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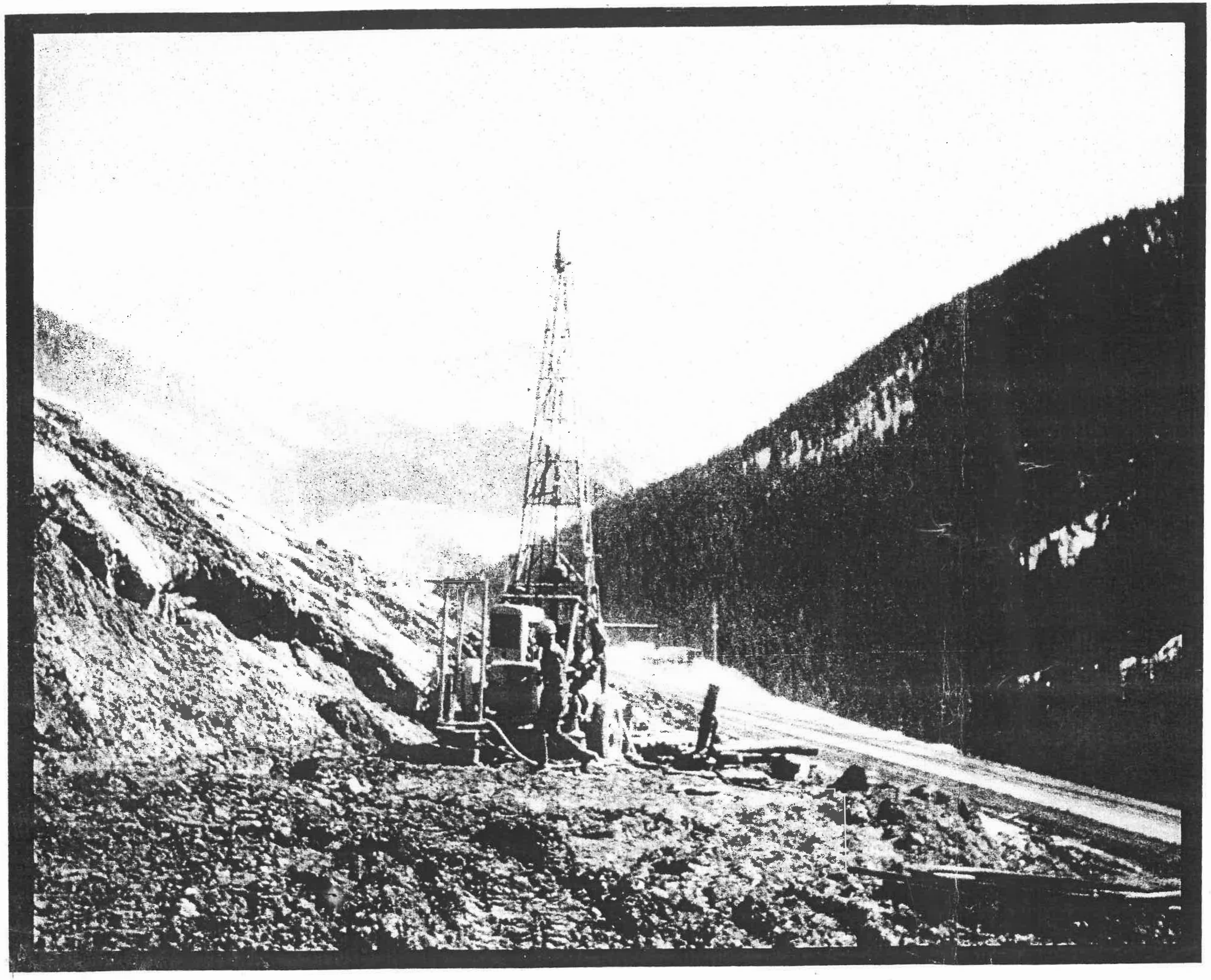

REPORT OF GEOLOGICAL INVESTIGATIONS AND RECOMMENDATIONS ON THE

STRAIGHT CREEK LANDSLIDES

by
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December 1971

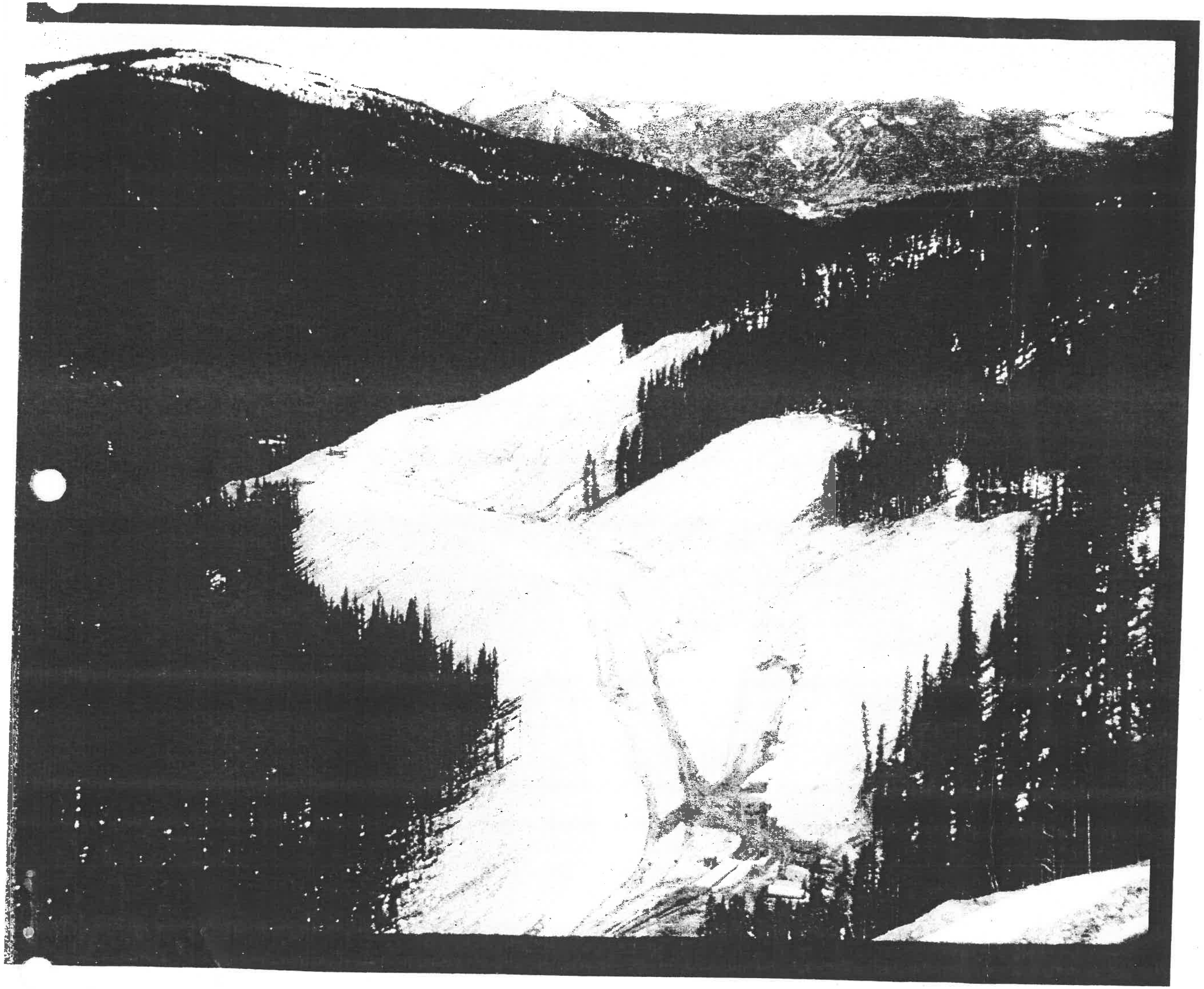


PHOTO II

Taken from the top of Slide A facing west. Slide B is located in the area where the aggregate is stockpiled on the westbound lane. Slide 1 is located beyond the tree-lined draw past Slide B. The near edge of Slide 2 is the last visible cut slope.

The Gore Range is visible at the top right and the Ten Mile Range is on the left. The north end of the Sawatch Range (Holy Cross Area) is barely visible between the two.

STRAIGHT CREEK LANDSLIDE INVESTIGATION

INTRODUCTION

PURPOSE

Construction of Interstate Highway 70 between the Blue River and the West Portal the Straight Creek Tunnel triggered six major landslides. Several relatively small l and cut failures have subsequently developed. The purpose of this investigation s to determine the causes of failure and to recommend corrections and/or preventive asures based on sound geologic principles.

LOCATION

The subject area is located in mountainous terrain of Summit County in north- tral Colorado, some 70 air miles west of Denver. The landslide zone stretches for e three miles along Interstate 70 between the small mountain community of Silverthorne the West Portal of the Straight Creek Tunnel.

Topography is characterized by the steep mountainous terrain of the Williams Range h approximate elevations in the study area running from 10,000 to 11,500 feet. The imate is characterized by long, hard winters and short, cool summers. Snow cover be expected from October until mid-June. The Straight Creek Drainage is vegetated dense forests of spruce and pine with intermingled groves of aspen.

PHOTO III

Slide A and surrounding terrain taken from Slide 2.

PREVIOUS CONSTRUCTION AND INVESTIGATION

Selection of the Straight Creek Tunnel location (1960) placed severe limitations on the approach alignment location from the west. Terrain, elevation difference, and sun exposure practically limited the Blue River-West Portal alignment to its present location.

In 1962, Continental Engineering Inc. prepared a topographic map of this area. A portion of this map has been reproduced (Figure 2) to illustrate the ruggedness of the original terrain, and to show the geologically suspicious lobate topography existing at Slide 2 and 3.

In the spring of 1963, the initial construction contract for the west approach to the Straight Creek Tunnel (Blue River - West Portal, (I 70-3(21)) was awarded. Construction was begun shortly thereafter, and the contract (grading and drainage) was completed in late 1965. Final construction (stabilization and paving) was to be delayed until just prior to completion of the Straight Creek Tunnel - originally targeted for 1969. Design, plans and estimates were based on cut slopes of 1:1, fill slopes of 1½:1 and grades averaging 6 percent.

In early June of 1964, slope distress was first detected. This was late outlined in a report by A. David Alcott (April, 1965) as follows:

1. On June 2, 1964, cracking and slippage was noted above the cut from Stations 295+00 to 300+00.
2. On June 6, 1964, as work progressed on the cut, cracks appeared from Stations 270+00 to 295+00.
3. By June 8, 1964, the maximum displacement at the scarp reached thirty feet. Movement into the roadway was estimated at forty feet.

The ninety foot cut slope from Stations 235+00 to 242+00 also cracked and slipped in early June of 1964, as did the cut between Stations 330+00 and 340+00.

It was initially concluded that slippage was occurring in unconsolidated glacial deposits underlain by badly weathered schist. The morainal-bedrock interface was thought to be lubricated by percolating ground water, forming a translational slip plane. Outcrops in the area were generally considered too weak to hold the glacial material and became part of the sliding mass. At this point, however, bedrock geology was not believed to have significant bearing upon the causes of the various slope failures. Alcott did note, that unlike the other slides, the failure from Stations 330+00 to 340+00 (Slide A) did seem to contain considerable exposure of weathered schist. Furthermore, Alcott stated that at several levels within the cut the foliation was dipping into the roadway.

The first attempts at correction were based on drainage and excavation. Corrugated metal pipes were installed near the crowns of each slide, and cut slopes were flattened to 1½:1.

Critical Factors

1. The muck excavation should be limited to a small area. Backfill should follow closely, replacing initially at least the volume of muck removed. Excessive excavation prior to backfilling could produce a massive failure, to the extent of interconnecting the fill and cut failures. Inadequate quantities of initial backfill could also produce failure.

2. The backfill (embankment) replacing the muck must be free draining. Native soils of the area, including those in Slide 1, are not free draining. Construction with soil that will not drain would create a damming effect, and excessive hydrostatic pressures could develop. Extensive fill failures could result. (Underdrain or other piping methods of drainage are not recommended. The "French" type is much preferred.)

GENERAL

The purpose of the investigations of the Straight Creek landslides was to obtain data for the design of remedial measures on Slide 1 and Slide 2. As a result of the investigations in the area, instability and potentially hazardous conditions were noted on Slide A, Slide B, Slide 3, Slide 4 and along the toes of the fills below Slides 1, 2 and 3. As an overall recommendation for the area of the Straight Creek landslides, it is suggested that topographic and geologic maps be made of the unstable and adjacent stable areas. Periodically, possibly as early in the spring as the areas are accessible, and prior to significant snowfalls in the fall, the areas should be examined and significant changes in the areas - as the dimensions, number of cracks or fractures, and their extension upslope - recorded on the maps. By comparison with previous years' work, it should be possible to tell if the landslides are growing, their rate of growth, and if there is developing a potential hazard to traffic on, or the stability of, the highway.

