methods used, foundation grouting was not considered necessary. Considering the low elevation of the multipurpose pool and short duration of the maximum pool, leakage around and under the embankment was not expected.

2.6.1.1. Pressure tests in the outlet works area were made in a sandstone and highly fractured clay shale that could be correlated for some distance under the outlet works structure at depths of 15 feet to 40 feet below final grade. Four 10-minute tests were made with water pressures of 22, 32, 42, and 52 pounds per square inch. No water was injected into the formation at these pressures, so it can be concluded that this sandstone and fractured clay shale is tight.

2.6.1.2. Sandstones in the south embankment area are all fine-grained or very fine-grained and took little or no water during pressure tests. During mapping of the south embankment inspection trench, sandstone fines were estimated to be 20 percent or more. The only holes that took excessive water were DH-224 and DH-205. DH-205 had a highly fractured lignite bed from elevation 5585 to 5600 which would readily take water. The bottom packer was set above the lignite bed in a highly fractured clay shale bed. It appears that the water escaped through the fractures in the clay shale to the highly fractured lignite bed where the water could move with ease. DH-205 had an 0.4-inch gouge zone in a sandstone at elevation 5640. Water lost in the falling head test could easily move through this gouge zone. Shear zones were rare in the exploration trench drill holes, so no provisions were made for a grout curtain.

2.6.2. The left abutment area of the south embankment received special attention in regard to seepage possibilities. This area contains the sandstones of the Laramie and Fox Hills Formations and thin coal seams of the Laramie, all trending across the foundation from 45° to perpendicular relative to the centerline of the dam (see Plate 4). Ten auger holes were drilled which showed a natural blanket consisting of lean clay, silty sand, and sandy silt from 1.8 feet to 4 feet thick. This natural blanket covered sandstone or fine grained sandy soil which, in turn, covered a tight weathered sandstone bedrock. This area will rarely be covered and only with a low head of water, due to its elevation. Permeabilities of the soil material below topsoil and the weathered top of rock were determined, by falling head infiltration tests in the uncased auger holes, to range between 8.13×10^{-4} cm./sec. and 1.68×10^{-5} cm./sec. These results were calculated by the use of the appropriate formula of the Naval Facilities Command DM-7(1971). The formula used was developed for flow in saturated material. Since the material in the auger borings was unsaturated material, the permeabilities were probably one or two magnitudes too small due to air interference to flow. However, even allowing for greater permeability values, the material had a very low permeability. The results of these investigations led to the judgment that special treatment to prevent seepage in the south embankment area was not necessary, other than for minor problems found during construction (one shear zone dental treated and the grouting of numerous prairie dog holes).

2.6.3. **Microseismic Monitoring:** A microseismic monitoring network was set up and operated for a 90-day period in the summer of 1979 by Woodward-Clyde Consultants, after the reservoir was filled to conservation pool. Previous microseismic networks had not revealed any seismic activity in the area. This network was to determine whether impoundment of the Bear Creek Reservoir had affected the level of seismic activity in the vicinity of the dam and lake. Six seismograph stations were used in the study. No positive identification of any microseismic activity was found within 10 miles of the Bear Creek Dam above a magnitude threshold of about zero. During the study period, 271 local events were detected. All those were concluded to be quarry, mining, or construction related blasts. No induced seismicity resulted from the filling of the reservoir.

CHAPTER III - GEOLOGY

3.1. **Location:** The Bear Creek Project is on the east slope of the Colorado Front Range, just 2 miles east of the Dakota Hogback which forms the first prominent ridge of the Rocky Mountains. Bear and Turkey Creeks flow eastward from their catchment areas in the mountains through gaps in the Dakota Hogback, across upturned edges of Mesozoic strata and join immediately upstream of the dam axis. Bear Creek valley drops approximately 80 feet to the mile in this reach. Aerial views of the site are presented on Photos 1 and 2.

3.2. **Physiography:** Bear Creek Dam site is located on the extreme western edge of the Great Plains Physiographic Province, very close to the Southern Rocky Mountain Province. Ground surface is generally sloping away from the mountains and except for a few locations has very little soil cover. Present topography has been carved by erosional activity from an older surface of upturned sedimentary rocks, generally clay shales and sandstone, which sloped eastward from the mountain area. Mt. Carbon is an erosional remnant of this older surface and stands 250 feet above the valley. Quaternary erosion is mainly responsible for shaping the present topography, which is generally gently rolling but is related to geologic structure and differential erosion of alternating hard and soft formations.

3.3. **Regional Geology:** The geologic systems present from the site to the foothills immediately west of the site are shown in the stratigraphic column, Plate 6. Bedrock formations involved in the project are Cretaceous and Tertiary in age. Five systems are missing, either by erosion or by lack of original deposition: Cambrian, Ordovician, Silurian, Devonian and Mississippian. This places the Pennsylvanian Fountain Formation directly over the Pre-Cambrian and shows that this area has probably been involved in previous uplifts. The Laramie, Arapahoe, and Denver Formations are considered to have been laid down in a general land area in lakes or by streams and are termed "continental" deposits. This is in contrast to "marine" deposits, such as the Pierre shale, which were laid down in the sea. Continental deposits are considered more variable and irregular than marine deposits. A significant compositional difference between these formations is that the largest particles in sandstones of the Laramie Formation are gravel sized chert or flint particles. The Arapahoe Formation contains coarse gravel sized particles in conglomerate zones. These particles, in addition to chert, are composed of granite. The Denver Formation contains thick zones of conglomerate containing cobble size pieces of basalt and granite. Continental deposition has been continuous since the beginning of Laramie time and is a result of the Laramide orogeny which uplifted the area of the present day Rocky Mountains. The existing relief of the Rockies is a result of renewed uplift during the Pleistocene. Various authors have redefined and renamed the original Denver and Arapahoe Formations (see Plate 6). This has been encouraged by a lack of clear cut fossil and stratigraphic demarcation between formations in this time interval. There is a subtle difference in the mineralogical composition between the Dawson on the one hand and the Denver-Arapahoe on the other. Mineralogy suggests a volcanic source area for the Denver Formation in the Denver area. Geologists have felt it necessary to use a different name, the Dawson, where they have not found similar mineralogical composition, even though these units are in essentially the same stratigraphic position.

3.4. **Structure:** The characteristic feature of the geologic structure of this area is the steep eastward dip to the formations. This represents the remains of the east flank of a huge anticline or monoclinal fold involved in the front range uplift. The dip actually becomes steeper toward the east until the damsite is reached (Photo No. 36). Here the beds become near-horizontal in an abrupt manner resembling a sharp flexure. Strike of the beds is generally northwest-southeast. The structural attitude of the beds is significant to the project in the following ways: (1) The steeply dipping beds (45-80°) at the heel of the dam provide a series of clay shale cutoffs to inhibit seepage deep into the foundation, (2) the near-horizontal (1-2° dip) beds under the center of the dam provide somewhat of a horizontal drain downstream, (3) the dip of the well cemented conglomerate-sandstone unit in the spillway area maintains the proper elevation for a good channel floor, and (4) where beds dip adversely for stability analysis it must be assumed possible that clay shale beds are probably present due to the alternating nature of bedrock.

3.4.1. **Earthquake Information:** An attempt was made to plot the epicenters of earthquakes of magnitude 3.5 or greater on the Richter Scale, that have occurred within 100 kilometers of the damsite (Plate 124). Earthquake locations were obtained in the form of a computer printout from the National Oceanic and Atmospheric Administration in Boulder, Colorado. Their listing was supplemented by that given by F. A. Hadsell in "History of Earthquake Activity in Colorado," Quarterly, Colorado School of Mines, Vol. 63, No. 1, January 1968. This publication contains a record of the older earthquakes, several of which occurred within the 100-kilometer radius. Magnitudes of the older events are not known but have been assigned probable modified Mercalli Intensities. Since the deployment of sensitive instruments in 1962, many earthquakes of magnitudes less than 3.5 have been recorded. These are too numerous to plot and have been ascribed to a liquid waste injection well northeast of Denver. No earthquake of intensity greater than VII had occurred in Colorado in the past 100 years of recorded history. The largest earthquake within the 100-kilometer radius and within the State was of magnitude 5.3 on 9 August 1967 (VII Intensity) located a few miles north of Denver and 20 miles from the damsite. This location may be near the epicenter of an 1882 earthquake estimated to have been of VII Intensity (Hadsell). Since minor earthquakes occurred frequently, it was assumed that a larger event was possible. In this case, it seemed appropriate to raise one magnitude from the largest event, that is, from 5.3 to 6.3, and assume the same epicentral location 20 miles northeast of the site.

3.4.2. **Golden Fault:** The Golden Fault is a major mountain front thrust fault structurally related to the present Rocky Mountain uplift. It trends 12 miles from Golden, Colorado, to south of the project area. The fault zone dips away from the dam and remains in the Pierre Formation as it crosses the project area slightly upstream of the permanent lake. Earthquakes attributed to the Golden Fault by R. B. Simon (see General Design

Memorandum PB-6, pages 5-3 and 5-11) in 1967 were less than magnitude 2 and were probably the product of quarrying operations. No other events have been attributed to this fault either before or after 1967. However, G. R. Scott in "Quarternary Faulting and Potential Earthquakes in East-Central Colorado," U.S.G.S. Prof. Paper 700-C, 1970, believes that the Golden Fault should be considered active because of geological indications of movement in Pleistocene time. However, any activity of the Golden Fault in light of the historical and geological record must be considered minor compared to the active faults in California. Although no one can predict that a major earthquake will not occur in a given location, it would not be appropriate to assume a major earthquake on the Golden Fault based on information available.

3.4.3. **Earthquake-Reservoir Relationship:** Staff members of MRD and MRO consulted geological, hydrological, and seismological specialists of the U.S. Geological Survey in Denver, on 2 February 1973, concerning the possibility of reservoir induced seismicity. U.S.G.S. experts felt that although earthquakes had to be considered possible in this situation, the only action necessary would be to monitor seismicity of the area during initial lake operation and to control the lake level accordingly. Seismic monitoring and MRD's recommendation for installation of piezometers in the Golden Fault zone were accomplished to enable correlation between earthquakes and reservoir water, if earthquakes did occur.

3.4.4. **Slides:** Slides at the damsite can be classified as to age of movement as follows: (1) Those that had movement during construction and (2) slumping that took place in the geologic past. All slumping observed, old or new, took place on the steep sides of Mt. Carbon except an old slide at Station 30+20, 950' U.S. in the impervious blanket area that is now deeply buried with fill. (See Excavation Procedures, Par. 4.6).

3.5. **Soil Materials:** Soil cover is generally thin, varying from zero at bedrock outcrops to 40 feet on the top of Mount Carbon. Mount Carbon is capped with a horizontal layer of sandy gravel approximately 40 feet thick. This is an alluvial deposit from a past geologic stage before formation of

Bear Creek and associated drainages had eroded down to their present levels. The elevation of bedrock level at the top of Mount Carbon is about 5730. There is a 2-foot thick caliche zone (calcium carbonate cement) near the top of this material. The side slopes around Mount Carbon are mantled with a thin soil cover amounting to a few feet. This material is soil derived from underlying bedrock and slope wash. Another stage of erosion may have cut Bear Creek down to the level of a previous broad valley which stretched from the present right valley wall to near the left abutment tie-in. The bottom elevation in this valley ranged between 5575 and 5640. Remains of alluvium from this older valley occur in drill hole DH-5 as 25 feet of sandy gravel. Above this layer are 12 feet of silty sand or clayey sand. In the spillway area beyond the left abutment, bedrock was encountered at depths varying from 3 to 18 feet. Bedrock here was overlain by a combination of residual soil, windblown fines, and a very small amount of sand and gravel. Alluvial material forms the present valley fill and is composed of 15 feet of gravelly sand overlain by about 3 feet of sandy clay. The site of the south embankment and borrow area for impervious material was covered by from 3 to 18 feet of generally residual soil. One exception was on the extreme right abutment from Stations 0+00 to 0+80. At this point, a cobbly sandy gravel is present from the top of ground to the top of rock. It is a terrace of Slocum Alluvium whose base is about 130 feet above the modern channel of Bear Creek. The residual soil is composed of the same material as the underlying bedrock, made up of lean clay, silty clay, fat clay, and clayey sand. A few inches of wind blown fines covered much of the area. Soil types are illustrated in cross sections and profiles in this report. All of the three alluvial gravel deposits have been or are being worked as sources of commercial gravel.

3.6. **Bedrock Stratigraphy:** Lithologic units of all formations involved, other than the Pierre Formation which is a fairly uniform clay shale, are alternating layers of noncemented to weakly cemented and overconsolidated sandstone, siltstone, clay shale, and conglomerate. These layers are generally less than 50 feet thick and may be as thin as a few inches. Most of the formations are composed of soft rock, easily drilled with tungsten carbide slug bits. In rare cases, well-cemented sandstone zones have been encountered in the Arapahoe Formation and are present in outcrops in the Laramie Formation. The Denver Formation conglomerate is well-cemented as a general rule and drills best with a diamond bit.

3.6.1. **Pierre Formation:** The Pierre is the lowermost unit involved as a foundation material. It makes up almost the entire reservoir area and underlies more than half of the south embankment. It is a marine compaction type clay and silt shale. Stratigraphic thickness totals 5,000 feet. As shown on Plates 4 and 6, this formation dips steeply northeast and strikes transverse to the south embankment. This formation contains a high percentage of montmorillonite and is generally considered a problem formation due to slides and swelling under structures.

3.6.2. **Fox Hills Formation:** The Fox Hills Formation is an interbedded olive gray to dark yellow-brown shale and sandstone. This formation is about 200 feet thick and represents a transition between the marine environment under which the Pierre was deposited and the continental deposition which followed. The upper and lower contacts are gradational. The Fox Hills Formation crosses under the south embankment, as does the Pierre Formation. This formation serves as a poor to fair aquifer in some parts of the Denver basin.

3.6.3. **Laramie Formation:** This formation consists of alternating beds of clay shale, siltstone, and sandstone with several thin coal beds. The lower 200 feet of the Laramie is mainly sandstone. Dips vary from about 68° to vertical, with signs of overturning in some outcrops. Total thickness in this area appears to be 1,000 feet. The Laramie also serves as a poor to fair aquifer in the Denver basin, especially the lower sandstones. Clay shales of this formation with high montmorillonite content have also resulted in swelling problems.

3.6.4. **Arapahoe Formation:** The Arapahoe forms the foundation for the main embankment. This formation contains coarser clastic material than the underlying Laramie Formation. The lower 100 feet of the Arapahoe

Formation is mainly weakly cemented sandstone and pebble conglomerate, with a considerable amount of granite particles. Pebble size particles are generally chert and other resistant materials derived from sedimentary rock. Granite pebbles become more frequent higher in the section. The Laramie-Arapahoe contact is reported to be abrupt in other areas but is gradational at this site. Upper portion of the Arapahoe is alternating sandstone, siltstone, and clay shale. Thickness of this formation is between 300 and 400 feet depending on what is considered as the top of the Laramie. Sandstone units of the Arapahoe Formation also serve as a fair aquifer in parts of the Denver Basin.

3.6.5. **Denver Formation:** The Arapahoe Formation grades into the Denver Formation, evidenced by a slow increase in ferromagnesian minerals which reflects basic volcanic material from a source in the highlands to the west. A conglomerate and coarse sandstone unit is prevalent in the area and is chosen as the base of the Denver Formation. This unit contains cobbles of basalt and other basic volcanic rock types as well as granite particles. It is poorly to well cemented, has a matrix of sandstone, and contains clay shale and siltstone zones. It is not uniform in thickness or composition but has a maximum thickness of about 60 feet. Strata above this conglomerate unit in the Denver Formation are clay shale, siltstone and sandstone. They were not involved in the dam or spillway construction other than perhaps forming part of the spillway backslopes. The entire thickness of the Denver Formation in the vicinity of the damsite is reported to be 950 feet.

3.7. Faulting:

3.7.1. **Outlet Works Area:** The dominant feature of the site is the abrupt change in dip from near vertical to near horizontal. This is labeled "structurally disturbed zone" on Plate 4. This change takes place in the space of a few hundred feet. Evidence gathered to date indicates a smooth bend in the beds rather than a fault. Plate 5 illustrates the change in dip. The bend or fold may exist downward through the various beds at an angle with an assignable dip, such as 60° E. Rock units are more closely fractured, disturbed, and intermixed in this zone (Photo No. 25). The possibility of faults transverse to the strike of beds (tear faults) has not been completely eliminated. Formations in this area had soft seams (Photo No. 19) which were encountered in core drilling and in excavations. They are gouge, very closely fractured or crushed zones, and softer-than-usual seams in parent material. A direct association between these features and clay shale, especially fat clay shale, is evident. The soft seams are essentially parallel to beds and within clay shale beds, indicating adjustments within these strata. They are indicated on Plates 15 through 22. Major slickenside fractures are a structural feature that, along with soft seams, break the continuity of the rock mass. Major slickenside fractures are those that cut the core in a smooth plane. The dips of these fractures have been recorded. Near vertical slickenside fractures are noted quite often above or below soft seams. Minor slickenside fractures are those that are small, irregular, and do not cut the core with a smooth plane on which dip can be measured. These features were logged if they formed a zone which might indicate movement. Otherwise, they were not logged individually but were included in the general description of the material. Actual amount of movement during the development of all of these features is not known, but it may be very small.

3.7.2. **Main Embankment Area**: Two faults were mapped in the left abutment of the main embankment inspection trench. One crossed the floor from Station 34+30 (right side) to Station 34+55 (left side). It had 2.5 feet of displacement and 1 inch of gouge. This fault had an east-west strike and dipped 60°S. The other fault crossed the floor from Station 34+94 (right side) to Station 35+84 (left side). It had a 4-inch gouge zone and 8 feet of displacement. It had a strike from N. 40° to 60° W and dipped 30° to 44° NE. Two other faults that crossed the outlets works trench were also found in the impervious blanket area trench in the left abutment. The first was mapped from Station 29+41 (718 feet upstream) with 1/2 inch of clay noted on the fault plane. Its strike is N. 52°W and its dip was 50° NE. This fault had 20 feet of displacement in the outlet works trench. It was followed for 6500 feet laterally from the south edge of the outlet works trench to the north side of the impervious blanket trench. It probably has considerable lateral extent beyond these limits. The second fault crossed the floor from Station 30+75 (607 feet upstream) to 32+47 (675 feet upstream). This fault had a strike of N. 57°W and a dip of 38°NE. One-fourth inch of gouge was noted on the fault plane and it had 1.5 feet of displacement where it crossed the outlet works trench. Displacement of these faults could not be measured in the impervious blanket trench. All of the faults, with the exception of the two in the left abutment, have attitudes roughly parallel to the bedding. The two faults in the left abutment have attitudes which cross the beds. However, they are buried deeply enough in the left abutment to make a very tortuous path for seepage problems.

3.7.3. South Embankment:

3.7.3.1. **South Embankment Inspection Trench:** Two shear zones were observed in the trench; one near Station 9+00 (Photo No. 41) and the other near Station 1+00. The shear zone near Station 9+00 had a strike of N. 46°W. and a dip of 74°NE, the same attitude as bedding in bedrock. Material in this shear zone was made up of alternating thin fractured stringers of ironstone, shale, and clay, with a total width of about 2 feet. On the downstream face five ironstone stringers were noted 1/2 to 6 inches thick. The ironstone stringers were highly fractured and water ran freely through these fractures on this side of the trench. A probable source of the water was a nearby irrigation canal. This shear zone was dental treated with lean concrete for an area of 5 feet wide and 5 feet deep to eliminate the possibility of piping through the impervious section of the embankment. A fault was observed near Station 1+00. It had 1 to 2-1/2 inches of clay gouge on the fault plane. A number of thin ironstone stringers appeared above the fault plane but not below, indicating displacement of at least 10 feet. On the downstream face the fault plane is curved, with a strike of N. 25°W. and a dip of 15°SW a few feet above the floor. On the upstream face, the fault dips 3° NE with the same strike as on the downstream face. Since this fault was near the end of the trench in the right abutment, it was felt that it would not affect the integrity of the foundation of the south embankment. If the water in the lake should ever rise to elevation 5673, the upstream side of the embankment should be observed for slumping. This is highly unlikely with the normal operating pool at elevation 5558, which is 115 feet below the fault.

