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I 70 ACROSS VAIL PASS

FINAL GEOTECHNICAL INVESTIGATIONS

by

Robert K. Barrett

COLORADO DEPARTMENT OF HIGHWAYS
Colorado Division of Highways
DISTRICT III
Grand Junction

August, 1978

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ABSTRACT

This paper presents an overview of final geotechnical investigations on the 22.5 kilometre (14 mile) Vail Pass Interstate 70 alignment. Final studies began in 1971 at the conclusion of the consultant's Intermediate Geologic Investigation. The final studies were conducted concurrently with alignment development in close coordination with the various design personnel. These geotechnical studies involved Division of Highways personnel and consultants from four engineering firms.

Several areas of extremely difficult geological conditions were traversed by the Interstate corridor, requiring unique and innovative designs to provide a stable, attractive and environmentally compatible highway. An area of saturated, fine-grained glacial deposits was discovered near Bighorn Creek that would have adversely affected a proposed cut slope. Sidehill viaducts were required to avoid cutting. Saturated lake deposits occurred on both sides of Black Gore Valley in some areas requiring use of high retaining walls to avoid major excavation that would have resulted in almost certain failure.

Landslides and bedrock failures were found throughout the corridor, with one complex over two miles long. At one location, two active landslides were constricting Black Gore Creek from opposite sides of the valley. A major buttress, completely filling the Black Gore channel and floodplain, was incorporated to cause the slides to push against each other. And in another area, a bedding plane failure was allowed to reactivate during construction as the economical and environmentally preferred choice of design alternatives, since cost of the failure corrections would be less than an alternative design that would have avoided the failure.

The roadway is now practically complete. Approximately 30 man-years of geotechnical expertise were involved along with 10 drill crew years and a host of other related items. Costs for geotechnical studies is estimated to have been two million dollars. One unanticipated failure occurred at a cost of $75,000 to correct.

I 70 ACROSS VAIL PASS

FINAL GEOTECHNICAL INVESTIGATIONS

INTRODUCTION:

Final geotechnical investigations on the 22.5 kilometre (14 mile) Vail Pass I 70 Project began in 1971 after completion of preliminary investigations by an engineering geology consultant. The preliminary and intermediate phases included four years of investigation by both Colorado Division of Highways (CDOH) engineering geologist, consulting engineering geologists, soils engineers, and rock mechanics engineers.

Preliminary and intermediate investigations identified several miles of potentially unstable areas where the routing of a four-lane interstate highway could be adversely affected by rock, soil and snow slides. It was recognized at the end of these early studies that the final alignment would necessarily be selected in conjunction with a comprehensive final geologic investigation.

Over the period from 1971 to 1977, geologists and soils engineers worked very closely with both consulting design engineers and CDOH design and construction engineers in selecting the optimum location for the roadway. This report describes some of the investigations that were conducted between 1971 and 1977 and describes, from a geologist's viewpoint, how and why various alignment and related special features were finally selected.

GENERAL GEOLOGY

The final geotechnical investigations added the third dimension to the Robinson-Lord geologic maps and provided soil and rock engineering properties along with ground water data. Aided by geologic maps;black and white, color and infrared photography; seismographs and drills, it was possible to create a complete picture of the recent geologic history of the Vail Pass Corridor and to predict impacts and consequences of various alignment alternatives.

It was discovered that a glacier had caused deposition of extensive silt, sand, and organic horizons high on the mountain side just east of Bighorn Creek at the west foot of Vail Pass. It was probably this same glacier, originating from Main Gore Creek, that dammed Black Gore Creek and caused widespread fine-grained lake sediments to be deposited on the hillsides for a mile up Black Gore Valley.

Many of the bedrock failures were drilled and much was learned about the failure machanisms. It was concluded that the failures originated on extremely weak, thin, fine-grained, silty, micaceous shale lenses within the predominately sandstone and siltstone bedrock. Bedrock failures on slopes as flat as 4^{o} were observed. In the areas between Stations 615 and 680, both valley walls of Black Gore Creek have failed from near their crest to below the level of the creek---a vertical distance exceeding 610 metres (2000 feet).

Soils were sampled and tested for strength and permeability. The predominant soil on Vail Pass was AASHTO classification A-2-4 and A-4 and was deceptively poor for highway purposes. These soils were highly micaceous and were relatively impermeable. While all the soils appeared visually similar, Hveem stabilometer "R" values varied from 5 to 82 and triaxial tests indicated a wide variation in strength parameters. (The Stabilometer test is a measure of relative stability of soils on a scale of 1 to 100).

SELECTED GEOLOGIC PROBLEMS AND SOLUTIONS

Station 310 to 340

The consultant's preliminary studies concluded that the hillside in the vicinity of Station 310 to 340 probably contained deep deposits of unconsolidated materials. There was concern expressed about the extensive side hill cuts proposed for that area (Refer to Geologic Section 1, page 17).

In 1972, drilling was initiated in the 310-340 area. Soils at the location initially selected for drilling consisted of granite boulders ranging to 1 metre (3 feet) in diameter in a matrix of sand, gravel, and cobbles. These materials could notbe penetrated with the standard rotary drilling equipment owned by the Department. It was drilled by a private firm using a percussion drill.

The drilling program verified that deep, unconsolidated glacial deposits were perched on the mountainside above the proposed extensive cuts. These deposits consisted primarily of sand overlaid by gravel and boulders, and contained organic horizons at various depths. The deepest deposit exceeded 43 metres (140 feet) and the water table was near the surface. Had cuts been attempted in this area, extensive failures---probably involving over a million yards---would have resulted.

Based on the drilling information, it was recommended to the designers that no cuts be made in this area. Two alternates remained. One, a standard fill slope; the second, a side-hill viaduct. Partly due to extensive condominium development and high land values, it was determined that a viaduct was the better choice.

During foundation investigations for the structure, it was discovered that the cross slope safety factor was only 2.0 in the existing hillside in the vicinity of one of the piers. Precedents established on Interstate projects required a 3.0 factor on structure foundations. After considerable review, CDOH management and FHWA personnel agreed to accept 2.0 on this area.