A series of closely spaced permanent bench marks should be incorporated in the roadway design through the slide area to aid in the detection of instability. The bench marks should be placed where they will not be disturbed by highway maintenance and will be readily accessible. The bench marks should be placed at intervals that will insure some are on stable ground and some on sections of the road that may be subject to movement.

Recommended Corrective Action

ıt is recommended that a rock buttress with a soil cap, as shown in ure 10 be constructed at the toe of Slide 2. This buttress is designed accommodate all probable water levels in the slide area and should pre- t extensive enlargement of the present slide area.

The soil cap will produce additional weight and should cost less than rock. Rock is required to the level indicated in Figure 10 in order to vide adequate factors of safety against failures through higher levels of buttress. Extensive reshaping and surface drainage construction are recom- ded. The drainage should consist of dozer-cut trenches, as opposed to ber-lined ditches.

Critical Factors and Methods

The following list contains critical factors, methods and sequences that contribute the success or failure of the corrective action.

1. The mathematical analysis is based on a comparison between existing conditions and a fully completed buttress. Construction should be scheduled and executed to produce the completed product in as little time as reasonably possible, both in cross section and in profile.

   The soil cap is an integral part of the buttress. It is most important that the cap placement closely follow the completed rock section. Should field conditions prohibit using material drifted down from Slide 2 for the cap, material should be imported from Slides 1 or A. (Snow and ice are not acceptable cap material.) Delays in cap placement could produce a failure that should not occur with the full section.

2. Excavation preceding the buttress should be limited to the minimum required for working room. This may cause complications and will cause the operation to be more expensive than ifno limitations were imposed. The slide toe area is now unstable and the buttress excavation will aggravate that condition; therefore, the smaller the area opened up ahead of the rock placement, the fewer the problems created by the excavation.

3. Excavation ahead of the rock placement should proceed only when rock is obviously readily available for placement. Rock stockpiling at the buttress site has not been recommended due to high costs; however, project personnel should constantly observe the excavation-backfill sequence and not permit a large area to be excavated and remain open, due to shortage of rock or any other reason.

The period of highest water levels, least stability, and greatest movement is between April and July. No attempt to construct the buttress should be made during those months.

Analysis

Slide 2 was mathematically analyzed using various "Slice" methods, a Bishop program on the CU computer, a Morgenstern program on the CU computer, and by Ken Medearis using a computer method that he had developed. The recommended correction was based mainly on the results of the "Slice" and Bishop methods, due to established credibility and confidence in these methods.

Various soil strength and weight perameters were used. Water levels were determined by piezometers, and depth of the slide was determined by "shear strips". Figure 9 shows the various drill holes and instruments along the critical section on Slide 2. Worksheets and explanation of methods are available and can be reviewed by contacting one of the report authors. (If unavailable elsewhere, any of the documents listed in the bibliography can be reviewed by contacting the authors.)

SLIDE 3

A geologic map of Slide 3 should be made covering the area from the road up to the upper diversion ditch. All surface cracks and landslide scarps should be located and measured. Reference marks should be placed beyond the upper area of movement and observed annually in midsummer to determine evidence of accelerated movement.

SLIDE 4

Slide 4 at the present presents no problems to the completion and maintenance of the highway; however, it should be periodically inspected for indications of movement.

FILL TOE FAILURES

Slide 1

The apparent failure of the fill toe at Slide 1 was not thoroughly investigated or defined. It appears that no immediate danger to the roadway exists; however, continued observation is recommended.

Slides 2 and 3

The toes of the fills at Slides 2 and 3 are currently in failure. Both problems apparently result from placing embankment on peat and organic soils. There does not appear to be interconnection between the cut slope failures and the fill failures at this time.

The fill failure at Slide 2 can be corrected in conjunction with the proposed line shift. Excavation of the peat and organic soils prior to placing the proposed embankment and constructing the lower portion of the embankment with an obviously free draining material should produce a buttress-like correction.

The same technique can be applied to the Slide 3 toe area failure.

CONCLUSIONS (Con't)

A program for periodic inspection of the slopes above the slides should be devel- and continued to note areas of failure and the trend of the slide growth. Slopes to the slides where water is dumped by the drainage ditches should be observed signs of failure.

RECOMMENDATIONS

INTRODUCTION

The geological investigations conducted during the spring and summer of 1971 on various stability problems in the Straight Creek area have resulted in recommen- ions for corrections. The thoroughness of the investigations permitted the authors accept relatively marginal safety factors in most cases. Construction personnel urged to comply with the geological recommendations set forth in this report. struction resulting in lesser features than recommended could prove disastrous. changes contemplated in the recommended correction features and methods should be cussed with the authors of this report.

SLIDE A

It is recommended that Slide A be disturbed as little as possible by construction. stress relief problem will probably abate as the slope becomes covered with rubble. lope of 1½:1 should be fairly stable with time.

litional ditch width should be allowed for the anticipated slough. The proposed ro. median should permit 20 to 30 feet of additional ditch. Any further width would uire widening the existing fill section, in which case, the cost would be greater n the benefit.

It is probable that some rocks will roll down the slope. A rock impact barrier in ditch is recommended to prevent the rocks from rolling onto the driving lanes.

It is recommended that the area in and around Slide A be visually inspected on at st a weekly basis while construction is in progress. A trained observer may be able detect evidence of impending movement. While we believe the probability of rapid ement is quite low, the additional safeguard of regular observation is recommended.

SLIDE B

No evidence of movement was noted on Slide B. Drainage basins and rubber-lined ches on the bench above the slide are presently in excellent condition and are rying surface water across the slide. The east end of the area was considered as source of material for line changes and rock for the buttress on Slide 2. Material ld be acquired along Hamilton Gulch with a minimum chance of causing failure in the pes.

SLIDE 1

In view of the amount of material required for the line change at Slide it was decided that an excavation correction would fit the overall project mu better than other possible methods. The investigation of Slide 1 was therefo directed toward the feasibility of excavation.

Excavation resulting in a 3:1 slope up the center of the slide area and tapering to no excavation three to four hundred feet each side (along centerline) should produce a stable slope. The headward limits are marked approximately by the uppermost rubber ditch. Depending on the eastward extension of the excavation, between 500,000 and 750,000 cubic yards of material can be obtained.

The included topographic map, Figure 5, shows the maximum excavation out line. Construction limits and slopes will be field staked and controlled by project personnel.

Outcrops and adverse terrain limit the excavation area. Current plans (November, 1971) include excavating the entire slide area, and there are no critical geologic factors known at this time. Construction personnel should, however, be on the alert for unexpected conditions, and regular visual inspection by a geologist is recommended during and for a time after construction.

SLIDE 2

Selection of Corrective Action for Slide 2

It is apparent that water is the primary contributor to continued movement within Slide 2. Control of the subsurface water to specific maximum levels would stabilize the area; however, methods relying on controlling the subsurface water have not been recommended. Slide 2 has not achieved the potential areal extent of failure. Unchecked, it is probable that the slide will progress several hundred feet upslope. Such progression will change existing conditions considerably, and it would be most difficult to predict long term results. It is not inconceivable that additional failure, in conjunction with dynamic stresses and temporary hydrostatic buildup, could produce rapid movement similar to a flow. Therefore, avoidance could prove unsatisfactory, particularly if the alignment relocation were insufficient. Further, avoidance could only worsen the adverse environmental and aesthetic impact of the slide area. The barren, highly erodible scar would remain, and could increase with time.

Slope flattening has not been recommended due to the additional slide potential above the present slide mass. It is possible that unloading the top of the existing slide area could trigger a higher slide, which could then fill up the excavated area - thus negating the corrective action. The additional movement could produce a worse situation than exists today.

STRAIGHT CREEK LANDSLIDE INVESTIGATION

SUMMARY

This geologic investigation of the Straight Creek Landslides along Inter-
ate Highway 70 west of the Straight Creek Tunnel was conducted to determine
e geology of the landslides, and to recommend remedial measures required by
ologic conditions. The landslides have hampered construction since 1964
spite extensive drainage and water diversion facilities, and flattening of
me of the slopes. Field investigations which were initiated in March, 1971
itially consisted of drilling and instrumentation of drill holes in Slides 1
d 2. The investigation was expanded to cover Slides A, B, 3, 4 and areas of
ilure in the road fill and valley floor beyond the road fill. Geologic map-
ng covered all of the slides except 3 and 4. The geologic investigations
re supplemented by geophysical investigation.

Bedrock in the area consists of folded metasedimentary rock with bodies
pegmatite ranging from sheets a few inches in thickness, injected along
liation planes, to large masses over 100 feet in thickness. The largest
sses of pegmatite occur in the center of the landslide area. A series of
ults subparallel to the pegmatite-metasedimentary contacts occur at approxi-
tely right angles to the valley. Bedrock is intensely altered and sheared
jacent to the faults.

Surficial deposits consist of weathered-in-place bedrock, material depos-
ed by streams and glaciation, and material deposited in swamps.

In Slide A, unlike the other slides, the metasedimentary foliation dips
ward the roadway. Unloading the face and toe of the slope by construction
s resulted in failure by stress relief along the foliation planes. During
e summer of 1971, a series of cracks cutting across foliation developed.
v surface cracks developed in the cut and on the slopes 500 feet above the
.

The landslides at Slides 1, 2, 3 and 4 occur in altered bedrock along the
ear zones in and adjacent to the pegmatite masses. Movement of the landslide
ss is greatest in late spring and early summer when ground water has reached
s highest level. Shear strips installed to a depth of 150 feet in drill
les on Slide 2 recorded movement at 65 feet below the surface. During the
mer of 1971, surface movement in Slide 2 occurred at a distance of 1500 feet
om the roadway. Evidence of new movement was not noted in Slide B.

Failure at the toes of the fill at Slides 2 and 3 resulted primarily from
placement of organic material below the fill. Saturated organic material
being squeezed out by the weight of the fill.

Based on these investigations, it was recommended by the Department's geologic staff that alignment changes in the highway be made at Slide A, Slide 1 and Slide 2. Much of Slide 1 is to be excavated; the material obtained is to be used for the alignment changes and for a buttress to stabilize Slide 2. The failures at the toe of the fill are to be remedied during construction of fill for the alignment changes.

A continuing program of observation of the areas of landslides along Straight Creek is recommended. This program should be based on an initial large scale geologic and topographic map of the slide areas and the adjacent stable areas.

CONCLUSIONS

Slides B and 4 are apparently stable; however, Slides A, 1, 2 and 3 are very unstable and the areas of failure will continue to expand. Failures in the fill and original ground at the toe of the fill have occurred below Slide 2 and Slide 3. Several localized lobes of unstable material were noted at the toe of the fill between Slide 1 and Slide 3, and failures may occur in the future. Several local cut slope failures occur between Slide A and the West Portal of the Straight Creek Tunnel. These local failures have the potential to enlarge upslope and cause serious maintenance problems in the westbound lane.

Drainage on the slides and from the slopes above the slides must be maintained. Maintenance-free methods such as dozer cut trenches are recommended.

Slide A is a growing area of slope failure. The area of greatest movement is in the central portion of the slide. As the material fails, zones of cracks develop and enlarge on both sides and above. A continuing maintenance program will be required to remove the buildup of debris along the ditch line.

Slide 1 shows evidence of instability in the slope below the upper bench level. The proposed excavation of this slide to provide borrow material for the line change should be started in the upper area to unload the upper slopes. During excavation, it is likely that there will be movement in the forested area between Drill Holes 3 and 4, and northwest of Drill Hole 5. It should be noted that much of this slope has already failed but has not moved downslope enough to destroy the forest.

Slide 2 is growing westward and northward. Movement in the lower slopes has removed support of the rock and material above. Construction of a buttress to prevent movement of material at the lower level, in conjunction with permanent drainage, will contribute to stability upslope. After a period of adjustment within the slide, movement should practically cease.

Slide 3 is a potential sleeping giant that should be watched. A rock buttress along the roadway presently provides stability of the landslide mass adjacent to the road and will provide protection if the upper slopes continue to move. The combined effect of the buttress and the diversion of surface water across the slide are contributing to minimize the instability of the slope. Maintenance of drainage is of great importance. The upper limits of the cracks and scarps should be marked to assist in future determination of the slope stability.

In July of 1967, a meeting was held between Bureau of Public Roads and olorado Department of Highways personnel. Several important decisions con-erning stabilization of the slides were made at this conference:

1. A photogrammetric contour map and cross sections should be constructed as early as possible.

2. Seismic and resistivity studies should be undertaken to determine the location of possible slip circles.

3. Corrugated metal pipe should be removed from the slide areas and be replaced with a system of rubber-lined ditches.

It was anticipated that the above measures could be completed during the 968 construction season.

The Ken R. White Company was selected to carry out the first systematic nvestigation of the slide areas. Actual field work began in the fall of 1967 ith the implementation of a direct current resistivity program. Several test oles were drilled in order to verify water table depths and to provide samples or laboratory testing. The slide areas were photographed from the air to pro-ide photogrammetric control. Measuring devices were set on the slides in the pring of 1968 and were read at weekly intervals throughout the year.