3.7.3.2. **Conduit Trench:** Five soft seams crossed the floor of the trench. Soft seams are composed of gouge and finely fractured or crushed material derived from associated rock. They are principally found in shale or clay shale. Most are probably bedding plane faults caused by small movement. Soft seams, larger slickenside planes, and faults were probably all formed at the same time in response to the same regional tectonic stresses. The five soft seams crossing the trench contained a trace to 1 inch of clay. The attitudes of four of the soft seams were the same as the bedding, striking N 40°W and dipping 80° to 86°NE. A 1-inch soft seam located 120 feet west of the control structure centerline had a strike of N 40°W and dipped 50°NE. This was a fault with small movement that crossed the beds. The soft seams represent small amounts of movement and do not seem to affect the stability of the foundation. The west three-quarters of the trench contained high plasticity shale that was moderately weathered and highly fractured. Minor settlement of this part of the conduit was expected when loaded with embankment materials, and this was considered in the design of the structure.

3.8. **Tectonic Forces:** Regional compressive forces have been active in the damsite area since the Laramide orogeny. Soft seams which are generally within clay shale beds or near contacts indicate slippage between beds. This was caused either by the flexing of beds or by horizontal compression. Clay shale layers of high plasticity, when favorably oriented, yielded to the forces. Vertical slickenside fractures above or below these "bedding plane faults" are probably drag features. Major slickenside fractures are generally at low angles in the borings and probably indicate horizontal compression. A stereographic plot was made of slickenside fractures from the exploratory excavation, where true orientation of the fractures was obtained. It was found that these features strike with the beds. Their dips plot around 70° NE and 70° SW. These dips are actually at low angles to the beds since the beds are steeply dipping in the exploratory excavation area. Forces transmitted down dip may account for their formation.

3.9. Jointing, Fracturing, and Weathering:

3.9.1. Outlet Works Area:

Rock units in the damsite area are not highly fractured or jointed as a general rule, although near the surface where rock material dries, slakes, rebounds, slumps, and generally weathers, they are highly fractured. Rock units are also highly fractured in movement zones at depth. Clay shale material of high plasticity is often highly fractured in outcrops, even beneath valley alluvium and the water table. Jointing in the Denver Formation conglomerate and sandstone takes the form of widely spaced vertical joints with very few horizontal joints. Other rock units have widely spaced joints which are probably related to regional tectonics. Jointing in the Denver Conglomerate probably relates to its sedimentary origin. A joint diagram for the area did not indicate a preferred orientation to the mapped joints. In the exploratory excavation, Plate 5, major slickenside fractures had a general attitude of N45°W, 70°SW and 70°NE. Other fractures had an attitude of N60°E, 50°NW, striking with and dipping into the valley. The joints and fractures are not open and are filled with clay material. Fractures parallel to bedding are also present but generally are widely spaced. Degree of fracturing was noted on the strip logs as "slightly fractured" or "widely spaced fractures" if the spacing was generally greater than 1.0 foot. If the spacing was generally between 0.5 foot and 1.0 foot, the notation "moderately fractured" was used. Fractures spaced closer than 0.5 foot were noted as "closely" or "highly fractured." The term "fragmented" was applied to core that came out of the core barrel in small pieces not measurable as core lengths. Highly weathered bedrock, that is, rock that has lost its rock strength and characteristics, generally is only a few feet thick. Weathering was controlled by type of rock, fracturing, and location. Moderately to slightly weathered rock usually extends down to 40 or 50 feet with some alteration of minerals and iron stained fractures. Fractures in this zone are usually closely to moderately spaced. Rock below this zone generally has widely spaced fractures and is unweathered. Weathering and fracturing are quite variable from hole to hole, and the boring logs must be examined to get a true picture of these rock features.

3.9.2. **Embankment Area**: Major fractures mapped in the valley and abutments had attitudes as follows: Strike E-W, dip 8° to 32°NW; strike N. 60°E, dipping 4° to 10°SE; strike N. 45°E dipping roughly 10° NW and 30°SE; and striking N. 75°W and dipping 30° to 35°SW. The openings in the fractures were very thin but half of them noted in the valley sandstone seeped water (see Photo No. 63.) Therefore, no more than half of the fractures are healed. Most of the joints in the Denver Conglomerate in the spillway were widely spaced, from 10 feet to 75 feet apart. Most of these had a strike of N. 30°W. and dipped 85°NE. They were measured as much as 65 feet in length but some are probably longer. When a sandstone or clay shale bed occurred in the conglomerate, bedding plane fractures were found in them. A few large, low angle, random fractures that crossed the beds had no preferred attitude. The beds to the east of the thick conglomerate bed are made up of sandstone, siltstone, and clay shale with an occasional thin conglomerate lens. These beds dip gently to the northeast. Bedding plane fractures are quite numerous, with spacing of 1 foot to 2 feet in some areas and up to 10-foot spacings in other areas. The widely spaced high angle fractures (strike N. 30°W. dip - 85°NE) were also noted in these beds. Many steeply dipping bedding plane fractures occur within the steeply dipping beds of the Arapahoe and Laramie Formations in the western part of the spillway. Highly weathered bedrock; that is, rock that has lost its rock strength and characteristics, is only a few feet thick. In mapping, it was noted to be 1/2 foot to 4 feet in thickness. Moderately weathered rock was 1 foot to 10 feet in thickness in the left abutment. In the valley and right abutment it was 2 feet to 4 feet thick. Moderately weathered rock retains its rock characteristics. Slightly weathered rock was noted to be 1 foot to 10 feet in thickness. This is rock where the only evidence of weathering is the iron staining or fractures. Weathering in any area is dependent upon permeability of the rock including fractures, bedrock structure, resistance of rock material to weathering attack, and the time in which weathering agents are allowed to work on a given rock material. Thickness of rock material which has actually changed completely in engineering characteristics from bedrock to residual soil is usually less than 1 foot in the main embankment, spillway, and impervious blanket areas. Downcutting by Bear Creek in the valley has in many cases allowed less time for weathering agents to work and has resulted in a smaller depth of weathering than in the abutments.

3.10. **Reservoir Area:** Maximum pool for Bear Creek Lake will be contained within a basin eroded into the relatively impervious Pierre Formation. The reservoir is contained on the north by higher elevations of bedrock, on the west by the Dakota hogback, and on the south by a series of east-west running knobs.

3.11. **Ground Water:** Ground water in the Bear Creek Lake basin can be classified as: (1) Water flowing down gradient in the alluvial aquifer and (2) water flowing eastward and down dip in the pervious bedrock aquifers, primarily in the sandstones of the Laramie and Arapahoe Formations. Precipitation, flow from Bear Creek, and seepage losses from irrigation ditches all contribute to the flow in the alluvial aquifer, which in turn recharges the bedrock aquifers. The Fox Hills, Laramie, and Arapahoe Formations produced from 2 to 10 g.p.m. locally, while the alluvial aquifer produced from 17 to 20 g.p.m. in the vicinity of Bear Creek.

3.12. **Seepage Analysis:** The bedrock materials as observed in core samples and determined by hydraulic pressure tests or infiltration tests is quite tight to the passage of water. This also includes the vast majority of sandstone material which usually contains fines. The more pervious zones in bedrock are highly fractured zones, coarse-clean sandstone layers, or coarse-clean sandstone channels within bedrock. Various drill holes were water pressure tested for estimating potential leakage under or around the embankment. The results showed an extremely low potential for seepage through rock materials below the highly weathered near-surface rock. The rock material, particularly clay shale and siltstone, has low permeability except where highly fractured. The sandstones and conglomerates ordinarily have low permeability since they are commonly argillaceous; however, there are some thin, uncemented, clean sand layers in these units. By assuming that the sandstone layers in the formations transmit water more readily than the clay shale and siltstone layers, the Dupuit recharge equation,

$$Q_r = \frac{2\pi kb\,(hw-ho)}{\ln\,(ro/rw)}$$ (Todd, Ground Water Hydrology 1959, Pg. 261)

for flow into a confined aquifer was used for approximations of permeability. By using a radius of influence of 178 feet and a hole diameter of 8 inches, the equation was reduced to k = .89 Q/bh where k is average permeability in the zone tested, b is the length of hole tested, h is the total head applied to the zone tested, and Q is the water take in each zone. This method was used in some cases to compute a rough permeability value for comparing tests. Based on all exploration methods used, foundation grouting was not considered necessary. Considering the low elevation of the multipurpose pool, short duration of the maximum pool, and the impervious cutoff through the most pervious sandstone-conglomerate unit of the Arapahoe Formation, leakage around or under the embankment is not expected.

3.13. **Engineering Characteristics of Foundation Materials:** Laboratory tests were performed on representative samples obtained from the exploratory borings. The laboratory tests consisted of the following: (1) Mechanical analysis, Atterberg limits tests and moisture determinations; (2) triaxial compression tests; (3) direct shear tests; and (4) permeability tests.

3.13.1. **Disturbed Tests:** Laboratory soil classifications were made in accordance with the Unified Soil Classification System. Similar samples were grouped by visual comparison and then representative samples of each group were tested and classified based on mechanical analysis and Atterberg limits tests. The disturbed test results are summarized on the detailed logs of borings on Plates 70 through 118.

3.13.2. **Undisturbed Testing:** Triaxial compression and direct shear tests were run on representative undisturbed samples of the valley and abutment bedrock materials. These tests were run on weathered clay shale, unweathered clay shale, unweathered sandstone, and unweathered siltstone. Direct shear "S" tests were run on the soft seam material found at the upper and lower sandstone-clay shale contact. Direct shear "S" (residual) tests were run on unweathered samples of clay shale. The detailed results of these tests, including test summaries and adopted strengths, are presented on Plates 125 through 140.

3.13.2.1. An abbreviated summary of adopted peak strengths in the main embankment area is as follows:

"Q" Strength		"R" Strength		"S" Strength	
Tan Ø	C, TSF	Tan Ø	C, TSF	Tan Ø	C, TSF
		Undisturbed Weathered Clay Shale			
-	1.35	0.35	1.0	0.60	-
		Undisturbed Unweathered Clay Shale			
-	8.0	0.28	4.6	0.86	-
		Undisturbed Unweathered Clay Shale			
-	-	-	-	0.11 (residual)	
		Undisturbed Unweathered Sandstone			
0.62	1.0	0.47	8.5	0.80	-
		Soft Seam Material at Sandstone-Clay Shale Contact			
-	-	-	-	0.31	-

3.13.2.2. An abbreviated summary of adopted peak strengths on representative samples of impervious overburden and weathered clay shale bedrock encountered in the vicinity of the south embankment is as follows:

"Q" Strength		"R" Strength		"S" Strength	
Tan Ø	C, TSF	Tan Ø	C, TSF	Tan Ø	C, TSF
		Undisturbed Impervious Overburden			
0	0.50	0.28	0.30	0.41	0
		Undisturbed Weathered Clay Shale			
0	0.70	0.24	0.90	0.60	0.0

3.13.3. **Permeability Tests:** Permeability tests were run on representative undisturbed samples of sandstone bedrock. The details of these tests along with permeability test results are presented on Plate 132.

CHAPTER IV - EXCAVATION PROCEDURES

4.1. **Excavation Grades:** Excavations were made to lines and grades shown on Plates 7 through 47. Excavations in the right abutment impervious blanket area on the side of Mt. Carbon were somewhat deeper than on the contract drawings. This was especially true on the far upstream end of the excavation to rock on the side of Mt. Carbon, roughly 850 feet to 1,000 feet upstream. Sliding occurred while excavating to locate mines in this area. Overexcavation took place to have a safe backslope to expose the mines for sealing. Other slide areas along the side of Mt. Carbon made it necessary to excavate deeper than on the contract drawings. Overburden slopes were 1V on 2H through the conduit section and 1V on 3H in the intake and stilling basin areas. Bedrock was cut on a 1V on 1H slope in the conduit area and 1V on 3H slope in the intake and stilling basin areas. Overburden and bedrock slopes through the south embankment inspection trench were 1V on 1H. Overburden cuts in the south embankment conduit trench were between 1V on 2H and 1V on 3H, and bedrock cuts for this trench were near vertical.

4.2. **Dewatering Provisions:** Dewatering in general was not difficult. There were no indications of excessive amounts of water flowing through the overburden sands, gravels, bedrock sandstones, and discontinuities.

4.2.1. **Dewatering the Valley:** In early September 1975 the Contractor excavated a dewatering trench approximately 980 feet upstream, from the right abutment to Bear Creek (Photo No. 81). The floor of the trench sloped gently so that water flowed by gravity to Bear Creek. In the middle of September 1975 the Contractor started excavating the impervious blanket trench and placing clay from 760 feet upstream to 960 feet upstream. This was just downstream of the drainage trench. By the end of September 1975, the impervious blanket trench was excavated and filled with clay from roughly Stations 13+00 to 23+00. This further sealed off water that might have flowed into the main inspection trench. Excavation of the main inspection trench was started in early November 1975. Trenches were excavated and impervious fill was placed from roughly Stations 13+00 to 23+00. This section of trench was completed on 6 December 1975. Next, the impervious blanket area at the toe of Mt. Carbon was cleaned off and filled with impervious fill from 960 feet upstream to the inspection trench. This further slowed the water flow into the remaining core trench on the right side of the valley. An estimated flow of 12 g.p.m. was encountered from Station 11+65 to 12+00 (125 feet U.S. to 220 feet U.S.) (Photo No. 63). This water was pumped into a water truck and hauled out of the excavation. The clay was then placed, sealing off the water that was seeping from a cleaner fractured sandstone and some seepage from the overburden as well. Bear Creek was diverted to the north by digging a trench just south of Morrison Road. Then the impervious blanket trench and the inspection trench were extended to the Bear Creek diversion, and were filled with clay. Bear Creek was then diverted south to the closure channel. The trenches were then extended north to the outlet works and filled with impervious fill material. This part of the work was completed by mid-July 1976. Berms on the upstream and downstream sides of the inspection trench had ditches cut into them prior to the final bedrock excavation to the trench floor grade. Water was pumped from these ditches, which took care of most of the excess water seeping toward the trench. Occasionally, seepage was enough to necessitate digging a sump into a low spot in the trench floor and pumping water before placing clay. The most difficult area to dewater in the valley inspection trench was from Stations 13+00 to 16+00. An estimated 50 g.p.m. was pumped from the drainage ditches and sump. Drainage ditches were dug on the left and right toe of the outlet works discharge channel, and water was pumped into Bear Creek. (Photo No. 48).

4.2.2. **Coyote Gulch Dewatering:** The inspection trench transected Coyote Gulch from the outlet works to Station 34+00. Ground water flowed from the overburden and bedrock down Coyote Gulch. To cut down the flow of water, the Contractor first dug a sump to bedrock at Station 32+30, 40 feet U.S. Water was pumped for a few days and the volume was sufficient that a trench was excavated across Coyote Gulch at Station 34+30 into bedrock. Water was pumped at the rate of flow of 10 g.p.m. from this trench and into Ward Canal. Considerable organic material had to be removed from the floor of Coyote Gulch before the core trench could be dug and the embankment materials placed. Next, a dewatering trench was dug from Stations 30+00 to 32+50, 40 feet U.S. Water from this ditch was pumped to Ward Canal. A dewatering ditch was dug into bedrock from Station 27+25 (190 feet D.S.) to Station 32+00 (40 feet D.S.). Water from this ditch was pumped into Bear Creek. Next, part of the impervious blanket trench was cut into bedrock across Coyote Gulch at approximately Station 33+90 (50 feet U.S. to 250 feet U.S.). This was filled with clay which further reduced the flow down Coyote Gulch into the core trench area. Seepage was then under control, and the bulk of the organic material was removed and replaced with random fill. The core trench was then dug and clay was placed. Water volumes during dewatering were small and the Contractor handled the flow adequately.

4.2.3. **Outlet Works Dewatering:** Ground water entered the excavated trench from the alluvial overburden material and from fractures in the upper part of the bedrock in the stilling basin trench. This water was easily disposed of during construction by diverting it to sumps and pumping it out of the excavations. Some very minor seepage at the overburden-bedrock contact did not exceed the evaporation rate. Water was pumped continuously from three sandy gravel filled channels in the Coyote Gulch area between stations 0+70 and 1+35. Pumping in this area continued until backfilling was almost complete. Water seeped through bedrock fractures on the north side of the trench at a rate of 0.33 g.p.m. between stations 0+00 to 0+25. In the stilling basin, seepage through bedrock fractures, mostly from below grade, was also at a rate of 0.33 g.p.m.

4.2.4. **South Embankment Dewatering:** Ground-water flow into the inspection trench or conduit trench was of very low volume and it was normally removed by the excavation equipment. One exception to this was where a high angle (N 45°W., dip 74°NE) shear zone crossed the inspection trench near Station 9+00. This shear zone also crossed underneath the irrigation ditch to the southeast. The main flow of water into the inspection trench came from the irrigation ditch by way of the shear zone. To cut off the flow of water into the inspection trench, the contractor dug a small dewatering trench approximately 3 feet wide by 15 feet long by 8 feet deep. This trench cut across the shear zone about 20 feet southeast of where the shear zone crossed the inspection trench. Water was pumped from this small trench at about 4 g.p.m. and eliminated most of the flow into the inspection trench. The shear zone was dental treated with lean concrete in the inspection trench. The small amount of water that seeped into the dental treatment excavation was pumped out before the lean concrete was poured. A small amount of seepage occurred toward the west end of the conduit trench and this was controlled by a small amount of pumping. The seepage, estimated at 2 g.p.m., was observed in bedding material placed under the 84-inch concrete pipe and the flow originated from a number of high angle (N. 40°W. dip 85°NE) fractured ironstone seams.

4.3. **Overburden Excavation:** Foundation preparation consisted of clearing the embankment area, spillway, outlet works area, borrow areas, and the entire reservoir area below the multipurpose pool level at elevation 5558. Clearing involved the removal of trees, heavy growths of vegetation, and all topsoil and organic materials (see Photo No. 3). The topsoil was stockpiled and later used on the areas to be seeded. Some undesirable organic materials were removed under the future embankment. This material was placed in the waste area just upstream of the dam in the valley. Dozers, scrapers, and loaders were used to excavate and place the overburden, and some materials were hauled to the stockpiles with dump trucks. In the early excavations, the overburden had to be stockpiled and was later placed in the appropriate zones of the embankments. Later, areas were available to place fill and the overburden was excavated and placed in the appropriate zones. Some material was excavated from the impervious blanket trench, and it was processed for pervious fill No. 1 to be used in the drains. Initial excavation started on 8 July 1974. Stripping was started on 30 June 1975. Initial south embankment excavation was started on 9 August 1975. Overburden excavation for the south embankment conduit was started on 30 October 1975.

4.4. **Bedrock Excavation:** Rock excavated consisted of siltstone, sandstone, clay shale, shale, conglomerate, and a few very thin coal seams.

Most of the rock removed was moderately to highly weathered. The bedrock removed from the south embankment inspection trench was hauled to the uncompacted fill section of the embankment. Rock removed from the conduit trench was stockpiled and later used for backfill around and above the conduit. The south embankment inspection trench was completed on 14 October 1975 and the conduit trench was completed on 21 January 1976. The floor of the outlet works area was taken to grade and lean concrete was poured from station 0+37 to -4+10 during the 1974 construction season. The rest of the trench was taken to approximately 3 feet above grade in the fall of 1974 (Photo No. 28). Due to unusually warm weather, excavation in the trench was resumed on 30 January 1975 downstream from centerline (Photo No. 27). Excavating to grade and pouring of lean concrete continued until 24 September 1975. As part of this contract, two short sections of the main embankment inspection trench were excavated, backfilled, and completed in April 1975. Occasionally, a deep overburden channel was encountered whereby the side slopes had to be steepened to reach the specified excavation of 5 feet into bedrock and still maintain the specified bottom width of the trench. The Contractor cleaned loose material from the bedrock prior to backfilling with clay. The inspection trench was backfilled within 8 hours after the excavation reached grade. Existing slumped material on the side slopes of Mt. Carbon in the impervious blanket area required considerable overexcavation to allow placement of clay on a good, clean rock surface.