STATION 425

Geologic mapping and subsequent instrumentation by a geological consulting firm defined an area where two active landslides were moving from opposite sides of the valley and constricting Black Gore Creek. After intensive studies and analyses, it was decided that an extensive earth buttress would successfully stop movement in the slides. This buttress would fill the channel and floodplain of Black Gore Creek and cause the slides to push against each other. This is illustrated in Geologic Section II, page 18.

One major consideration in this decision centered around the fate of Black Gore Creek itself. Based on economics, it would have been desirable to place the creek in a large pipe under the embankment; however, the pipe alternate was deemed esthetically unacceptable by several disciplines. Keeping the stream flowing on the surface posed major design problems. An impoundment was required upstream from the earth buttress and a run-down or waterfall was required on the downstream end. Due to the marginal stability of the area, design and construction procedures were quite involved. The choice for the run-down included stepped Gabion Walls with deep foundations acting as cutoff walls with post-grouting to reduce permeability through the rock baskets.

STATION 438-450

Subsurface investigations revealed the presence of a lake deposit consisting of silt and fine sand perched on the hillside where a balanced cut-fill alignment was planned. The lake sands were saturated and cuts into these deposits would certainly be unstable. Pre-drainage was not a practical alternative. Neither was a standard all-fill template, since moving the alignment out to an all-fill section would have necessitated extensive rechannelization of Black Gore Creek. A channel change was not recommended due to the presence of unstable unconsolidated lake deposits on the opposite hillside. The channel change was also not esthetically acceptable.

The remaining choices were high wall or sidehill viaduct. Due to foundation conditions and cost factors, a Reinforced-Earth wall was selected. Prior to construction of the wall, organic soils in the floodplain of Black Gore Creek were excavated and a drainage blanket was placed over most of the wall foundation area and on the slope behind the wall. Extensive underdrain systems were installed to further assure continued adequate drainage (See Geologic Section III, page 19).

STATION 499

Instrumentation installed during the Intermediate Study identified an active landslide on the north side of Black Gore Creek. This discovery resulted in the final alignment being placed totally south of the creek and required one high retaining wall. This retaining wall was the first pre-cast tieback wall to be constructed on a highway project. There was a substantial amount of instrumentation on this wall, including load cells, inclinometers, and strain gauges. The wall system proved effective and efficient. Geologic Section IV, page 21, illustrates the final cross section.

STATION 545-555

The most difficult and challenging problem for geotechnicians on Vail Pass was in the area known as the Miller Creek Slide. This slide is over one kilometre long, nearly one kilometre wide, and about 46 metres (150 feet) deep. The slide consists of up to 21 metres (70 feet) of surficial silty soils overlying some 24 metres (80 feet) of failed bedrock. Water levels were erratic and varied from surface ponds in some areas to dry in other areas.

During the earliest drilling, the lowermost failure plane was thought to be at the soil-rock interface. Two core samples of 6 metres (20 feet) below this contact indicated intact sandstone and siltstone dipping about 4^{o}. This matched the geology in the surrounding area. It was found, however, that this did not match a deep core hole drilled previously by the Denver Water Board in conjunction with a proposed water diversion tunnel. A third hole was drilled to 46 metres (150 feet) and several obvious shear zones were found. Additional drilling revealed areas of completely disrupted bedrock. Competent, intact bedrock occurred below this zone. The bedrock failure plane corresponded with the 4^{o} bedrock dip in the lower reaches of the slide.

During the course of the drilling, a buried soil profile was uncovered in the toe area of the slide. Carbon-14 dating showed that a sample of organic material from the soil layer was 1000 years old, $\pm$ 70 years, which indicated that the movement was relatively recent.

The topography in the Miller Creek Slide, shown on Geologic Section V, page 21, area included a deep canyon at the slide toe into which the slide spills during active periods. Severe grade restrictions, both up and down station from the slide area, dictated that the alignment must cross the slide toe. In other critical areas, it was usually possible to vary vertical and/or horizontal alignment to optimize alignment and geological conditions.

The first alignment investigated included major fills ramping onto and off the toe area with the roadway in cut and fill across the toe area proper. Cuts of up to 15 metres (50 feet) were required, and due to the relatively recent movement that had occurred, it was decided that the risk was too great. The safety factor would have been reduced some 25% in the immediate area.

The second alignment investigated included twin bridges with caisson foundations into intact bedrock. In conjunction with this alternate, a consultant presented a European concept that included oversize, eliptical, concrete-lined caisson holes with free standing caissons inside. This technique would keep horizontal pressures from acting on the caissons and would allow monitoring of any creep that may develop. This alternate was ruled out based on evaluations of existing safety factors, required long-term monitoring, maintenance costs, and on the consequence of failure.

The remaining alternate was a high, vertical, Reinforced Earth wall whose toe would be placed on the edge of the steep canyon wall and whose base would necessarily have to be placed on intact bedrock. In place, this design raised existing safety factors by an insignificantly small number; however, excavation of the toe of the slide to permit construction showed a mathematically significant reduction in the safety factor on the critical circle.

A detailed geotechnical investigation followed a tentative decision to try the wall concept. It was decided that if the water table could be lowered some 11 metres (35 feet) to 17 metres (55 feet) below the ground line for 91 metres (300 feet) horizontally behind the excavation that it would be possible to construct the wall. Based on readings from several water level monitoring sites, it was also decided the wall would have to be constructed during the winter months, the period of lowest ground water levels and least ground water recharge.

In March of 1974, a series of horizontal drainage holes were drilled in an effort to lower the groundwater table. A drill access road was attempted along the lower margin of the slide toe along the rim of the canyon. The area was saturated and not frozen. A 2.1 metre (7 foot) snow cover had not allowed frost penetration and the dozer became helplessly mired. A second road was unsuccessfully built about 6 vertical metres (20 feet) higher that allowed drill equipment access. Minimum expectations from drainage holes at this level were to help dry the lower area for a future drainage project.

The horizontal drilling proved successful and interesting. Some intact blocks of rock were as much as 24 metres (80 feet) across, and almost invariably, great bursts of water would flood from the drill holes when the bit broke through into a shear zone. One such flow was measured at 575 liters per minute (200 gpm). Most flows dropped off substantially in 30 minutes to two hours.

