GEOLOGIC CONSTRAINTS--VAIL PASS INTERSTATE 70

by

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ABSTRACT

The complexity of the geology in the Vail Pass area of Colorado presented many engineering problems in the design and construction of Interstate Highway 70. Precambrian igneous and metamorphic rocks and Pennsylvanian-Permian sedimentary rocks had been extensively folded and faulted. Glacial and stream erosion and deposition had modified the topography. Large complex landslides that involved bedrock and surficial deposits, which could not be avoided by changes in highway alignment, were the major environmental constraints. The engineering solution to these geologic problems, and the integration of the engineering solutions with other environmental factors, resulted in a minimal environmental impact. The Vail Pass route of Interstate 70 can serve as an example of the value of defining the geologic environment in an environmentally complex area and incorporating the environmental constraints into the design and construction of a major highway to minimize the environmental impact.

INTRODUCTION

The geology of the area, and the geologic processes operative within an area, determine the environment. The modification of the environment for any purpose must consider the geology and the geologic processes active in an area. Good engineering will be compatible with the geology and geologic processes. Minimal environmental impact will occur when the engineering is integrated with the geology and the geologic processes at work in an area. On Vail Pass every effort was made to integrate the geology and geologic processes into the design and construction of the Interstate highway in order to minimize the environmental impact, assure a safe highway and minimize the maintenance of the highway.

In 1969 the Colorado Division of Highways entered into a contract with Charles S. Robinson and Associates, Inc., Engineering Geologists and R. V. Lord and Associates, Inc., Soils and Foundation Engineers, for an intermediate geologic study of the Vail Pass area (Figure 1). After completion of the geologic study in 1971, Charles S. Robinson and Associates were retained to work with International Engineers, Inc. in the environmental studies of the Vail Pass area.

GENERAL GEOLOGY

Interstate Highway 70 across Vail Pass crosses terrains typical of the geology of the high mountains of Colorado. The route follows the valleys of Black Gore Creek that flows north from Vail Pass and the West Fork of the Ten Mile Creek, which flows south from Vail Pass (Figure 1). These streams flow along the west flank of the Gore Range--a northwest trending mountain range bordered on the east by the Blue River. The Gore Range is an uplifted block of granite and metamorphic rocks, which is flanked on either side by sedimentary rocks--chiefly beds of sandstone, siltstone, shale and some limestone. Figure 2 is a generalized stratigraphic section of Vail Pass and Figure 3 is a generalized geologic map of the Vail Pass area.

Subsequent to the uplift of the Gore Range, the area was subject to glaciation and stream erosion. The deposits related to the glaciation, erosion and weathering of the rocks are unconsolidated and locally, subsequent to their original deposition, have slid, forming areas of extensive landslides. The bedrock as a result of the extensive faulting has also formed extensive areas of landslides. Most of the deposits of surficial materials and most of the areas of landsliding--with a few notable exceptions--were relatively stable. Construction across these deposits, however, could easily have caused landsliding or activated old landslides.

Previous geologic work in the area was mostly general and not specifically for engineering purposes, except for that by geologist for the Denver Board of Water Commissioners, Dr. Ernest E. Wahlstrom and

Dr. Lawrence A. Warner, Consulting Geologists and V. Quentin Hornback, Geologist, Denver Water Department, who made geologic investigations in connection with proposed water collection, diversion and storage projects in the vicinity of Miller and Black Gore Creeks, between Black Gore and Gore Creeks and between Gore and Booth Creeks. Those data were made available to the author. General geologic studies that included parts of the area of interest were those of Lovering and Tweto (1) on the geology and ore deposits of the Minturn quadrangle; Bergendahl (2), (3) on the geology of the Ten Mile Range and the Dillon quadrangle, and Tweto (4) on the geology of the Gore Range - Eagle Nest Primitive Area.

GEOLOGIC CONSTRAINTS

The intermediate geologic investigations defined the geologic conditions and geologic processes that were to be considered in the location, design and construction of Interstate Highway 70 through the area. Active landslides, and the potential for reactivating old landslides or creating new landslides were the principal constraints in the location, design and construction of the highway. The existence of ground water and ground-water drainage, foundation conditions--such as areas of swamps--and suitable footings for structures were considered based on the intermediate and subsequent detailed geologic investigations including seismic investigations and instrumentation of some slopes.

LANDSLIDES

The geologic studies of the Vail Pass area showed that more than 50 per cent of the alignment north of Vail Pass and 10 per cent of the alignment south of Vail Pass of U.S. Highway 6 had been constructed on landslides (Figure 4). It was recognized that Interstate Highway 70 could not be built across Vail Pass and avoid all the areas of landslides. The initial geologic studies, and subsequent more detailed studies, were able to define the landslides and their activity, and an alignment was chosen to avoid the more active areas.

The area along the west flank of the Gore Range has been an area subject to landsliding for a long period of time. Most of the landslides were not the result of the activities of man, but of geologic processes.

Landsliding has been occurring in the area before and since glaciation of the area. Most of the older landslides are now stable. The landsliding has involved the bedrock--which constitutes the larger and older of the landslides--and the surficial deposits--which constitute the young and, at present, the more active landslides Table 1 gives the location and dimensions of the larger areas of landsliding along the highway alignment.

Bedrock

Large areas of bedrock failed to form areas of landslide. Many of those areas failed before or during the periods of glaciation. The failure of the areas of bedrock are related to faulting or to over-steepening of the valley walls as a result of erosion related to the glaciation. The landslides in bedrock have involved both the igneous and metamorphic rocks and the sedimentary rocks.

An area of landsliding in the igneous and metamorphic rocks occurs south of the Gore Creek Campground (Figure 5). In this area, blocks of bedrock separated by arcuate faults form a series of steps from Gore Creek up the mountain to the south of the campground. The slope of the steps is toward the mountain to the south. Undrained depressions or small draws have developed at the back of the steps, probably as a result, in part, of erosion along the fault--or landslide slip plane. The faults or landslide slip planes were probably formed prior to the glaciation as the outcrops show evidence of glaciation. The southern limit of the steps is a major northeast trending fault. There is no evidence that there has been any movement of the landslide blocks in recent time, and the landslide is considered to be stable.