As the result of the Ken R. White Company's field investigation, a number f significant conclusions were reached:

1. Slide movement is directly related to ground water activity. Movement begins in early May with the advent of the spring thaw and continues through December when the ground freezes.

2. The slides are translational in nature and average between 25 and 80 feet in depth.

3. Upslope drainage must be installed to stabilize and to prevent enlargement of the existing slide areas.

cordingly, the Ken R. White Company made several recommendations summarized n their final report of January, 1969 which were implemented as follows:

1. Drains were installed at fifteen foot depths in selected areas on the assumption they would adequately divert percolating ground water.

2. A large drainage gallery was constructed under Slide 2 parallel to the Interstate alignment and emptying into Straight Creek.

3. Relief wells were drilled to intercept and reduce hydrostatic pore pressure within known aquifers.

4. Rubber-lined ditches were constructed to intercept and drain surface run-off above the slide areas.

5. Slopes at Slide A were flattened from 1¼:1 to 1½:1.

The major part of this construction was completed by fall of 1970. However, Slides 1 and 2 continued to show signs of significant instability. It soon became obvious that the landslides still presented a major obstacle to the successful completion of Interstate 70 to the west portal of the Straight Creek Tunnel.

In October, 1970 plans were made to update the slide investigations commencing with construction of a detailed contour map of Slides 1 and 2, (Figure 5). Planning continued throughout the winter and culminated in a meeting held on March 31, 1971 at the Silverthorne Resident Engineer's office. Personnel from District I, District III, Central Lab, Federal Highway Administration and C. S. Robinson and Associate were present. Agreement was reached on a geologic investigation of which this report is a final result.

INVESTIGATION

INTRODUCTION

This investigation was under the supervision of R. K. Barrett, District III Geologist, Division of Highways. Field investigations were supervised by M. W. West, Geologist, Colorado Department of Highways, and D. M. Cochran, Geologist for C. S. Robinson and Associate.

The investigation consisted of geologic and topographic mapping, drilling and drill hole instrumentation and refraction seismic surveys. Field work began in mid-March, 1971 and continued into early September, 1971.

The scope of the study, as outlined at the March 31, 1971 meeting, included only Slides 1 and 2. As the investigation progressed, additional areas of instability were observed and included in this investigation. The following table, taken from the Ken R. White Report, 1969, and amended shows the slides and their extent.

TABLE 1

Landslides along I-70 in the Straight Creek Area

Slide Designation	Station	Length Along Road	Extent from Centerline	Difference in Elevation Head to Toe
A*	327 to 340	1300 Feet	1500 Feet Lt.	700 Feet
B	302 to 322	2000 Feet	400 Feet Lt.	200 Feet
1*	290 to 302	1200 Feet	700 Feet Lt.	330 Feet
2*	268 to 290	2200 Feet	1500 Feet Lt.	540 Feet
3*	235 to 243	800 Feet	1200 Feet Lt.	440 Feet
4	210 to 215	500 Feet	1300 Feet Lt.	500 Feet
Fill Toe Slide 1*	295±	250 Feet	500 Feet Rt.	200 Feet
Fill Toe Slide 2*	275±	150 Feet	400 Feet Rt.	200 Feet
Fill Toe Slide 3*	238 to 242+50	400 Feet	300 Feet Rt.	70 Feet

*Active slides during 1971

DRILLING

Drilling was initiated on March 15, 1971 in the westbound ditch line of the toe
Slide 2. An early spring start was believed necessary in order to avoid muddy con-
ions and resultant loss of mobility caused by the snow melt; however, deep snow
eady present and a series of late spring storms combined to produce conditions that
iced efficiency. By the time the weather improved, the thaw was well under way,
the ensuing morass only served to compound problems. The drilling program did not
ch full efficiency until mid-June.

The project employed between one and five drills. The majority of the work was
e by three trailer-mounted core rigs owned and operated by Boyles Brothers Drilling
pany of Golden, Colorado. Three other more specialized rigs were utilized during
course of the program: a truck-mounted Failing 1500 owned by Boyles Brothers, a
new 500 and an Acker Mack II, both owned by the Division of Highways. Drilling was
pleted on September 3, 1971.

PHOTO IV

Drill rigs on location, Slide 2

The drilling can be divided into four broad categories:

1. Geologic drilling
2. Instrument drilling
3. Fill studies
4. Toe of fill studies

Geologic Drilling

This phase of the project was designed to provide third-dimension geological information concerning the cause and size of Slides 1 and 2. Drill site were placed on probable critical cross sections selected on the basis of slid geometry. Drilling along these sections provided information as to the depth to bedrock and to possible slip planes. Soil sampling and coring allowed geologists to examine and interpret in situ slide material. Every effort was made to have a geologist log core as soon as it was recovered; however, due to manpower shortages and the complexity of the project, this was not always possible.

Instrument Drilling

The instruments utilized in the slide investigation required down-the-hole installation. Potential instrument locations were selected on critical sections in close proximity to geologic drill holes. Diameter and depth of instrument holes were largely determined by the size of the instrument and the geological information required.

Fill Studies

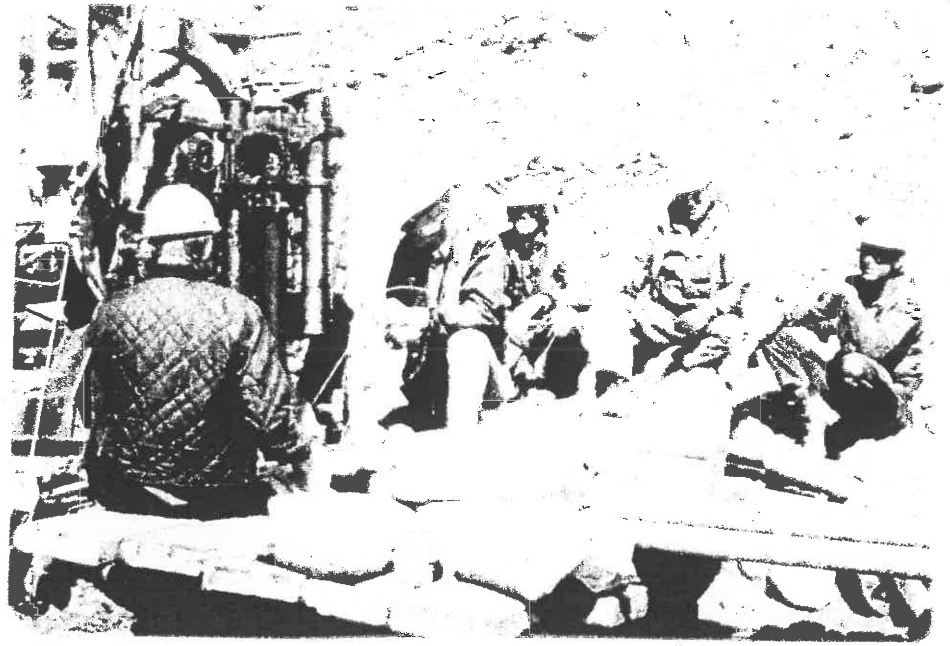
Early in this investigation, the stability of several large fills below the slide areas was questioned. It was decided that drill holes would be appropriate at points of possible fill failure. The primary purpose of the drilling was threefold: (1) to determine depth to the fill-ground interface, (2) to determine depth to water table, and (3) to sample and examine material beneath the fill. However, due to the rocky nature of the fill, this phase of the drilling proved too expensive and was abandoned. Somewhat later, fill distress in several areas along the roadway was discovered. A decision was made to install multiple point drill hole extensometers to determine the extent and rate of fill movement. The nature of the fill material prohibited completion of the extensometer holes. This phase of the study was also abandoned.

Toe of Fill Studies

Subsequent to the abandonment of the extensometer holes, plans were made to drill a series of holes at the toes of the fills at Slides 2 and 3. These holes were drilled to determine the depth to material of acceptable bearing capacity, in conjunction with proposed slide corrections and alignment change at these sites. These holes were completed with few problems.

PHOTO VI

Piezometer Installation, Slide 2



SEISMIC SURVEYS

Refraction seismic methods were utilized extensively on Slide 1, Slide 2 and below the toe of the fill. A portable, twelve-channel S.I.E. refraction seismograph was used. This machine is owned by the Division and has depth capability exceeding 100 feet. Explosives are required to initiate the shock wave. The purpose of the seismic survey was to confirm and supplement the results of the drilling program. Since refraction data is based on relative velocities in differing materials, it can, under proper conditions, delineate the interface between unconsolidated deposits and bedrock. Furthermore, seismic methods can be applied in areas where drilling is either physically impossible or the cost is prohibitive.

Location of seismic traverses on Slides 1 and 2 was largely controlled by slide geometry and topography. In instances where geologic features were readily apparent within the slide masses, geologists requested that traverses be run to cover them, to aid in interpreting data from questionable areas. Traverses were also run above and to the sides of what was considered to be the limits of active movement, thus providing additional control for interpretation of data within the slides. In most cases, layer depths and velocities were averaged for ease of analysis and presentation.

Velocities of the surficial layer varied from 350 to 1200 feet per second The average depths of the surficial layer, indicated by the survey, ranged fro 0 to 13.5 feet.

Velocity of materials in the intermediate layer was 2000 to 3600 feet per second in the zone where shear strips indicate movement. In the vicinity of extensive surface cracks, the velocity commonly ranged between 2200 and 3000 feet per second.

The seismic data correlated quite well with the drilling and instrumentation. Material with a higher velocity was indicated at approximately the depth of the shear strip breaks, and where drill hole core recovery indicates more competent rock. Velocity of the deepest layer ranged from 6,000 to 20,00 feet per second. This was assumed to be intact bedrock. This data is shown on Figure 7.

GENERAL GEOLOGY

The Straight Creek slide area is 1-1/2 miles west of the crest of the Front Range of the Colorado Rocky Mountains. The Front Range is a structurally complex area that consists predominantly of Precambrian metasedimentary and igneous rocks. The Straight Creek slide area is northwest of the Front Range mineral belt, a northeast-trending belt of Laramide intrusive rocks and ore deposits, and 2-1/2 miles east of the Williams Range Thrust Fault.

The geology of the Front Range mineral belt is described in a report by Lovering and Goddard (1950) and the Williams Range Thrust Fault is described by Wahlstrom and Hornback (1962). A report dealing with the Straight Creek Tunnel area, adjoining the Straight Creek slide area, (Robinson and Lee, in publication) has been used extensively in the preparation of this report.

REGIONAL GEOLOGY

The oldest rocks of the Front Range, chiefly of sedimentary origin, were metamorphosed, deformed and intruded by igneous rocks in Precambrian time. These metasedimentary rocks were mapped by Lovering and Goddard (1950) as Idaho Springs Formation and the Swandyke Hornblende Gneiss. The Idaho Springs Formation consists of a variety of biotite-quartz-microcline and plagioclase gneisses with lesser amounts of lime-silicate-gneisses and amphibolites. The Swandyke Hornblende Gneiss consists of hornblende- and biotite-quartz-plagiocl gneisses and amphibolites. Lovering and Goddard included the metasedimentary rocks of the Straight Creek slide area in their Idaho Springs Formation and Swandyke Hornblende Gneiss. Radiometric dating has shown that these rocks wer metamorphosed about 1700 to 1750 million years ago, (Peterman and Hedge, 1968)

The Precambrian igneous rock unit in this area is the Silver Plume Granit and related pegmatite. The Silver Plume Granite is, for the most part, a quar monzonite in composition. The Silver Plume Granite has been dated 1440 millio years, (Hedge, 1970).

PHOTO V

Bent casing. Drilling was not possible without casing, and sometimes not possible with casing.

LOGGING

Logging of soil samples and core recovery was approached from the standpoint that virtually nothing was known about the landslide masses and that any detail might prove to be potentially important. In general, geologists were concerned with several overlapping areas of petrographic description:

1. General lithologic description
2. Type and degree of alteration
3. Description and approximate orientation of jointing, fracturing and foliation
4. Degree and approximate orientation of shearing
5. Degree and size distribution of fragmented and/or gouge zones
6. Percent core recovery
7. Drilling characteristics as observed by geologists or related by drillers

All core was boxed, labeled and stored for future reference and correlation.

INSTRUMENTATION

Shear Strips

Perhaps the most significant instrument used in the slide study was the "shear strip" designed and constructed by Terrametrics of Golden, Colorado. The shear strip consists of a brittle plastic strip along which an electrical conductor of known resistance has been attached. Read-out wires are fastened to either end. The entire package is waterproofed and then inserted into the drill hole. By employing a Wheatstone Bridge-type readout box, the actual in-hole length of the strip can be indirectly measured either from the top down or the bottom up. Once the shear strip is securely grouted into the drill hole, movement at depth within the slide mass will cause the strip to break, thus disrupting the electrical circuit. The readout box gives the depth to the break and, accordingly, to a slip plane. Reading the strip from either end provides a check and also enables the instrument to detect multiple breaks. The shear strip is considered "lost" when slide displacement reaches a point where the readout wire from the bottom is broken.