4.5. **Excavation Methods:** Conventional excavation equipment consisting of dozers, scrapers, and loaders was used to remove overburden and weathered bedrock. The Contractor used Caterpillar 631 and 637 scrapers. The dozers and push cats used were Caterpillar D-8 and D-9's. An Allis-Chalmers HD-41 dozer with a Kelley ripper was used extensively for heavy-duty ripping in the spillway. D-9 Caterpillars with rippers were also used in the spillway. Caterpillar 966 and 988 front end loaders were used for many jobs on the dam. Caterpillar 12 and 16 graders were used. A small Case backhoe was used for mine exploration work. Blast-hole drills used were Joy MS-21-261, Gardner-Denver PR-55 and Ingersoll-Rand VL-140. A Northwest 9570 dragline was used extensively. Caterpillar 769B trucks were used to haul oversize rock. Many other pieces of equipment such as rock rakes, pumps, water trucks, etc., were used. Bedrock excavation methods varied in each of the areas excavated. The areas excavated were the inspection trench, outlet works discharge channel, spillway, impervious blanket trench, and the mine openings.

4.5.1. **Inspection Trench:** The main embankment inspection trench was excavated to the top of rock with dozers and scrapers (see Plates 7-9). In the valley, a small Case backhoe was used to dig drainage ditches at the toes of these slopes. The trench was then dug 5 feet into bedrock, with drainage ditches located on berms. Bedrock excavation was also done with dozers and scrapers, with ripping used as the normal procedure in slightly weathered to unweathered bedrock. Ripping was more difficult in sandstone, especially in the sandstone concretions and conglomerate zones. Drainage ditches were not necessary at higher elevations in the right and left abutment trenches.

4.5.2. **Outlet Works and Discharge Channel:** The methods used for excavation of this trench were the same as the inspection trench except at the Pioneer Union Ditch Drop Structure (Plates 36-47). A ripper was required to loosen unweathered sandstone, especially to break sandstone concretions and conglomerate zones (Photo No. 10). A Bantam backhoe was used to excavate the bedrock to grade for the concrete pours. Some well cemented sandstone concretions were encountered that had to be removed with jackhammers (Photo No. 46). The contract specifications for excavation in the outlet works provided for three different pay items: (a) Overburden excavation, (b) Bedrock Excavation, and (c) Foundation Preparation Excavation. The Geologist for this project was relied on to identify the bedrock-overburden contact in these soft foundation formations and to decide when a clean, firm foundation had been attained. The originally planned outlet works alignment was perpendicular to the main embankment centerline, along the line of holes DH-60, 46, 59, 47, 58, 48, 57, and 74. This alignment was relocated by approximately 75 feet northwest along the embankment centerline and reoriented parallel to the existing ground slope. Although this resulted in an alignment askew to the embankment centerline, it reduced the amount of excavation and afforded a more constant bedrock foundation elevation.

4.5.3. **Spillways**: In the western one-quarter of the spillway, rock was excavated using dozers and scrapers, with some ripping to expedite removal (Plates 28-35). In the eastern three-fourths of the spillway, the weathered rock was removed by conventional methods. The slightly weathered and unweathered rock was excavated with difficulty, requiring heavy-duty ripping or blasting and secondary breakage and blasting. The blasting consisted of 287 individual blasts located between Stations 30+65 and 74+00. Many oversize boulders were loaded with front end loaders onto Euclid type trucks and hauled to the oversize zones. The smaller sized rock was hauled by scrapers to the appropriate zones of the embankment.

4.5.4. **Impervious Blanket Area**: Conventional equipment was used to remove most of the rock in this area. Some heavy-duty ripping was required in the well cemented, cliff-forming sandstones along the north side of Mt. Carbon. The Contractor started removing overburden and bedrock from the top of the excavation area (elevation 5684.5) along the north side of Mt. Carbon. Dozers pushed the overburden and bedrock down the slope until a pile of material was formed. Scrapers then moved the material to the appropriate zones of the embankment. This operation was repeated until the side of Mt. Carbon was excavated to grade from elevation 5684.5 to the valley floor. Bedrock in this area was exposed for a long period of time prior to placement of clay. A front end loader cleaned off the bedrock face to remove weathered material just before impervious fill was placed against the slope. Existing slump material along the north slope of Mt. Carbon was removed with dozers and scrapers. Removal of materials to a clean bedrock surface in the valley and left abutment areas of the impervious blanket trench, was accomplished with dozers, scrapers, and loaders.

4.5.5. **South Embankment**: Previously described conventional excavation methods were used to excavate the inspection trench (Plates 25-27). A grader blade was used to shape the 1V on 1H side slopes, and a ripper was used to cut to the bottom 2 feet of the trench through a harder sandstone from Stations 16+50 to 17+40. Ripping was not necessary in the rest of the excavation, as bedrock could be removed with a scraper. The south embankment conduit trench was dug with a Bantam backhoe.

4.5.6. **Mines:** The exact approach to sealing the mine portals was decided in the field as the Contractor excavated the old caved or partially caved portals (Plates 4 and 10). Each mine had its own topographic situation, inclination, and caved portal characteristics. Excavation and sealing methods were different for the mines in the impervious blanket area as compared to those outside of that area (see Plate 4 for the locations of mines).

4.5.6.1. **Mines in the Impervious Blanket Area:** Mines No. 3 and No. 4 were clay mines located in the impervious blanket area on the north side of Mt. Carbon (Plate 10). Exploration work to locate the mine portals was started on 30 August 1975. Numerous openings were observed on the No. 4 clay mine. The near horizontal or inclined drifts were exposed by exploring with dozers, loaders, and a small backhoe where an attempt was made to determine the floor elevation of the lowest mine drift. The backslope was then cleaned off on a slope between 1V on 1H and 1V on 2H with a dozer, the mine opening was cleaned out with a backhoe, and as the first stage of sealing, random material was dozed into each fresh opening to within 5 feet of the ground surface. A backhoe then cut a key around the portal 2 feet deep on the sides and top, 2 feet wide on the sides, and 5 feet wide on the top (Photo No. 73). The random backfill in the drift then extended to within 3 feet of the opening. A 5-foot thick cap of lean concrete was poured into the openings, to the edge of the key and 2 feet below the floor of the mine. The cap extended 3 feet into the mine opening and 2 feet into the keyed portion, which made it highly unlikely that the concrete slab would move later. The concrete was hauled by trucks and placed by a dragline-controlled concrete bucket.

4.5.6.2. **Mines Outside of the Impervious Blanket Area:** The No. 1 and No. 2 coal mines were located along the side of Mt. Carbon outside of the blanket area. The Contractor started slope cleaning above the suspected mine openings with dozers to push overburden, bedrock, and tailings down the slope. Excess material was hauled away with scrapers, and a backhoe or loader was used to locate openings. After exploring the slope, eight drifts were found in mine No. 1 and three in Mine No. 2. The backslope was approximately 1V on 1H. Scrapers hauled in clay from Borrow Area No. 1 and dozers pushed it up the hill and compacted it by track walking until the entire trench dug into the hill was filled. The clay layer was a minimum of 10 feet thick over the mine openings. The rest of the trench up to the old ground surface was filled with random material. Depressions in the ground surface were explored in the No. 5 mine area on the side slopes of a hill north of Bear Creek upstream of the dam. Dozers excavated upslope and downslope to expose mine portals. Two openings were found and subsequently opened with a loader and a backhoe. The backslopes were roughly parallel to the old ground surface. Random fill was stuffed into the mines up to the floors of the trenches, and clay was used to fill the trenches the same way as on mines No. 1 and No. 2. The clay layer over the mine openings had a minimum thickness of 10 feet. The rest of the trench up to the old ground surface was filled with random fill.

4.6. **Slumps:** Numerous slumps were encountered during excavation. Active slumps required careful excavation, while old slumps required only "cleanup" of the material.

4.6.1. **Slides During Construction:** Two of the larger slides were observed 1,000 feet upstream on the north side of Mt. Carbon as shown in Photos 51, 52, and 57. Slumping took place in the steeply dipping clay shale beds near the top of the Laramie Formation on an old slide plane during cleanup of the impervious blanket area to bedrock and while the Contractor was attempting to locate a mine entrance to be sealed. The first slumping occurred on 2 February 1976. The slide plane had a strike of N. 45°E. and dipped approximately 60°NW. About 3,000 yards of material moved down the slope. The slide material was removed by dozers and scrapers, and the old slide plane was undercut to prevent future sliding. On 7 February 1977, sliding occurred in roughly the same area when the Contractor was attempting to expose clay mine No. 3. A fault plane striking N. 30°W and dipping 45°NE was undercut at the toe of the slope, and 450 yards of clay-shale slumped downhill. Since the backslope of the slumped material that was to be removed was unstable and very steep, and the opening to the mine was under the slumped material, a decision was made to start a new excavation up the slope with a lesser grade to intersect the mine. The Contractor undercut a fault striking N. 60°W. and dipping 45°NE shortly after the mine had been exposed, and 3,000 yards of bedrock slumped downslope. Luckily, the mine to be sealed was not covered by the slumped material. The slump material was not removed because the slide was so far upstream, and the material was impervious clay shale. This slide area was later buried under a deep layer of fill. Three small slides of only 2 to 20 yards of material that slumped during construction were removed and the slide plane was undercut (see Photos Nos. 55, 56, and 61).

4.6.2. **Old Slides:** Four areas of slumping that occurred in the geologic past were on Mt. Carbon, 420 feet upstream, in the main embankment inspection trench at station 7+65, and in the impervious blanket area at stations 7+35 and 30+20 (Photos 50, 53, 67, and 68). These slides resulted from unfavorable attitude of major fractures in relation to steep side slopes and undercutting by Bear Creek during flood periods. The Contractor unloaded the down block of the slump material and later buried the areas with considerable fill.

4.7. **Foundation Preparation:** Foundation preparation was of two types. The first was the preparation of floors and sides of the inspection trench and impervious blanket areas to receive clay fill. This preparation allowed a positive cut-off which controlled underseepage. The second was the more extensive cleanup of bedrock in areas where concrete was placed.

4.7.1. **Preparation of the Inspection Trench and Impervious Blanket Area Foundations:** The inspection trench extended a minimum of 5 feet into bedrock. The side slopes of the inspection trench were kept stable and the bedrock floor was kept relatively free of water (Photo No. 80). Side trenches and dewatering sumps were excavated. Loose material was removed from the floor just before placement of clay. No definite depth into rock was required in the upstream impervious blanket excavation, so the excavation was made to firm bedrock which also was cleaned of loose material before placing clay. The only exceptions were in the far upstream slide area from 850 feet to 1,000 feet U.S., and the old slide area at 45 feet U.S. on the side of Mt. Carbon, where firm bedrock did not underlie clay. The floors were dry when clay was placed (Photo No. 62).

4.7.2. Preparation of Bedrock Surfaces Where Concrete or Fill Was Placed: All rock surfaces were cleaned and sealed in conformance with the contract specifications. Bedrock surfaces upon which concrete was placed were damp, clean and free from frost, ice, and standing or running water, mud, oil, drummy rock, or unsound fragments. Soft seams were cleaned out to a depth twice the width of the seam and to firm rock on the sides. All rock surfaces were cleaned thoroughly by an air jet just prior to placing concrete or applying Sika Seal aerospray binder-sealing material (Photo No. 13). Concrete or sealing material was placed within 2 hours after the floor or sides were taken to grade. Lean concrete or structural concrete was placed within 48 hours of taking any surface to grade. When frost protection on rock was needed, it was placed within 2 hours of excavating to grade.

4.8. Safety Precautions: The project safety program followed guidelines as called for in the Corps of Engineers manual "General Safety Requirements" EM-385-1-1. Prior to commencement of construction, a safety indoctrination was held with each Contractor and all safety requirements were thoroughly reviewed. Construction equipment was checked for rollover bars, backup alarms, seat belts, windshield wipers, etc. A detailed safety inspection was made by the Contractor's head mechanic, and a report was made for each piece of equipment three times per year. Weekly "tool box" safety meetings were held with the workers on all contracts. Prephase safety meetings were held with the Contractor before each new phase of construction was started such as cleaning and grubbing, blasting, etc. All personnel were required to wear hard hats within the construction area. All equipment operators were required to wear seat belts. Traffic control patterns were laid out and haul roads maintained and watered for dust control. Adequate lighting was provided for night operations. In addition to observing all the safety requirements of the Corps of Engineers, special precautions were taken against possible rock slides when working in deep trenches. The Government Project Geologist inspected all slopes and excavations for possible movements. To prevent vehicles from being driven into trenches, cable barricades were placed along the tops of slopes.

CHAPTER V - CHARACTER OF FOUNDATION

5.1. **Scope:** This part of the report includes the geology and foundation conditions as observed in the excavations, as well as descriptions of the discontinuities encountered, effects of rock weathering on the foundation, and entrance of water into the excavation.

5.2. **Outlet Works Area:** In the outlet works, most of the weathered material was removed by excavation so that the entire floor consisted of slightly weathered or unweathered bedrock, with two exceptions. A few patches of moderately weathered clay shale remained between stations -7+40 and -7+80, where the beds were steeply dipping, and between stations 0+90 and 1+10, the depth of cut into rock was very shallow. These two areas may be somewhat weaker foundation zones. During excavation of material for the outlet works it was observed that, in general, the gently dipping shales were moderately to highly weathered in the top 5 to 7 feet. The next lower 5 feet were slightly weathered. Where the beds dipped steeply, weathering was somewhat deeper. Occasionally, beds in the highly fractured shales were moderately weathered to a depth of 20 feet.

5.2.1. **Outlet Works Foundation Rock Surface:** The four rock types in the excavation were siltstone, clay shale, conglomerate, and sandstone. The clay shales contained many fractures, soft seams, and slickensides; thus they were the most difficult to clean up prior to concrete placement (Photo No. 32). The weathered clay shales were more highly fractured than the unweathered shales. The clay shales varied from very silty, sandy clay shales to those with high plasticity. When exposed, they slaked rapidly and disintegrated into small fragments. During foundation preparation excavation, they produced most of the drummy rock and unsound fragmental surfaces. Frequently, hand cleaning and air jetting was necessary right up to the time of the concrete pour. The more competent siltstones (Photo No. 29), sandstones (Photo No. 31), and conglomerates were, by contrast, very easily cleaned, except where faults or bedding plane fractures were present at final grade elevation. Most of the bedding plane fractures were at low dip angles and required removal of some loose rock blocks below grade. Excellent cleanup was accomplished by the contractor. Because of fragmentation and weathering of the foundation rock, foundation preparation excavation could not be held to a minimum of 4 inches below grade line. Measurement for payment for foundation preparation was by the yards of concrete necessary to raise the foundation to the specified grade. Overrun of estimated foundation excavations was about 20 percent. From station -0+92 right of centerline and station -0+86 left of centerline to station 0+37, placement of lean concrete was not to job specifications, and it was removed and replaced by the contractor at no additional cost to the Government. All concrete was placed on a dry, sound foundation.

5.2.2. **Outlet Works Foundation Rock:** Bedrock in the outlet works foundation was composed of approximately 50 percent clay shale, 25 percent sandstone, 15 percent siltstone, and slightly less than 10 percent conglomerate, all in the Arapahoe Formation. Depth of excavation into bedrock varied from 0.5 foot in the Coyote Gulch area to 32 feet in the stilling basin area. The clay shales were the less competent rock materials. The siltstones varied from clayey to sandy and were quite competent except where faulted or highly fractured. The conglomerates were soft, clay-bound, and compact. Less competent areas in the bedrock foundation were: (1) A highly fractured clay shale through Coyote Gulch between stations 0+40 and 1+50 (Photos Nos. 33 and 30) and (2) a disturbed clay shale unit from stations -7+05 to -8+00 (Photo No. 34). Although these clay shales are described as less competent than other bedrock types present, they still have adequate strength to support the outlet works and embankment loads.

5.2.3. Nine reverse faults crossed the excavation, four upstream of the main embankment centerline and five downstream. Displacement on the faults was from 4 inches to 20 feet. The faults had preferred northwest strikes with northeast and southwest dips, which range from 18 degrees to 36 degrees. The nine faults are outlined below:

Location on Floor (Sta.)	Strike	Dip	Maximum Displacement Feet
-6+03	N40°W	35° NE	20.0
-5+14 to -5+06	N62°W	34° NE	1.5
-4+39	N74°W	28° NE	19.0
-1+27	N42°W	36° SW	0.5
2+35	N36°W	35° NE	5.0
7+00	N47°W	34° SW	(Considerable but could not be measured)
8+10	N6°W	28° SW	1.0
8+80	N10°E	23° NW	0.3
9+60	N73°W	18° SW	3.2

The fault movement at station -4+39 was rotational since there was displacement of 19 feet on the left face (Photo No. 25) and only 11 feet on the right face of the outlet works trench. In this fault zone, clay or crushed shale varied from 1/4 inch to 1-1/4 inches thick. It was inferred that the fault at station 7+00 had considerable displacement, since it had a 1-1/4-inch gouge zone. The faults with the most displacement crossed the trench nearly normal to centerline. With this attitude, the stability of the side slopes was affected very little.

5.2.4. An important characteristic of the formations in the outlet works trench was the presence of soft seams, which occurred as gouge, very closely fractured or crushed zones, and softer-than-usual seams in the parent material. These soft zones were associated with fat clay shale. Nearly vertical, slickenside fractures were often located above and below the soft seams. In the outlet works excavation they were paper thin to 6-1/2 inches thick. The most well-developed soft seams were in the disturbed shale from stations -7+05 to -8+00 (Photo No. 32). There was a marked decrease in soft seams downstream as dip of the bedding became more gentle.

5.2.5. **Disposition of Water:** Water entered the outlet works excavation from the buried channels of Coyote Gulch through bedrock fractures in the stilling basin trench, and through bedrock fractures on the left side between stations 0+00 to 0+25. Also, some very minor seepage occurred immediately above the overburden-bedrock contact but this flow did not exceed the evaporation rate. Water issuing from the three sandy, gravel-filled buried channels was continuously pumped from the excavation at approximately 10 g.p.m. until backfilling was complete. Water seeped into the stilling basin from fractures in the bottom of the excavation, and from bedrock fractures on the left side of the trench between stations 0+00 to 0+25, at the rate of 1/3 g.p.m. Seepage was pumped from sumps into drainages toward Bear Creek.

5.3. Coyote Gulch Area Foundation Rock: Bedrock surface was below designed excavation grade in Coyote Gulch from stations 0+40 to 1+50 (Photo No. 33). Some overexcavation was necessary in this reach to achieve a firm bedrock foundation. Backfilling with lean concrete raised this section of the foundation to grade. Between these stations, the rock was clay shale with numerous fractures and an occasional soft seam. Bedrock surface was deep where three gravel filled buried channels crossed the excavation between stations 0+70 to 1+35 (Photo No. 30). Many fractures had paper thin layers of clay on their surfaces, inferring small amounts of movement. Three soft seams with 1/16 inch of clay crossed the excavation floor. Weathering was shallow, 1 to 2 feet deep, and the excavation was cut deep enough to ensure that all the floor was slightly weathered rock except between stations 0+90 to 1+10 where it was moderately weathered. Bedrock in the trench had a gentle dip to the northeast from station -6+00 to the downstream end of the excavation. Upstream from station -6+00 the beds dipped at ever increasing angles until they became almost vertical. This extreme change in dip took place in a few hundred feet. The rock units were more fractured and disturbed through this zone. There were numerous soft seams and highly fractured zones which in all cases dipped at the same angles as the bedding planes. Some movement was suspected on most of the soft seams, but the displacement could not be distinguished. A highly fractured clay shale crossed the excavation floor from stations -7+05 to -8+00 (Photo No. 34). The upper contact at station -7+05 was with a sandstone and at station -8+00 the lower contact was with a siltstone. Both the sandstone and the siltstone were more competent and the two thickest gouge zones were near these contacts. Four inches of gouge was noted on the soft seam at station -7+05 with a 1.0 to 1.5 foot, very highly fractured zone on both sides of the gouge zone. The gouge zone had a strike of N46°W and appeared to dip nearly 60°NE. Nine additional soft seams or major fractures crossed the trench in this clay shale bed between stations -7+05 and -8+00. Most had a 1 to 3 foot highly fractured zone associated with them. The soft seams and major fractures dip to the northeast, from 40° to nearly vertical. A highly fractured zone occurred in the floor from stations -7+26 to -7+44 (Photo No. 32). Although the foundation for the intake structure is located where the foundation rock was disturbed and steeply dipping, the allowable bearing capacity of the rock was determined to be 5 TSF, which is well above the maximum computed loading of 2.7 TSF beneath the structure.