The largest landslides in the Vail Pass area involve bedrock of sedimentary rock. These landslides developed as a result of faulting and the erosion of Black Gore Creek. Most of the sedimentary rock landslides occur on the east or north side of Black Gore Creek north of Vail Pass (Figure 1). Only one landslide in sedimentary rock occurs south of Vail Pass. Most of the bedrock landslides are, in large part, covered by surficial deposits (Figure 6). The surficial deposits, because of the movement in the bedrock or because of depositional instability are also moving locally. In such areas landslides are sliding on landslides. Most of the areas of sedimentary rock landslides are stable, only locally within an area of a landslide are blocks of the bedrock sliding. The upper limit of the landslide areas is typically a fault scarp. The faults are generally parallel to the valley and are believed to be realted to the Gore Fault to the east of the area (1). The lower limit of the landslides is Black Gore Creek. Typical of the areas of sedimentary bedrock landslides are large undrained depressions that resemble sinkholes in a karst region. These depressions have generally an elongated elipitical shape. They range from less than a half meter wide and two meters long to tens of meters wide and hundreds of meters long. Some depressions represent very old movement as they have trees to as much as a third of a meter in diameter growing within their limits (Figure 7). Other landslides show evidence of recent movement as cracks in the sod in the bottom of the depression. Some of these cracks have been probed to depths of more than 5 meters. Blocks of sedimentary rock are exposed in the landslide masses. Some of the blocks are tumbled, but most are about parallel in strike to the beds of the undisturbed bedrock, but increased dip. The blocks within a landslide area move different amounts at different times as indicated by the differences in age of the depressions. The blocks of sedimentary rocks are somewhat like randomly oriented and shaped wooden shingles on a steep roof; if one shingle is moved, support from one or more shingles is removed and they move, which in turn allows others to move, until equilibrium is again established. For the sedimentary rock landslides, Black Gore Creek erodes away a piece of a sedimentary rock block, which allows the block to move towards the stream. Blocks upslope will then move downslope. This process is believed to have been going on over a long period of geologic time. Because these landslides are composed of blocks of sedimentary rock, and the movement is generally along and about parallel to the bedding, the landslides are not thick. Drilling and the installation of instruments has indicated that the maximum depth of movement in this type of slide ranges from 6 meters (20 ft.) to about 21 meters (70 ft.). The movement does not occur along a single slip plane, but there may be several about parallel slip planes in a single area of a landslide. Movement occurs along weak bedding planes between beds in a single block of sedimentary rock, or between overlapping landslide blocks of sedimentary rock.

The areas of sedimentary rock bedrock landslides probably started to form during the period of glaciation. Black Gore Creek undercut the edges of gently dipping ledges of sedimentary rock. Blocks of sedimentary rock broke off and moved toward the stream. This process has continued to the present. The upslope limit of the landslides was controlled by pre-existing faults in the sedimentary rocks that parallel the valley. The erosion of the toes of the landslide areas and movement of blocks was probably at a maximum during the periods of melting of the glaciers in the surrounding mountains.

Surficial Deposits

Landslides have developed in the surficial deposits on both sides of Vail Pass. The landslides are the result of the deposition or accumulation of surficial deposits on steep bedrock slopes and then the periodic movement of the deposits (Figure 8). Failure has been the result of steepening of the slopes by erosion, by changes in the groundwater regime, or by movement of the bedrock. All the types of surficial deposits are involved in landslides, but most of the landslides are found in the moraine or colluvium.

The scarps of the individual slumped areas are recent. Most indicate movement of the surficial deposits during historic times--many show annual movement. The individual scarps range in length from a meter to about 150 meters (500 ft.). They average about 60 meters (200 ft.) in length. The vertical offset across the scarps ranges from less than a meter to several meters. The abundance of scarps in an area of landslides, and their relative short length and small offset, indicates that the depth of movement is relatively shallow. Drill logs indicate that the individual landslides in the surficial deposits are generally less than 15 meters (50 ft.) thick.

The individual scarps may represent a single small landslide or an active segment of a large landslide area. The landslide area may be a bedrock landslide, and the scarp represents slumping in the surficial material as a result of movement in the bedrock. The landslide area may also be a large landslide in the surficial deposits. The individual scarps indicate the active segment of the large landslide.

The causes of most of the landslides in the surficial deposits are the result of the surficial deposits being deposited or formed on a bedrock slope that was over steepened by glacial erosion. The surficial deposits at the time of deposition were poorly drained and many swamps were developed. The permeability of the surficial deposits is different in different areas and numerous springs occur throughout the deposits. Much of the year when the surface is not frozen, the deposits are saturated with water. With the spring runoff, there is a period of rapid erosion during the time of maximum saturation. This results in minimum stability for a mass of poorly sorted and unconsolidated material on a steep slope with the lower edge at a stream channel. Along Black Gore Creek, down cutting of the Creek has not been able to keep up with the movement of the landslides into the valley. The gradient of the Creek above the landslides has been lowered and alluvial deposits formed because the landslides have partially dammed the creek (Figure 9).

GROUND WATER

The Vail Pass area is typical of the high mountain areas of Colorado. Precipitation occurs in the form of snow during the winter months--generally November to April--which accumulates to several feet in thickness. Most of the snow melts in a relatively short time--April to July--and the streams are full from the spring runoff. Precipitation during the summer months is from thundershowers--local heavy precipitation during a short period of time and a heavy runoff. Because of the accumulation of the snow pack each year, the ground is saturated with water for part of the year. The length of time of total saturation depends on many factors (source, porosity, permeability, altitude, etc.).

The ground water occurs in the fractures and in the pore space of the bedrock and in the surficial deposits. The fractures and granular porosity of the bedrock are probably saturated most of the time. The fractures in the igneous and metamorphic rocks and the sedimentary rocks contain only a small amount of water. The granular porosity of the igneous and metamorphic rocks is nil. The poor sorting of the grains and the abundance of clay in the sedimentary rocks limits the porosity of these rocks. Most of the ground water in the Vail Pass area is in the surficial deposits. Of particular importance is the ground water in the landslide areas.

The occurrence of stagnant surface water in swamps and the locations of springs were mapped during the geologic investigations. The swamps occur where the ground water table intersects the topographic surface and there is no drainage. The springs occur where the ground water table intersects the topographic surface and there is drainage. The estimated flows ranged from less than 1 to 265 liters (70 gal.) per minute. The springs occur where there is a change in permeability and/or porosity. They are common at the edges of surficial deposits and bedrock outcrops, at the margins of landslide areas, at the heads or toes of slump areas, along draws or stream valleys in surficial deposits where there is a thinning of the deposits, at contacts between types of surficial deposits, and at the toes of surficial deposits adjacent to the major streams.

FOUNDATION AND SLOPE STABILITY

The foundation and slope stability of the geologic materials was defined by the geologic studies and the final highway location, design and construction considered the geologic information.

The igneous and metamorphic rocks include gneissic granite and migmatite. The gneissic granite is generally a massive, competent rock.

The upper few feet are rippable, but for major cuts drilling and blasting are required. The rock is faulted and jointed. Next to the faults the rock is sheared and altered for up to a foot or so to either side of the fault. Cut slopes in the gneissic granite stand vertically except where faults or joint systems approximately parallel the face of the cut. The excavated granite serves as excellent fill. Structures were founded on unfaulted and unaltered granite. Ground water occurs in the faults and joints. In placement of fill, or structures on the gneissic granite, care was taken to insure that the movement of ground water through the fractures towards the streams was not impeded.