The installation of the first shear strip on Slide 2 involved considerable difficulty and eventually resulted in damage to the instrument. The strip was inserted into a cased drill hole, and due to the small diameter of the hole and the 150 foot length of the strip, some damage occurred by overflexing the strip as it was inserted. Furthermore, the casing had to be hammered out of the hole before grouting could be completed. This process resulted in caving and more damage to the instrument. Consequently, it was decided to place 1½" plastic conduit (PVC) inside the casing to the bottom of the hole. The casing could be pulled while the conduit would keep the hole open, even if caving did occur. The shear strip could then be installed and grouted inside the conduit. The lead from the far end of the strip was placed in 3/8" nylon tubing so that it would not break when the grout initially sheared. This method of installation was used in all later shear strip holes.

Piezometers

Piezometric levels in the slide masses were measured with piezometers installed in drill holes on or near critical sections. The piezometers measure hydrostatic pressure either in feet of water or pounds per square inch. Installation includes a permeable blanket of sand immediately around the instrument, with a bentonite seal on either side to prevent vertical permeability in the drill hole. Several installations of this type can be made at different depths in a single hole.

During initial attempts at installing piezometers, some difficulty was encountered with premature expansion of the bentonite. As soon as the bentonite came in contact with moisture, swelling would occur, completely plugging the hole. Powdered bentonite, prill bentonite, and finally, bentonite balls were used. By soaking the bentonite balls in a dilute solution of polyvinyl alcohol, swelling was retarded while the bentonite sank to the bottom of the hole. When the polyvinyl alcohol dissolved, the bentonite would then swell to form a vertical piezometric seal. Laboratory observations indicated that the alcohol would dissolve in no more than 24 hours.

The regional structure of the Front Range is the result of deformation efly during Precambrian and Tertiary times. Tweto and Sims (1963) have established that the Colorado mineral belt was a belt of Precambrian structures along which extensive faulting, intrusion of igneous rocks and the formation of ore deposits took place during Tertiary times.

The original Precambrian sedimentary rocks were metamorphosed, plastically deformed and intruded by plutonic rocks. A later period of Precambrian deformation was more limited in distribution and changes in rock texture were chiefly cataclastic in nature, (Moench, 1964, p. 66).

The Laramide period of orogeny started in Late Cretaceous time with uplift of the area and retreat of the Cretaceous Sea. Following the uplift, major thrust faults - as the Williams Range Thrust Fault, about 2-1/2 miles west of the Straight Creek slide area (Wahlstrom and Hornback, 1962) - developed along the western margin of the Front Range. The intrusion of the igneous rocks, some following the development of the major thrust faults, was preceded, accompanied, and followed by faulting, mineralization, and hydrothermal alteration. In late Tertiary time, the Front Range was vertically uplifted one or more times, probably accompanied by faulting. Subsequent to this uplift and faulting, stream and glacial erosion and deposition have developed the present topography.

The Straight Creek landslide area is typical of the glaciated mountain regions of the Front Range. The valleys of Straight Creek and its tributaries re occupied by mountain glaciers up to an average altitude of about 12,000 feet. Above this altitude gentle slopes are generally covered by soil and rock debris as a result of frost action and solifluction. The gentle slopes are dissected by broad shallow valleys where steep-walled cirques were formed at the head of the glaciers. Large areas of bedrock are exposed in the cirque walls. Morainal deposits on the valley floors and sides have locally dammed the drainage and formed swampy areas and thin peat bogs.

Below the upper level reached by glaciation, steep-walled canyons extend down to the valley floor of Straight Creek. Along these steep walls, moraines accumulated and formed benches. Locally some of these morainal deposits have slid down the oversteepened slopes.

BEDROCK

Most of the bedrock in the Straight Creek slide area is covered by surficial deposits. Few bedrock exposures appear in the landslide masses. Many isolated outcrops occur on the steep forested slopes above the slides, and large areas of bedrock outcrop on the ridges above timber line. Areas of abundant outcrop as shown on Figures 3, 4, 5 and 6 are enclosed in a dotted line and the rock type is indicated by a letter symbol.

The bedrock of the mapped slide area consists primarily of metasediments, gmatite and migmatite. Small areas of granitic rock are exposed in the slides on each side of Hamilton Gulch.

Metasedimentary Rock

Metasedimentary rocks in the area are chiefly biotite-quartz-plagioclase gneisses and some hornblende-biotite-quartz-plagioclase gneisses. The mineralogic varieties are interlayered and gradational so a distinction was not attempted. In general, the hornblende gneisses are restricted to Slides A and B in the vicinity of Hamilton Gulch.

The gneiss is fine- to medium-grained and the grain size differs from layer to layer. The rock is layered light to dark gray depending on mineral composition. Some rocks have a greenish cast as a result of partial alteration of biotite and hornblende to chlorite. Zones of rock are light tan to brown where biotite has been intensely altered to limonite.

Migmatite

Rock composed of alternating bands of gneiss, pegmatite and granitic rock was mapped as migmatite. The mixed rock types are genetically related and could not be mapped separately in outcrop. Contacts of the metasediments and migmatites are gradational.

Pegmatite

Exposures of pegmatite ranging in length from 50 feet to nearly a thousand feet occur in greatest abundance near the central portion of the slide area. The pegmatite is composed of coarse-grained orthoclase, microcline, muscovite and locally, quartz and biotite. Microcline, orthoclase and muscovite crystals up to 10 cm. in length are common. Garnetiferous zones contain fractures and highly altered individual garnets up to 15 mm. across.

The pegmatites were injected along foliation planes in the gneiss and along joints and faults, and cut across foliation as commonly as they follow it. Pegmatites injected as sheets along foliation or crosscutting the foliation are usually from 2 to 6 feet thick. The thickness of the large masses measures in the tens of feet.

STRUCTURE

Regional foliation of the metasedimentary rocks mapped by Lovering and Goddard (1950) strikes northwest and dips northeast. Locally near Hamilton Gulch, the strike of the foliation swings to the northeast and the dip is southeast paralleling the contact with the Silver Plume Granite along the Continental Divide.

A northeast-trending fault three-fourths of a mile south of Straight Creek and parallel to the creek, separates Silver Plume Granite on the south from the metasediments which extend through the slide area. The northward extension of a fault along Keystone Gulch, that follows Frey Gulch, abuts into the northeast trending fault. To the east, across the Continental Divide, is the northeast-trending Loveland Pass-Berthoud Fault Zone and to the west is the northwestward-trending Williams Range thrust fault.

North of Straight Creek a series of shear zones exposed in the slides trend N. 44° W. parallel to foliation. Gneiss and pegmatites adjacent to the faults are intensely altered.

The foliation of the metasedimentary rocks in the slide area generally conforms to the regional pattern. The foliation strikes northwest and dips to the northeast. The foliation in outcrops in the landslide masses dips steeper (60° to 90°) than was generally observed in the outcrops above the slide.

East of Hamilton Gulch in the central portion of Slide A, the foliation is at right angles to the regional trend and dips south towards the road.

Alternating bands of gneiss and pegmatite exposed in the slides lie in highly altered zones adjacent to nearly-vertical northwest-trending faults. Inclusions of unaltered pegmatite blocks several feet in each dimension occur in these zones. In much of the material in these zones the structure of the parent rock is intact, but the rock is so decomposed that it consists of sandy clay and rock particles. Along the exposed dry faces the decomposed gneiss and pegmatite air slakes and sloughs. In saturated zones the decomposed rock flows out of the exposed face as a mealy debris forming small fans. Clay gouge zones adjacent to the faults are commonly saturated and form long narrow channels where mud flows occur periodically.

SURFICIAL DEPOSITS

Surficial deposits composed of silt, sand, gravel and boulders derived from weathering and glaciation of the Precambrian metasedimentary and igneous rocks cover most of the area mapped. The deposits range from a thin cover of less than one foot to a thickness of more than 70 feet.

Morainal materials are located on benches above the landslides and in ridges along the valley floor. These deposits are composed of unsorted silt, gravel and boulders. The morainal deposits are generally free draining and will stand in steep banks. Lenses of silt occur locally within the moraines, impeding drainage.

Colluvial deposits develop from the weathering of bedrock and the movement of the weathered material downslope in response to gravity. Colluvial deposits consist of angular blocks of rock at the base of cliffs and mistures of sand, silt and angular boulders. Talus deposits are not common within the slide area but are prevalent above Slide B, and 150 feet east of Slide A. The mixtures of sand, silt and angular boulders cover much of the steep forested slopes above the slides.

Alluvial deposits were formed by stream action of Straight Creek and its intermittent tributary streams. The valley along Straight Creek is a subsequent alluviated modification of a glaciated valley floor affected by debris from landslides, slopewash, reworked moraines, beaver damming, silting, avalanches and peat deposits.

Morainal ridges on the benches have disrupted and dammed local drainages causing the development of peat bogs. The peat is usually 3 to 5 feet thick but above Slide 1 one peat bog partially excavated by a drainage ditch contains several layers ranging in thickness from 2 feet to 8 feet.

SURFACE WATER

Surface water, which accumulates on the slopes above the slide areas, in general has been intercepted by catch basins and ditches, and is diverted around the slides or conveyed across the slides by rubber-lined ditches. Surface water that influences the instability of the slides therefore is primari derived from the snow pack that accumulates on the slides during the winter and from the frequent summer rainstorms. The snow pack is typically from fou to six feet deep. Melting begins in April and continues through May. Some of the runoff occurs while the ground is still frozen and does not enter the soil. Much of the runoff is intercepted by surface cracks and diverted into the landslide masses. During the 1971 spring thaw, most of the rubber-lined ditches on Slides 1 and 2 were filled by mudflows and destroyed by surface movement. During the period of major runoff, surface water from the slopes above these two slides flowed across and into the slide masses.

The rubber-lined ditches on Slides B, 3 and 4 were not disrupted by mudflows or extensive surface movement and continued to function properly throug out the summer.

PHOTO VII

Rubber-lined ditch disrupted by slide movement, Slide 2

GROUND WATER

Ground water is one of the main factors affecting the stability of the slides. The source of the ground water is the melting snow and rainfall on the slide areas and percolation of water through the soils from streams upslope from the slides.

Much of the water from the melting snow is trapped in the hollows, depressions and open cracks on the slide surface. The water entering the ground travels through the surficial layer to zones of fractures and glide planes. The water migrates through the slide mass until it emerges at the surface on the face of the slide as a spring or seep.

some water was seeping in N slope

Springs having the largest flows are located in the pegmatite zones along the exposed ribs of resistant pegmatite blocks. The springs migrate laterally along the pegmatite face. The flows of water from the fractured and decomposed pegmatite carry quartz and feldspar grains and muscovite flakes from the pegmatite mass to construct saturated unstable bulges on the steep slope. The mass of unconsolidated pegmatitic debris creeps downslope under the influence of gravity. The fronts of these masses usually have a steep convex face appearing as roll. As a mass moves downslope exposing the face of the pegmatite, the unsupported and undermined pegmatite blocks slump and fall into the fine grained mobile mass. The additional weight of the blocks often accelerates the movement which may continue downslope a few feet or 50 or 60 feet.

Springs of significant flow normally do not occur in the areas of gneiss. The wet zones in the gneiss are usually along faults where highly altered bands of gneiss have been converted to clay. These saturated zones release very small flows and would actually be classified as seeps. The saturated clay is soft and the orientation of the bands up the slope provides chutes for movement of unstable accumulations of debris from higher up on the slide mass. Movement of material down these chutes is more prevalent immediately after the spring thaw but reoccurs at intervals throughout the summer. Clay exposed in the chute is scoured to a depth of several inches to 3 feet by the moving material thereby deepening the channel. The most highly developed chute is located on the western side of Slide 2. Reoccurring slides widened and deepened the channel causing failure of the altered gneiss adjacent to the sides of the chute.

Above the slides, surface streams are located in ravines that probably follow the extension of the shear zones crossing the slides. Local slump masses along the stream channels and morainal deposits have obstructed the streams and formed swampy areas. At some of these obstructions, the streams disappear into the ground and emerge in the channel downslope. Some of the water entering the ground migrates below the interception basins and ditches to the slide masses.

Ground water is unevenly distributed in the slide mass. The common concept of a water table with an even sloping surface does not exist in the slide masses. Ground water is confined to zones of open fractures in the rock.

Observation of water levels in adjacent drill holes shows a wide difference within a few feet. The water level in one drill hole may be 5 feet below the surface and in a drill hole 10 feet away may be 90 feet below the surface. Oxidation along joints in core samples from some drill holes indicates zones of water 170 feet below the surface. An 84-inch diameter drainage gallery through bedrock 30 to 100 feet below the surface of Slide 2 intercepts no significant water bearing zones. Two wells intersect the gallery. The ground water intercepted by the gallery and the wells was a constant flow from May to September, 1971, estimated at one pint per minute.