5.4. **Main Embankment Area:** The main embankment is situated over essentially horizontal beds of the Arapahoe Formation. However, the upstream toe of the embankment overlies steeply dipping beds of both the Arapahoe and underlying Laramie Formations. The left abutment tie-in overlies the Denver Formation which is stratigraphically above the Arapahoe, see Plate 4. A competent bedrock foundation was exposed during the excavation. Impervious fill was placed on a relatively dry bedrock floor of either siltstones, clay shales, sandstone, or conglomerates. In the excavations where concrete was placed on rock, the clay shales were the most difficult to clean up. The sandstones and siltstones were competent and had few fractures, soft seams and slickensides, so they were cleaned up with ease. Concrete was placed on a dry, sound floor or wall. Very little clay shale was observed in the Pioneer Union Ditch drop structure. Considerable clay shale was noted in the other trenches that received impervious fill. The clay shales contained many fractures, soft seams, and slickensides. Weathered clay shales were more highly fractured than those that were unweathered. Variations in plasticity were extreme and usually changed within a unit, both laterally and with depth. The clay shales with the higher plasticity were the most fractured. Therefore, the most incompetent rocks on the site were highly weathered, high plasticity clay shales. Sandstone units of all of the formations varied considerably in character. Generally they were fine-grained, bound by clay or silt size particles, and very compact. They were cemented either partially or completely by calcite, silica, or other cementing agents. The sandstones were either permeable or nearly impermeable depending on the degree of cementation and intermixed fines. These sandstone beds were sheet deposits and channel deposits, with the channel deposits containing coarser material. A few thin zones of clean loose sand were encountered; these were noted in boring logs as clean uncemented sandstone. Highly weathered rock was usually only about 1 foot thick but was several feet thick in isolated instances. Rock units, in general, were not highly jointed or fractured. Highly fractured zones occurred most commonly in clay shale. These zones varied from very thin to throughout the entire clay shale bed. Most fracturing of the Arapahoe beds in this area appeared to be related to regional tectonic forces. Since clay shale layers were weaker and less competent than the sandstones and siltstones, more adjustments occurred within them. The possibility exists that there may be undiscovered "soft seams" within the clay shale beds. Faults at this site were difficult to locate due to the many crushed, fractured, and slickenside zones between beds and due to the rapid change of material typical of continental deposits. The main embankment was also founded on overburden. This material in the valley was valley alluvium generally consisting of silty sandy gravel. This material averaged about 15 feet in thickness. It contained cobbles and boulders. A thin zone of clayey sand generally covered the gravel material.

5.4.1. <u>Left Abutment Tie-in Area</u>: The left abutment tie-in is located in an area consisting of Denver Conglomerate. This conglomerate contains basalt and granite cobbles, well cemented in a sandy matrix. The formation was near-horizontal and contained sandstone phases. Below the highly weathered zone, this unit had few fractures. Vertical fractures were widely spaced but prominent. Overlying soil material appeared to be mainly soil derived from bedrock, with some sand and gravel. Soil material, which was a gravelly, sandy clay, was very thin in DH-30 and was only 6.4 feet thick in DH-67. Water levels in these two borings was about 23 feet below ground surface as shown in the Record of Borings. In a brief falling-head test the water level brought to the top of the hole dropped 4.2 feet in 2 hours. Hole depth was 103.7 feet. It does not appear that the conglomerate was very permeable from the results of this test, especially in view of the 18 feet of highly weathered material at the top of the hole which may have taken most of the water.

5.4.2. **Left Abutment Area:** The left abutment is made up of Arapahoe sandstone, siltstone, and clay shale. The bottom of the Denver Conglomerate was considered as the top of the Arapahoe and is not present between DH-67 and DH-29. Dip of the beds as measured between DH-69 and DH-70 amounted to a little more than 10 feet of drop in 400 feet to the northeast. Bedrock was highly weathered for a thickness of 2 to 5 feet. Weathering was as thick as 10 feet in isolated areas, depending on the type of rock and degree of fracturing. Some well cemented layers or concretions were encountered in the sandstone units. Fracturing, as in other areas of the damsite, varied by zone or type of rock material. Near surface rock is generally more fractured than deeper rock. Water levels in the borings showed that water occurred in the alluvial material a few feet below the surface, although the water level in bedrock might have been different. Drill hole DH-16 had a water level 30 feet below surface on 10 March 1971. Drill hole DH-62 had a water level 50 feet below surface on 15 May 1972. These holes had casing down to clay shale, so water from the soil material was sealed out and they indicated water levels only in the rock material. Pressure tests showed that the rock had a low permeability, but it must be emphasized that more permeable channels in sandstone units are possible.

5.4.3. **Right Abutment Area:** The right abutment is made up of the Arapahoe Formation. The general nature of this material has already been given. Attitude of the beds is near horizontal, although they are steeply dipping a short distance upstream. Thickness of highly weathered rock in DH-93 was about 10 feet. In DH-144 the zone of highly weathered rock was 3 feet thick. The fractured nature of rock in this area follows previous descriptions of this material. DH-144 and DH-145 were drilled to double check correlation between DH-17 and DH-32 (refer to Plates 94, 73, and 76) for assurance that a knob on the right abutment was not an old slump block. Soil material on this abutment was a thin covering of slope wash over bedrock. Water levels in the borings on the right abutment were quite deep, 124 feet in DH-145, which was close to the ground-water level in the valley. Pressure tests in DH-17 did not show the formation at this location to be very permeable.

5.5. <u>Spillway Area:</u> The spillway is made up of rocks of the Denver, Arapahoe, and Laramie Formations. The Arapahoe - Laramie contact was at the far western end of the spillway excavation at station 22+00. The Arapahoe - Denver contact was near station 31+25 at the toe of the north slope. Therefore, roughly the western one-quarter of the spillway is made up of Arapahoe and Laramie beds. They are steeply eastward-dipping beds of siltstone, sandstone, and clay shale with a few thin lenses of conglomerate. This represents the remains of the east flank of a huge anticline or monoclinal fold involved in the front range uplift. Near the base of the Denver Formation the beds become nearly horizontal in a matter of a few hundred feet. The steeply dipping beds of the Arapahoe are highly fractured and contain numerous soft seams, especially where the abrupt change in the dip of the beds takes place. The rest of the spillway to the east (roughly three-quarters) is made up of a thick bed of moderately to well cemented conglomerate of the Denver Formation. The principal cementing agents are minerals of the zeolite group. The rock in the spillway east of the basal conglomerate consists of alternating beds of siltstone, sandstone, clay shale, and a few thin conglomerate beds. Eastward from the Denver - Arapahoe contact the unweathered rock required considerable blasting, heavy-duty ripping, and secondary breakage.

5.6. <u>Impervious Blanket Area:</u> The upstream impervious blanket of clay covers the upturned ends of high angle beds that cross the valley. (See Plate 6). They are highly fractured and contain numerous soft seams. These discontinuities cross the valley rather than paralleling it. The impervious blanket area north of the left abutment curves toward the dam centerline and ties into the clay core of the dam between stations 33+00 and 34+00. In this area, there is an abrupt change in the attitude of the beds from near vertical to horizontal. On the right abutment the impervious blanket covers the side of Mt. Carbon from centerline to 1,000 feet upstream and from the valley up the slope to elevation 5684. The western two-thirds of the beds are steeply dipping and the eastern one-third is gently dipping. Exposed beds are of the Arapahoe Formation except for a small wedge of Laramie beds on the far upstream edge of the Mt. Carbon impervious blanket area which extends into the valley floor to station 17+50, 960 feet upstream.

5.7. **South Embankment Area:** Rock in the conduit trench excavation was about 25 percent siltstone in the eastern one-quarter and 75 percent shale in the western three-quarters. The Laramie, Fox Hills, and Pierre Formations strike N. 45° W. and dip 77°NE through vertical to 73°SW. The siltstone was sandy, moderately weathered with few fractures at floor elevation, and quite competent. The shale had high plasticity, contained many bedding plane fractures, and was moderately weathered at floor elevation. This shale was the least competent bedrock in the south embankment area. Numerous very thin ironstone and limestone stringers were noted in both the shale and siltstone parts of the trench. Their attitude was the same as the shale and siltstone, dipping steeply from 77°NE through vertical 73°SW, with a strike of about N. 45°W. Most of these stringers were highly fractured and in the western one-third of the trench produced seepage. This caused a small dewatering problem prior to placing of No. 2 bedding material.

5.7.1. **Laramie Formation:** Approximately 600 feet of the inspection trench from the left abutment towards the center of the south embankment, stations 22+00 to 16+00, exposed the Laramie Formation. It consisted of alternating beds of clay shale and sandstone with several very thin coal seams. The beds strike N. 45°W. and dip steeply at 75 to 80°NE. In this part of the excavation, sandstone beds made up two-thirds of the bedrock. One-third of the rock was clay shale, with the coal seams making up considerably less than 1 percent of the rock. The clay shales were medium gray in color, about medium plastic, and occasionally carbonaceous. The fractures mostly followed the bedding planes, were tight, and often cemented with calcium carbonate. The sandstone beds were light gray or light brown in color with a salt and pepper appearance and were fine grained. It was estimated that they contained over 20 percent fines. Many tight bedding plane fractures were observed and many were cemented with calcium carbonate. Weathering occurred in the clay shales and sandstones as follows: The top 1 to 2 feet was highly weathered; the next 4 to 5 feet was moderately weathered; and when bedrock was excavated deeper, the balance of the rock excavated was slightly weathered to the floor of the trench. The coal seams were only a few inches thick and were so highly weathered in the trench that they were impervious.

5.7.2. **Fox Hill Formation:** The next 300 feet from approximately stations 16+00 to 13+00 in the right embankment inspection trench was the Fox Hills Formation. In this part of the inspection trench the strike of beds was N. 45°W. The lower part of the Fox Hills was exposed at station 13+00, and the strike of the beds was N. 40°W. The rock consisted of interbedded brown shale, siltstone, and sandstone dipping 75° to 80° to the northeast. The upper and lower contacts were gradational. It was estimated that about one-half of the formation was shale, a little less than one-half sandstone, and about 5 percent was siltstone. The shales were dark brown and medium plastic. Many bedding plane fractures were observed which were tight and often cemented with calcium carbonate. The sandstones were light brown, very fine-grained, and contained many tight bedding plane fractures. It was estimated that they contained more than 20 percent fines. Weathering of bedrock was noted as follows: The top 2 feet was highly weathered and the next 4 feet was moderately weathered. Where the trench was excavated deeper than 6 feet into rock the balance of bedrock to the floor was slightly weathered. The siltstone stringers were very thin and varied from clayey to sandy.

5.7.3. **Pierre Formation:** The bedrock in the rest of the right embankment inspection trench, from the right abutment to somewhat beyond the center of the dam (station 13+00 to station 0+45), was composed of beds of the Pierre Formation. The beds dipped very steeply, from 74° to almost vertically to the northwest, and had a strike of N. 45°W. The trend of the beds across the trench was at an angle of 60° to the trench centerline near the Fox Hills contact and nearly perpendicular to the centerline after centerline passed the point of curvature and straightened out to the right abutment. The centerline trend at the Fox Hills contact was N. 20°E, and centerline trend from the point of curvature to the right abutment was N. 48° 43°E. Most of the Pierre Formation in the excavation was in the upper transitional part of the Pierre. It was estimated that a little over 75 percent of the rock in this part of the trench was shale, slightly less than 20 percent was siltstone, and about 5 percent was sandstone. Thin limestone and ironstone seams up to a few inches thick were found throughout this part of the trench. These seams had the same attitude as the shale, siltstone, and sandstone. Most of the shale was dark brown and was highly plastic. Many tight bedding plane fractures were observed, some of them filled with aragonite. The rocks of the Pierre in the trench were highly weathered for about the top 5 feet. The remaining rock beneath this depth was moderately weathered. Near the center of the inspection trench (station 8+00 to station 12+00), where the top of rock was the lowest in elevation the shale exposed was wet to saturated. This was due to water seeping down slope from an irrigation ditch at a higher elevation. Sandstones noted in the Pierre were light brown and contained over 15 percent fines. The siltstones ranged from sandy to clayey and appeared to be quite competent.

CHAPTER VI - FOUNDATION TREATMENTS

6.1. **Foundation Drains:** Eighteen drains inclined 60° from horizontal were drilled beneath the Pioneer Ditch drop structure floor slab. These drains were installed to relieve any uplift from induced bedrock pore pressure. Caissons Inc., drilled the 17-inch diameter drain holes with an auger utilizing a Williams rotary drill. The holes were drilled a depth of 31 feet during the period of 27 February 1976 and 1 March 1976 to elevation 5450.5. H. W. Siddle Inc., started installing drains on 1 March 1976. The Contractor placed a plastic pipe to the bottom of the drain holes and flushed them with clean water until the return was clear. Then Schedule 40, 4-inch diameter PVC drain pipe was set in the hole to elevation 5451.5, a depth of 30 feet. Three centering devices located at depths of 29, 24, and 12 feet were used to center the pipe. The drain pipe had 3/8-inch diameter perforations on 120° spacing, with 18 holes per linear foot of pipe. The drain pipe consisted of a 20-foot length and 10-foot length joined with a Schedule 40 cement type coupling. Next, the filter material was placed by a tremie made of 4-inch PVC pipe. Filter material was washed through the tremie pipe with a constant flow of water, beginning 1 foot above the hole bottom. The tremie pipe was moved up the hole approximately 1 foot at a time until the hole was filled with filter material. The filter material met Colorado Highway Department specs. No. 67 for gradation. Very little caving was experienced in the holes, as evidenced by the wash water cleaning up rapidly. No difficulty was noted getting the 4-inch PVC drain pipe to the bottom of the holes. Completion of drain installation was on 9 March 1976.

6.2. **Outlet Works Drains:** Eighteen drains inclined 60° from horizontal were drilled through clay shale, siltstone, and sandstone beneath the stilling basin concrete floor slab to relieve any possible uplift pressure from induced bedrock pore pressure. Amidon Drilling Co., subcontractor, augered the 10-inch holes on 15 and 16 September 1975. Centric Construction Co., installed the 4-inch diameter, perforated, Schedule 80 PVC drain pipe on 19 September 1975. Prior to placing the drain pipe, each hole was flushed clean with water through a 2-inch pipe inserted to within 1 foot of the bottom of the drill hole. The bottom of holes was at elevation 5460. The installed drain pipe was factory perforated with 3/8-inch holes in four rows on 4-inch centers (Photo No. 37). The pipe had centering devices at 9-foot intervals. All drains were installed by 23 September 1975.

6.2.1. **Filter Material:** The specified filter material was changed by field modification from a well graded sand and gravel with 80 percent passing the 3/8-inch size to a uniformly graded fine gravel with 5 percent to 15 percent passing. This change was made to eliminate the possible entry of large amounts of filter material into the drain pipe through the 3/8-inch perforations. Since only 7 yards of material was required, a readily available material was approved for placement that approximated the required specification. The filter material used was somewhat finer with 23 percent passing the 3/8-inch screen.

6.2.2. **Water Levels:** After drilling the holes, water levels stabilized between elevation 5478 and 5479. This area had been dewatered since June 1975; therefore, water levels were expected to rise when dewatering was discontinued.

6.3. **Sealing Water Wells:** Abandoned water wells encountered in the outlet works excavation and work areas were sealed by subcontract with Halliburton Services of Denver, Colorado. They were sealed to prevent possible future contamination of the ground-water aquifers in accordance with regulations specified by the State of Colorado, Division of Water Resources.

6.3.1. **Procedures:** The well casing was cut off slightly below grade. The well was then inspected for blockages by lowering a string of drill pipe into the well. The wells were sealed with Portland cement grout using a water-cement ratio of 1 to 1 by volume. The wells were grouted from the bottom upward by tremie pipe.

6.3.2. The locations of the four wells sealed by this contract are shown on Plate 63. Known data on the sealing is listed below:

Well Designation	Original Sealed	Grouted Depth	Date Sealed	Grout Required
Davis Well	90 Ft.	62 Ft.	11/29/74	17 Sacks
Yarger Well	1282	1176	11/27/74	200 Sacks
Moritz	180	180	11/29/74	34 Sacks
Garen	-	72	11/29/74	19 Sacks

It required 270 sacks of cement to seal a total of 1,490 linear feet. Prior to grouting, a suite of geophysical logs was run in the Yarger well by the Missouri River Division Laboratory. Some of the logs were run to a depth of 900 feet. The logs were made to assist in future correlation of the formations underlying the project. The types of logs made include SP, Resistivity, Caliper, Gamma-Gamma, and Neutron.

6.4. **Grouting of Prairie Dog Holes:** In a study conducted in South Dakota, prairie dog holes were observed up to 109 feet in length. A prairie dog colony existed in the south embankment foundation area. In order to prevent piping through the dam foundation by an interconnected network of prairie dog holes, the holes were grouted. In the fall of 1974, the Corps of Engineers conducted a study of the prairie dog holes in the dam foundation area. A drill crew experimented with cement-bentonite mixtures that contained a minimum amount of water to allow the smallest amount of shrinkage of the grout when it cured. Four prairie dog holes were chosen to be grouted. Prior to grouting, water and liquid detergent were poured into the holes to evict the prairie dogs. Then a small diameter flexible pipe was inserted into the hole as far as possible, and grout was pumped into the hole till it was full, using a 4-inch Gardner-Denver piston pump. After the four test holes were grouted, the borrow system was exposed with a backhoe, and the grouting was found to be effective in sealing the holes.

6.4.1. **Contractor Methods in Grouting Prairie Dog Holes:** Prior to 9 August 1975, when stripping of the south embankment foundation was started, the prairie dog holes within and adjacent to the foundation area were grouted. A bentonite-cement grout mixture was used to fill the holes and its contents are listed below:

1 sack cement (94#)

1 sack bentonite (100#)

60 gallon of water

The cement and bentonite were mixed prior to hydration. Sixty gallons of water was the minimum amount that could be used and still have a pumpable grout. Grouting of the holes progressed from the holes that were the highest in ground elevation to the lowest to facilitate gravity flow. The holes were regrouted a second time to ensure the holes were filled with grout. The top of grout had subsided in some of the holes, so this proved to be a good procedure. A total of 610 holes were grouted with 235 sacks each of bentonite and cement. Observations of grouted holes after stripping had taken place showed that the grout was in good condition and all the voids were filled.

6.5. **Pervious Materials:** Processed pervious materials were required for the chimney drain, the downstream drainage system, the upstream pervious blanket, and the gravel road surfacing material on the main embankment. Pervious fill was used in the south embankment for the downstream drain and bedding for the conduit. Pervious No. 1, No. 3, and gravel road surfacing material were obtained on the site. Pervious No. 3 was obtained from an aggregate supplier that processed material on the site prior to acquisition by the Corps of Engineers. The contractor did not reprocess this material. The 36,000 yards of pervious No. 3 material used in the upstream pervious blanket in the left abutment represented a small percentage of the total. The 7240 yards of gravel road surfacing material processed from Borrow Area No. 4 also represented a small percentage of the total pervious material processed. Approximately 553,000 yards of pervious No. 1 material represented the bulk of the pervious material used. It was processed overburden from Borrow Areas No. 2, No. 3, and No. 4, the impervious blanket trench, and Coyote Gulch drain trench. Oversize cobbles and boulders were used for riprap in the outlet works discharge channel.