The migmatite is less competent than the gneissic granite because of the variation in composition of the layers. The biotite rich layers, because of the micaceous structure, will be weak compared to the granitic layers. Much of the migmatite was rippable. Drilling and blasting was required in some cuts where a high percentage of the rock was granite. The principal direction of weakness in the migmatite is the foliation. The rock is also jointed and locally faulted. Cut slopes in the migmatite were designed to the angle of dip of the foliation or the joint set that most closely parallels the direction of the cut. The migmatite excavated into tabular blocks with the longer dimensions parallel to the foliation. Structures can be founded on unfaulted and unfractured migmatite. Ground water occurs in the faults and joints.

The sedimentary rocks included a wide variety of lithologic types. These, in order of abundance, are sandstone, siltstone, shale and limestone. The engineering characteristics of the sedimentary rocks are chiefly dependent upon the grain size of the sand and the percentage of clay present, and the structure. Sandstone constitutes about 75 per cent of the structure. Sandstone constitutes about 75 per cent of the sedimentary bedrock. The other types of clastic sedimentary rocks are interbedded and gradational with the sandstone. The sandstone is typically medium- to coarse-grained, conglomeratic (with pebbles of igneous or metamorphic rock to 0.15 meters (6 in.), arkosic, micaceous, and poorly sorted. The rock is generally friable--calcium carbonate cementation does occur at the base of some beds. The typical sandstone grades into fine-grained sandstone and siltstone, which are micaceous and clayey which, in turn, grade into sandy and silty micaceous claystone or shale. Beds of limestone up to 10 meters (30 ft.) thick occur in the vicinity of Stations 380 to 385 and Stations 560 to 570.

The sedimentary rocks are generally massive competent rocks. The rock was rippable. The design of cuts was dependent upon the structure. The sedimentary rocks are jointed with the joints forming generally widely (greater than 0.5 meter) spaced sets. Most joints are about vertical and vertical cuts are possible. The alignment of the cuts was determined by the strike of the joint sets. Most cuts in sedimentary rocks ravel with time. The sedimentary rocks contain a small percentage of montmorillonite clay, which expands and contracts with changes in humidity and temperature. The rocks, as a result, are repeatedly stressed and small pieces work loose. The siltstone and shale beds, which contain a higher percentage of clay, ravel more, and overlying sandstone beds are undercut, allowing joint blocks of sandstone to fall. The sedimentary rock serve as excellent fill if properly placed. Structures on the sedimentary rock were founded on the massive sandstone or limestone beds. In placement of fill on the sedimentary rock, particular attention was paid to the direction of dip and to groundwater drainage.

The surficial deposits of the area include a wide variety of materials that have resulted from weathering of bedrock in place (colluvial ? deposits), transport and deposition by streams (alluvial deposits), transport and deposition by glaciers (morainal deposits), and residual deposits ? including terrace deposits, swamp deposits, and boulder trains.

Construction on the colluvial deposits presented problems. The deposits were at their natural angle of repose, and were moving, but very slowly. Cut slopes in the dry material of 1:1 were possible, but allowance was made for continuing raveling of the slope. The slopes ravel (regardless of the angle, if steeper than the natural slope) because of the continuing movement in the slope. Where the colluvial deposits were saturated with water, slopes of 2:1 or 3:1, depending upon the average size of the rock fragments, the percentage of clay, and the height of the cut, were required for a realtively stable slope. For maintenance of slopes, consideration of drainage was important, particularly in the colluvium derived from the sedimentary rocks that contain a relatively high percentage of clay.

Construction on the morainal deposits presented problems. The deposits were at their natural angle of repose and cut slopes steeper than this angle would cause raveling and local failure. Slopes of 1:1 were relatively stable, except for continued minor raveling in the dry morainal material derived from the igneous and sedimentary rock. Maximum slopes of 1½:1 in the dry morainal material derived from the sedimentary rocks would be relatively stable. Where wet, or subject to saturation, slopes of 2:1

or 3:1 if not protected or planted, would ravel and slump locally in either type of morainal material. In the maintenance of stable cut slopes the control of drainage was important.

Construction on the alluvial deposits presented a few problems. The alluvial deposits in the major stream valleys had a limited bearing capacity. Test drilling and sampling were required to determine the suitability of these materials for footings for structures. Cuts intersected the toes of alluvial fans at the margins of the larger stream valleys. Most of these alluvial fans consist of well sorted and stratified granular materials that were saturated with ground water. With adequate drainage control, slopes in these materials would be stable at 1:1--some raveling would be expected except that most of the slopes were layed back and planted.

Classified as residual deposits were terrace deposits, swamp deposits and boulder trains. The terrace deposits were characteristic of the alluvial deposits, and presented similar problems in construction. The swamp deposits, which consisted mostly of organic rich fine sand, silt and clay, range from less than 0.1 meters to as much as 3 meters (10 ft.) thick. The swamp deposits were not suitable for use except as top soil. The swamp deposits were removed and adequate drainage developed before the placement of fill across a swampy area. The boulder train deposits probably range in thickness from 1 to 15 meters. Cuts through the boulder trains revealed a concentration of the finer material at depth. With adequate drainage slopes of 1:1 were stable in the boulder trains.

ENGINEERING SOLUTIONS

The geologic environment and constraints were defined by the intermediate and detailed geologic investigations. These data then were integrated with the other environmental factors and constraints and a preliminary alignment and design established. This was chiefly the responsibility of International Engineer, with whom Charles S. Robinson & Associates, Inc. worked closely.

All areas of landslides could not be avoided and maintain highway standards. The studies, including the instrumentation, had indicated those that were the most active and those that were relatively stable. The highway was designed to avoid the more active landslides. Where the highway crossed older landslides the lanes were separated as far as possible in conformity with the requirements of standards for line and grade. The separation of the lanes allowed the heights of cuts and fills to be held to a minimum. In several areas of landslides, ground-water drainage was increased by drilling horizontal drains well below the level of the highway and the fills. The drainage across the old landslides was improved and carefully controlled to reduce infiltration into the landslide mass.

One area of landslides was between Stations 415 and 425 (Figure 10). Active bedrock landslides from either side of Black Gore Creek had their toes in the creek. The landslides on either side of the creek were instrumented and their movement monitored. The maximum movement was during the period of high ground-water levels, which was during the period of the spring runoff. The solution to the stabilization of these two landslides was to fill the valley transferring the thrust of one landslide against the other, and putting the stream and the highway on the valley fill.