RESULTS OF INVESTIGATION

The results of the slide investigations are presented in a description of each slide. The geology of Slides 1 and 2 was mapped on a topographic base map at a scale of 1 inch equals 100 feet. The base map was prepared by Falcon Air Maps Division, the Ken R. White Company, October, 1970, (Figure 5). The map shows locations of cored drill holes and seismic traverses made during the investigation. The map also shows the location of exposed bedrock, landslide surface cracks and scarps, and springs and swamps. Nineteen cross sections were prepared for Slides 1 and 2, (Figure 7, sheets 1 through 6). The cross sections present graphically the interpretation of the cored drill holes, data obtained from shear strips installed in drill holes, surface cracks, surface bedrock exposures, and the depths and velocity of subsurface units recorded by seismic survey.

Base maps were unavailable for Slides A, B, 3 and 4. Sketch maps were prepared for Slides A and B, using the available remaining slope stakes, tape, compass, hand level and recently installed centerline stakes for control, (Figures 3 and 4).

A plane table map was made of the roadway, buttress and fill at Slide 3, (Figure 6). Results of a seismic traverse along the toe of the fill from Slide B to Slide 3 is shown on Figure 8.

SLIDE A

The easternmost large landslide is designated Slide A. This slide is in the face of a steep ridge east of Hamilton Gulch. The ridge slopes uniformly from timberline at an elevation of 11,600 feet to 11,000 feet, and more steeply from 11,000 feet to the valley floor at approximately elevation 10,480 feet. The landslide is triangular in shape. The base is about 1600 feet long at the road level. Tension cracks in the ground have been located 570 feet horizontally beyond the apex. Landslide debris covers the westbound lane for a distance of several hundred feet (see oblique photo, Figure 11). Slide A is pictured in Photos VIII, IX and X and oblique photo, Figure 11.

Geology

The slide is in Precambrian gneiss and igneous rock. A central area of biotite gneiss dipping toward the valley is separated by faults from granite bordered by hornblende gneiss and migmatite in the eastern and western sections of the slide. Recently, mountain glaciers moving down Straight Creek cut steep valley walls in the bedrock.

PHOTO VIII

Slide A

Bedrock

Bedrock exposed in the slide consists of metasediments, migmatite, granite and pegmatite. The metasediments are predominantly biotite-quartz-plagioclase gneiss. The gneiss is fine - to medium-grain, light to dark gray rock. In most outcrops the rock is fresh. Gneiss is the most abundant rock exposed in the central section of the slide. It is exposed in isolated outcrops from the base of the slide to the top of the cut, and forms the large rock faces near the center of the slide 300 to 700 feet left of the roadway.

A variety of hornblende-biotite-quartz-plagioclase gneiss, fine - to coarse-grained, with a more definite light to dark gray color banding, occurs in the western and eastern sections of the slide. The hornblende gneiss ranges from fresh to highly altered. In the zones of alteration the rock is greenish to deep brown. The gneiss is exposed in the western section of the slide in an arcuate band where it grades into migmatite. In the eastern section, large irregular bands of intensely altered gneiss are adjacent to migmatites and granites.

The rocks composed of alternating bands of gneiss, pegmatite and granitic rock were mapped as migmatite. The migmatite consists of alternating light and dark mineral layers and stringers that range from less than an inch to several inches. The rock has been folded and contorted. The light colored layers consist of plagioclase feldspars, quartz, microcline feldspar and minor amounts of biotite. The darker layers consist of plagioclase feldspar, hornblende, biotite, quartz and microcline feldspars. The migmatite is believed to have been formed where extreme heat and pressure caused partial melting of the original rock, mineral segregation, plastic flow and where granite magma was intruded into the rock.

Migmatite was noted in both the western and eastern sections of the slide In the western sections, the outcrops occurred in a narrow zone between the hornblende gneiss and the granitic rock. The contacts on each side are gradational. In the eastern section of the slide, migmatite is in small irregular bands bordering the altered gneiss and granitic rocks. Many of these bands are too small to be indicated on the map and are included with the predominant granitic or pegmatitic rock.

The granite is pinkish gray, medium-grained, and consists of quartz and microcline and plagioclase feldspars. The rock is moderately to highly altere It is poorly exposed in the slide. In general it is covered by rubble left by construction equipment. In the western area the granite is exposed in two dee cuts made above the location of the rock crushing operation. The granite is bordered downslope and to the east by migmatite. In the eastern section of the slide an area approximately 200 feet in diameter is underlain by granite. This area is completely covered by rubble except for a small outcrop in the face of a landslide scarp. The granite is surrounded on three sides by moderately to highly altered gneiss. The upper border is covered by moving surfici material.

Crosscutting all rocks are pegmatitic bands composed of feldspar and quar The bands range from a few inches to 8 feet in thickness. In the biotite gnei the pegmatite bands branch into sheets that have been injected along foliation planes. These sheets may follow the foliation plane for 30 to 50 feet and the cut across several gneiss layers and parallel another foliation plane.

Structure

The geologic structure of the bedrock in this slide is controlled by two small granitic intrusive masses and several northtrending faults. The area between the granitic masses, predominantly biotite gneiss, is separated from the granitic masses by faults.

Foliation in the gneiss is probably the result of the original bedding. The strike of foliation in the gneiss adjacent to the granitic masses, is nort west or northeast.

Joints in the gneiss in the western section of the slide have a strike of N. 20° W. and dip 42° SW. Large open cracks along these joints developed in the late summer of 1971.

The gneiss bordering the granitic masses, though strongly foliated, generally does not break along the foliation planes. The strike of the foliation ranges from northwest to northeast and dips 60° to 85° northeast or southeast.

Biotite gneiss in the central section of the slide has a strong foliation that causes the rock to break into thin slabs. (See Photo IX below.) The foliation strikes east-west, parallel to the face of the slide, and dips 40° to 50° southward toward the road. This orientation of the foliation is one of the main contributing factors to the instability of the slope. The dip of the foliation steepens at intersections with pegmatite sheets that cut through several layers of gneiss. The larger bands of pegmatite, 2 to 8 feet in thickness, that cut across the gneiss are nearly horizontal or dip 15° north. A strong set of joints parallel to the strike of the foliation dips 62° north. At the base of the largest gneiss face, large blocks of rock have separated along one of these joints and moved several feet downslope forming an overhang of 4 to 7 feet.

PHOTO IX

Foliation surfaces, Slide A

Fault zones divide the slide into the three sections. Faults striking N. 5° to 9° W. and dipping 82° to 86° SW separate the western section from the central section. The fault dividing the central and the eastern section was implied by a long north-south scarp and the different rock types, and the change of attitude in foliation on each side of the scarp.

A series of northwest trending faults dipping between 40° and 70° SW were mapped in the migmatite and granite in the western section. Some of these may have been correlative with faults mapped in the displaced blocks exposed on the lower slopes of the central area.

It is probable that several of the larger trends of surface cracks across the slide are related to bedrock faults.

Slope Failure

Failure of the slope during the summer of 1971 was recorded by geologic mapping. The map (Figure 3) shows areas of outcrop and the bedrock types, foliation, joints and faults. Areas of failure were mapped and indicated by a hachured line, which represent the location of a landslide scarp. A number on the hachured line represents the vertical displacement in feet. Surface cracks are represented by a heavy line.

Slope failure occurred in May while the slide was covered with about 5 feet of snow. An area in the eastern section 200 feet by 250 feet moved as a unit 35 to 60 feet downslope. At the head of the scarp the vertical displacement was 15 feet. The toe of this mass formed a surface roll 25 feet high. Rock exposed in the scarp was intensely altered gneiss, migmatite, and granite. The material in the toe of the mass is predominantly biotite gneiss. A zone of clay gouge approximately 60 feet wide along the eastern side of the slide was not involved in the movement. No further movement was observed in this part of the slide during the summer. (See Photo X.)

Movement during the summer of 1971 was concentrated in the bedrock failure along a 300 foot zone in the central area 300 to 700 feet left of centerline. A large face of biotite gneiss is exposed 600 feet north of the road. The top of the face is 400 feet vertically above the road level. Throughout the summer, this face was actively deteriorating. The exposed rock is the dip slope of the foliation. The rock separates along the foliation planes due to tension and falls free to the rubble pile below.

East of the large rock face movement in the gneiss formed a straight scarp 400 feet long. Rock rubble to the west of the scarp dropped 3 to 6 feet.

Material was removed from the lower slopes at the western end of the slide for crusher run. In August, 1971, after crushing had been completed, a series of vertical cracks and diagonal cracks, dipping northwest, developed in the large rock face. The diagonal cracks cross through the rubble at the base of the face and extend to the western part of the slide area into the migmatite and hornblende gneiss. The hornblende gneiss and migmatite broke off in blocks 5 to 10 feet across along these cracks.

Movement in the slope above the rock face occurred during the summer. Several zones of surface cracks developed back of the high rock faces.

A series of surface cracks developed on the upper slope in the surficial landslide rubble along the eastern side of the slide. Surface tension cracks that were present in the forested slope above the cut slope in the fall of 1970 expanded to develop an arcuate scarp in the spring of 1971. The area of failure is "horseshoe" shaped. The eastern end of the scarp intersects the cut slope approximately 900 feet from the roadway centerline. Cracks continue down across the cut slope 150 feet in a southeasterly direction. The western end of the scarp intersects the cut at the apex, and a zone of cracks extends down the cut slope 150 feet in a southwesterly direction. Displacement along the scarp ranges from 1 to 3.5 feet. The dip of the scarp at the head of the landslide ranges from 64° to 70°. At the present time, most of the trees on this moving mass are still standing and this extension of the slide is not visible from the roadway.

PHOTO X

Taken from central area of Slide A facing east and south. The rubble in the foreground was derived from the outcrops in the center of the slide. Also visible is the head scarp of the slide in the eastern portion of the slide. Both lanes are visible on the extreme right.

A zone of surface tension cracks branch westward from the scarp. The zone extends 300 feet west in an arc through the forest. Displacements range from visible cracks in the surface to vertical displacements of 1 foot. At the west end of the zone, the surface cracks trend down the slope and pinch out. Upslope 150 feet above this zone, isolated surface cracks were noted. A search was made in late August, 1971, on the steep slopes above the surface cracks upward to timberline and no further cracks were located.

Summary

Slide A is divided into three distinct geologic units. The eastern and western sections have similar bedrock types. In these sections gneiss and migmatite borders granitic intrusive rocks. Alteration is more intense in the eastern section. Slope failure is not as extensive in these sections and seems to be related to failure in the gneiss and migmatite bordering the granite.

The central section is biotite gneiss cut by pegmatite bands. Foliation of the gneiss strikes east-west and dips 40° to 50° toward the road. Large rock faces have been exposed by failure at the base of the slope. Tension cracks parallel to foliation allow the rock to break off along the high rock face.

Tension cracks have developed on the cut slope above the actively failing rock faces. A series of diagonal and horizontal cracks cutting across the roc structure in the central area extended into the lower part of the western section.

Scarps and tension cracks have developed along a 700 foot long zone above the cut slope.

SLIDE B

Slide B, located between Slides 1 and A, is presently a stable area that shows no indication it will cause future construction or maintenance problems. A sketch map (Figure 4) was made of the cut slope and bench above the cut from Station 309 to 325, when it was determined that additional borrow material should be located for slide corrections. Slide B is visible in Photo II and Figure 12.

Geology

The area consists of Precambrian metasedimentary rock intruded by granite The metasediments have been faulted and altered in the vicinity of granite.

Bedrock has been cut by glaciers that moved down Straight Creek and were joined by glaciers that moved down Hamilton Gulch. Steep valley walls were cut above the slide and a bedrock bench was beveled along the north canyon wall. Morainal materials were deposited on the bench as the ice receded and talus deposits accumulated on the bench at the base of the steep canyon walls.

Bedrock

Bedrock consists of metasedimentary rock, migmatite, granite and pegmatite. The metasediments consisted of biotite-quartz-plagioclase-gneiss. The gneiss is a fine - to medium-grained, light - to dark-gray rock. The rock is generally fresh in the western part of the slide with a thin band of alteration along minor faults. Alteration of the gneiss is more intense from Station 318 321, where the gneiss is intermixed with pegmatite and grades into migmatite. Migmatite consists of alternating bands of gneiss, pegmatite and granitic rock. At the eastern end of the area the rock is nearly all composed of pinkish granite.

Structure

The foliation of the gneiss strikes northwest and dips northeast. Minor faults and shear zones are subparallel to the foliation. The migmatite is intensely faulted and jointed.

Surficial Deposits

Moraines were deposited on the bedrock bench that is from 150 to 350 feet in width. The morainal ridges on the surface of the bench have restricted drainage and formed slight depressions where swamps and shallow peat bogs have developed. Drainage basins have been constructed to collect the surface water, and rubber-lined ditches convey the water across the benches. The excellent condition of the rubber-lined ditches indicates that the area is presently stabilized.