Water levels were reduced almost exactly 11 metres (35 feet). Due to the low cost and success of the drainage program, it was decided it would be worthwhile to drill another series of holes at a lower elevation in conjunction with the construction project. When the second series of drain holes were completed over two years later, the toe area had, in the interim, dried substantially. The second series lowered water levels to about 15 metres (50 feet) below the ground surface.

Prior to construction, three inclinometer holes were installed upslope to monitor any movement that may result from the excavation. The construction plan included very stringent procedures to minimize the amount of slide toe area excavation to be left unsupported at any given time. These restrictions coupled with a winter work requirement caused considerable consternation, both from CDOH construction personnel and from the bidding contractors. Some painted a bleak picture for success of the plan.

An unusually dry autumn and snow-free beginning of winter in 1976 permitted construction to proceed as planned. The backfill was all large (2.5 cm to 20 cm) (1" to 8") gravel and cobblestones (tailings from early gold dredging operations in the Blue River) which was workable at all temperatures, thus achieving density on subzero days was not a problem. The high, [21 metres (70 feet)], steep (1:1) temporary slopes to the slide toe remained stable, and no movement was detected with the inclinometers.

STATION 615-680

Bedrock failures were observed throughout the upper reaches of Black Gore Creek. One failure series was continuous from station 615 to station 750±. Alignment location was first split, with east bound on the south valley wall while west bound utilized the existing U.S. 6 platform. This concept was abandoned when it was discovered that a bridge from the west valley wall would have to be located on marginally stable failed bedrock.

The remaining choice was to place both directions of travel on or near the existing U.S. 6 alignment. The roadway template was minimized by using a median wall, which allowed a better fit on the steep hillside. Several attempts were made at defining critical failure circles and strength parameters through this area. None were felt to be entirely reliable, and the final design was accepted by geotechnical personnel on the basis that it caused the least disturbance, that is, the least reduction in safety factor on mathematical models. It was the consensus of opinion that the final alignment had a reasonable and acceptable probability of success (see Geologic Section VI, page 22).

STATION 700-715

The alignment traversed an area of extensive bedrock failure, a continuation of the failure that begins at Station 615. Topographic restraints limited design choices to a through cut into failed bedrock or twin viaducts running above and parallel to the channel of Black Gore Creek. Cost for the cut section was estimated at $700,000 vs. $2,000,000 for the viaducts. It was decided that the cut was also esthetically and environmentally more acceptable due to a variety of factors. After geotechnical personnel estimated any failure that may occur could be successfully controlled at less total cost and environmental damage than the bridge alternate, the cut alternate was selected

During construction through this area, two failed bedrock areas reactivated. These were stabilized via a grade adjustment, horizontal drains and a rock buttress at a total cost of $810,000. Thus, the final cost was still approximately $500,000 less than the alternate that would have avoided failure.

GEOTECHNICAL RESOURCE EXPENDITURES

During the period between 1968 and 1977, geotechnical investigations were virtually continuous. It is estimated that 30 man-years of geotechnical expertise were involved along with 10 drill crew years. Approximately 6096 metres (20,000 feet) of vertical and 2438 metres (8000 feet) of horizontal drilling was accomplished. Several hundred standard split spoon samples and about 50 thinwalled tubes were obtained. Several hundred feet of penetrometer holes were also accomplished.

Instrumentation utilized consisted of 32 inclinometers, 11 borehole extensometers, 12 piezometers, 40 gloetzl soil pressure cells, 63 electrical strain gauges, and two shear strips. Geophysical studies were conducted by the Colorado School of Mines, and by the CDOH with single and multi-channel seismographs.

Total expenditure for geological investigation on the Vail Pass project is estimated to be 2 million dollars. According to the Robinson-Lord study, approximately 11.2 of the 22.5 kilometres (7 of 14 miles) traversed by I 70 were across unstable to marginally stable terrain. Only one unanticipated failure in excess of 153 cubic metres (200 cubic yeards) occurred as a result of construction. This occurred during the spring of 1978 and cost about $75,000 to repair.

SLOPE DESIGN

Cut and fill slope angles across Vail Pass were based on geotechnical data and on experience in similar materials in similar climatic conditions. Many areas on Vail Pass required cuts and fills that approached critical heights.

At the highest cut, a 91 metre (300 foot) high bedrock cut between Station 605 and 614, the Department retained a rock mechanic specialist to evaluate the slope design and to design and interpret an instrumentation system. In fact, all significant cuts and fills were reviewed by at least two geotechnical specialists in an effort to minimize stability problems during construction.

The final slope configuration, especially the moulding and sculpturing that is visible to the Interstate traveler is the result of intensive efforts by landscaped architects working with construction and geotechnical personnel. Individual grading projects were staffed with landscaped specialists who prepared conceptual plans for the final appearane of cuts and fills and other related features. These plans were reviewed by geotechnical personnel to insure compatibility with site geological conditions, and with construction personnel to insure that the concepts were reasonably constructable.

Slope design was yet another product of cooperation by several disciplines.

CONCLUSION

Geological conditions on Vail Pass are generally unfavorable for construction and maintenance of a four-lane highway facility. Severe constraints and limitations were placed on designers by extensive areas of soil and bedrock failures, by steep topography, and by a cold and wet climate. Successful completion of a project of this magnitude can result only from combined efforts and cooperation of several disciplines under strong and enlightened leadership. These elements were present throughout the Vail Pass Project.

The substantial amount of monies expended for geotechnical aspects of the project were justified by the successful and timely completion of the project. This project, from a geotechnical point of view, stands as a model for future major engineering endeavors in difficult geological conditions.

ACKNOWLEDGEMENTS

The final geotechnical studies are a composite of efforts by many capable and dedicated individuals. The successful completion of this project was due to excellent interdisciplinary cooperation and coordination. Geologic constraints were given appropriate consideration at every level and during each phase of project development. All of the geotechnicians involved appreciated this opportunity to participate in a challenging area and within a cooperative atmosphere.