Slope stability was maintained by careful design of back slopes. The east and west bound lanes were separated where space, line and grade allowed and the heights of back slopes and fills kept to a minimum. Slopes in surficial material were layed back as far as practical, contoured, covered with topsoil and seeded. Particular care was taken to control surface and ground-water drainage on all cut and fill slopes. On bedrock slopes, the different types of material were treated differently depending upon their ability to stand. The slopes in more competent units approach vertical, where those in less competent units were layed back, and often seeded. The natural breakage of the rock, as along joints, were followed and the backslopes in bedrock conform in appearance to natural rock slopes.

One area of slope stability of particular concern was between Gore and Big Horn Creek. Along the alignment were surficial deposits--mostly glacial moraine--on Precambrian igneous rock. The surficial deposits were at their maximum angle of repose, and most of the year saturated with ground water. The choices for the placement of the highway were restricted by privately owned lands in the valley. Cuts in this area could have caused major slope failure. The solution was to put much of the highway on a structure.

ACKNOWLEDGMENTS

The geologic problems in the Vail Pass area were first recognized by R. K. Barrett, District Geologist District III, Colorado Division of Highways (5). His recognition and report on the geology was the basis for the contract with Charles S. Robinson and Associates, Inc. The field investigations were conducted by Charles S. Robinson and Dale M. Cochran of Charles S. Robinson and Associates, Inc., assisted by Gary T. Whitt of R. V. Lord and Associates, Inc. The contract was conducted under the supervision of Richard A. Prosence, District Engineer and Robert K. Barrett, District Geologist, Colorado Division of Highways.

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TABLES

Table 1. Major Areas of Landslides Vail Pass Area

TABLE 1

MAJOR AREAS OF LANDSLIDES VAIL PASS AREA

Approximate Stations	Description
380 to 390	Stabilized landslide in igneous and metamorphic rocks. (Not outlined as active landslide area).
415 to 440	Bedrock slide of sedimentary rocks with cover of moraine and colluvium. Two slides, one on either side of Black Gore Creek.
480 to 520	Bedrock slide of sedimentary rocks with cover of rocky colluvium.
540 to 560	Surficial slide in moraine and colluvium. Older slide with active segments.
610 to 675	Bedrock slide of sedimentary rocks with cover of moraine and colluvium.
735 to 775	Bedrock slide of sedimentary rocks with cover of moraine and colluvium. Very active locally.
785 to 800	Bedrock slide of sedimentary rocks with cover of moraine.
845 to 855	Bedrock slide of sedimentary rocks with cover of rocky colluvium on alignment of eastbound lane.
	Copper Mountain slide. Slide of talus material--south of proposed alignments.