6.5.1. **Gradation of Materials:** Materials for compacted pervious fill consisted of clean sands or sands and gravels obtained from natural deposits. These materials were reasonably well-graded within the following limits:

Pervious Fill No. 1

Sieve Size	Percent Passing
3"	100%
3/4"	70% - 95%
No. 16	30% - 70%
No. 200	0% - 5%

Pervious Fill No. 2

Sieve Size	Percent Passing
6"	100%
3/4"	50% - 100%
No. 16	20% - 70%
No. 200	0% - 15%

Pervious Fill No. 3

Sieve Size	Percent Passing
2"	100%
3/4"	75% - 85%
No. 16	40% - 50%
No. 200	0% - 16%

Gravel Road Surfacing Material

Sieve Size	Percent Passing
2"	100%
1-1/2"	90% - 100%
3/4"	50% - 90%
No. 4	30% - 50%
No. 200	0% - 8%

CHAPTER VII - RECOMMENDATIONS

7.1. **Settlement Under the Structures:** Although the foundation design is conservative and no excessive settlement is anticipated, monoliths founded on weaker portions of the foundation rock should be monitored. Specific areas include: (1) The Coyote Gulch area, (2) the area of soft seams between stations -7+05 and -8+00, and (3) areas near the faults listed in Section 3.7.

7.2. **Stilling Basin Drains:** The inclined stilling basin floor slab drains should be checked periodically to assure that they remain open and function properly.

7.3. **South Embankment:** A small amount of settlement may occur in the western three-quarters of the south embankment conduit when it is loaded with embankment material. This area will be only rarely covered with low hydrostatic heads. When this does occur, seepage through the foundation under the embankment should be very small, since the foundation is relatively impermeable (See Par. 3.7.3.1.). This area should be observed for signs of slumping after or during high pools above elevation 5673.

7.4. **Mine Area:** The exploration and sealing operations are sufficient to assure no structural hazards to the dam or to the safety of the public. A piezometer into the main coal seam and two or three piezometers in the right abutment between the mines and centerline are recommended, along with monitoring of the area for subsidence.

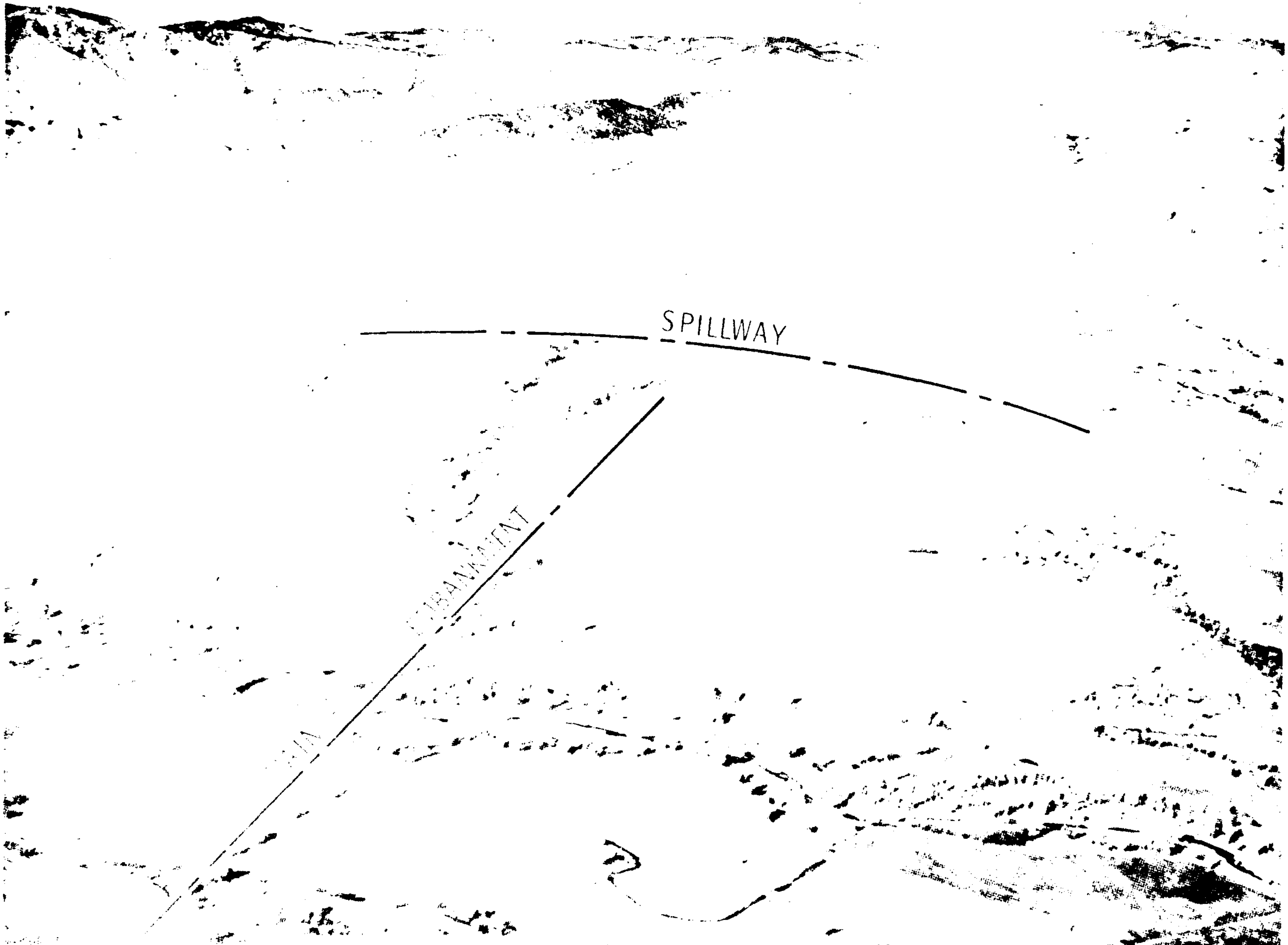

PHOTO NO. 1. Aerial view of preconstruction

PHOTO NO. 2. Aerial view of preconstruction

PHOTO NO. 2a. 1969 Aerial photograph

PHOTO NO. 3. Outlet works grubbing and stripping Sta. 0+75, 50' rt. looking north. 7/8/74

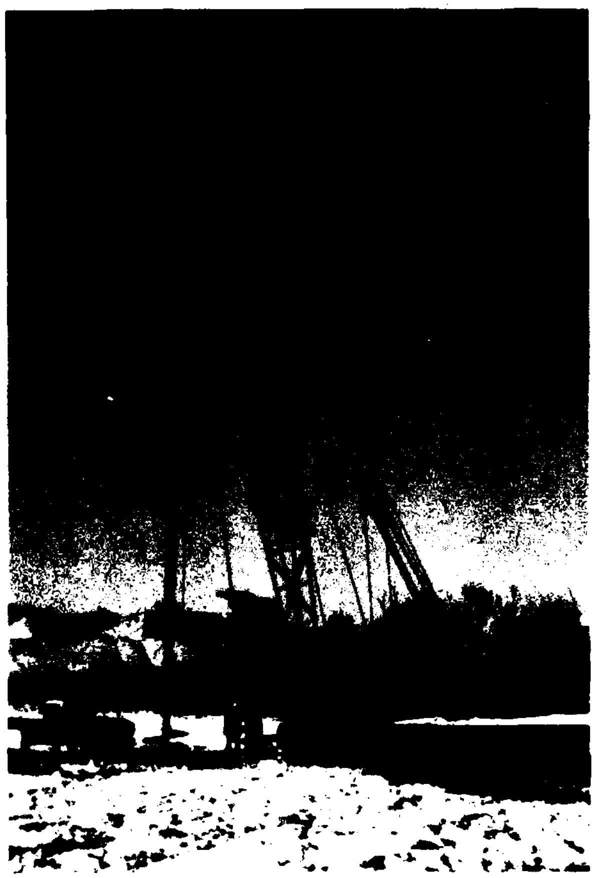

PHOTO NO. 4. Hole D-2 being drilled with a crane mounted drill. 12/4/73

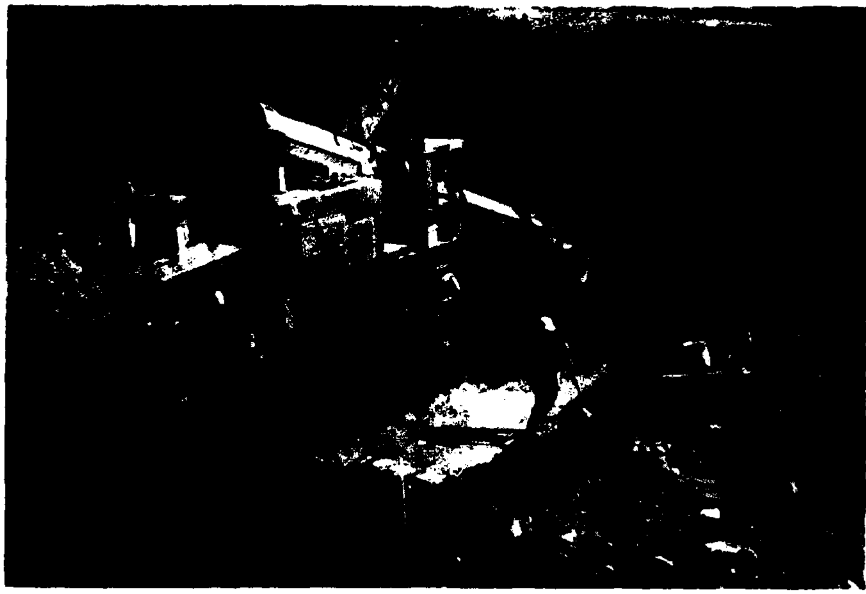

PHOTO NO. 5. Cleaning outlet works floor,
Sta. 0+37 to 0+10. Looking northeast.
9/3/74

PHOTO NO. 6. Filling prairie dog holes with grout,
using Azar piston pump. Looking
west. 8/1/75.

PHOTO NO. 7. Augering 10" drain holes in outlet works stilling basin. Looking northwest. 9/15/75

PHOTO NO. 8. Placing clay in impervious core zone, el. 5528. Looking south. 7/29/77

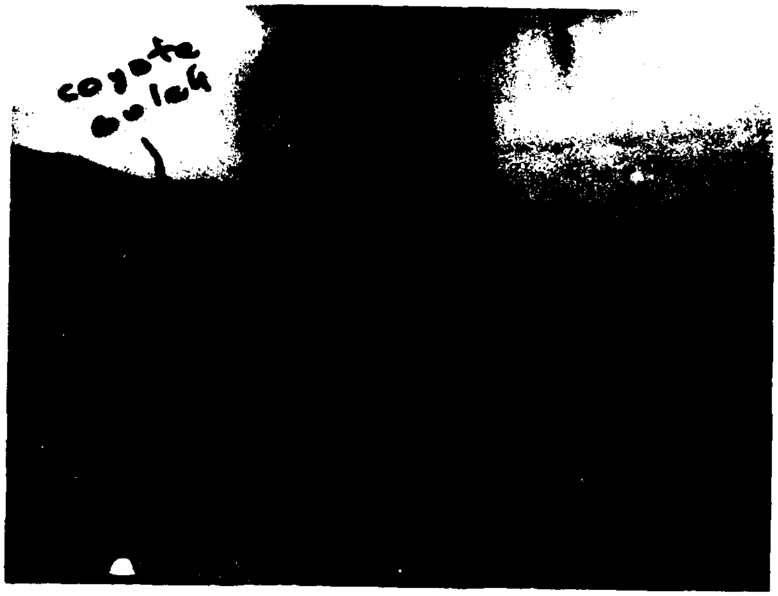

PHOTO NO. 9. Loading blasted conglomerate from spillway into scrapers. Looking northwest. 9/16/77

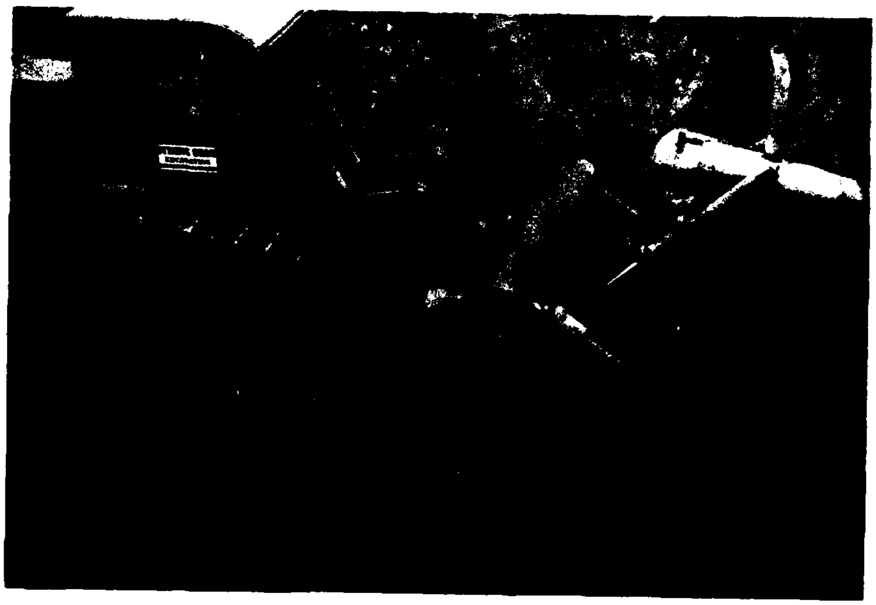

PHOTO NO. 10. Ripping conglomerate in outlet works, sta. 4+50, el. 5511. Looking north.

PHOTO NO. 11. Test pit to locate lignite seams.
Sta. 1+00 to 1+55, tape at el. 5667.3.
7/17/74

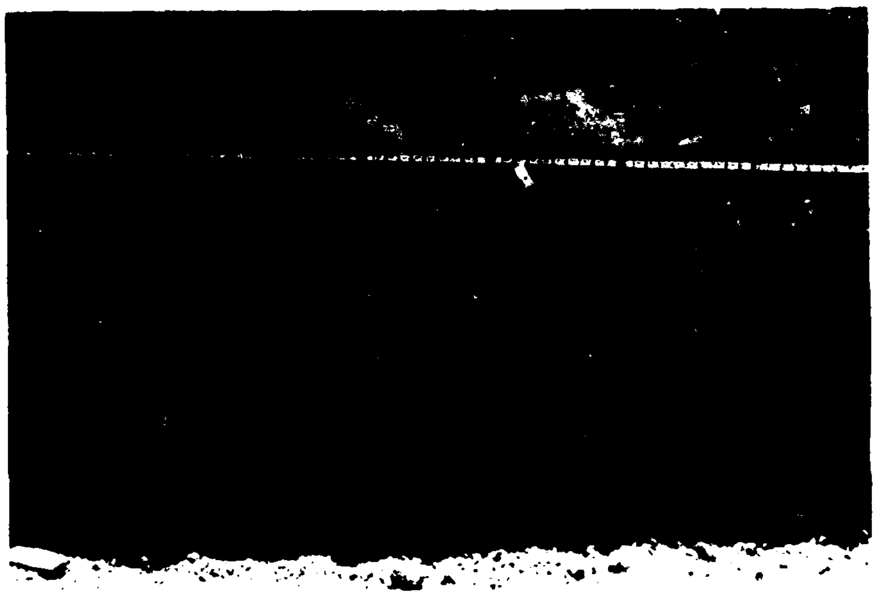

PHOTO NO. 12. Test pit, overturned beds from
Sta. 5+83 to 5+87. Alternating sand-
stone and shale. Looking south.
7/19/74

PHOTO NO. 13. Outlet works floor cleaned from Sta. 0+37 to -0+05, aero-spray binder being applied. 9/3/74

PHOTO NO.14. Outlet works floor, Sta. 0+00 to -0+40, primarily sandstone with a few fractures. Looking northeast. 9/4/74

PHOTO NO. 15. Outlet works floor, Sta. -0+42 to 0+00, cleaning nearly comple... Looking northeast. 9/4/74

PHOTO NO. 16. Outlet works floor, Sta. -1+26 to end of Keyway. Looking north. 9/10/74

PHOTO NO. 17. Outlet works floor sprayed with binder and covered with straw and plastic insulation. Sta. -3+34 to -4+10. Looking northeast. 11/22/74

PHOTO NO. 18. Reverse fault in outlet works at Sta. -5+14, with 1.5' displacement on left face. Looking north. 3/14/75

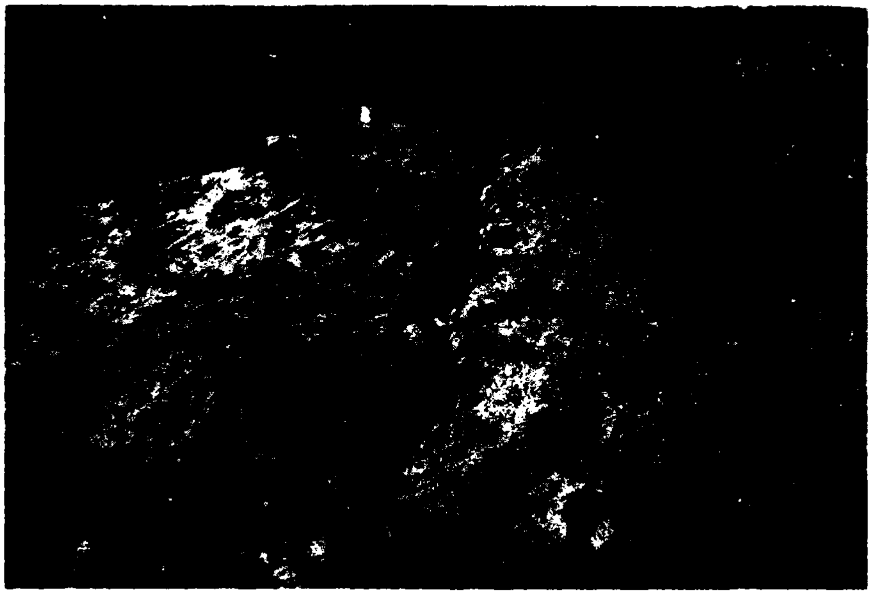

PHOTO NO. 19. Soft seam crossing floor of outlet works, from Sta. -7+44 to -7+41. Looking northwest. 3/24/75.

PHOTO NO. 20. Sandstone floor from Sta. -6+15 to -6+65 of outlet works. Looking northeast. 3/31/75.

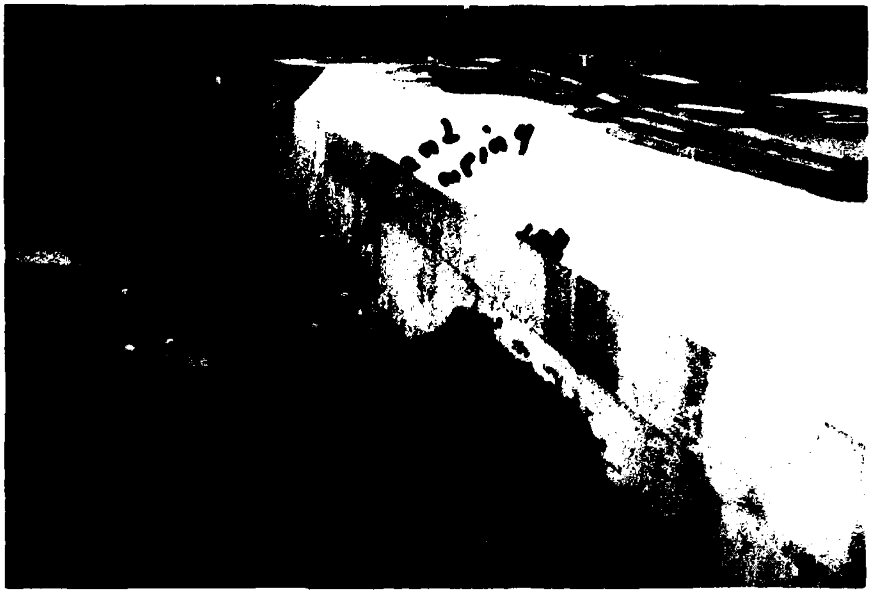

PHOTO NO. 21. Placing impervious material on the right side of monolith #31, outlet works. Looking west. 4/9/75.