Major contributors to the final studies include: Mr. J. B. Gilmore, Chief Geologist, CDOH; Mr. R. P. Moston, Former CDOH District III Materials Engineer; Mr. A. C. Ruckman, CDOH District III Materials Engineer; Dr. C. S. Robinson and M. D. Cochran, C. S. Robinson and Associates; Dr. Dwayne Nielson, IECO; Dr. Mike Bokovansky, Dames and Moore; and Mr. Horst Ueblacker, Ueblacker and Associates.

Drawing and legends in this paper are based on those in the Robinson-Lord Joint Venture report entitled, "Intermediate Geologic Studies, 1971", and were modified for this paper by Jim Lance, CDOH District III Landscape Architect.

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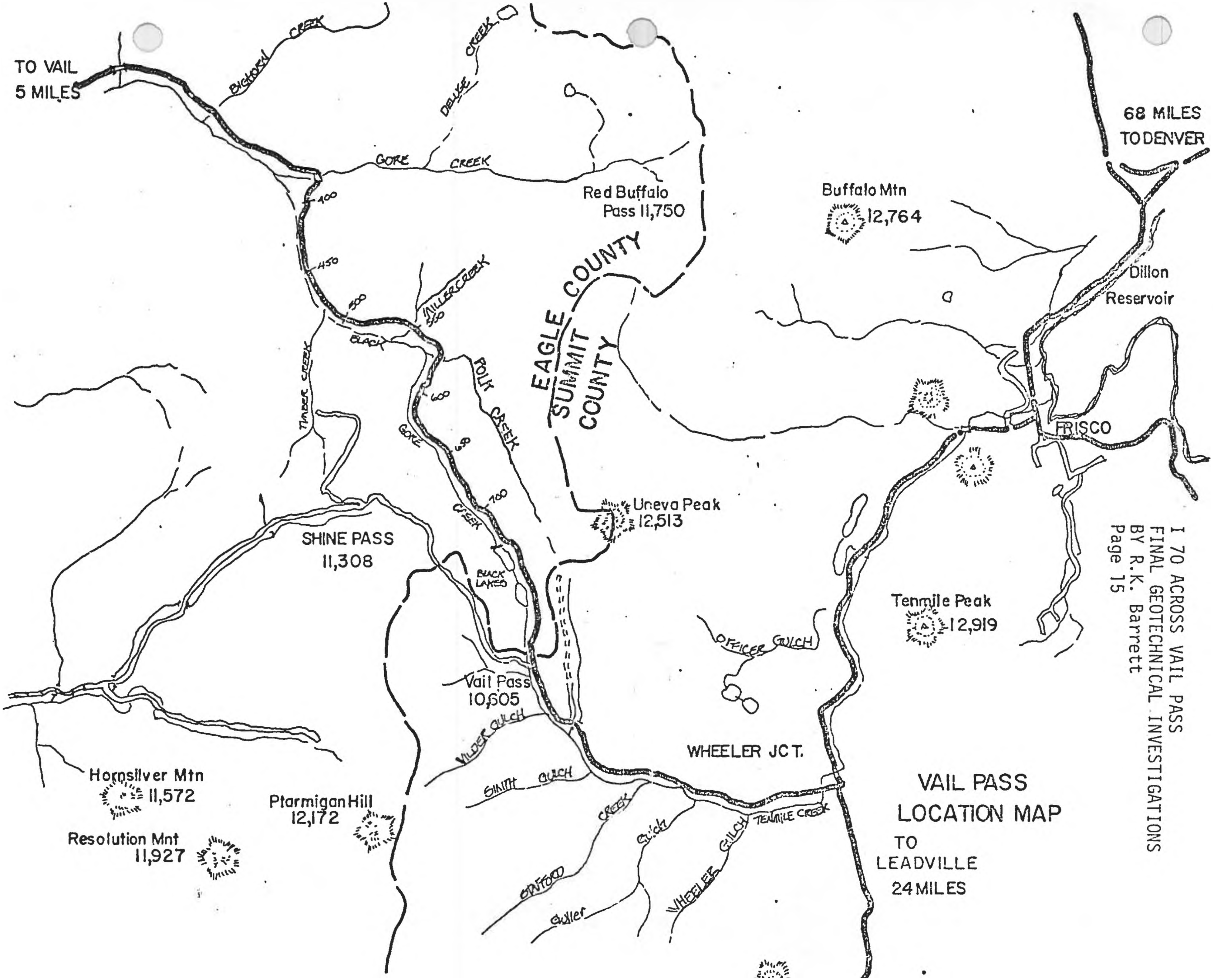

TO VAIL
5 MILES
GORE CREEK
Red Buffalo
Pass 11,750
Buffalo Mtn
12,764
68 MILES
TO DENVER
Dillon
Reservoir
EAGLE COUNTY
SUMMIT COUNTY
MILLER CREEK
BLACK
TIMBER CREEK
GORE CREEK
FRISCO
Uneva Peak
12,513
SHINE PASS
11,308
BLACK LAKES
Tenmile Peak
12,919
OFFICER GULCH
Vail Pass
10,605
WHEELER JCT.
VAIL PASS
LOCATION MAP
TO
LEADVILLE
24 MILES
Hornsilver Mtn
11,572
Ptarmigan Hill
12,172
Resolution Mnt
11,927
SMITH GULCH
WHEELER GULCH
TENMILE CREEK

ta

Talus

(Recent deposits of angular boulders below cliffs; thickness 2 to 50 feet)

cf

Colluvium-Fine

(Predominantly sand and silt with some angular fragments. Material derived from local bedrock and moving downslope in response to gravity; thickness 1 to 10 feet)

cr

Colluvium-Rocky

(Predominantly angular fragments and blocks with some sand and silt.Material derived from local bedrock and moving downslope in response to gravity; thickness 1 to 25 feet)

a

Alluvium

(Boulders and gravel derived from adjacent deposits. Includes sand and silt in bars and at margins of channels, and fine grained sediment with abundant organic material where stream has been dammed, such as beaver ponds; thickness 0 to 50 feet)

af

Alluvial Fans

(Material washed by tributary streams from adjacent slopes into main stream valleys. Partially rounded and assorted colluvium; thickness 1 to 30 feet)