ILLUSTRATION

Figure 1. Index Map of the Vail Pass Area

Figure 2. Generalized Stratigraphic Section, Vail Pass Area

Figure 3. Generalized Geologic Map, Vail Pass Area

Figure 4. Map of Landslide Areas, Vail Pass

Figure 5. Cross Section of Bedrock Landslide in Igneous and Metamorphic Rock

Figure 6. Cross Section of Bedrock Landslide in Sedimentary Rock

Figure 7. Photograph of Trees Growing in Landslide Scarp Depression

Figure 8. Cross Section of Landslide in Surficial Deposits

Figure 9. Alluvial Deposits as Result of Damming of Stream by Landslides

Figure 10. Cross Section through Abuting Landslides

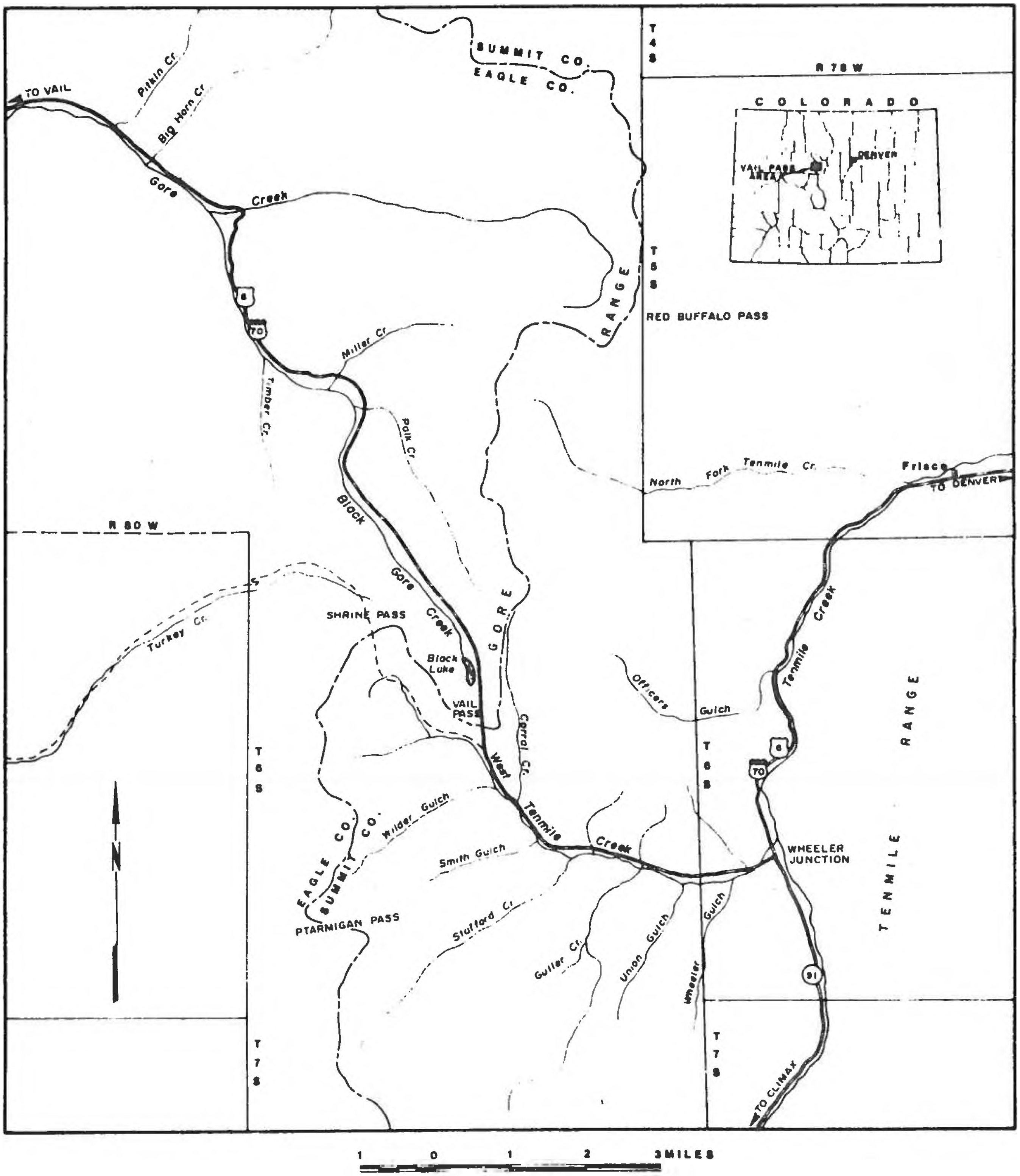

FIGURE 1.--INDEX MAP OF THE VAIL PASS AREA

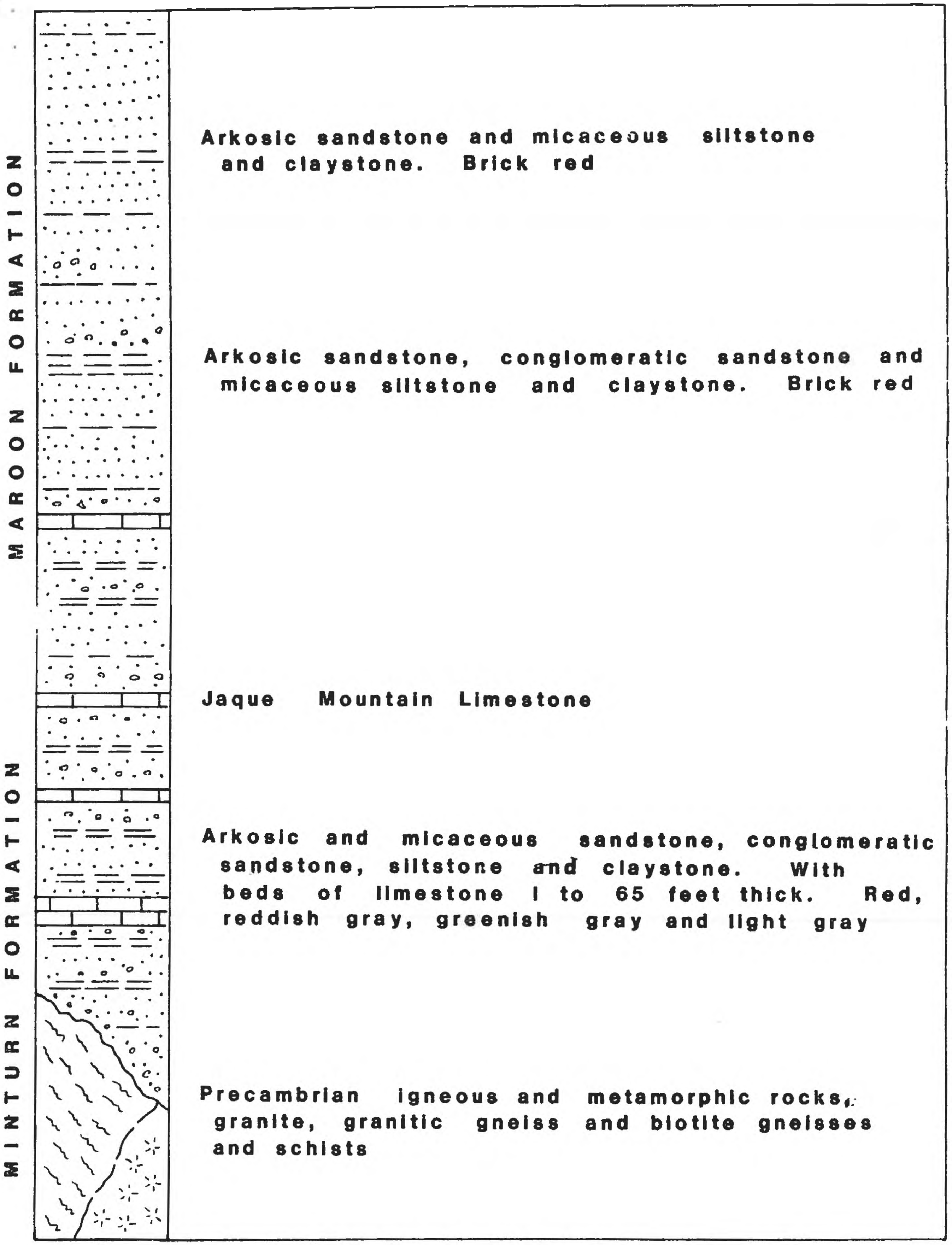

Figure 2

GENERALIZED STRATIGRAPHIC SECTION
VAIL PASS

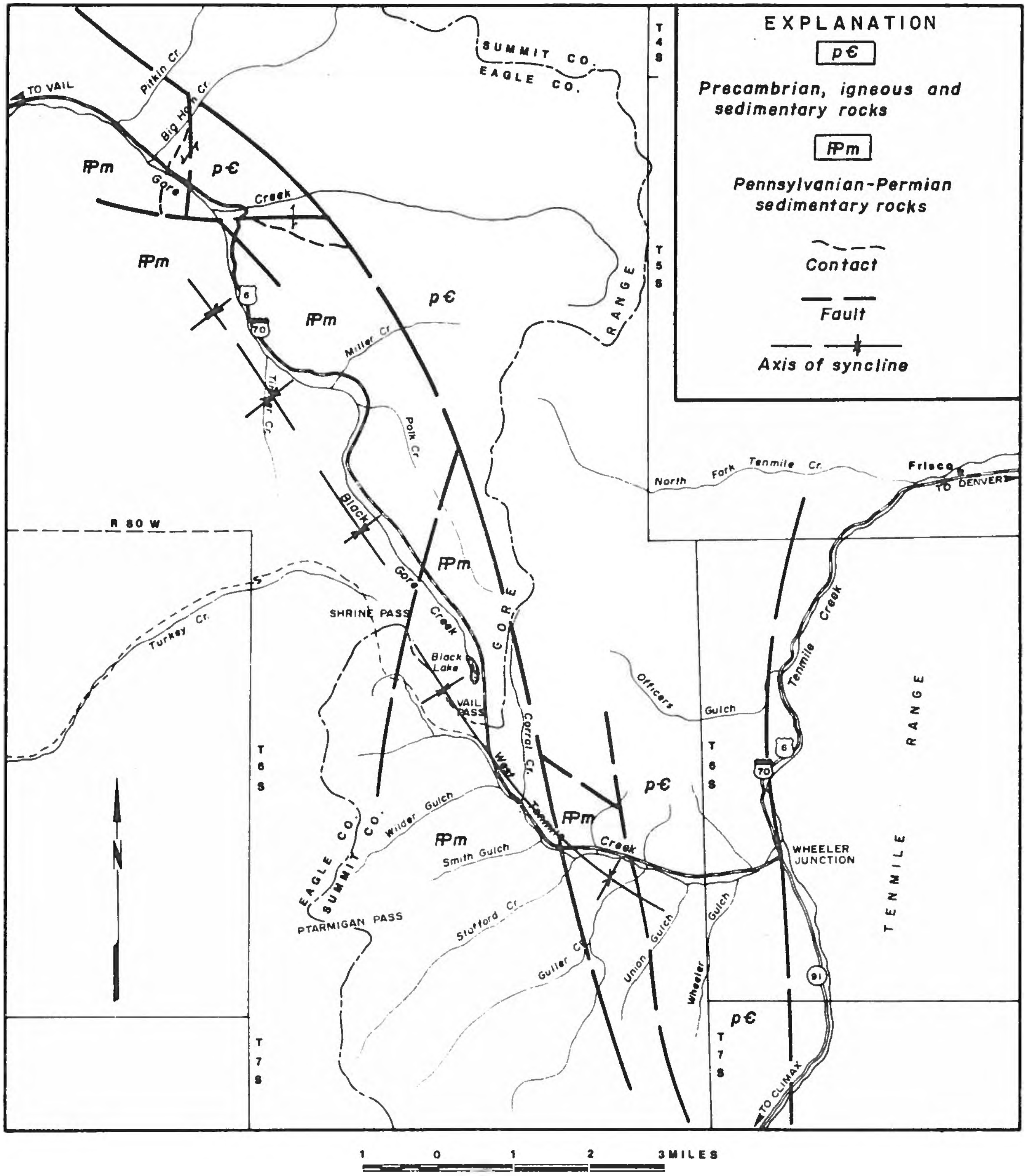