The westbound lane along this area has been utilized as a stockpile area for crushed gravel. The stockpile at the present is in effect serving as a buttress for the slope and may be contributing to the stability of the slope. There is no present indication, however, that removal of the stockpile will cause failure or movement in the slope except for minor local failures along shear zones.

The rock in the east end of Slide B may be suitable for buttress material, and a properly designed cut would be stable.

SLIDE 1

Slide 1 is in an area west of Slide B. The original slope failure along the roadway was between Station 290 and Station 301. A zone of surface tension cracks above Slide 2 extends eastward into Slide 1, and the two are practically contiguous. Slide 1 is shown in Photos II and XI, and in oblique photo Figure 13.

Geology

At Slide 1 Precambrian gneiss has been intruded by a large mass of pegmatite (Figure 5). Foliation of the gneiss strikes northwest and dips to the northeast. The pegmatite mass trends parallel to the foliation of the gneiss. series of faults occurs in the pegmatite and in the adjacent gneiss. Alteration, fracturing and shearing is intense in both rock types along the faults. The gneiss bedrock forms the two northwest trending ridges on each side of the flat at the top of the slide and pegmatite bedrock occurs between the ridges. The flat and steepsided ravines at the head of the flat result from erosion of the fractures and altered rock along the faults and slope failure in the sheared zones.

The flat above the slide corresponds to the level of a morainal bench east of the slide. The slopes below the flat were steepened by glaciers and left unsupported when the ice melted. Adjustment of the steep slope by erosion, and slope failure by mudflow and sliding, was still taking place when road construction began.

Bedrock

Bedrock exposed in the slide is gneiss and pegmatite (Figure 5). The gneiss is a light gray fine - to medium-grained rock composed of biotite, quartz and plagioclase. The gneiss is generally highly altered and decomposed. A bedrock exposure of unaltered gneiss forms a prominent steep face on the west side of a fault that separates Slide 1 from Slide 2. This was the only bedrock not highly altered and decomposed. In several locations, gneiss was altered in zones to clay gouge. The isolated gneiss outcrops were located in a diagonal band from the central part of the slide along the road up to the western edge near the top of the cut slope. The gneiss is exposed in the ridge west of the bench above the slide. Surficial blocks of gneiss on the east side of the bench indicate gneiss bedrock in the ridge east of the bench.

Pegmatite, composed of coarse-grained orthoclase, microcline and muscovite, occurs in isolated outcrops in the slide, and as massive pinnacles along the two deep ravines that converge at the head of the bench above the slide. The pegmatite exposed in the slides is usually highly altered and decomposed. Isolated blocks of unaltered pegmatite several feet in diameter are surrounded by the decomposed material.

Structure

Structure based on isolated exposures of bedrock in the landslide indicate a northwest trending shear zone through a large pegmatite mass between gneiss bedrock east and west of the central part of the slide (Figure 5). Samples recovered from drilling consisted, in a large part, of rock fragments, numerous clay seams and highly altered rock.

Outcrops of gneiss in the ridge above the landslide had foliation striking N. 40° W. with dips ranging from 22° to 85° NE. At the top of the cut slope at the western edge of the slide, the foliation in the gneiss in the face of a scarp strikes N. 37° E. and dips 60° SE toward the road. Two sets of shear zones were mapped in the slide, one trending N. 20° W. and one trending N. 65° W. These shear zones can be projected upslope through the flat above the slide and correlate with shears exposed along the ravines. The shear zones are also projected downslope to the creek along zones of open surface cracks.

Surficial Deposits

Surficial deposits covering much of the landslide are a mixture of colluvium and swamp deposits that slid from the upper slopes. Roots, stumps and trunks of large trees are incorporated in the material. On the slopes above the slide are morainal

Surficial Deposits (Con't)

deposits composed of unsorted silt, gravel and boulders. The moraine was deposited in a bench along the slope and as ridges on the flat above the slide. The ridges along the eastern side of the flat have been modified by alluvium carried down by small streams. The morainal ridges restricted drainage on the western side of the bench where peat formed in the resulting swamp. Several layers of peat interbedded with sand are exposed in the cut excavated to provide drainage of the swamp. The surficial layer of peat is approximately 8 feet thick.

Slope Failure

Failure of the slope has occurred by both surface and bedrock landsliding. The limits of slope failure were determined by mapping the landslides, scarps and surface tension cracks. Scarps are indicated on the map (Figure 5) by a barred hachured line; surface cracks are indicated by a heavy line. Drill Hole 2 in the center of the slide was selected for installation of a 150 foot shear strip to determine the depth of sliding. Plastic casing installed in the hole was pinched closed at a depth of 65 feet before the shear strip was installed. The mapping in 1971 indicated the upper cracked zone had not migrated higher than those noted on the map prepared by Ken R. White Company in 1968. Movement has occurred within the same area in 1970 and 1971.

PHOTO XI

Disrupted access trail, Slide 1

Movement of surficial slides occurred in the spring of 1971 during and immediately after the spring thaw. This resulted in scarps with displacement from one to four feet high in the center of the slide.

An extensive zone of surface cracks, soil rolls, and scarps is in the forested area at the break in slope between Drill Holes 3 and 4 and in the forested slope north and northeast of Drill Hole 5. The steep slopes in thes two areas are very wet and may involve only the movement of surficial deposit

A large mud flow originating in the lower edge of this area occurred in early August. The flow destroyed 200 feet of the newly repaired rubber-lined ditch.

Movement in bedrock is occurring at the top of the cut on the western edge of the slide. The top of the upper scarp is 90 feet vertically above the toe. The failure is occurring in gneiss located at the intersection of several faults. The gneiss along the faults is intensely altered and decomposed. Seeps of ground water on the face of the scarp saturate the decompose rock. Failure of the decomposed rock undermines the unaltered rock causing it to fail.

Drilling in the slide indicates that the bedrock is highly sheared and altered. The percentage of core recovered from four of the drill holes was very low between the depth of 0 to 65 feet. The core recovered consisted of rock fragments, clay and highly altered rock. Core recovered from greater depth indicated many clay zones in the undisturbed rock.

A seismic survey of the slide indicated a zone of rock with a velocity between 2200 to 4500 feet per second down to 32 to 65 feet below the surface overlying rock with velocity ranging from 6000 to 20,000 feet per second.

Summary

Fractured and altered bedrock along a zone of northwest trending faults is failing on the steep slope above the roadway. Drilling and seismic data indicate a zone of disturbed rock between the surface and a depth of 32 to 65 feet. Movement in the bedrock is related to the periods of high ground water

Surficial material on the slope is moving at a faster rate than the bedrock. The material moves by creep and mudflow.

The limits of the slide have not extended beyond the tension crack zones noted in 1968, except at the upper western edge of the slide.

SLIDE 2

Slide 2 is one of the largest landslides along Straight Creek (Figure 5) The slide is located between Station 268 and 290 and extends 1500 feet upslop from the roadway centerline. Several areas of movement were noted during the investigation. Photographs include Photos II, V, VI, VII, XII, XIII and XVI and oblique photo Figure 13.

Geology

In this area, Precambrian metasedimentary rock has been intruded by large masses of pegmatite that occur as lens-shaped masses subparallel to the foliation. The foliation of the metasediments strikes northwest. Northwest trending faults through the central part of the slide have broken and intensely fractured the rock. Alteration along the fractured zone has resulted in alternating bands of clay and decomposed rock. The clay and decomposed rock is confined by unaltered bedrock on both sides of the zone. Failure is occurring where the decomposed rock is exposed on the steep cut slopes made during construction.

Bedrock

Bedrock exposed in the slide consists of metasedimentary rocks and pegmatite. The metasedimentary rocks are biotite-quartz-plagioclase-gneiss, a fine - to medium-grained light - to medium-gray rock. Along faults, the gneiss is intensely altered and decomposed. In some zones it has been altered to clay. The altered and decomposed rocks disintegrate into a loose mass of soil when exposed to air, water or foot traffic. Altered gneiss is exposed in isolated outcrops in the central area of the slide and in the face of the drainage gallery approximately 80 feet below the surface.

Gneiss exposed in the slopes above the slide and on the cut slopes along the road east of Station 280 generally shows little to no alteration, however, the gneiss on the cut slope has been disturbed by ripping, and the broken rock covers the slope. It is possible to determine the general configuration of the rock exposures and to locate the contacts between the rock units to within a few feet, but because of the breakage and disturbance of the material, structure cannot be accurately determined.

Pegmatite composed of feldspar, quartz and muscovite occurs in massive outcrops, and in zones where blocks of the rock are surrounded by decomposed pegmatite. In the decomposed rock, quartz and feldspar grains, muscovite plates from silt size to 3 inches across, and clay, are easily eroded by running water, leaving pegmatite blocks exposed as ribs. The pegmatite is exposed in isolated outcrops in the slide. Massive pegmatite forms crags to the west and on the slopes north of the slide. See Photos XII and XIII.

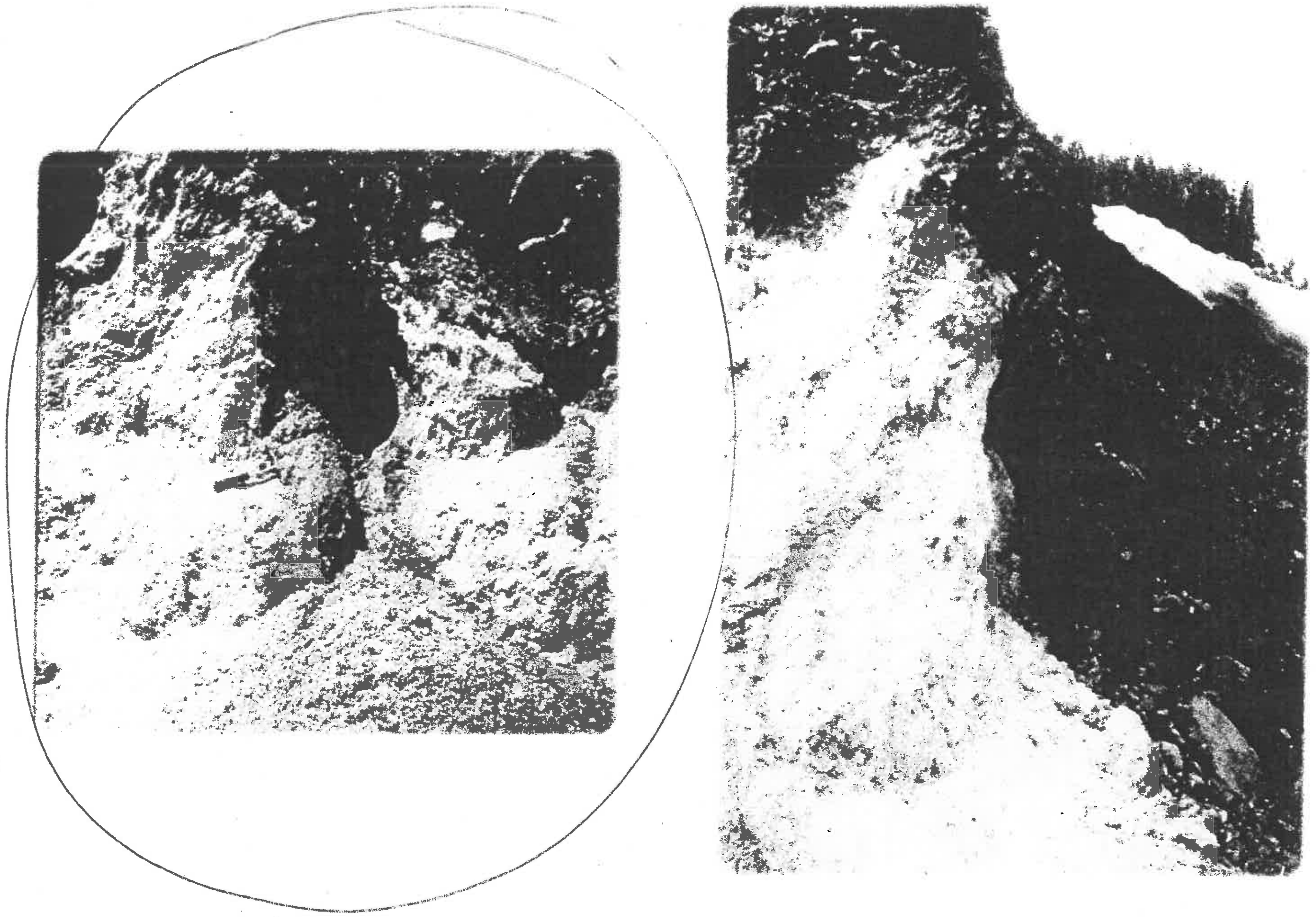
Structure

The structure of the bedrock is controlled by the foliation of the gneiss and the zone of faults in the central part of the slide. The foliation of the gneiss strikes northwest and dips 22° to 85° northeast. The foliation dips much steeper along the faults than in the outcrops above the slide area. The large lenticular masses of pegmatite are oriented subparallel to foliation of the gneiss. The pegmatite was probably injected along the foliation and faults.