m

Moraine

(Boulders, gravel, sand and clay, unsorted. Deposited as ridges along valley walls and in bottoms of valleys. Includes lateral and recessional moraines. May include lenses of fluvial material; thickness 5 to 50 feet)

mf

Moraine-Fluvial

(Morainal material that has been washed or partially reworked by glacial or post glacial streams; thickness 5 to 100 feet)

mt

Moraine-Talus

(Talus material from slopes generally above moraines that have moved down and become admixed with upper part of morainal material)

mcf

Moraine-Fine Colluvium

(Morainal material admixed with material derived by weathering of underlying bedrock. Includes rounded morainal boulders and fine colluvium; thickness 1 to 10 feet)

mcr

Moraine-Rocky Colluvium

(Morainal material admixed with material derived by weathering of underlying bedrock. Includes rounded morainal boulders and rocky colluvium; thickness 1 to 25 feet)

Igneous and Metamorphic Rocks

(Granite, gneiss, and schist)

Sedimentary Rocks

(Sandstone, siltstone, shale and limestone)

MAP SYMBOLS

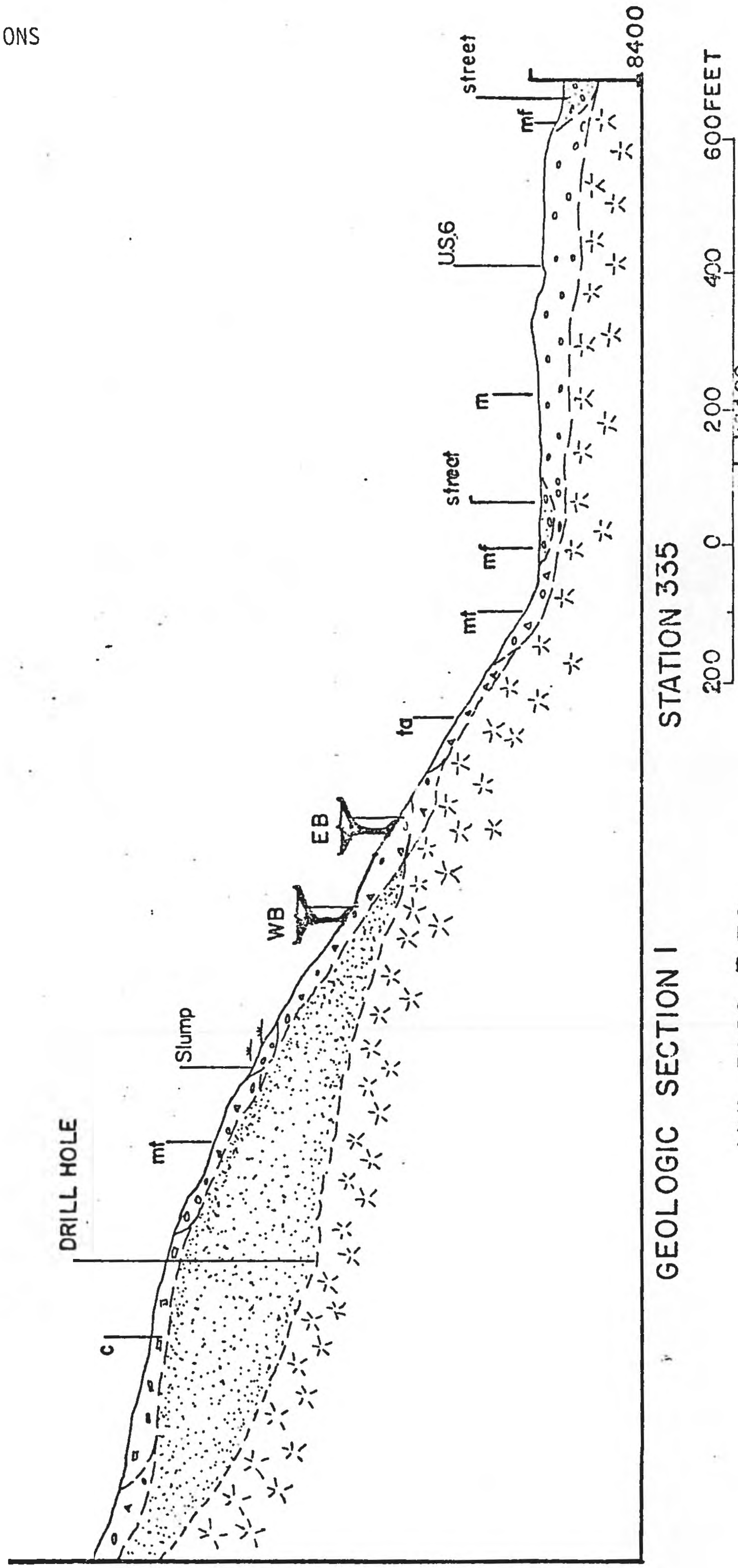
Contact

Fault

Inferred Fault

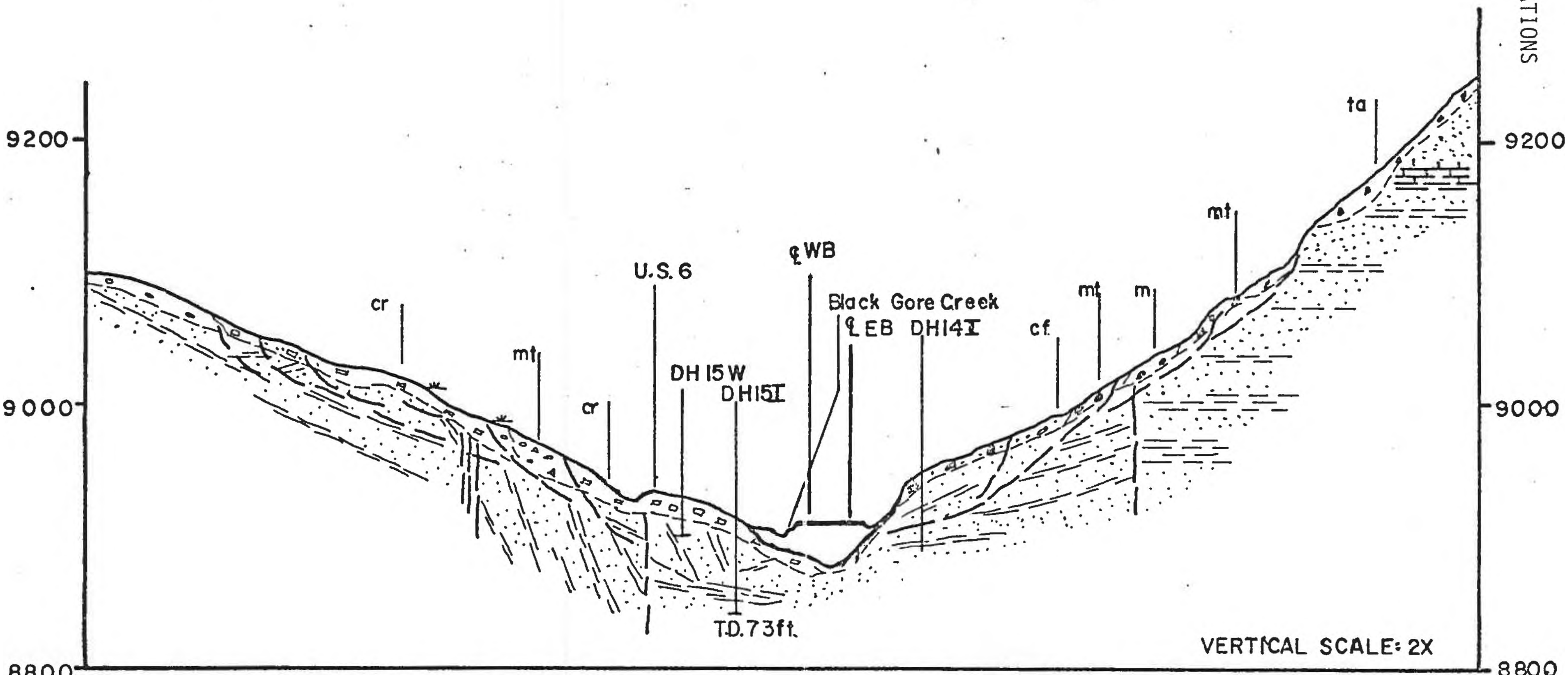
Landslide Slip Plane

Landslide Blocks of Sedimentary Rock



GEOLOGIC SECTION I

VAIL PASS I-70



GEOLOGIC SECTION 2

STATION 425

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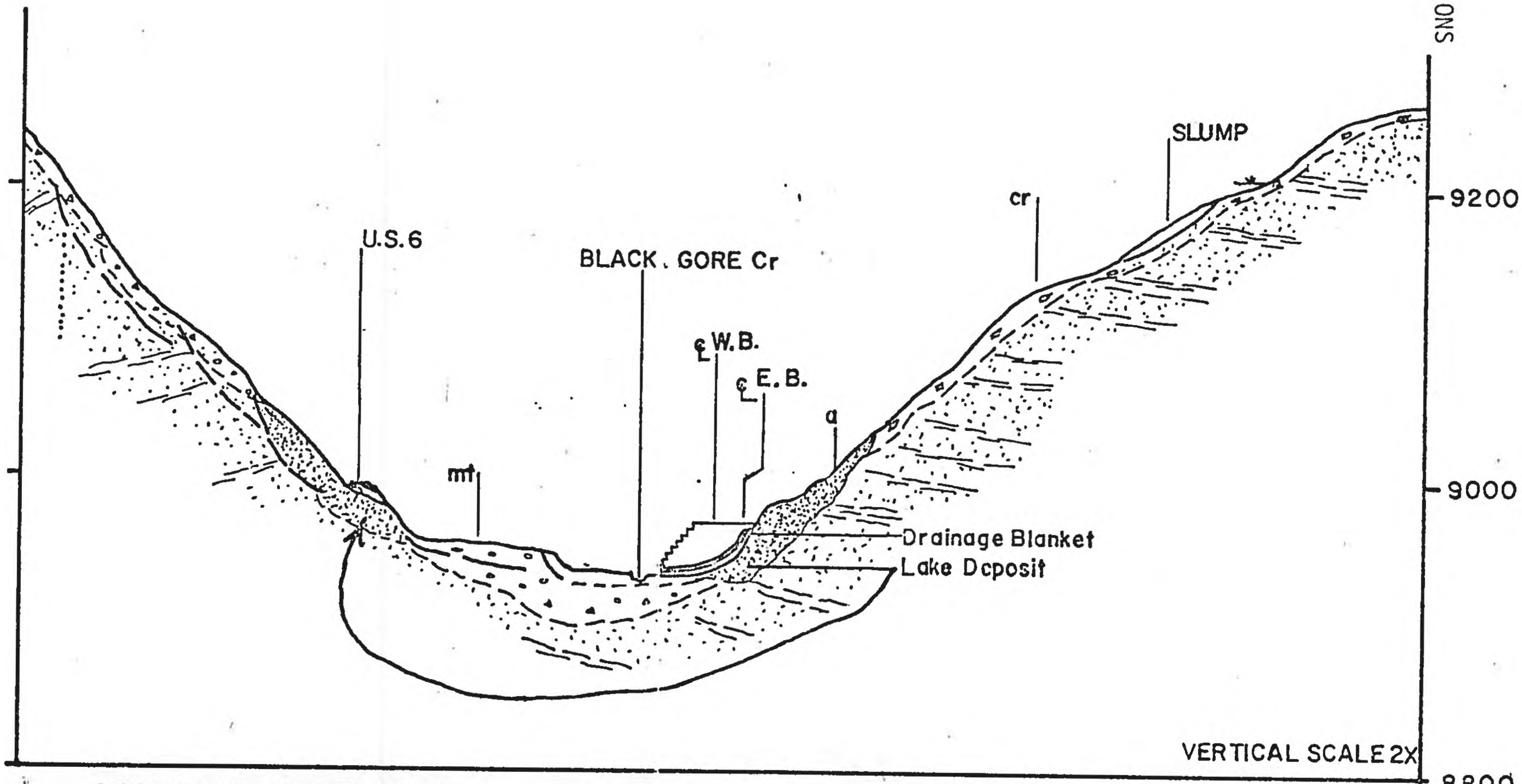
SCALE 1:2400 FEET