PHOTO NO. 22. Outlet works floor, Sta. 7+00 to 7+60, entirely in shale. Water seeping along fault. Looking northwest. 4/22/75.

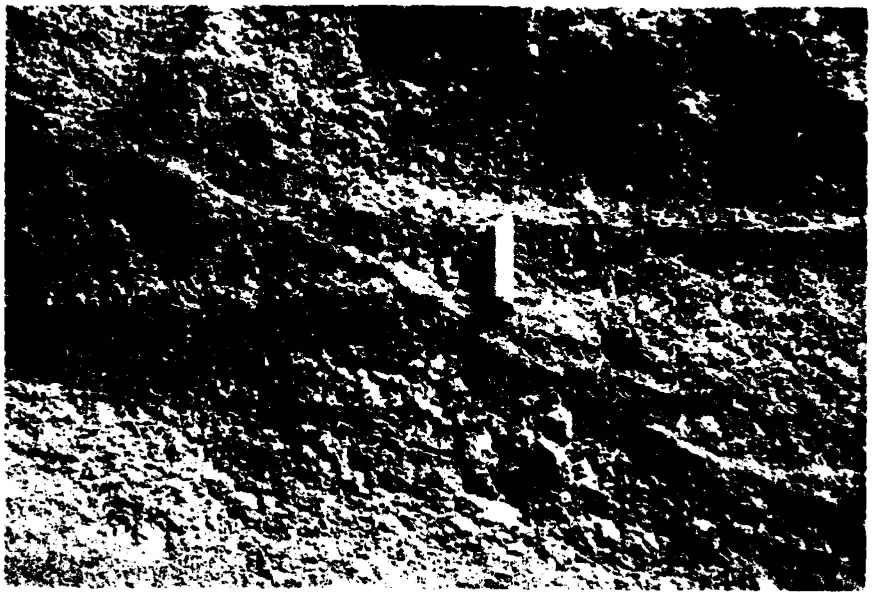

PHOTO NO. 23. Fault with 1' displacement on right face, Sta. 8+33, el. 5503. Looking south. 4/24/75.

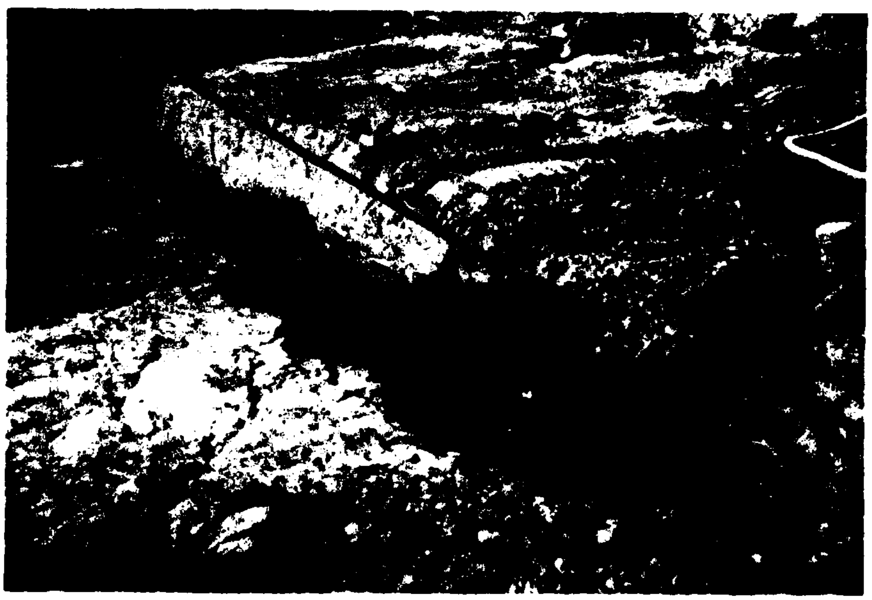

PHOTO NO. 24. Outlet works keyway at Sta. 10+68, near siltstone-shale contact. Looking northeast. 9/8/75.

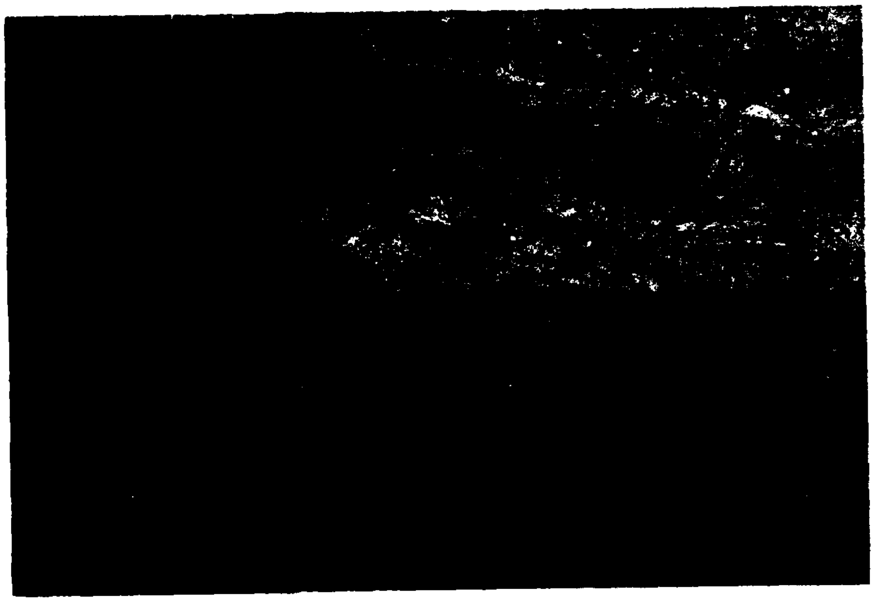

PHOTO NO. 25. Reverse fault with 19' displacement onleft face of outlet works trench. Looking north.

PHOTO NO. 26. Backhoe breaking up conglomerate at Sta. 3+00, outlet works trench. Looking northeast.

PHOTO NO. 27. Cold weather protection for outlet works monolith #25. Looking southeast.

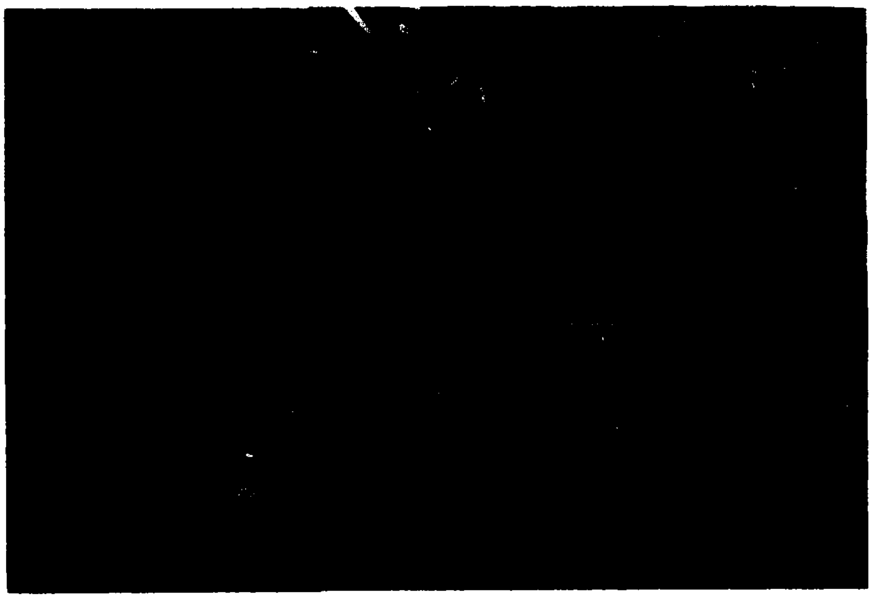

PHOTO NO. 28. Alternating sandstone and siltstone lenses in outlet works floor, Sta. -2+64 to -3+36. Looking northeast.

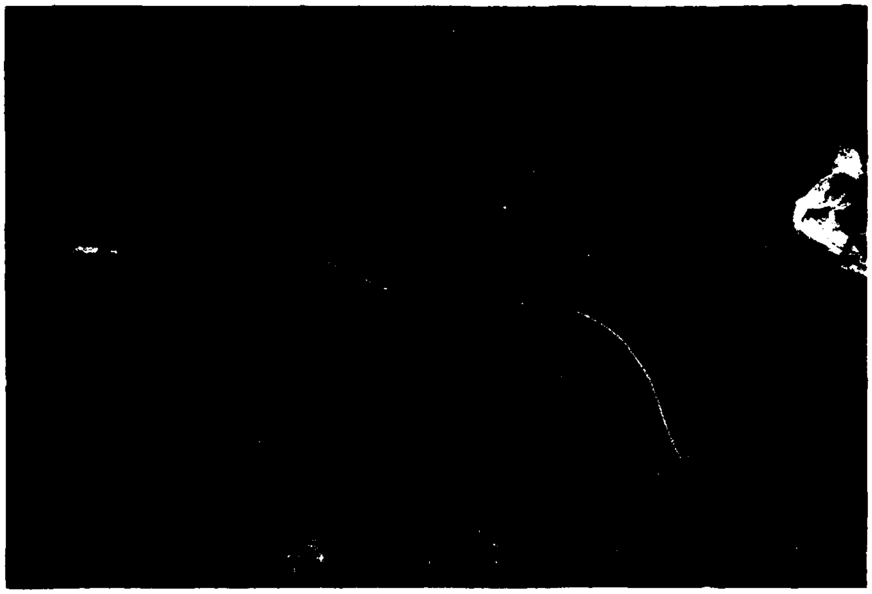

PHOTO NO. 29. Siltstone in outlet works floor, Sta. -4+60 to -4+80. Looking north.

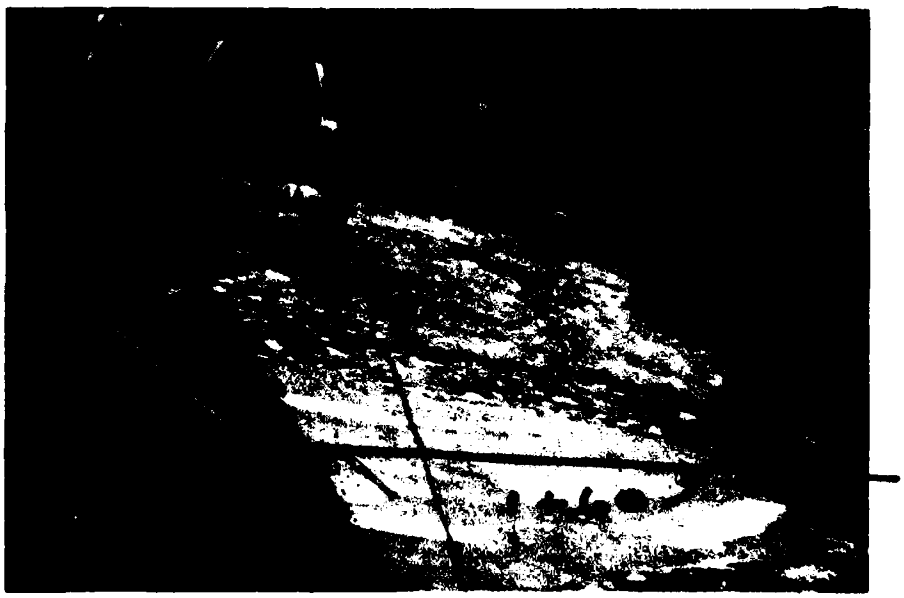

PHOTO NO. 30. Outlet works floor near Coyote Gulch, Sta. 1+09 to 1+60. Looking northwest.

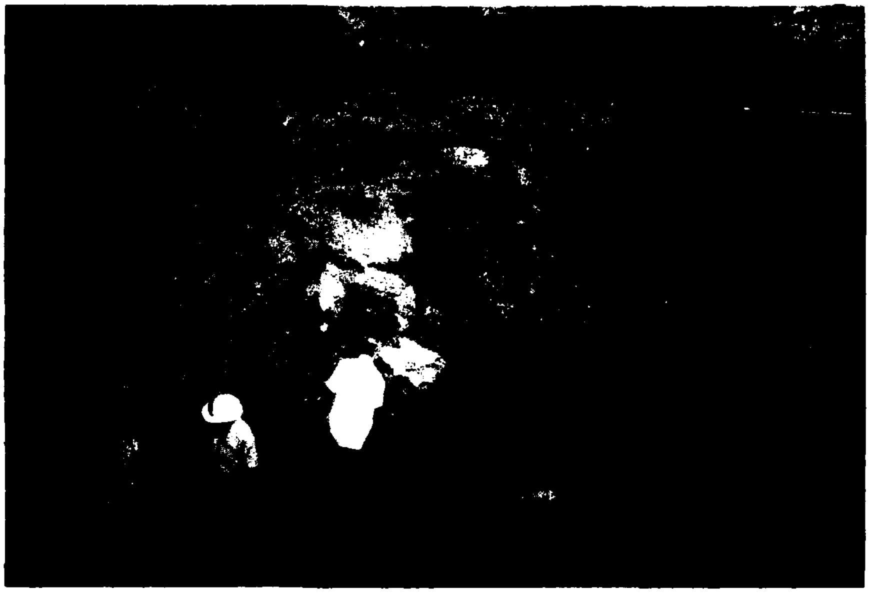

PHOTO NO. 31. Sandstone in outlet works floor, Sta. -0+50 to -0+74. Looking northeast.

PHOTO NO. 32. Highly fractured shale zone in outlet works trench, Sta. -7+26 to -7+44. Looking northwest.

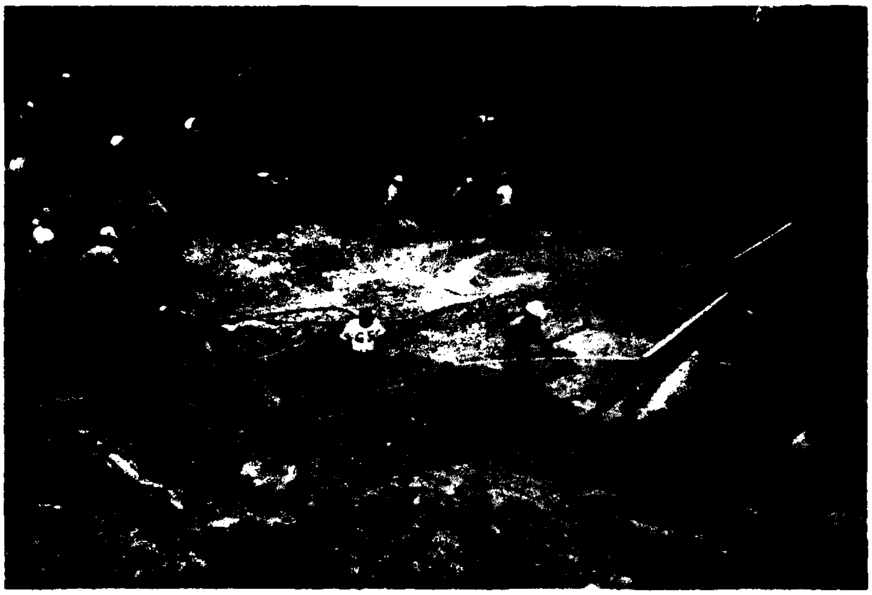

PHOTO NO. 33. Hand cleanup of outlet works floor in Coyote Gulch area, Sta. 0+65 to 1+09. Looking northeast.

PHOTO NO. 34. Highly fractured shale zone in outlet works, Sta. -7+85 to -7+80. Looking south.

PHOTO NO. 35. Sealing fractured shale zone at Sta. -7+87. Looking south.

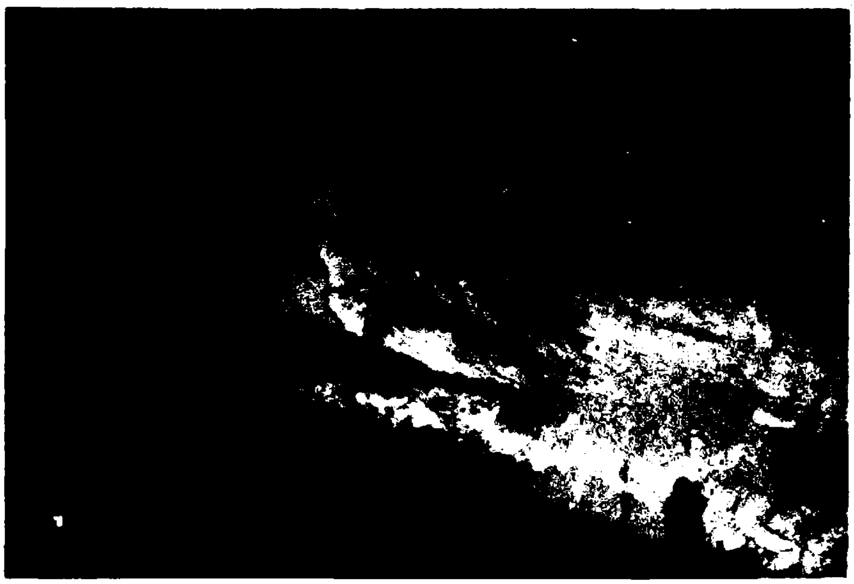

PHOTO NO. 36. Bending of sandstone unit on left face of outlet works trench, Sta. -6+77 to -7+20. Looking northwest.

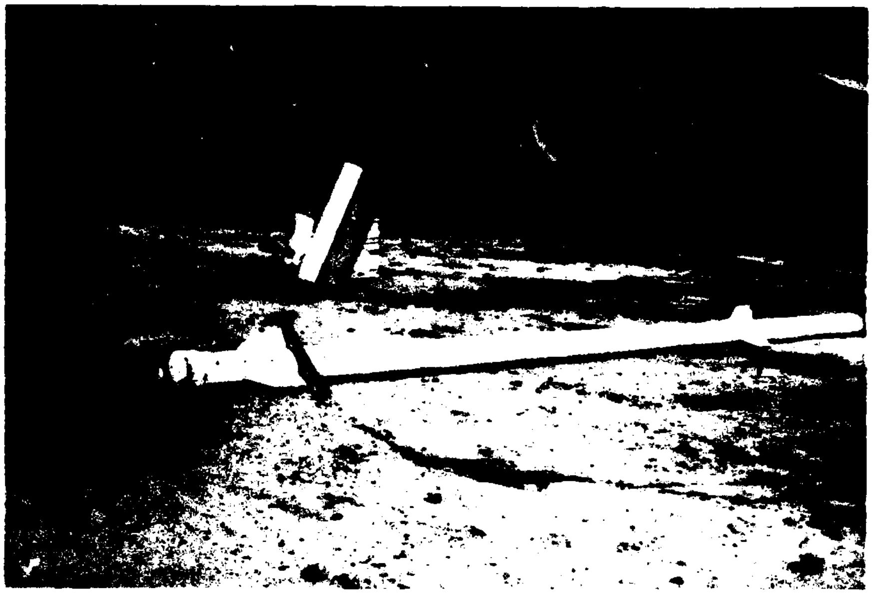

PHOTO NO. 37. Four-inch pvc drain pipe used in outlet works stilling basin drains. Looking northeast.