The pegmatite has been fractured and sheared more intensely than the gneiss, probably because it was more brittle. The zones of alteration are more intense in the pegmatite and in the gneiss adjacent to the pegmatite. Several vertical faults trend north 45° west through the center of this area.

PHOTOS XII and XIII

Decomposed pegmatite, Slide 2



Surficial Deposits

Surficial materials are chiefly unconsolidated colluvial deposits formed by the weathering of bedrock materials, which have moved downslope in response to gravity. The colluvium is composed of silt, sand, gravel and boulders. Residual deposits of organic soils and thin peat bogs have developed in swampy areas and closed depressions.

Slope Failure

Sliding is occurring in bedrock and surficial materials at several locations. Prior to the start of field investigation, a critical section was selected for subsurface investigation and instrumentation. The critical section corresponds to Section 0 + 15 (Figures 9 and 10) and Section 2-3 (Figure 7, sheet 3). The section was chosen from aerial photos taken in October, 1970, which showed it to be the centralized area of the unstable slope. Slope failure was recorded by mapping the surface cracks and landslide scarps. Landslide scarps are indicated by a hachured line. Vertical displacement along the scarp is noted in feet above the hachured line. Bedrock sliding was detected and the depth of movement was recorded by shear strips installed in drill holes on the slide.

Two types of surficial landslides were observed: (1) sliding occurring in the unconsolidated landslide debris that consists of mixed soil, peat, logs and bedrock fragments; and (2) sliding occurring in the unconsolidated colluvial and swamp deposits above the cut slope.

The remobilized surficial layer is from 1 to 20 feet thick. The material moves downslope by creep and mudflow at a faster rate than does the underlying bedrock slide. The greatest movement occurs on both sides of the critical section along ravines in the cut slope. Movement is most rapid during and immediately after the ground thaw in May and early June. During this period, mudflows are active daily and show greatest activity in the afternoon. By mid-June, 1971 the activity of the mudflows subsided, and for a period of several weeks the surface appeared to be stabilized. Hairline surface cracks form and expand as the ground dries. Material dried to a depth of a few inches to a foot below the surface while the material below was still saturated and partially frozen and often moved downslope below the dry crust. The saturated material below the crust periodically broke out and flowed down the steep slope. The overlying crust subsided and floated down on the flow.

"Glide" planes, formed between the base of the moving mass and the stable underlying soil, do not heal later or disintegrate when the material above and below dries to a uniform degree. Mica flakes become aligned parallel to the glide plane and form an impervious layer. These glide planes become a permanent feature of the soil mass, until they are destroyed by actual breaking up of the soil unit at the toe of the slide. During the late summer, the saturated subsurface material continues to move downslope, carrying surface material along and causing surface cracks to expand.

Failure in the surficial colluvial and swamp deposits is first noted by surficial tension cracks or leaning trees. In most of these areas failure of bedrock is probably occurring also, and is responsible for the long and generally straight zones of tension cracks and scarps.

In mid-August, 1971, west of the slide, an area where old surface cracks and fallen timber had been noted, moved downslope. The remaining trees were toppled and an 8-foot surface roll was formed at the front of the slide. This area is shown in Figure 7, sheet 3, section 2-1.

A surface crack has developed approximately 500 feet back of the previously recognized upper zone of surface cracks. The crack is continuous for approximately 500 feet. The western end dies out in a ravine 100 feet upslope from an area 250 feet by 60 feet which had moved down approximately 2-4 feet in early August. The eastern end of the crack presently dies out on the steep slope above the slide. A projection of the crack indicates it could be an extension of a cracked zone crossing throug the timber at the east end of Slide 2.

The zone of cracks at the east end of the slide intersects the rim of the cleared slope approximately at Station 285. The zone can be followed downslope along an old scarp that is partially rubble covered. The trend of the scarp intersects the westbound ditch in the vicinity of Station 290.

The surface cracks and scarps above the rim of the cleared slope extend westward for 500 feet. Maximum vertical displacement along the scarps is 6 feet. Near the western end of the cracks the zone branches with a zone of smaller cracks trending south for 300 feet down the slope. The main branch of the surface cracks die out on the nose of a ridge.

PHOTO XIV

Tension cracks at the upper limits of clearing on Slide 2

At several locations, surface cracks abruptly end; however, inspection of eas where open cracks expose rock below the surface reveals that the cracks in the rock continue without surface expression. The soil cover apparently bridges the crack. Periodic checking of the areas often revealed extension of cracks when further movement below surface overcame the bridging action of the surface crust. Many of the cracked zones can be projected for several hundred feet beyond the termination of the surface ruptures. The projection of cracked zones are indicated on the map (Figure 5) by a dotted line.

Bedrock failure in the central area occurs in a zone of crushed and decomposed rock and along zones of weakness above the slope cuts.

The failure in the central area of the slide is related to the sheared and altered rocks along a northwest trending fault zone. The rock in the slide is chiefly decomposed and altered pegmatite with interlayered bands of moderately to intensely altered biotite gneiss. Faulting has fractured the pegmatite and provided openings that permit water to infiltrate the zones of crushed and broken rock. Much of the rock in these zones has been altered to clay.

The maximum depth of movement recorded by shear strips installed in the drill holes was 65 feet below the surface. Movement was indicated by several other shear strips breaking at lesser depths and by shifting of several drill holes during drilling. Table 2 gives the data obtained from the shear strips placed in drill holes on Slide 2.

TABLE 2

Shear Strips installed in Drill Holes on Slide 2

Drill Hole No.	Date Strip Installed	Depth	Date Strip Broke	Depth of Deepest Break
3	5/3/71	0-150'	5/19/71	63'
6	5/14/71	0-150'	5/25/71	54'
8	5/22/71	0-150'	6/3/71	51'
14	5/28/71	0-150'	6/1/71	51'
1	6/14/71	0-75'	*	*
19	6/17/71	0-118'	6/29/71	18'
20	6/17/71	0-75'	6/24/71	9'
21	7/11/71	0-75'	*	*
22	7/12/71	0-75'	*	*
23	7/15/71	10-70'	*	*
24	7/21/71	10-70'	*	*

*Unbroken on 9/3/71

Core samples from the drill holes indicated the rock is broken and disturbed to a depth of 40 to 65 feet below the surface. Numerous zones of clay and randomly oriented foliation of rocks were encountered. Seismic data indicated a zone of rock with low velocity to a maximum depth of 65 feet overlying rocks with a velocity ranging from 6,500 to 20,000 feet per second.

The deep movement recorded by the instruments occurred in May and June, corresponding to the period of the highest level of ground water. Failure of the slope progressed outward from the central area from June through August.

Movement in the central areas of altered and decomposed rock removes support from unaltered rock adjacent to the fault zone allowing failure to progress outward. Failure in the unaltered rock occurs along planes of weakness such as faults or joints. Failure along these planes would explain the long straight zones of tension cracks above the slides.

Summary

Landsliding along Straight Creek in Slide 2 is occurring in the surficial deposits and in the underlying bedrock. Surficial materials slide at a faster rate than bedrock, and mask much of the evidence and result of bedrock movement.

Instruments indicate movement in a zone 65 feet below the surface at the center of the slide. Core samples and seismic data indicate a zone of decomposed and unconsolidated rock 30 to 60 feet below the surface. The rate and time of movement is related to the elevation of ground water.

Failure of bedrock in the zone of altered and decomposed rock has allowed bedrock in the adjacent areas to fail along planes of weakness.

SLIDE 3

Slide 3 is located between Station 235 and 243 and appears to be partially stabilized in the vicinity of the highway by a large rock buttress. Recently formed scarps and surface tension cracks, however, were noted 1200 feet north of the roadway centerline.

Geology

Precambrian metasedimentary rock with intrusions of pegmatite is overlain by morainal materials and colluvial deposits. Swampy areas and peat bogs occur on the slide and on the valley floor at the base of the slope. Massive outcrops of pegmatite form the steep slopes west of the slide. Metasedimentary rocks were not exposed in the slide, but were encountered in drill holes at the base of the slope. The metasedimentary rock was biotite gneiss, moderately to highly altered.

The morainal deposits overlying the bedrock consisted of unsorted silt, sand, gravel and boulders. Colluvial deposits consisted of rock fragments and clay derived from the weathering of the bedrock.

PHOTO XV

Slide 3, with buttress

Slope Failure

The slide was not fully investigated or mapped during 1971. A map was prepared in September, 1971 of the toe of the fill where active movement occurred during the early summer, and was extended to the top of the rock buttress (Figure 6). Some of the surface cracks and recent landslide scarps above the buttress were located and noted during a brief reconnaissance traverse, but the details of the landslide shown on the maps above the buttress do not represent the extent of the many cracks, depressions and scarps present.

Movement of surficial material is occurring in the slope at the eastern end of the buttress along the small stream east of the slide area (Figure 6). Surface movement, fallen timber and fresh scarps trend upstream 600 feet north of the buttress. Approximately 500 feet north of the buttress there is a series of landslide scarps parallel to the roadway. Displacement along the scarps is commonly 2 to 4 feet. Vertical displacement along the uppermost scarp ranges from 3 to 15 feet. Many of the scarps die out in benches and depressions that mark the extent of movement of prehistoric landslides. It was impossible to determine the annual movement in this area. A supposition can be made that considerable movement occurred in the past year based on recently fallen trees, fresh uneroded scarps and an absence of any accumulation of pine and spruce needles, aspen leaves, or decayed matter in some of the open cracks.

A series of continuous surface cracks, beyond the limits of the map, occu along a ravine, starting about 800 feet upslope from the western end of the buttress. The cracks extend 400 feet to the northwest and die out at an uppe stream diversion and drainage ditch at an elevation of 10,430 feet. These cracks are up to one foot wide and usually show a displacement of less than 1 foot vertically. The cracks cross pegmatite outcrops exposed along the ravine At the pegmatite exposures, cracks at right angles to the main trend can be followed along the outcrop but could not be traced into the adjacent unconsolidated surficial material. This network of surface cracks appears to be a very recent development that may indicate reactivation of old former landslide masses.

Summary

As of October, 1971, the roadbed and slope immediately above the buttress at Slide 3 appear stable. If the slope at the east end of the buttress fails, the landslide debris would probably be confined to the creek bed and timbered flat to the east, requiring only minor work to clear the culvert. The potential damage to the highway resulting from failure higher upslope was not dete mined by this investigation.

SLIDE 4

Slide 4 is located between Station 210 and 215 and extends 1300 feet nort of the roadway centerline. No evidence of significant movement in the year prior to October, 1971 was observed. The slide was not mapped during this investigation.

PHOTO XVI

Slide 4

Geology

The slide is located on the steep slope below a narrow fault valley which ies right angles to the roadway. Large masses of pegmatite are exposed along both sides of the valley. Gneiss occurs in the valley between the masses of pegmatite. The gneiss exposed in an excavation along the west side of the valley and below on the face of the slide is a tan color and moderately altered. A zone of greenish colored, highly altered gneiss and clay occurs adjacent to the fault. The clay zone is 4 to 6 feet wide and is saturated.

Foliation of the gneiss strikes north 15° to 35° west and dips northeast. Along the west edge of the valley a fault trending north 40° west and dipping northeast is exposed in the excavation at the head of the rubber-lined ditch and in a diagonal band down the cut slope.

Surficial material consists of colluvium from the weathering of bedrock and swamp deposits that formed in the enclosed basins above the slide. Recent failure in surficial material occurred in an area approximately 60 feet by 60 feet midway up the slope, and has moved a few feet downward by creep. Minor adjustment of surficial materials occurred along the westbound ditchline. Unconsolidated surficial debris was eroded by spring runoff, and local areas of slope failure have occurred along the edges of the steep ravine at the upper portions of the slide.

Above the cut slope, the ravine has been filled to provide drainage in a former swampy area. Drainage of a swampy bench at a higher level has been verted eastward through the divide behind the ridge that forms the east oundary of the slide. The divide may reflect the trace of an east-west fault or ancient landslide scarp.

Several swampy benches occur at higher elevations on the slope, some resulting from morainal deposits and landslides.

SLIDES BELOW FILL AREAS

During the investigations of the slides above the highway, it was noted that there was failure in the surficial material at the toe of fills below the highway. These areas of failure were briefly investigated by mapping and drilling. A summary of the results of these investigations follows.

Fill Area, Slide 1

An old lobe of surficial material that appears to have moved into the valley below the road from Station 284 to 293 is now constricting Straight Creek. Material exposed at the toe of the lobe is unconsolidated silts, sand, gravel and boulders.

The toe of the lobe has a roll-like surface at creek level overriding llen trees that now lie in the creek bed. Material moving into the creek ed has deflected the creek and is pushing it into the opposite bank where the alluvial terrace is being undercut by the creek.

Several surface cracks were mapped on the slope above the toe of the lobe, but most of the surface has been covered during road construction by fill material, so that the extent of the cracks could not be determined. An extensive set of surface cracks, which was noted in the fill covering the lobe, reflect movement of the original ground, or may have been caused by the settlement of the uncompacted fill material.