FIGURE 3.--GENERALIZED GEOLOGIC MAP VAIL PASS AREA

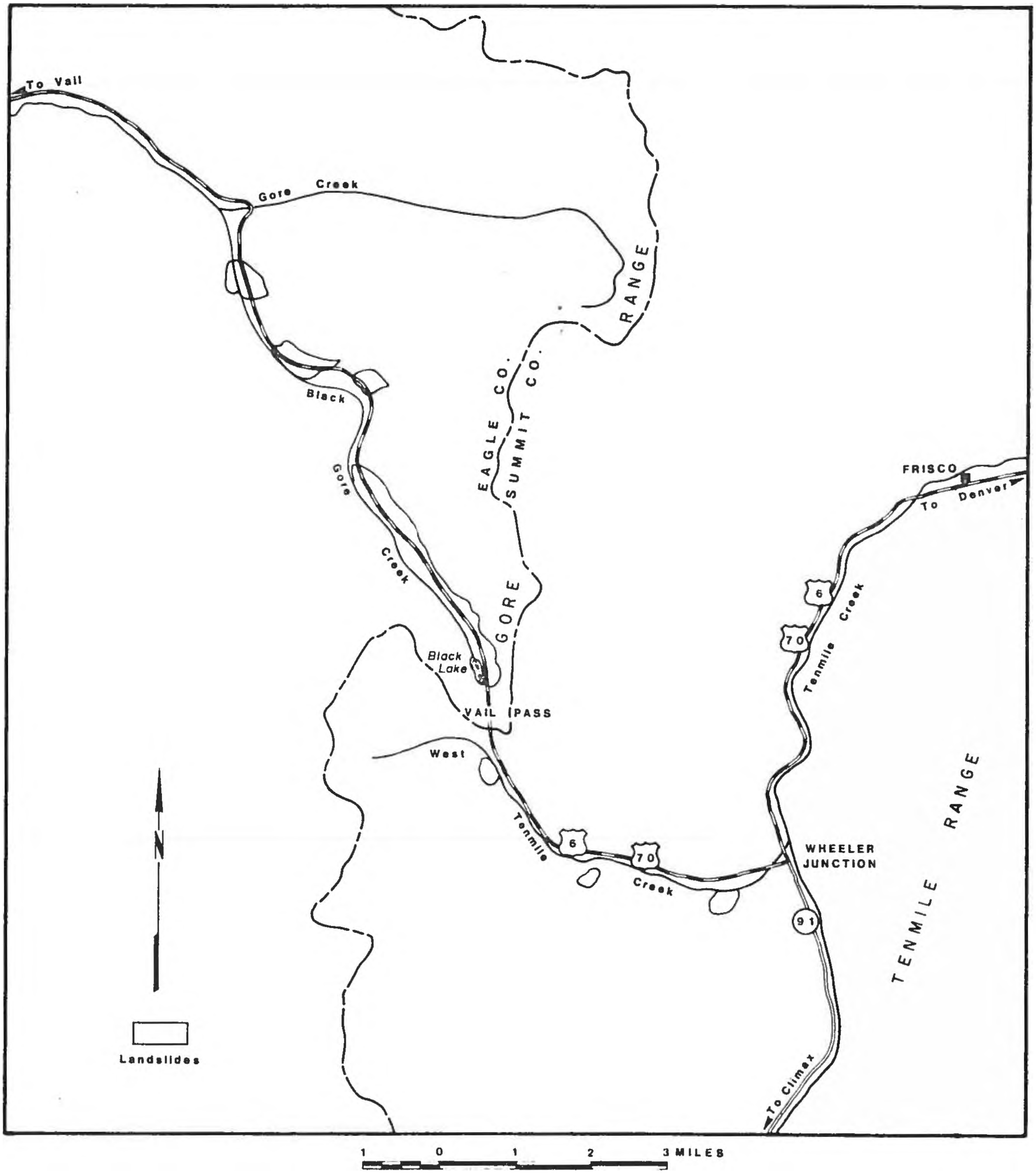

Figure 4 MAP OF LANDSLIDE AREAS, VAIL PASS

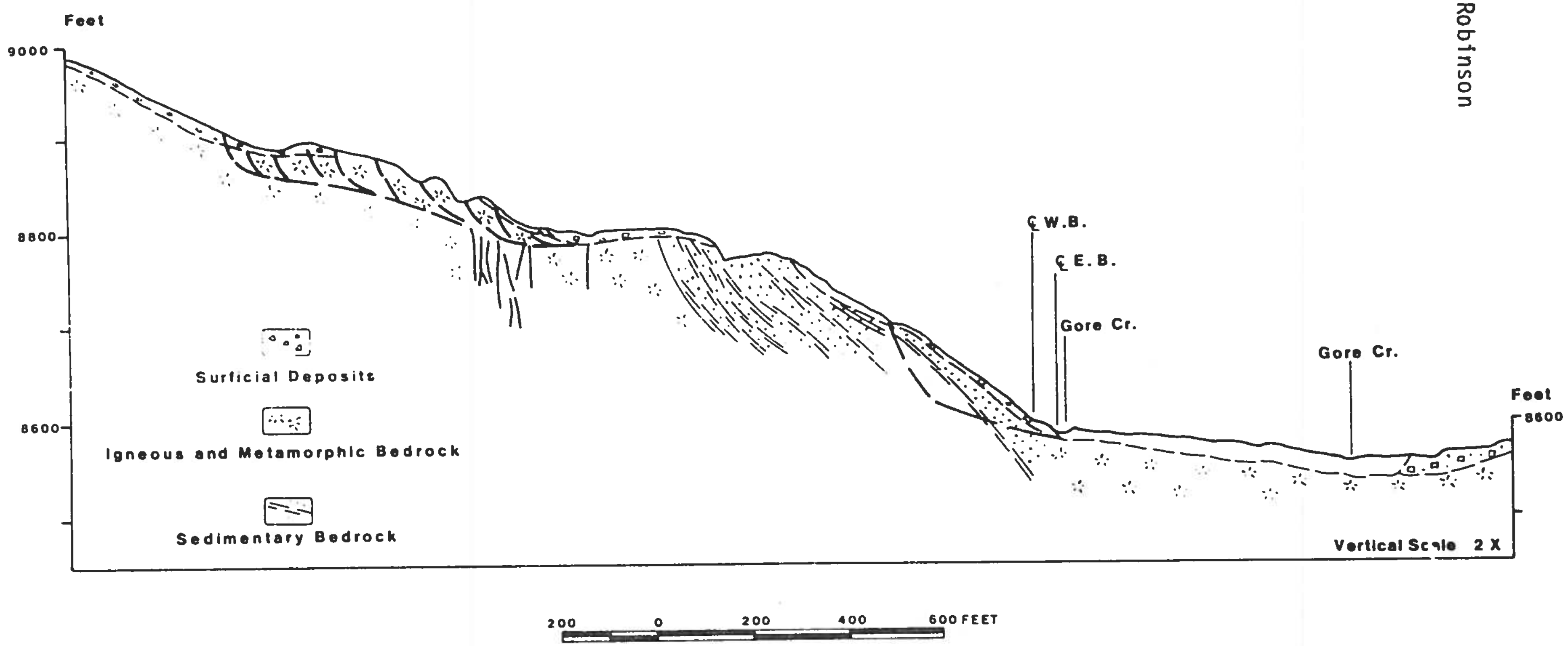

Figure 5 CROSS SECTION OF LANDSLIDES IN IGNEOUS & METAMORPHIC ROCK
(ABOUT STATION 380 + 00)

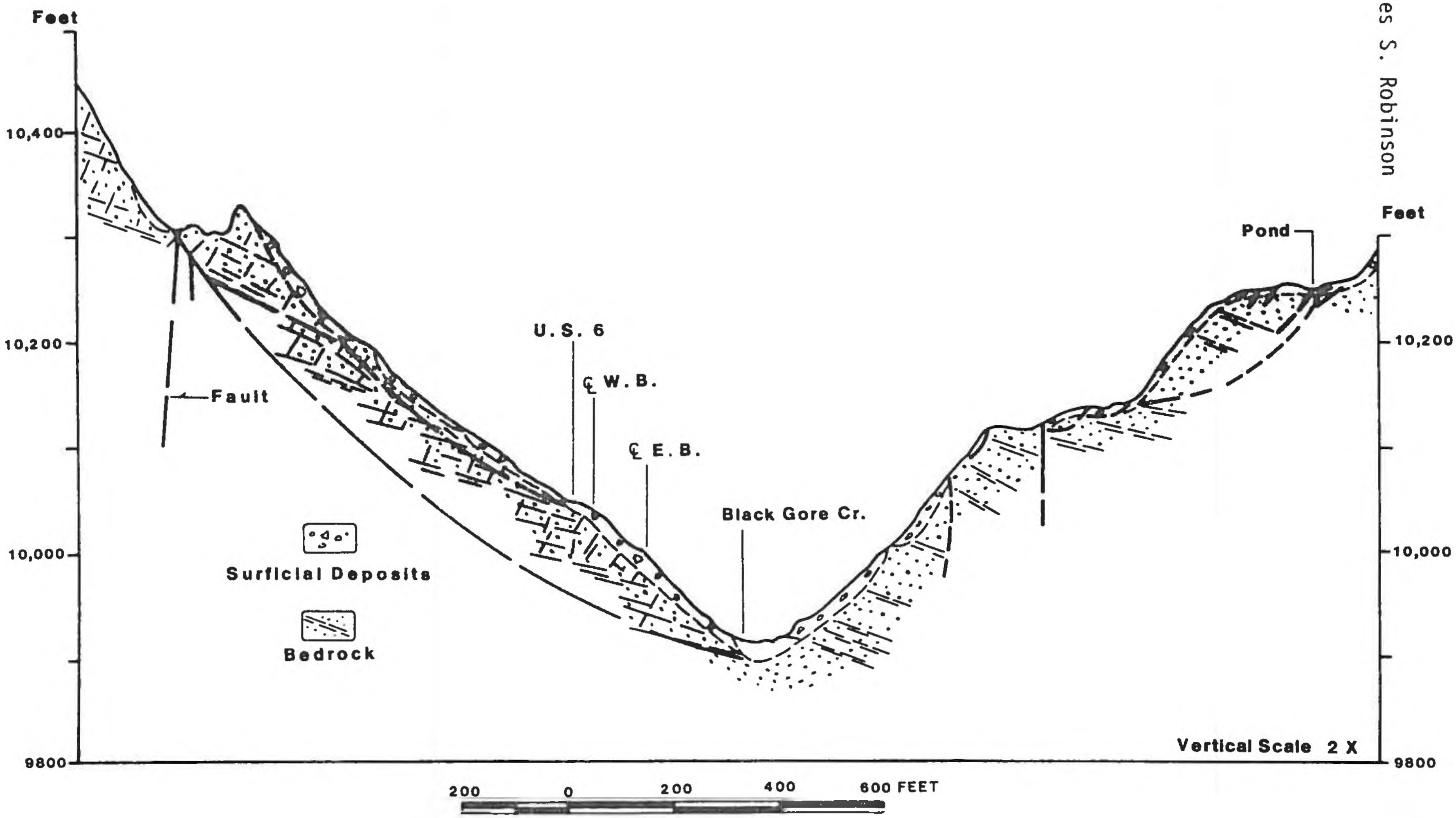

Figure 6 CROSS SECTION OF LANDSLIDES IN SEDIMENTARY ROCKS

(ABOUT STATION 640 + 00)

Figure 7.