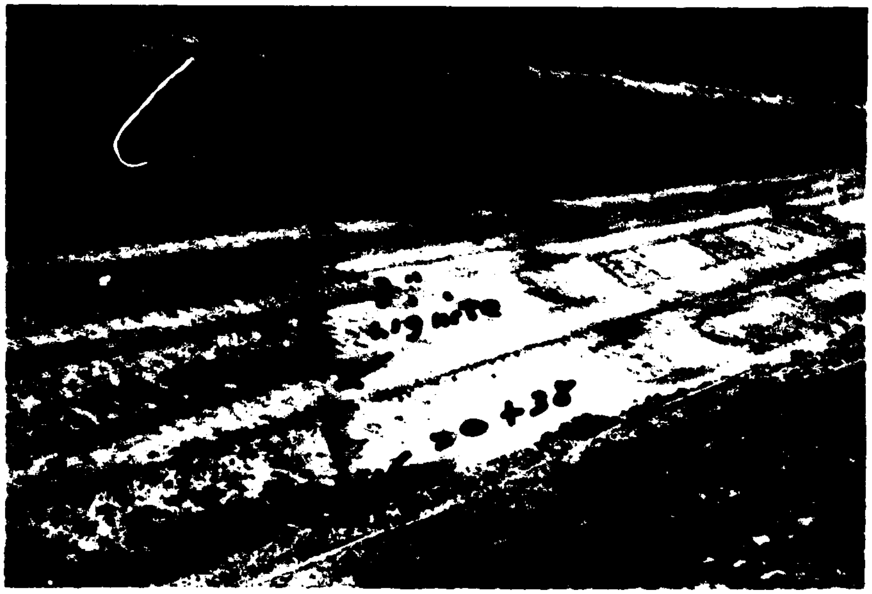

PHOTO NO. 38. Highly weathered lignite seam crossing south embankment trench, Sta. 20+38 to 20+14. Looking southeast.

PHOTO NO. 39. Bending of shale, sandstone and siltstone beds in south embankment trench, Sta. 12+35 to 12+70. Looking south. 9/9/75.

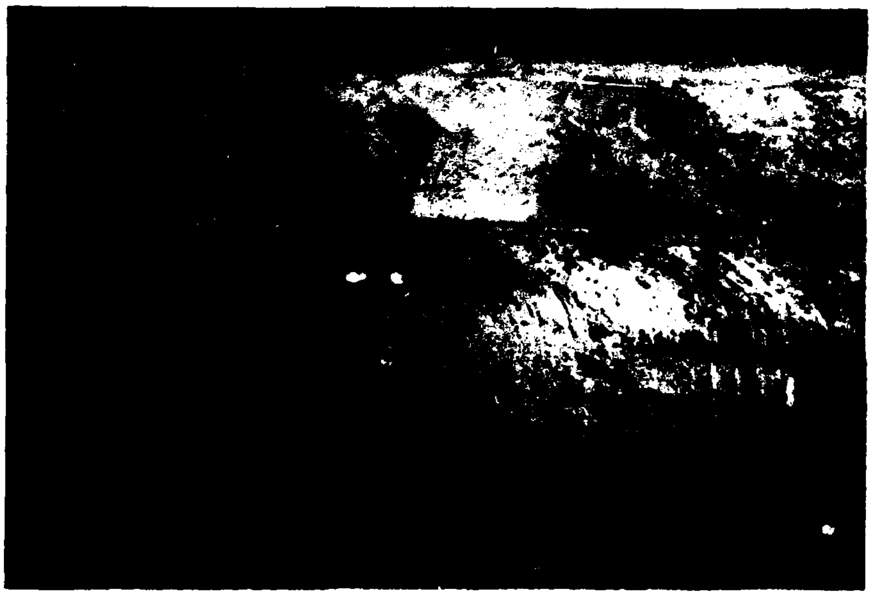

PHOTO NO. 40. Two grouted prairie dog holes in sou.h embankment trench at Sta. 11+97, el. 5615. Looking west.

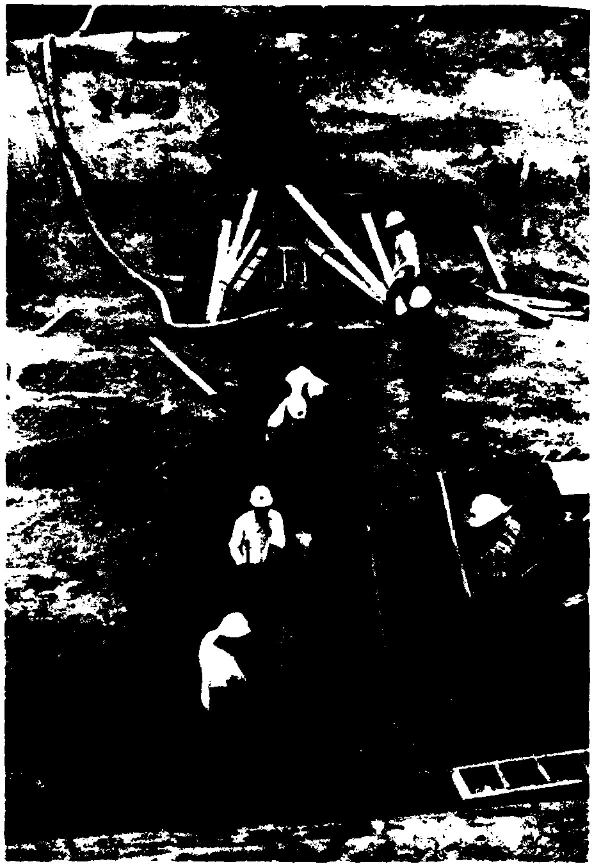

PHOTO NO. 41. Dental cleaning of shear zone across south embankment trench. Sta. 9+03 Looking northwest. 9/16/75.

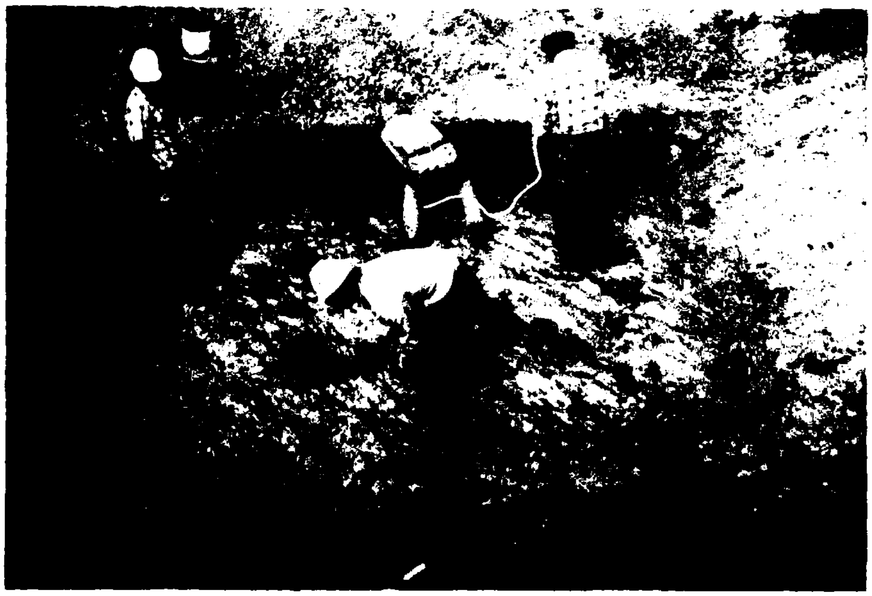

PHOTO NO. 42. Placing sikaseal on to north face of south embankment conduit trench. Looking northwest. 10/30/75.

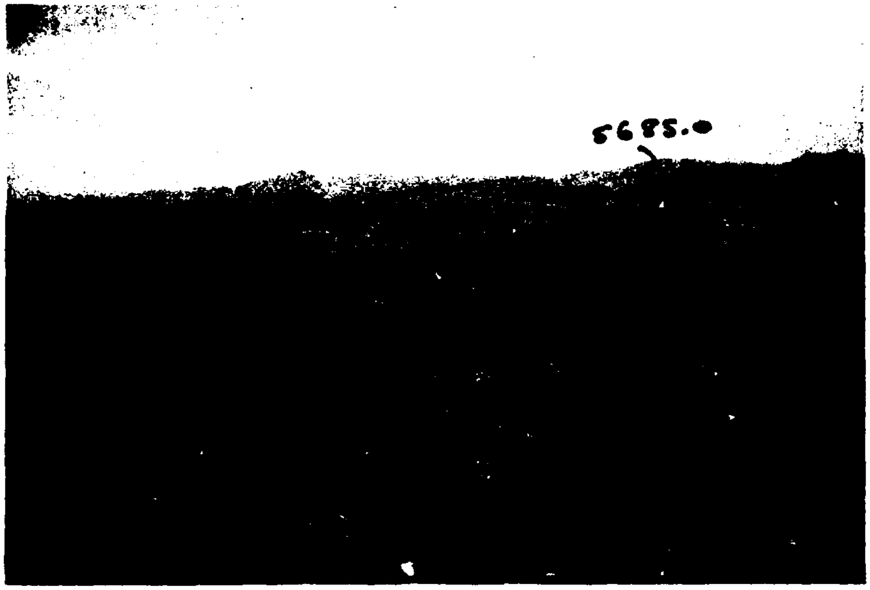

PHOTO NO. 43. South embankment, looking south. Top of dam at el. 5685.0. 7/14/77.

PHOTO NO. 44. Top of rock on north face of Warrior Ditch relocation, Sta. 56+25 to 57+25. Looking northeast.

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BEAR CREEK LAKE COLORADO VOLUME 1 TEXT AND PHOTOS(U)
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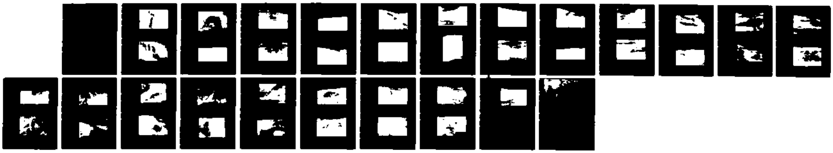

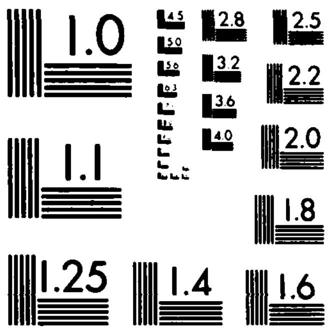

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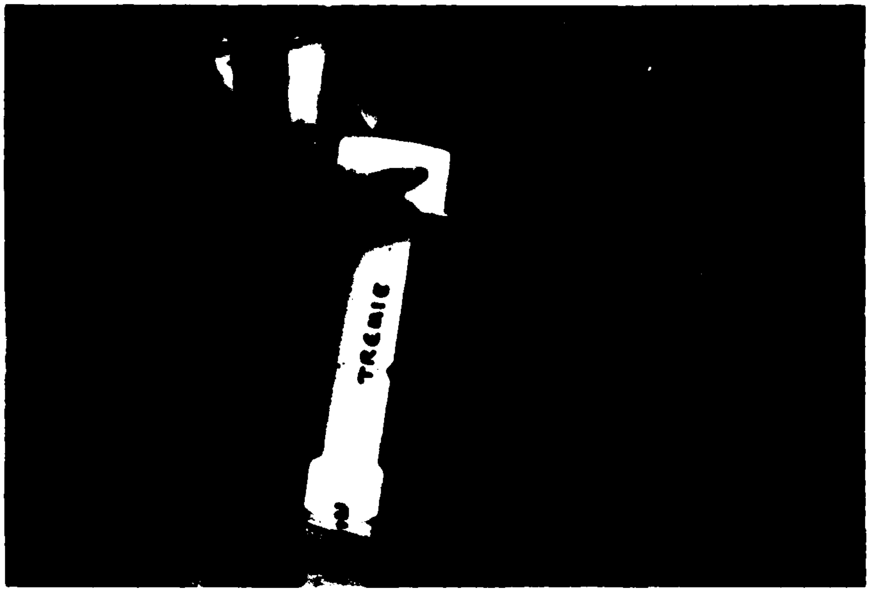

PHOTO NO. 45. Tremieing filter material around drains under Pioneer Ditch drop structure. Looking east. 3/2/76.

PHOTO NO. 46. Jackhammering a 2' thick concretion in Pioneer Ditch drop structure trench, Sta. 18+68 to 18+70. Looking south.

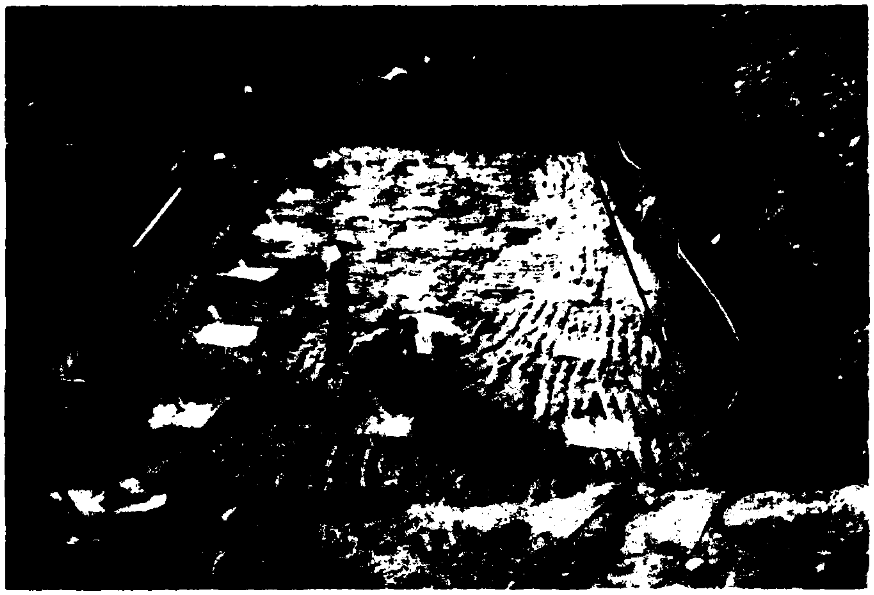

PHOTO NO. 47. Pioneer Ditch drop structure floor. Drains extending from sandy siltstone and silty sandstone floor. Looking west. 3/18/76

PHOTO NO. 48. Drainage ditches in toes of slopes to outlet works discharge channel. Looking southeast. 9/13/76.

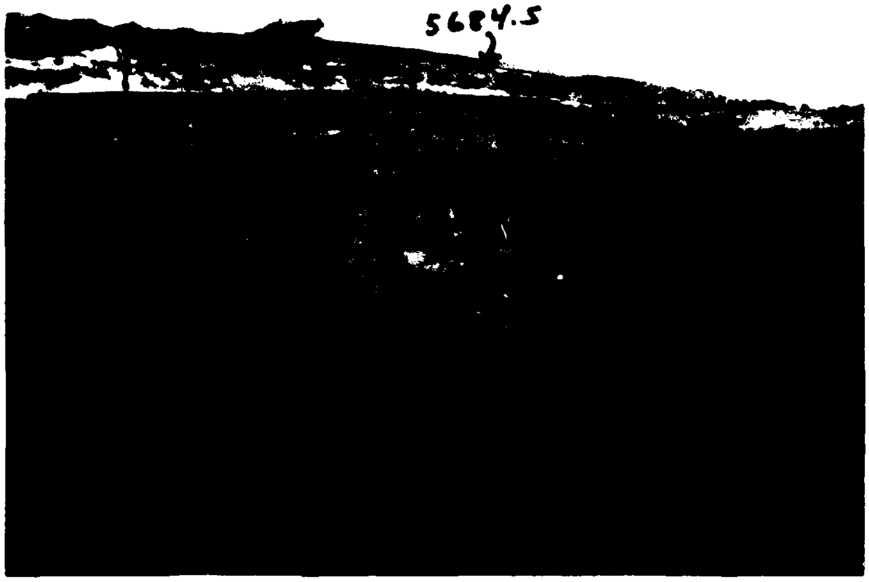

PHOTO NO. 49. Evidence of two slides on Mt. Carbon approximately 420' U. S. from top of 1 on 1 slope down to el. 5634. Looking west. 11/22/75.

PHOTO NO. 50. Probable area where material above the slide plane still remains. Looking south. 11/22/75

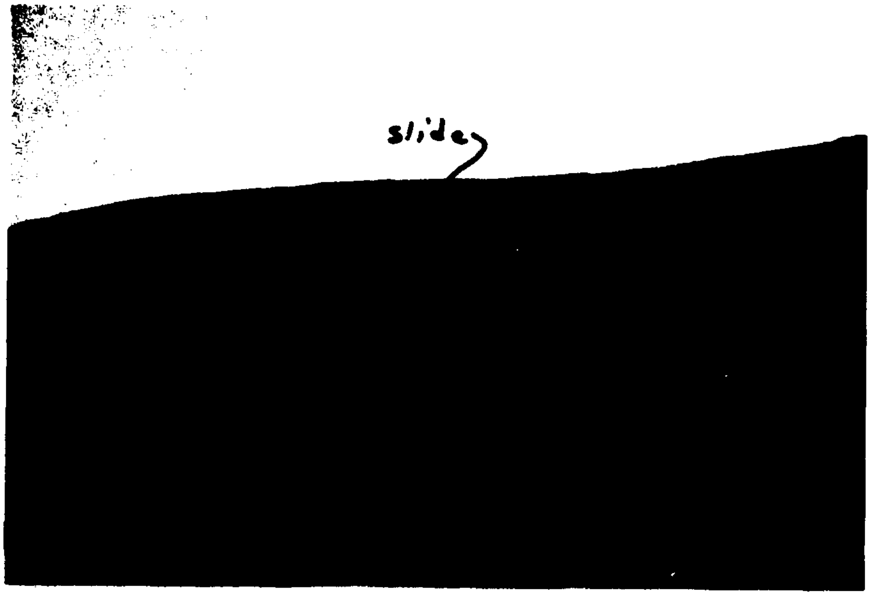

PHOTO NO. 51. Distant view of slide on Mt. Carbon slide plane dipping 58° NW. Looking south. 2/3/76.

PHOTO NO. 52. Close view of Mt. Carbon slide, maximum width from 970' U. S. to 1045' U. S. looking southwest. 2/3/76.

PHOTO NO. 53. Slide plane at overburden-bedrock contact at Sta. 7+65, main embankment inspection trench. Looking west. 4/13/76.

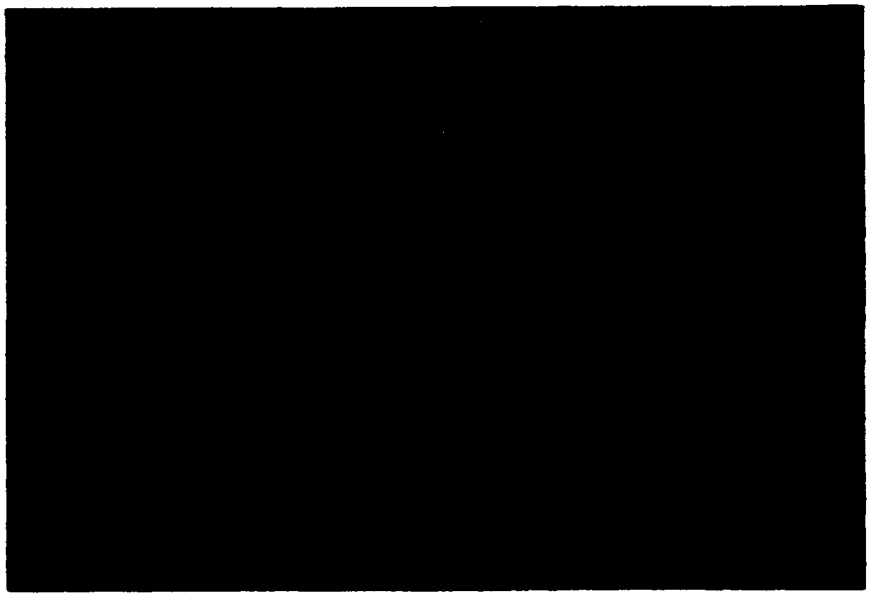

PHOTO NO. 54. Slide plane between disturbed shale and shale bedrock on downstream face, main embankment inspection trench. Looking north. 5/4/76.

PHOTO NO. 55. Small slide with 15-20 yds. material, 450' U. S. to 475' U. S. in clay blanket area. Looking south. 5/21/76.