East of the lobe just described, a topographic map prepared by the Ken R. White Company, 1968, shows a lobe at the toe of the fill at Station 296+70 directly below the lobe of a landslide mass that pushed out onto the westbound lane. A subsequent line shift and widening of the fill had covered the lobe at the toe of the fill so that it is not reflected on the topographic map prepared in 1970. The fill at this location does not show indications of instability at this time.

Fill Area, Slide 2

Below the roadway at Station 275, movement has occurred in an elongated lobe and in the valley floor on each side of the lobe. The lobe is 100 feet wide and extends from the fill 140 feet out onto the valley floor. Willow swamps underlain by peat 2 to 4 feet thick border the lobe. Drilling in the lobe indicated silt, sand, and gravel to a depth of 10 feet overlying 7 feet of micaceous silt. Below the silt, boulders, gravel and silt were encountered to a depth of 30 feet. The slope of the valley floor dips 5° to 10° toward the creek.

PHOTO XVII

Overriding lobe, Fill Toe, Slide 2

Fill Area, Slide 2 (Con't)

The front of the lobe is a convex roll 15 feet high. Tension cracks in the surface are from 0.5 to 3 feet wide. Several blocks between the cracks have dropped 1 foot. The cracks extend outward beyond the lobe onto the valley floor and on each side one crack merges with a surface roll 1 foot to 1.5 foot high. Surface cracks can be traced up to the toe of the fill and disappear under the fill material. Cracks in the fill and movement of fill material above this area have been noted.

A grove of large and medium size spruce trees are growing on the lobe. Several spruce trees, 3 feet in diameter and growing at the lip of the lobe, lean outward at 20° to 25°. Large spruce trees that were growing on the lip have fallen outward on the valley floor, and the lower portions have been overriden by the lobe. Small aspen and willow trees still rooted and growing have rotated with the front of the lobe and are hanging downward.

The size and age of the trees on the lobe indicate it is a feature that was relatively stable for at least 50 to 80 years. The magnitude of the recent movement in the lobe, though located directly downslope from the section of Slide 2 where surface movement was greatest in 1971, could not be directly connected to upper slide movement. Movement or stress was not observed in the road nor in the fill adjacent to the road, thus separating the area of movement on Slide 2 and the area of movement directly below on the valley floor.

Any connections between the movement of the two areas may only be inferred. Topographically a broad arcuate feature on the valley floor directly below the active portion of Slide 2 from Station 270 to 280 represents an alluvial fan derived from outwash of the landslide debris from former periods of movement, remnants of the toe of an old landslide, or material thrust up by movement of the present landslide mass upslope. Observations of the local failures in the unconsolidated and highly erodible fill material left the impression that the failures probably were more extensive, but could not be identified in the loose material. Cracks, which are the first indication of movement, are very faint and often overlooked until they have become several inches wide. On the steep slope of the fill, loose rubble fills most of the cracks and material from road maintenance fall down the slopes. Cracks in the fill slope must be of a large magnitude to be noted. Many of the cracks were located by periodic checking of areas where crack trends were suspected.

Fill Area, Slide 3

Failure has occurred in the fill for the eastbound lane between Station 238 and Station 242+50, below the eastern half of Slide 3. The fill in this area is from 25 to 40 feet high. Failure has progressed up the fill slope to the roadway shoulder where material has dropped 8 feet vertically.

The area is located at the break of slope where the toe of an old - perhaps temporarily stabilized - landslide meets the valley floor. At the break in slope a swamp developed between the toe of the slide and a low morainal ridge that converges with the creek downstream. The swamp was fed by surface drainage across the old slide and by springs at the toe of the slide. The drainage was ponded by beaver dams which contributed to the development of peat layers.

Bedrock consisting of moderately to highly altered and fractured biotite gneiss was encountered at 23 and 25 feet below the surface in drill holes.

Surficial deposits overlying the bedrock consist of a mixture of sand, gravel and boulders derived from glaciation and landslides. Peat and organic materials interbedded with silt, sand, and boulders were encountered in drilling at 4 to 10 feet below the surface. The peat layer thins to approximately two feet in thickness in the easternmost drill hole (DH1, Figure 6). The peat is saturated and very compressible.

Failure was noted in the shoulder of the road fill and at the edge of th swamp. Three exploration holes were drilled along the toe of the fill to determine the characteristics and extent of the unstable materials. The toe of the fill was mapped to locate areas of failure and zone of surface cracks. A seismic traverse along the toe of the fill was conducted to determine the depth of the subsurface materials.

The weight of the fill material that was placed on peat and organic swam deposits is squeezing them out into the swamp area along the fill toe. A surface roll 2 to 5 feet high has formed along the lower edge of the swamp and is riding out into the forest. Failure in the fill slope has resulted in a series of tension cracks and scarps that extend up to the roadway shoulder. The toe of the fill is saturated and the loose wet material moves downslope under the weight of a person. An attempt was made to move the drill rig alon the toe of the fill to a location 70 feet west of Drill Hole 2 (Figure 6), but the D-6 cat was unable to cross the swampy area or cut an access road int the toe of the fill, which was saturated and soft.

An underdrain system previously installed under the fill is now only partially successful in providing drainage. Fine material has clogged some of the drains and compression of soil at the toe of the fill has probably constricted the water flow.

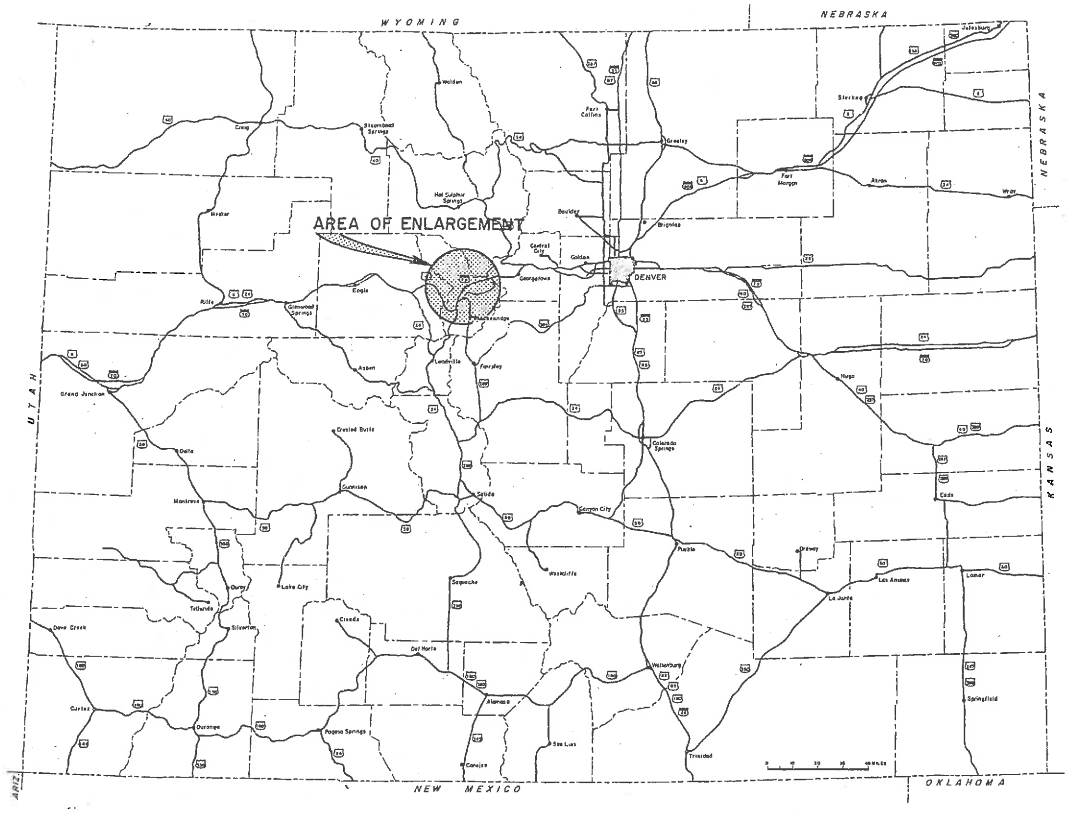
Soil below the layer of peat should be a competent foundation material for the road fill. Peat should be removed and adequate drainage provided for water now being trapped in and behind the fill.

SMALL SLOPE FAILURES BETWEEN SLIDE A AND THE WEST PORTAL, STRAIGHT CREEK TUNNEL

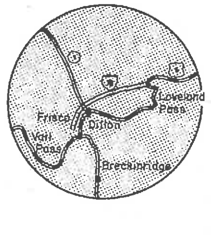
The road cuts between Slide A and the West Portal of the Straight Creek Tunnel were beyond the limits of this investigation. Several areas of local slope failure, however, occur, and the potential for enlargement of these are exists. A summary description of these critical areas follows:

1. A small slope failure has occurred adjacent to the fault at Station 359.
2. A slide has occurred in the ravine at Station 364. Soil creep is prevalent up the draw for a distance of 300 feet.
3. Movement of materials has occurred in the cut slope from Station 375 to Station 378+50, along both sides of the stream which crosses the road at Station 376.

FIGURE I

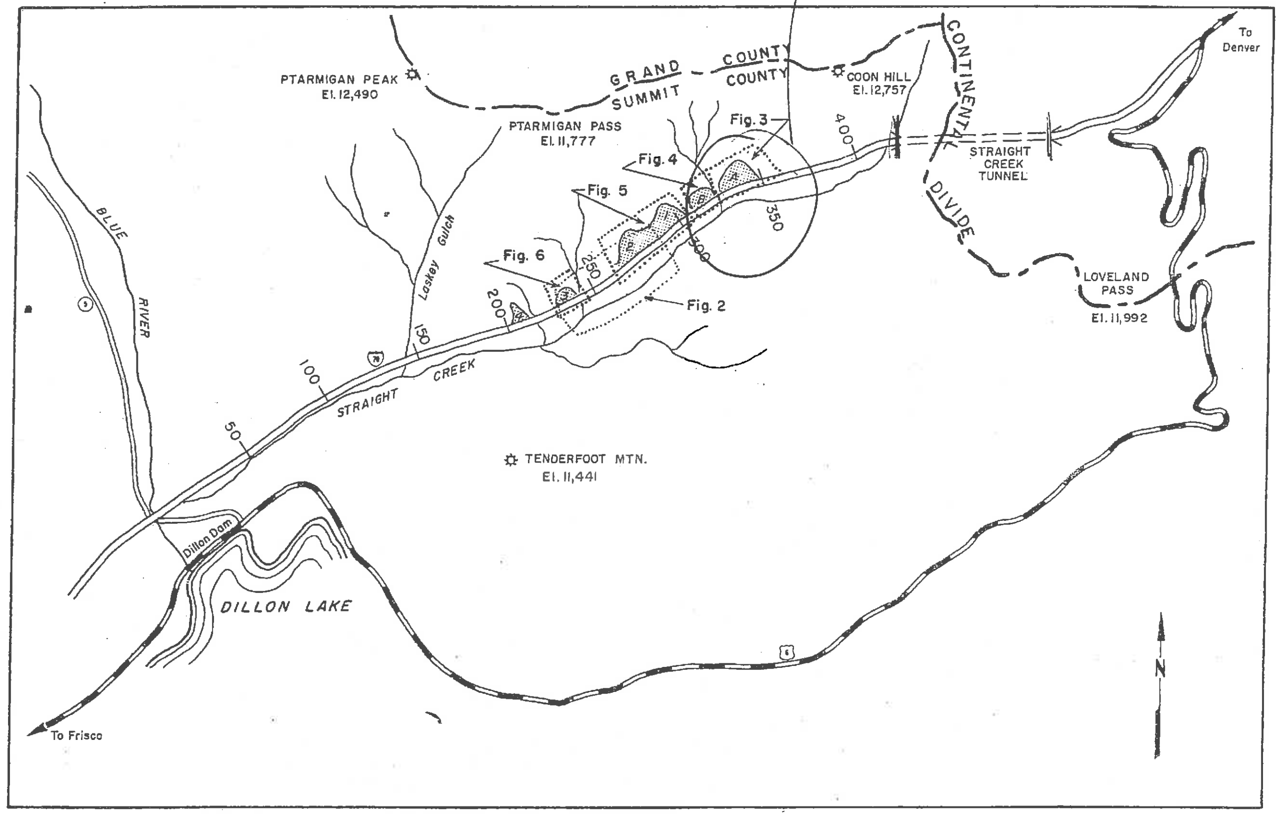


MAP OF COLORADO



AREA OF ENLARGEMENT

CSM Research Site



INDEX MAP TO STRAIGHT CREEK SLIDE AREA MAPS

1 0 1 2 3 4 MILES

Slide A, B, 1

COLORADO DEPARTMENT OF HIGHWAYS

INDEX MAPS, STRAIGHT CREEK SLIDE AREA, SUMMIT COUNTY, COLORADO

COLORADO DEPARTMENT OF HIGHWAYS
AND
ROBINSON & ASSOCIATES
SEPTEMBER, 1971