Photograph of trees growing in landslide scarp depression

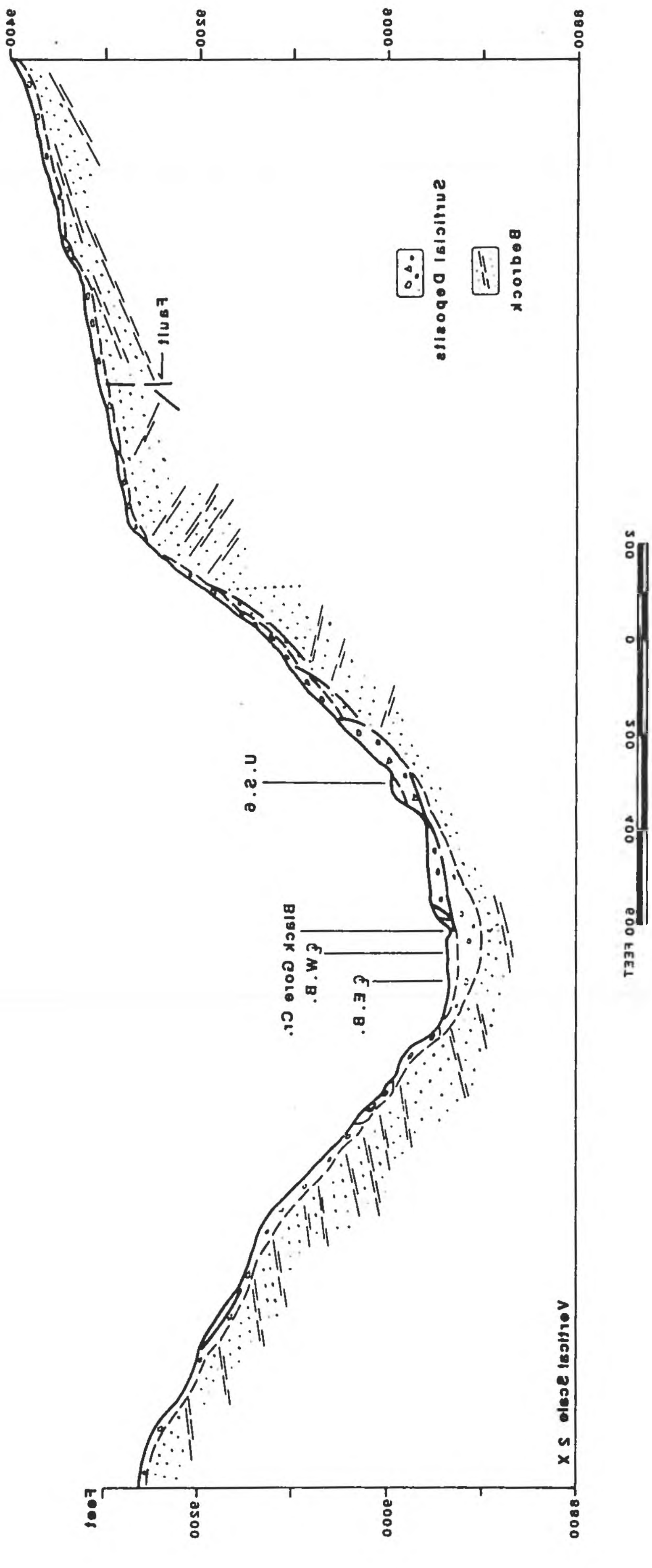

Figure 8 CROSS SECTION OF LANDSLIDES IN SURFICIAL DEPOSITS

(ABOUT STATION 440 + 00)

Figure 9.

Alluvial deposits as a result of damming of stream by landslides

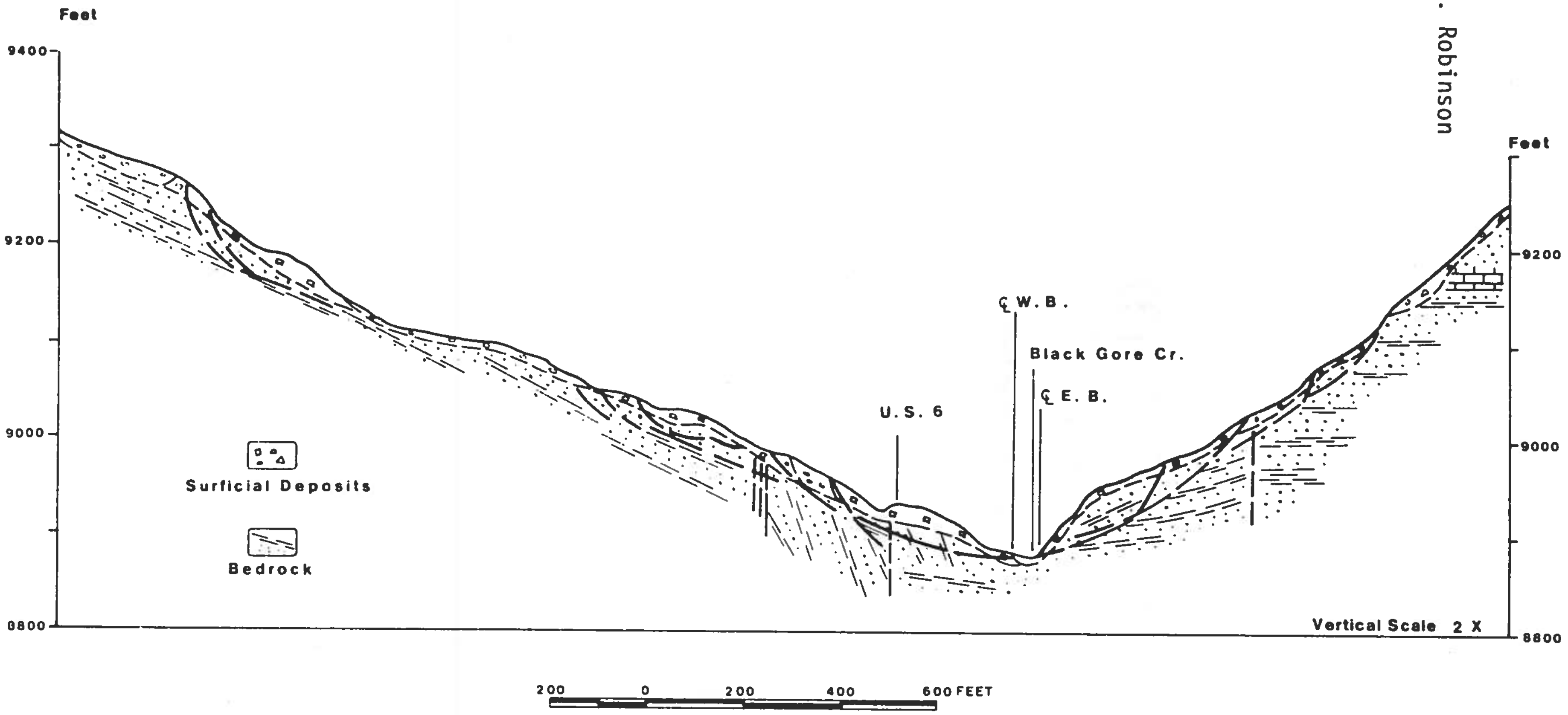

Figure 10 CROSS SECTION OF ABUTTING LANDSLIDES

(ABOUT STATION 420+00)