VAIL PASS I-70



GEOLOGIC SECTION 3

STATION 450

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SCALE 1:2400

VAIL PASS I-70

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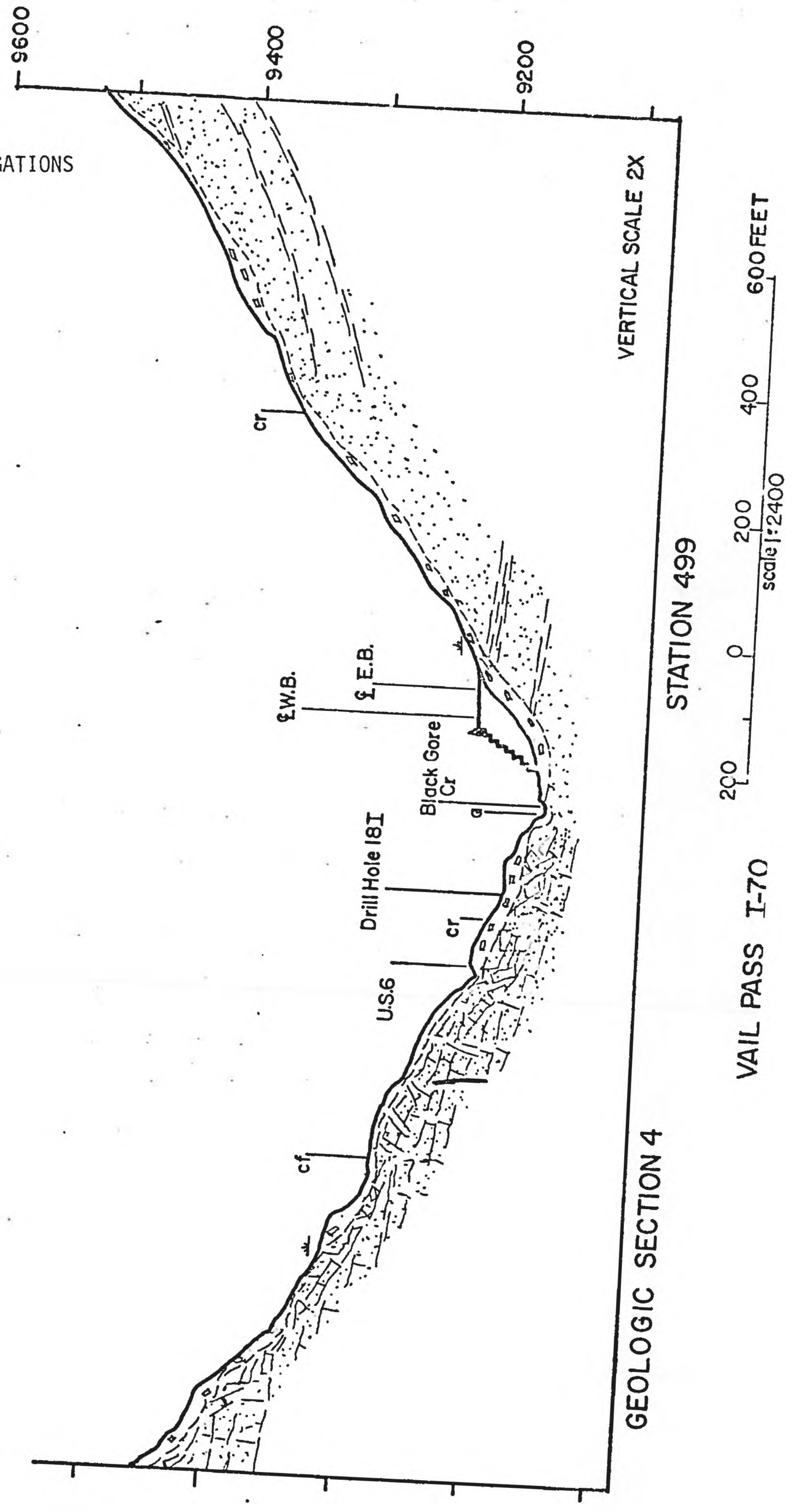