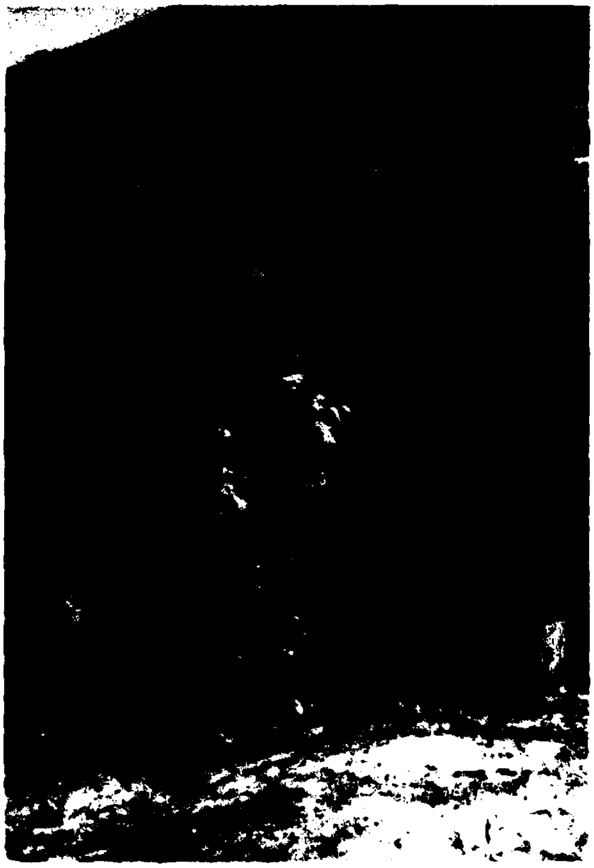

PHOTO NO. 56. Small slump in shale at two intersecting slicked fractures, Sta. 9+19 to 9+25 in main embankment inspection trench. Looking east. 6/4/76.

PHOTO NO. 57. Slide caused by excavation to explore mines. Estimated 3,000 c.y. of material in slide. 2/23/76.

PHOTO NO. 58. Drilling blast holes in spillway conglomerate, Sta. 30+40 to 31+75. Looking west. 3/22/77.

PHOTO NO. 59. Largest boulder, observed in pile after spillway blasting, 5'x5'x7'. Looking northeast. 3/25/77.

PHOTO NO. 60. Spillway blasting, rock pile from #2 blast. Poor blast w/many large pieces. Looking south. 4/29/77.

PHOTO NO. 61. Clay blanket area floor cleaned for placement of clay, 960' U. S. to 870' U. S. Looking south. 5/11/76.

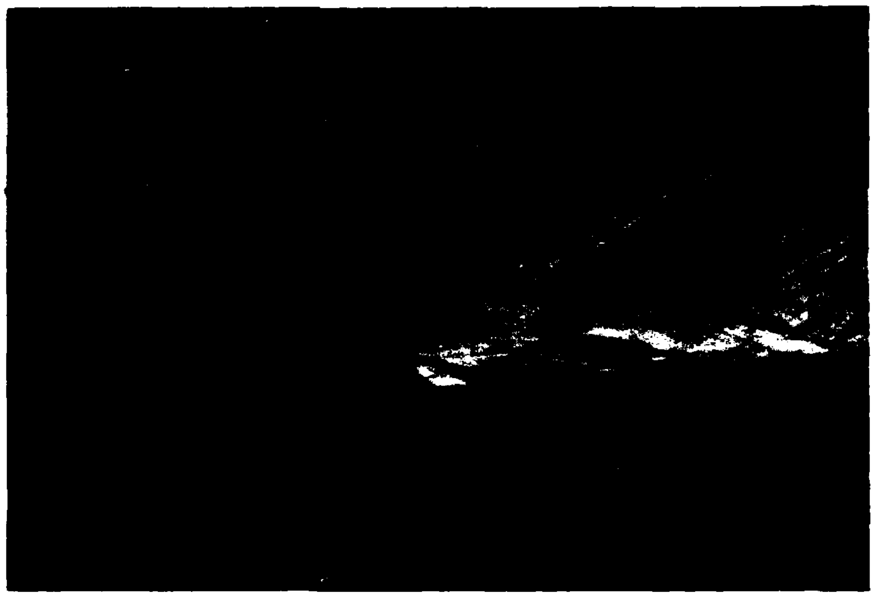

PHOTO NO. 62. Clay blanket area floor from 880' U. S. to 510' U. S. Rock on right dips 30°. Looking east. 5/14/76.

PHOTO NO. 63. Pond formed by seepage from sandstone, overburden, and shale fractures in clay blanket area, Sta. 12+00 to 11+65. Looking southeast. 5/20/76.

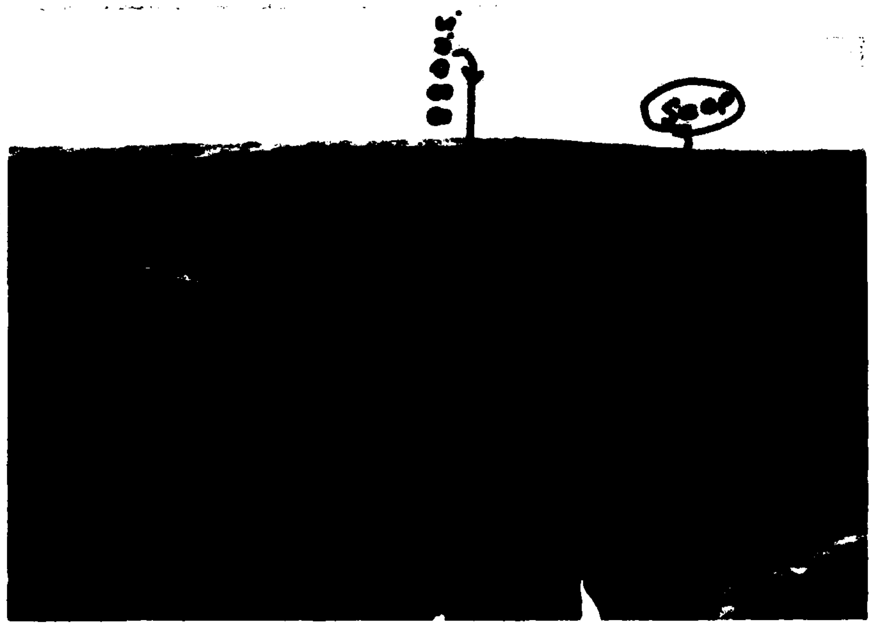

PHOTO NO. 64. Impervious blanket area adjacent to Mt. Carbon. Note minor seepage on slope, concrete cap over Mine #3 in center foreground. Looking south. 3/15/77.

PHOTO NO. 65. Impervious blanket area floor ready for first lift of clay. Looking southeast. 5/3/77.

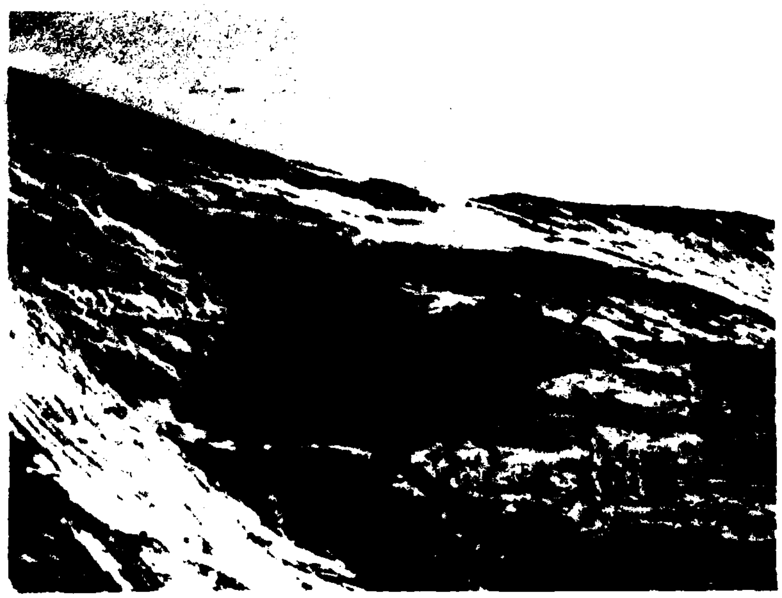

PHOTO NO. 66. Slide south of Mine #3. Looking south. 3/3/77.

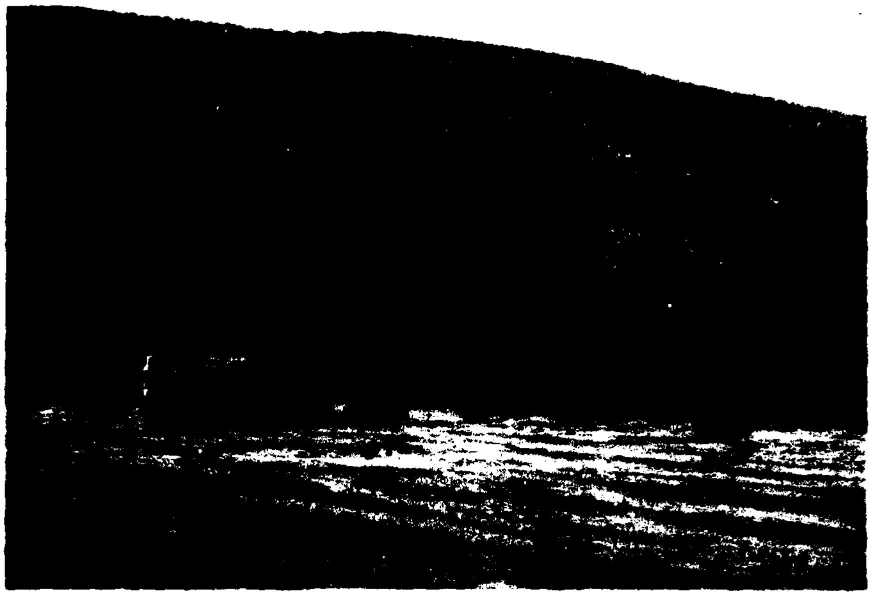

PHOTO NO. 67. Slump in impervious blanket area, Sta. 7+35, 175' U. S. to 220' U. S. Looking south. 4/14/77.

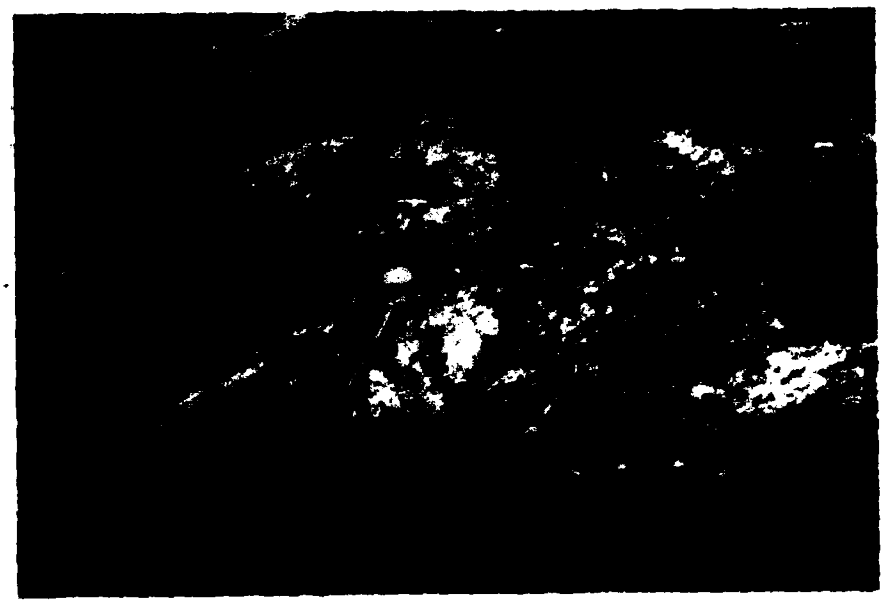

PHOTO NO. 68. Slumping at Sta. 30+20, El. 5579.5, in impervious blanket area. Looking northwest. 4/22/77.

PHOTO NO. 69. Slumping shale block on west face of impervious blanket area. Looking west. 4/28/77.

PHOTO NO. 70. Slumping highly weathered clay shale in impervious blanket area, Sta. 7+00, 225'-250' U. S. Looking east. 5/21/77.

PHOTO NO. 71. Exposed slide plane, Sta. 7+10, 250' U. S. in impervious blanket area. Gravelly clay above slide plane, shale below. Looking south. 5/23/77.

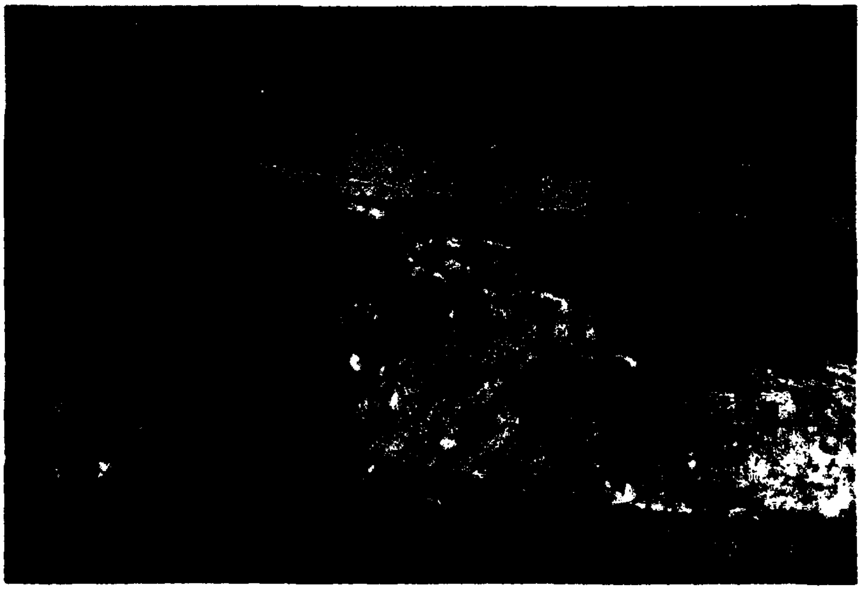

PHOTO NO. 72. Distant view of slide block noted moving on 6/17/77, in impervious blanket area. Looking south.

PHOTO NO. 73. Lowest level of Mine #4 being cleaned for concrete cap placement. Looking south. 3/1/77.

PHOTO NO. 74. Cleaning and keying Mine #3 for concrete cap placement. Looking north. 3/7/77.

PHOTO NO. 75. Backslope of Mine #1 excavation, showing openings of drifts, raise, and a crosscut into coal seams. Looking south. 6/21/77.

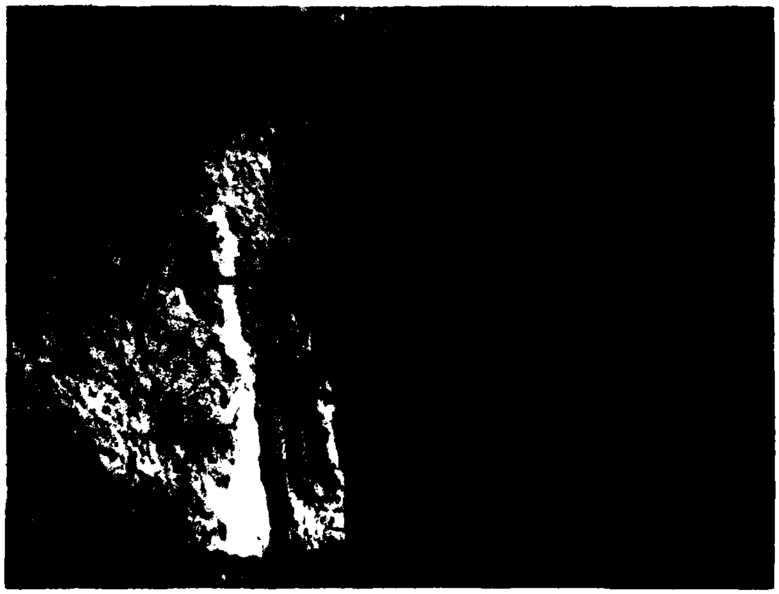

PHOTO NO. 76. Mine #4, keyed and cleaned for last concrete pour to seal the bottom two drifts. 10/13/77.

PHOTO NO. 77. Mine #4, completed lean concrete pour on bottom two levels. Looking south. 10/20/77.

PHOTO NO. 78. Main embankment inspection trench from Sta. 42+00 to 35+75, ready for clay placement. Looking south. 6/9/77.

PHOTO NO. 79. Main embankment inspection trench from Sta. 10+00 to 6+50. Looking south. 6/17/76.

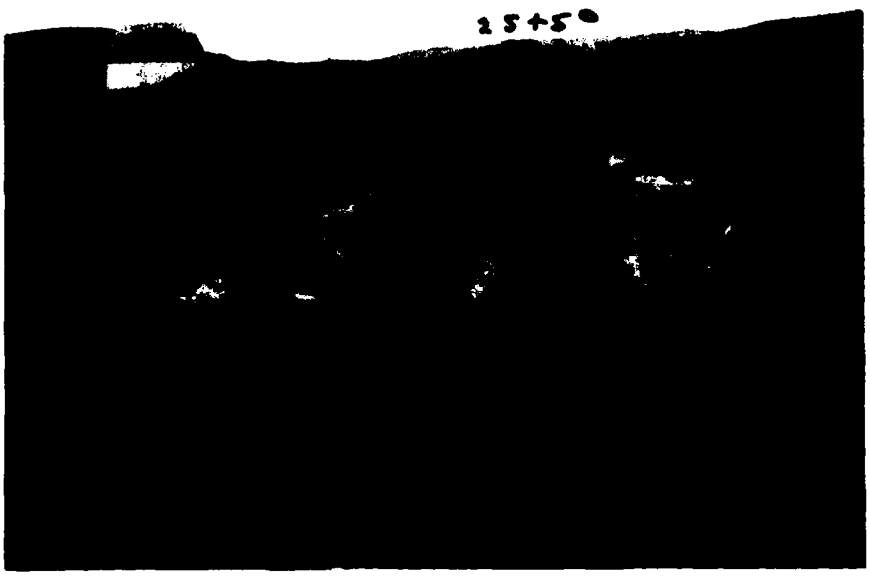

PHOTO NO. 80. Main embankment inspection trench from Sta. 23+00 to 25+50. Clay in trench to slow flow of water. Looking north. 7/15/76.

PHOTO NO. 81. A small drainge ditch at approximately 960' U. S. for water control. Looking north. 9/8/75.

PHOTO NO. 82. Dewatering trench, from Sta. 30+00 to 32+50, 40' U. S. Water pumped to Ward Canal. Looking south. 9/9/76.

PHOTO NO. 83. Dragline excavating undesirable material at Sta. 28+00, 160' D. S. Main embankment trench. Looking northwest. 9/21/76.

PHOTO NO. 84. Main embankment inspection trench from Sta. 34+00 to 30+00. Looking south. 10/9/76.

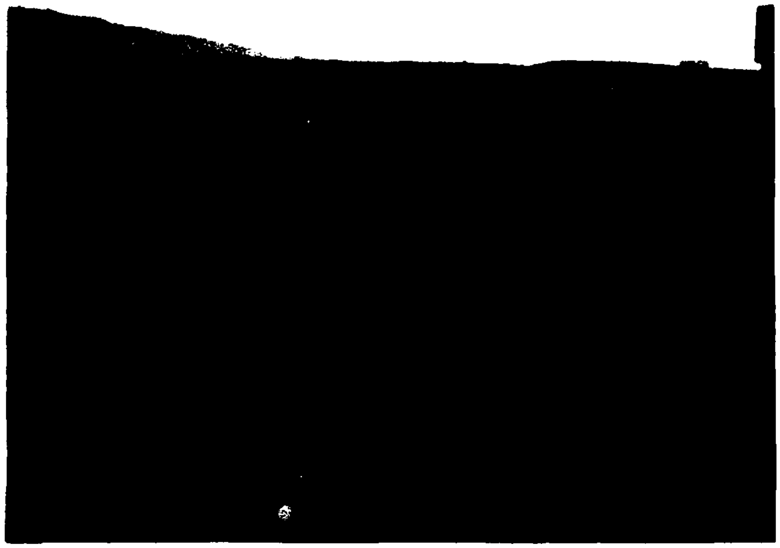

PHOTO NO. 85. Water stabilized at el. 5530 on low level intake at time of closure. Looking northeast. 7/22/77.

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