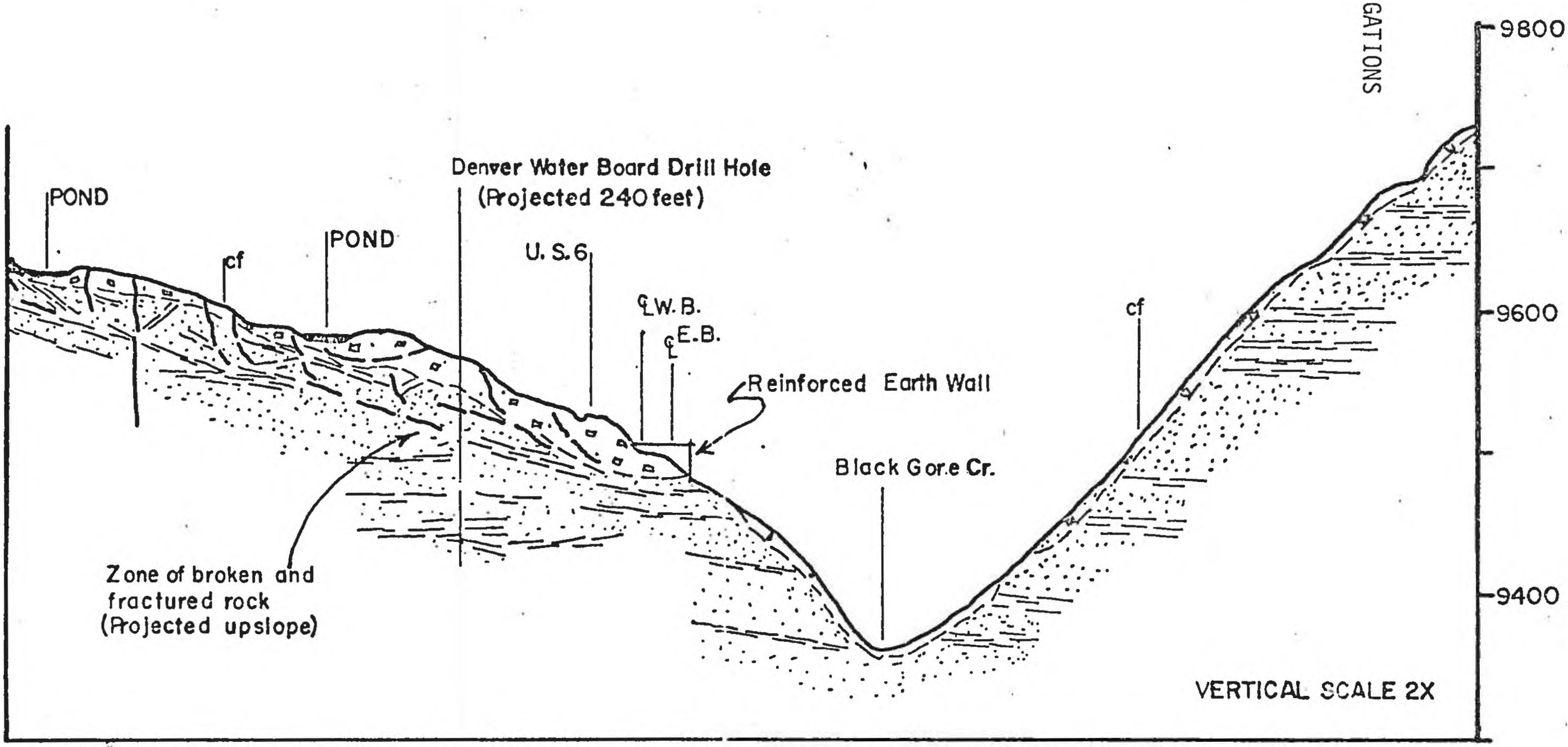

GEOLOGIC SECTION 5

STATION 550

VAIL PASS I-70

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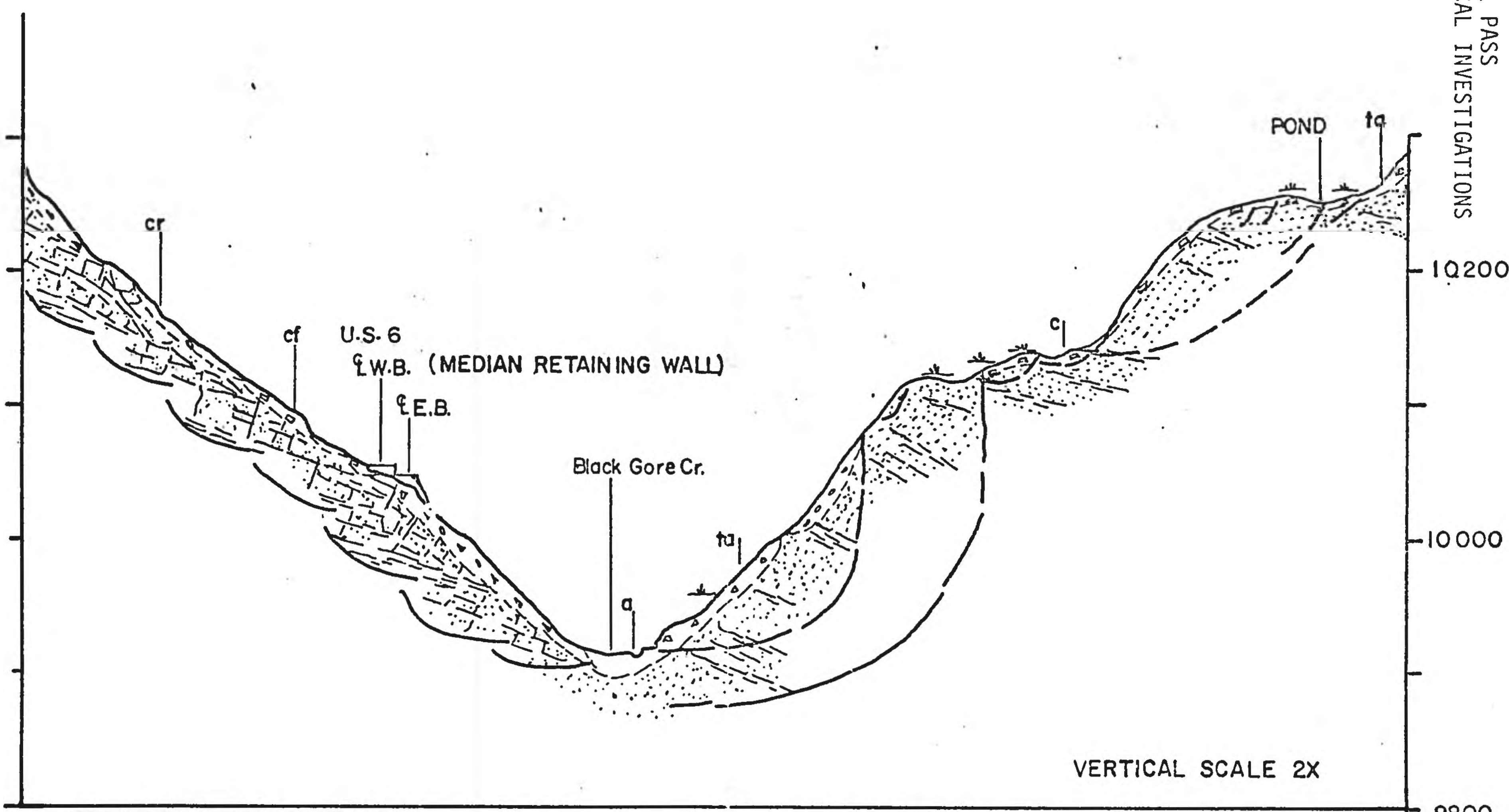

GEOLOGIC SECTION 6

STATION 640

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SCALE 1: 2400

VAIL PASS I-70